Where was I and what was I doing?

The impact of interface elements and information access cost on task behaviour and resumption.

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ABSTRACT

Modern computing devices are prone to constant interruptions. The design of interfaces has a great impact on our behavior and ability to resume and we make conscious tradeoffs to use our memory or rely on the interface to deal with this interrupted task flow. But how exactly do these elements impact our performance, and in particular, so they aid mitigate the disruptive effects of interruptions? An empirical study was conducted to investigate the impact of placekeeeping elements and information access cost on task performance and resumption behavior. Participants performed 50 trials of a packaging task, with either placekeeping elements visible or invisible on the interface, and were interrupted by easy and hard interruptions. The cost to access important information was manipulated to investigate the use of memory-based or display-based strategies. The main findings of this study show that a higher cost to access information and a memory-based strategy has negative effects on performance. We found mixed results as to the contribution of placekeeping elements. In most cases, they provided help and reduced the number of errors, but also led to clutter in cases of high memory load. These results confirm the importance of considering quick information access and placekeeping elements when designing modern devices that bring new challenges to human cognition.

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INTRODUCTION

Modern technology is allowing us to perform multiple tasks and communicate on personal devices, fast becoming the seat of our working lives. Using these devices involves navigating, accessing information on other screens and all the while, being prone to countless interruptions, such as phones calls, incoming messages, emails and screen lockouts. Can the design of interfaces help us deal with our interrupted workflow?

In a number of professional settings, individuals often have to maintain focus on primary task, but are interrupted very frequently. Recent studies have shown that over the course of a typical work week, an office worker can be interrupted at least once during every task performed throughout the day (Czerwinski, Horvitz, & Wilhite, 2004). Interruptions are very common in safety-critical environments, such as healthcare (Back, Brumby, & Cox, 2010; Coiera, 2012; Speier & Vessey, 2003), military operations (E. Altmann, 2007), flying commercial aircrafts (Dismukes & Nowinski, 1996; Ho, Nikolic, Waters, & Sarter, 2004), driving (Alm & Nilsson, 1995; McKnight & McKnight, 1993) air traffic control (Ho et al., 2004), and nuclear power plants and oil rigs (Edwards & Gronlund, 1998). In these settings, errors in the tasks and bad time management can have dire consequences, yet sources of interruptions continue to creep in these environments.

The ability of individuals to cope with interruptions is often critical to their performance, and we have yet to establish clearly how people recover from interruptions and how computer interfaces may provide help. A wide body of research has documented the disruptive effects of interruptions (D. M. Cades, Werner, Boehm-Davis, Trafton, & Monk, 2008; Cutrell, Czerwinski, & Horvitz, 2001; Gillie & Broadbent, 1989; S. T. Iqbal & Horvitz, 2007). Overall, these studies indicate that attributes of the interruption and of the interface have a great effect on our behaviour and performance in these tasks. Can interface elements help us recover from interruptions and deal with information that is harder to access?

Modern technology is evolving in a direction that enables interruptions and multitasking to occur. Mobile devices in particular are becoming the point of convergence of our communications through phone calls, text messages, online messaging, emails, and social network notifications. Unintended interruptions by phone calls are rare (3%), however, rate of interruption of another task by a smartphone communication is high (Oulasvirta, Tamminen, & Roto, 2005). Recent engineering trends have favoured display-based strategies and cognitive offloading to mitigate disruptions and aid in multitasking but the real consequences remain obscure (Carroll, 2003; Dror & Harnad, 2008).

These trends in the evolution of technology and the way they shape our interactions and communications have made the topic of interruptions and task switching a prime concern for the field of human-computer interaction and psychology. A vast body of literature exists on the topics of multitasking (Salvucci & Bogunovich, 2010), task-switching (Avrahami, 2007; Band, Jolicœur, Akyürek, & Memelink, 2006; H M Hodgetts & Jones, 2005; Helen M Hodgetts & Jones, 2006), and on the varied characteristics of primary task and interruptions such as complexity (D M Cades, Trafton, Davis, Boehm-Davis, & Monk, 2007; D. M. Cades et al., 2008; Gillie & Broadbent, 1989; Speier & Vessey, 2003).

However, few empirical studies have investigated the effect of interface elements and information access-cost on general performance and resumption. We will investigate such effects and we feel that it could provide more empirical data in the field and also inform interface designers on the potential benefits and drawbacks of manipulating these interface elements.

The following chapter will review the literature pertaining to our topic, first providing an overview of the latest developments in interaction paradigms for personal devices, and the use of certain interface elements, addressing the "computer" side of the Human-computer interaction coin. The second part of the literature will look at the human side and explore interruptions, their disruptive nature, and they will help us conduct our investigation.

The third chapter will present an experiment during which participants were asked to perform a primary packaging task, while being interrupted multiple times with varying degrees of complexity. Interface elements were different between participant groups, and participants experienced changes in the cost to access information. This chapter will also report the results of the experiment. Chapter 4 will discuss the results and interpret them to explain behaviour strategies, as well as relating them to the literature. We will also include implications of our findings for design, and reflect on the limitations of this study.

LITERATURE REVIEW

The following chapter will present a review of the literature relevant to the topic of this research. We will begin by presenting the recent evolution of graphical user interfaces and interaction paradigms. This will inform the reader on the first motivations of this research. We will introduce the information access-cost and placekeeping elements, and the studies on their effects. This first part accounts for the “computer” part in the human-computer interaction duo.

The second part of this review will look at the human side, presenting an account of the research on interruptions, their disruptive effects, and what factors influence their disruptiveness. We will also shed light on the theoretical explanations of interruption behaviour, and the cognitive elements present during the resumption after an interruption. We will conclude by identifying the research question, knowledge gap and the novelty that this research will seek to bring.

Interface elements

In the head and in the world – Interface design

In recent years, designers and engineers of human-machine interfaces have started incorporating cognitive considerations in the design of interfaces (Norman, 1986). Observations of “information overload” and interface “clutter” (Kaber et al., 2008; Rosenholtz, Li, Mansfield, & Jin, 2005) have lead designers and ergonomists to consider their design based on the limits and characteristics of human cognition, and trying to find a balance between what should and should not be displayed. This balance of information can be visualized at what information is “in the head” and information “in the world”. This balance is sensible to a number of factors and has been a hot topic of discussion among engineers, designers and ergonomists.

As computing interfaces become ubiquitous, the decision to place information on the interface or relying on the user’s memory and mental model is important. Mobile and tactile devices are a particularly interesting domain where this trade-off is present. These devices have brought a whole new set of challenges and pushed the boundaries of the “W.I.M.P.” (Windows, Icons, Mouse, Pointers) framework, with the use of new interaction paradigms for tactile interfaces that embed the controller in the user (Jacob et al., 2008). Experts in the field have called this new paradigm “O.C.G.M.”, for Objects, Containers, Gestures and Manipulations (Jetter, Gerken, & Reiterer, 2011). Without going deeply into the interaction considerations of this new paradigm, we must point out the relevant implications that it has on information access and place-keeping elements on a user-interface, and thus affect task-switching behaviour.

Traditional labels an icons are proving to be unfit for touch-based interfaces (Jetter et al., 2011; Wigdor & Wixon, 2011). This affects the presence of place keeping cues and labelling of on-screen information, affecting further the balance between information displayed “in the world” and information “in the head” of users. This balance has been put forward by Don Norman, guru of cognitive engineering and user experience, himself expressing reservations as to the credibility of ”Natural User Interfaces”, arguing that manufacturers are often releasing designs that appear usable, but these “natural” interactions may in fact be illusionary, as little research (both ergonomic and cognitive) has been performed to support up these design decisions (Norman, 2010).

Another evolution concerns information access and display. As more computing activities are taking place on these small screens, designers and engineers have to face screen "real-estate" limitations. Since the release of the iPhone in 2007, Apple has consistently encouraged developers to use full screen displays on both the iPhone and iPad, as opposed to the traditional overlapping windows.

Enabling a window of your app to assume full-screen mode, taking over the entire screen, provides users with a more immersive, cinematic experience. Full-screen appearance can be striking and can make your app stand out. From a practical standpoint, full-screen mode presents a better view of users' data, enabling them to concentrate fully on their content without the distractions of other apps or the desktop. (Apple Human-Interface Guidelines, 2012)

The latest versions of the popular desktop operating systems Mac OS X "Lion" and Windows 8 are changing profoundly their display strategy in favour of full-screen applications instead of the traditional overlapping windows. The "Launchpad" view has been ported from the iOS of the iPhone and iPad to the Mac computers, and similarly, Microsoft is implementing its "Metro" interface, displaying a tilled interface (Baxter-Reynolds, 2012), that heavily focuses on the full-screen display of applications.

This evolution of the Graphical User Interface reflects the immense success of touch interfaces and the desire of manufacturers to port this success to our computers (Tuddenham, Kirk, & Izadi, 2010). The desire to bring the "touch" interaction paradigm to more traditional computing devices has the merit of reducing the distance, the "gulf of execution" (Norman, 2010) between the physical and the digital world, by embedding the interaction in the user's hand rather than though a tool, in this case, the mouse. These design choices have deep consequences for how information is displayed and the ability to switch from an application to another. The use of full screen application puts a number of restrictions on the access to information. Having to switch from an application to another will take a certain time, enough to necessitate the activation of memory and remembering a number of information chunks. Thus information access is also to be considered when designing modern interfaces.

Profound changes are happening in the way we interact with interfaces, namely the evolution from WIMP to OCGM, driven by touch devices. This evolution has consequences on interface design, place-keeping cues, and information access. Concurrently, as more computing is done on mobile devices, users are more likely to be interrupted, hence another justification to pursue our research into interruptions and resumptions.

Information access cost

Many tasks in our working environment require us to load and access a piece of information present on another page, another window, another device. Individuals pay a price in accessing a piece of information by manipulating, memorizing, and carrying forward information between applications. The trend in interface design towards full screen applications mentioned earlier only contributes to higher costs in accessing information on other applications. Information access-cost can be manipulated by the need for the user to pay an added cost (task switching or screen lock-out) to re-access a piece of information. Increasing the IAC leads to higher demand placed on memory (Gray, 2000; Gray, Sims, Fu, & Schoelles, 2006). Studies have demonstrated that users adapt to changes in the information access cost to adapt either display-based strategies or memory-based strategies if the cost is too high (Gray, 2004; Waldron, Patrick, Morgan, & King, 2007). This strategy can be further explored through the use of interruptions as users need to recall the goal state, and ask themselves about what it is they were doing.

Manipulating the information access cost will act on the need to access the goal-state and the ability of the individual to resume a task. We will investigate whether or not a higher access cost leads to different behaviour strategy and memorization strategy.

Global placekeeping

Global placekeeping information are the collection of interface elements indicating progress in the completion of a task (W. Gray, 2000). These elements are here to aid the user in knowing where the action is taking place. In interface design, these elements have taken the popular form of labels, arrows and highlighted elements. They are key to resumption as they provide visual pointers to the locus of interaction.

However, the evolution of mobile and tactile devices, has lead interaction specialists to reconsider the use of these traditional elements. Concurrently, web users are faced with countless web forms, and other tasks during which interruptions can occur, and placekeeping information is important to the completion of these tasks (Chen, Ratwani, & Trafton, 2010a).

Place keeping information has shown to aid to prevent post completion errors (Chen et al., 2010a), also indicating that the presence of global placekeeping cues had no effect on uninterrupted task performance. We wish to investigate the impact of these elements on interrupted trials, in order to observe resumption behaviour. The impact of placekeeping cues could be visible on several performance indicators such as completion time, the error rate, and the number of visits made to the instruction screen.

The soft constraints hypothesis

The evolution of devices and the underlying trend in software design are influencing our cognitive strategies and are challenging human memory in new ways. A recent strain of research has started exploring the possibility that constraining the user into memorizing more information and going towards a more effortful strategy could potentially yield performance gains (P. L. Morgan & Patrick, 2010a). This proposition takes root in the ACT-R theoretical framework (Anderson et al., 2004; Anderson & Lebiere, 1998). Studies in different environment have confirmed the potential benefits of reducing information access, such as information lock out for nurses in healthcare environment (Back et al., 2010), resulting in fewer input errors. The soft constraints hypothesis materializes a point of contact between cognitive research and interface design.

Interruptions

The impact of interruptions of task performance have been studied extensively and in great detail As human beings, our limited cognitive and memory capacity are greatly challenges by interrupting tasks, and results in conflicts between primary tasks and interruptions (Miyata & Norman, 1986). Interruptions are events in the timeline of a task, in many different forms and durations. At the most fundamental level, an interruption consists of a sequence of four events illustrated in the following diagram from Trafton (Trafton, Altmann, Brock, & Mintz, 2003).

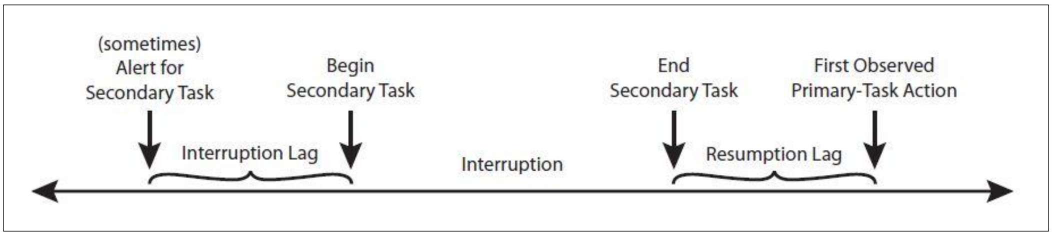

Figure 2.1 The external interruption timeline (Trafton et al., 2003)

Anatomy of an interruption

To correctly identify what makes up an interruption, academics have taken a logical approach to dissect the events taking place during an interruption. Trafton (2003) describes in great details the elements that have been identified in various task analyses across a range of different activities and settings.

The premise for an interruption is an individual working on a primary task, usually of long and complex nature. Such tasks can be data-entry, research, writing and driving. A general definition of a primary task can be found in Czerwinski (Czerwinski et al., 2004).

This primary task is interrupted in general by an alert, signalling the impending interruption. Alerts can take many different forms, from a person entering a room to a notification sound from a mobile device. The scope of our research being man-machine interaction, we will focus on interruptions coming from a computer. After the alert occurs, a length of time passes before the person attends to the interruption. This lag is called the "interruption lag" and occurs between the appearance of the interruption and the moment when the person's attention switches from the primary to the secondary task. Once the interruption has been dealt with, the individual resumes to the primary task. A similar time gap occurs between the end of the secondary task and the "First Observed Primary-task Action" as called by Trafton (2003). The attributes of the resumption lag will be of prime concern in our research as we will focus on resumption behaviour and the impact of interface elements on such behaviour.

As we can see, the events that are interruption and resumption lags and associated alerts often occur in very short lengths of time. The cognitive system and human memory is extremely relevant in this context as we struggle to manage incoming interruptions, and resume to the primary task. Furthermore, interface elements and the presence of cues change the cognitive input and affect greatly how these events are dealt with (Rudzka, Arif, & Berreau, 2000; Waldron et al., 2007).

The disruptive nature of interruptions

Research studies have shown in multiple settings that interruptions have generally negative consequences, in particular on the performance of the primary task (D. M. Cades et al., 2008; Czerwinski et al., 2004; Gillie & Broadbent, 1989; S. Iqbal, 2007; S. T. Iqbal & Horvitz, 2007; Monk, Boehm-Davis, & Trafton, 2004). Interruptions create a break in the flow of our task and disrupt the course of events. Numerous studies have been conducted to evaluate the consequences of interruptions, and it has been generally observed that interruptions have detrimental effects on performance (Speier & Vessey, 2003). In the light of these studies, we feel that interruptions are essential in studying the impact of interface elements as they put pressure on the cognitive system, and should highlight behavioural effect.

Interruption complexity

Not all interruptions are equal. As we have seen they can vary in modality and urgency, but their complexity also has a great impact on the way we treat them (D. M. Cades et al., 2008; Speier & Vessey, 2003). Complexity of task has been defined by the number of mental operations required to process the interruption (Baron, 1986), to the amount of memory “chunks” that need to be activated to perform the task (E. Altmann, 2002). Interruptions have been categorized has complex as a result of the amount of mental operators required to complete the task (Bloom, 1984). An increase in the number of element in memory corresponds to an increase in complexity and the use of declarative memory, and the maintenance of a problem state (D. M. Cades et al., 2008).

A number of studies show a distinct positive correlation between the increase in complexity and decrease in numerous performance variables such as completion time (Christopher A Monk et al., 2004; Trafton et al., 2003) and accuracy (Edwards & Gronlund, 1998). This correlation is confirmed in a more recent study by Cades et al (2008), showing slower resumption lags when using complex interruption, and thus providing empirical support for the memory-for-goals model (E. Altmann, 2002).

Theoretical approaches to interruptions

In the effort to create a unified explanation of human cognition, several theoretical frameworks and cognitive architectures have been proposed to explain how the human mind deals with tasks and goals. They are important to consider because they make assumptions and predictions on how goals and tasks are prioritized by humans, and our work on interruption and resumption should be considered against the theoretical explanations of such phenomena.

Several researchers have taken an activation-based approach to memory and developed the memory-for-goals theory (E. Altmann, 2002). Like many other constructs around human cognition, Memory for goals finds its roots in the ACT-R (Adaptive control of though-Rationale) cognitive architecture (Anderson et al., 2004). This framework states that goals will decay over time and need to be reinforced. In order to establish priority in the goals, one goal must be continuously reinforced and reminded so that it keeps a dominant place in the order of execution. Goals must be associated to visual reminders to link the goal state to the user, and these cues would be available both before and after an interruption. In the absence of such cues, the goal memory will decay and the role will be forgotten.

Goal activation is heavily dependent on strengthening and priming (E. Altmann, 2002). Strengthening and priming can be expressed through the recency and frequency at which the goal state is displayed. The priming constraint of the goal depends on associate cues in the mental and physical context. As we can see, the presence of cues and the access to information are already appearing as fundamental agents that act upon these constraints. Interface cues can play a major role in strengthening and priming as they act directly on the cognitive input received by a user. According to the theoretical framework we can argue that interface cues are determinant in the resumption process after an interruption. We are proposing to investigate the importance of these interface cues and the access to information to link the theoretical research and research in the cognitive sciences with the current evolution in computing devices.

Resuming after an interruption

We have seen that interruptions are largely considered detrimental to work in general, and we will take a closer look now at the event happening after an interruption is over, resumption to the primary task. Resumption is a very sensitive period of time when a person comes back to the primary task after dealing for an interruption. It is the time to "collect one's thoughts" and come back into the task that was previously abandoned. The cognitive system and human memory are put under heavy load during this time as individuals combine memory information and sensory input to find their way back to the primary task (E. Altmann, 2004; Andrews, Ratwani, & Trafton, 2009; C A Monk, 2004).

The act of resumption can be divided into two important pieces of information that the person has to recover. The first piece of information is the location of the primary task "Where was I?" In the context of human-computer interaction, this corresponds to the screen, the window, the field, where the primary task was taking place before the interruption occurred. Secondly, the individual has to recall the action, what was being done in the task. This could be an action of taking data from the device, reading a text, listening or watching content. The user can also be outputting data to the device, as data entry and also performing command operations on the primary task (searching, selecting and navigating). This sensitive moment when a person needs to re-access memory is easily prone to errors (Back et al., 2010) and variations in time taken to resume (E. Altmann, 2004). The user interface and interaction design of modern devices are the theatre of recurring interruptions (Oulasvirta et al., 2005). This interaction between interruptions and interface elements are what we seek to investigate.

Summary

The literature shows that interruptions change the course of the primary task, and that multiple factors can act on the level of disruption. Interface elements have been manipulated to observe different cognitive strategies, and measuring performance outcomes. Concurrently, modern personal computing devices show an increasing potential for interruptions and smaller screens have made information access a real challenge. The scientific literature has scarcely explored the impact of placekeeping element and information access cost on behaviour, notably on the ease of recovery and performance in the primary task.

Can we mitigate disruptive effects by manipulating interface elements and information-access cost? Are effortful strategies better for dealing with interruptions and easier to resume to the primary task? Is easy access to information more important than interface elements when faced with demanding interruptions? Does manipulating these elements contribute to a quicker and less error-prone resumption to the primary task?

We seek to contribute to the field of human-computer interaction by providing an empirical investigation on these questions. This will inform both cognitive scientists, seeking to understand human behaviour, and designers who shall consider our results useful when making design decisions for more user-friendly devices. An experiment designed to answer our research question will be described in the next chapter.

EXPERIMENT

In order to investigate our research question, an experiment was designed. The experiment is composed of 50 trials of a primary task in which participants read an instruction sheet, memorised the order, and composed the order on the screen using a menu navigation interface. This primary task was interrupted at random by a secondary task. This secondary task was either an easy 0-back number recognition task, or a 2-back number recognition task, that necessitated the participant to memorise 2 numbers. The experiment measured all events using timers and logging every input from the participant. This allowed for a complete analysis of all actions and time lags occurring during the trials.

This experiment manipulated important attributes of an interface and should shed light on memory strategies. Furthermore, manipulating placekeeping information will gather data to investigate their fundamental roles in performance and as guides on an interface. Based on previous research, we expect to see poorer general performance when participants face harder interruptions (D. M. Cades et al., 2008; Gillie & Broadbent, 1989; Speier & Vessey, 2003), but the presence of placekeeping cues should mitigate this complexity (Chen et al., 2010a) and lead to fewer error rates. The work on information access cost and soft constraints leads us to believe that there should be a clear shift from display-based strategy to memory-based strategy (W. D. Gray et al., 2006; P L Morgan, Patrick, Waldron, King, & Patrick, 2009).

Method

Participants

Sixteen participants were recruited through the subject pool of the UCL Psychology department. Participants were all at least 18 years of age and cleared for any disabilities. In order to perform the between-subjects part of the analysis, participants were assigned to group A or B on alternating arrivals to the lab. Participants were paid £7 for their time.

Design

The purpose of this study was to investigate whether the presence of placekeeping elements and the level of information access-cost would affect behaviour and performance. To address this question, the experiment followed a 2x2x2 mixed factorial design with the independent variable of placekeeping information (visible; invisible) between subjects and the independent variables of information access cost (Low: High) and interruption demand (Easy; Hard) tested within subjects.

Independent variables

Place-keeping: The place-keeping variable was materialized by the indication of selection and completion of an item in the selection menu. Manipulating this variable will act on the participant’s ability to see what has been completed in the task. The place-keeping information will either be visible or invisible. In the visible condition, once the participant has selected an item in a category (i.e.: Blue, in the Colour category) the interface will show “Blue” next to Colour, indicating that this selection has been made , giving place keeping information to the user about what selections have been made, and which ones have not.

In the invisible condition, after a participant has made a selection in one of the menus, the interface will not display the choice next to the category. This will act on the number of cues present on the main interface and presumably have an effect on the behaviour strategy and ability to resume after an interruption.

Half of the participants will test with placekeeping visible, and the other half will test with placekeeping invisible. To preserve the consistency of the interface and be able to test for this variable, it was deemed the appropriate option not to manipulate this variable during the course of the trials, and therefore use the presence of placekeeping elements as a between subjects factor.

Information access cost IAC:

The information access cost variable is materialized by the instruction loading time. A text box containing an order for a drink that consists of 4 pieces of information: Size, Colour, Shape, Quantity and Packaging.

This information will have two possible states: low cost of access or high cost of access. In the low cost condition, the participant will have to click on the text box for a very short time (0.1 seconds) before the information becomes accessible. In the high cost condition, the participant will have to click and hold over the text box for 10 seconds, making the information harder to access. The decision of a 10 seconds cost for the high condition was made to mimic situations of window switching, page loading, and other time lags encountered during online browsing for example.

This factor was distributed so that half of the trials were performed with the easy condition and the second half of the trials was performed using the hard condition. Half of the participants started with the easy condition, and avoid an undesired training effect in one way or another.

Interruption demand (ID):

The experiment will also test participants with varying degrees of difficulty in the interruption. In order to manipulate the difficulty of the interruption, the participant can be interrupted by an easy interruption or a hard interruption.

The interruption will use an n-back working memory task (Lovett, Daily, & Reder, 2000), using two levels of difficulty. The easy level (0) is simply number matching and is a low-demand interruption. The user will see a number appear, and should click on the corresponding number within three propositions displayed bellow. The hard n-back interruption requires the memorization of 2 numbers to be carried forward to the next screens. This requires significantly more working memory and resources to be dedicated to the task.

The choice of these interruption tasks fit well within the theoretical framework for memory such as the Memory for goals model, which posits that the ability to resume to the primary task depends largely on the demands of the interruption and the ability of the individual to rehearse and practice the primary task.

A number of measures were considered to gain insight into the impact interface elements on performance. We considered the following dependant variables:

The dependent variables collected during this experiment were average trial time, resumption lag, instruction visit counts, instruction visit duration, error rate, number of subtask revisit, time allocation and post-resumption behaviour. See table XX for definitions.

Dependent variable	Definition
Total task time	The total time taken to correctly complete and process an order.
Resumption lag	The time taken by the participants between the end of the secondary task and the first subsequent action taken by the human operator in the primary task. The time needed to "collect one's thoughts" and restart a task after an interruption is over. (E. Altmann, 2004)
Error rate	The amount of incorrect orders entered by the participant in each trial.
Instruction visit counts	Number of times the instruction screen was visited during each trial.
Instruction visit duration	Time spent on the instruction screen per visit.
Number of subtask revisits	Number of times the participant went back to the subtask menus to verify the information entered in the order.
Time allocation	Time spent on each screen of the task.
Post resumption behaviour	First action taken upon resumption. This variable tested if the participants resumed to the primary task or re-visited the instruction sheet immediately after an interruption.

Table 3.1 Definition of dependent variables

Materials

In the study, participants had to complete 50 trials of a packaging task, first accessing an order on an instruction screen, and entering the corresponding information using navigational controls and process the order. The interruptions were number memorization tasks. Both the primary and secondary task was displayed in the same window on a standard computer monitor. Figure 1 shows the main screen of the primary task

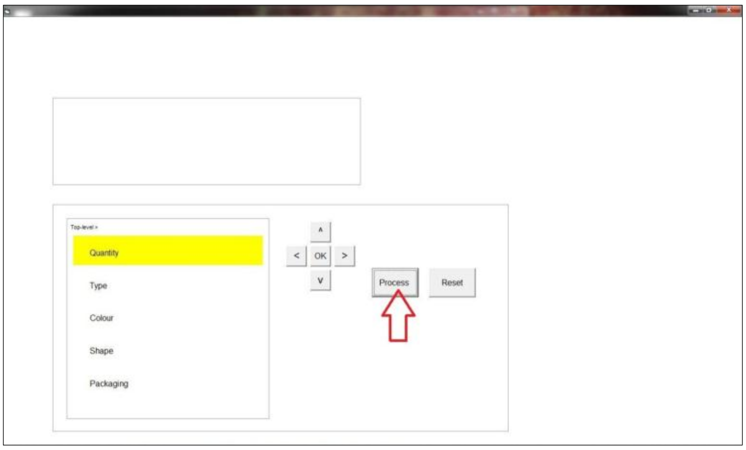

Figure 3.1 Screenshot of the primary task main screen (process button indicated by an arrow)

Primary task

The packaging task required participants to fill in an order using a navigation menu. The menu was designed as a standard drill down menu, with the top level composed of each characteristic of the order. Selecting one of these menu items and clicking either the "OK" button or the right arrow would lead to the selection of the given characteristic. The controls present on the interface were standards 4-way controls, using the up and down arrow to move up and down the menu items, and the left and right arrows to move from the top level to second level of the menu. Selecting an item in the menu could be done either using the right arrow or the OK button. A reset button was also present on the main screen, allowing participants to reset the characteristics entered in the trial.

On the menu frame, placekeeping elements were present in the form of labels indicating which segment of the order had been selected. In the other condition, participants would select a value in the drill down menu, and return to the top level, without being shown what they had selected.

To perform the packaging order, participants had to access an instruction sheet located above the navigation menu. To access this instruction sheet, participant had to click and hold the mouse cursor over this instruction frame to reveal the order.

Figure 3.2 Screenshot of the instruction screen

The participant had to maintain the mouse button pressed and the pointer over the instruction frame to keep the instruction displayed. Any release of the mouse button or if the mouse pointer was to leave the instruction frame, the order instructions would disappear. Participants were able to consult the instructions has many times as needed until the order was complete. The order showed the 5 characteristics of the order, each having 4 possible values: Colour (blue; purple; white; red), Shape (oval; square; triangle; circle) Quantity (25; 50; 250; 500), Type (Pill; Patch; Tabs; Lozenge) and packaging (Tin, Foil, Tub, Bottle). These combinations created a total of 1024 different orders. The selection of each characteristic was random. The number of possible combinations avoided a possible training effect. After memorizing the order, the participant had to fill in the corresponding fields in a frame below the instruction frame using a four-way navigation arrow and a selection "OK" button in the centre of the section arrows.

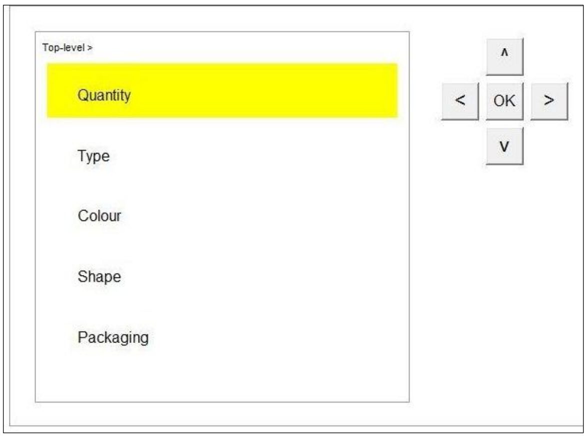

Figure 3.3 Top-level of the menu with Place-keeping elements invisible.

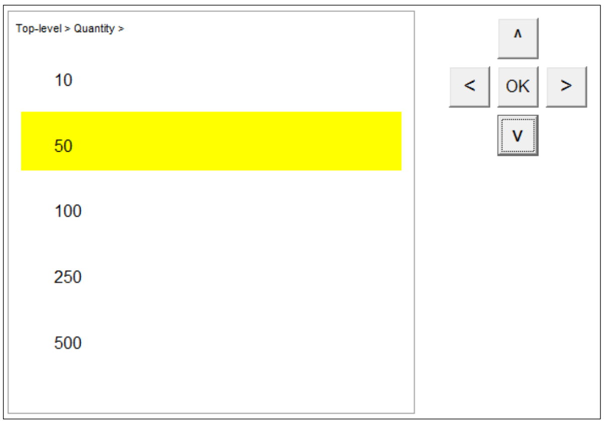

Figure 3.4 Seconds level of the menu (quantity category)

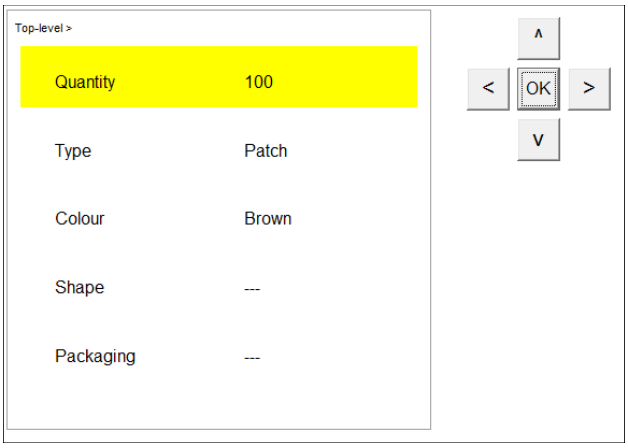

Figure 3.5 Top-level of the menu with Place-keeping elements visible

Once all the characteristics of the order have been selected, the participant has to process the order by pressing the process button. If all the characteristics of the order are correct, the participant is allowed to proceed to the next trial. If the order contains any errors, the program displays a feedback message explaining the presence of errors in the order and locking out the participant of any action for 5 seconds while this feedback is being displayed. The participant is sent back to the main screen until the order is correct.

Interrupting tasks were designed in order to observe the resumption behaviour of participants. As was explained in the literature review, interruptions were chosen in the form of a number recognition task, providing a simple way of manipulating the working memory load without introducing interfering elements. This type of interruption has a good track record in cognitive psychology studies (D. M. Cades et al., 2008; Lovett et al., 2000).

The interruption took the form of an n-back working memory task, with easy and hard interruptions. The easy interruption was a 0-back number recognition task, where the participant had to recognize the number being displayed and clicking on the matching number from a selection of three buttons displayed bellow.

In the hard setting, the interruptions were 2-back number recognition tasks, where participants had to keep a set of 2 numbers in memory and carry them forward to the next screen. The following screenshots show the process of the hard-interrupting task.

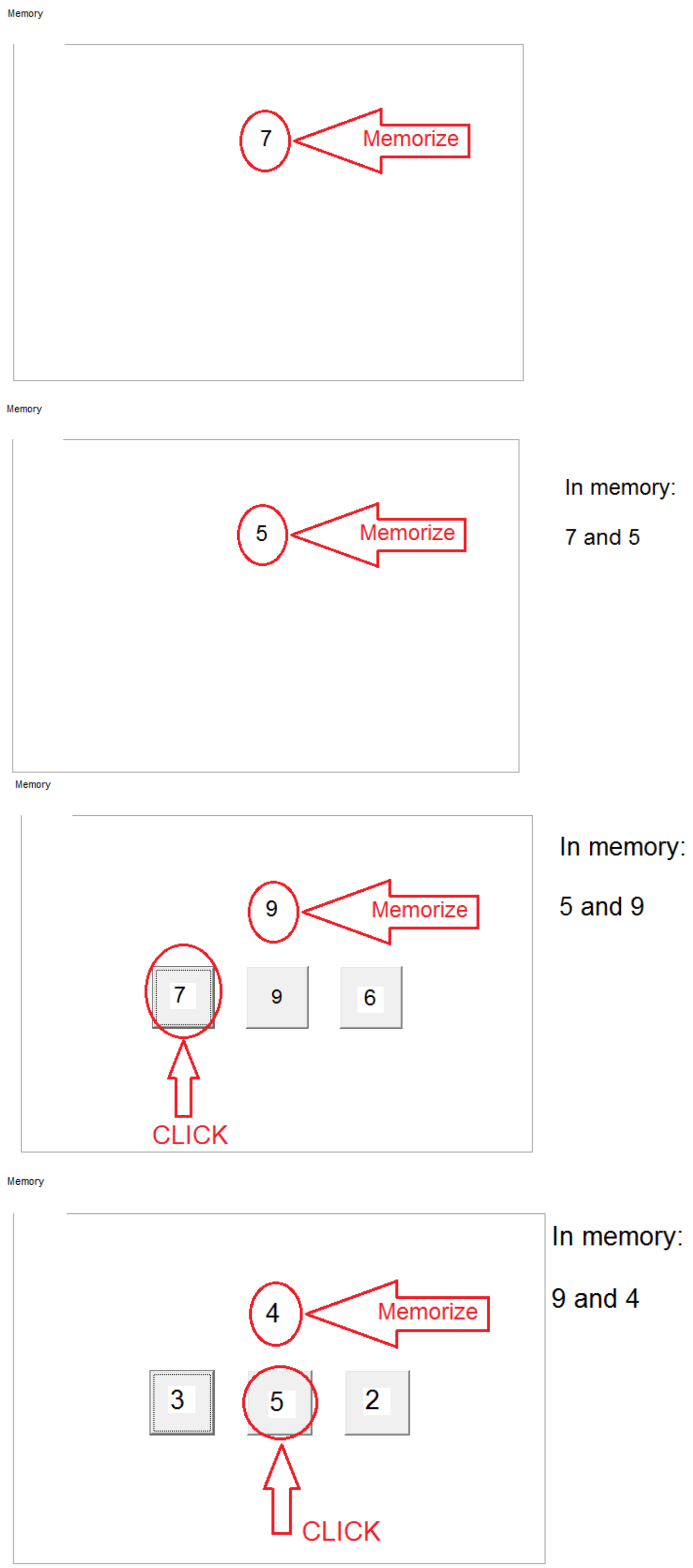

Figure 3.6 Screenshots of the hard interruption.

Interruptions were triggered randomly on mouse-click events, and could occur at any given time during the primary task, between the first mouse click and the completion of the order.

Participants were interrupted on 24 trials out of 50, with 12 interruptions for each Information access-cost condition. Interruptions were distributed across the 50 trials, so that the participant could practice once on each interruption during the 5 practice trials. During the 20 non-practice trials, the remaining 10 interruptions were distributed randomly. Interruptions lasted for a fixed duration of 30 seconds, regardless of the progression in the interruption. This decision acted as a safeguard in case the participant was not able to complete the hard interruption, and to ensure that interruptions could not be discarded prematurely.

The performance on an interruption has no impact on the outcome of the experiment; as participants were instructed to keep going through send back tasks until the interruption stopped. Participants were therefore blinded from this information, so that they would immerse in the interruption as they would with a real-life situation.

By crafting the entire experiment from the ground up using a single GUI platform, full control was maintained over the tasks, timing and interruptions of the trials, and did not allow for potential disturbances from other devices to interfere with the procedure. Introducing a mobile device available commercially would have created a cofounding variable with potential users as part of the participants. Conditioning and training effect would be likely to introduce bias in the participants' behaviour. Introducing an alert in the design of our experiment represents a threat of cofounding variable, considering the varying degrees of alert habit that some participant may have over others. Depriving the users of alerts will likely accentuate the impact of interface cues, making them easier to identify.

Procedure

Participants arrived in their corresponding timeslots, and were welcomed into the lab, asked to sign the consent form and seated in a cubicle. Participants were shown an instruction video of 5 minutes explaining the tasks, the interruptions, the commands available to them and the procedure of the trials. The video instructed participants on the primary packaging task, how to access the instructions, and how to navigate in the menus to complete the order. They were also instructed on the interruptions, both easy and hard. Participants were not told that the interruptions would last for a fixed amount of time regardless of their performance, to ensure continuous focus and avoid that the subject would simply wait for the interruption to be over. Showing a video ensured rigor in the procedure as well as maintaining the blind conditions intact for all participants. Participants were asked for any questions or clarifications needed after watching the video and before performing the experiment. They were asked to turn off their phones and other devices. The keyboard was removed from the cubicle, and the experiment code was launched by the researcher and switched to full-screen to avoid interruptions or exit from the application.

Participants performed 5 practice trials after which 20 regular trials were performed. After the first 25 trials, the information access cost condition changed (The order of the information access cost condition was randomly assigned and balanced across participants). Again, 5 practice trials allowed for participants to practice the new conditions, after which 20 regular trials were performed, coming to a total of 50 trials per participants. The experiment lasted for approximately 1 hour. Once the last trial was completed, the screen displayed a completion message and the participants were told to exit the cubicle and alert the researcher. Participants were paid and escorted out of the lab.

A total of 16 participants ran the experiments, with a total amount of trial of 800. Of the total 800, 160 were practice trials, leaving a remaining 640 trials. The study considered only interrupted trials, 320 in total.

Results

We will now present the results of our experiment, looking at each dependent variable, and their variations. The raw data were the sequence of events of the entire duration of the experiment. Using the R statistical tool, data were checked for inconsistencies and aggregated to produce a file containing reports for each dependant variable. Data were filtered for distribution and error assuming normal distribution, any value outside of 4 standard deviations was considered an outlier and excluded from the analysis. Effects were judged significant if they reached a .05 significance level. A 2x2x2 mixed factorial ANOVA design was used for analysis, using the variables of placekeeping elements (Visible, Invisible), information access-cost (HighCost, LowCost) and interruption demand (HighDemand, LowDemand).

Total task time

Trials took on average 78.8 seconds to be completed, with a standard deviation of 12.67 seconds. The first significant effect to note is the access to information. Participants took on average 16 seconds more to complete trials when the cost of accessing information was high (M=86.8 s, SD =15.19 s), F (1,14) =35.37, p <.05. When the cost of information was low, the average task time was shorter (M=70.9, SD=10.14s). This corresponds to an increase of 22.4% in total trial time.

Results show that trial time was on average longer when participants had PK elements present (M=84s, SD = 8.22 s) than when PK elements were absent (M=73.7 s, SD =17.11 s), $F(1,14) = 1.8$, p <.2. This result shows strong significance and is the second strongest effect on total completion time. Interruption demand had very little effect on the total task time, with an average task time of 78.5s (SD= 14.03s) for when the trial was interrupted by a complex interruption, and 79.1 seconds (SD=11.31s), F (1,14)=0.126,p=0.728. This effect is considered insignificant.

When the two primary variables are compared, the results show that participants took the longest time with high access cost and PK elements invisible (M=91.2 s, SD=19.89s) and only 65 seconds (SD=5.95s) with low access cost and placekeeping elements visible.

We note that the presence of placekeeping elements mitigated the effects of interruptions. In high demand interruptions the total trial time went from 82.2s (SD= 14.48s) when placekeeping elements were absent, to 74.8s (SD=8.14s) when placekeeping elements were present on the interface, $F(1,14)=3.04$, $p<.1$.

The same effect occurs in low demand interruptions, with an average time of 85.7s (SD=19.74s) with PK elements absent, and a much shorter time of 72.5s (SD=8.31s).

When mixing the interruption levels and the information access cost, we note that a reduced cost of access to information mitigated the interruption effects $F(1,14)=2.7$, $p<.13$. In high demand interruptions, low access cost reduced the total task time (M=68.7s, SD= 7.74s) compared to high access cost (M=88.4s, SD=14.88s). A similar effect can be observed for low demand interruptions, with a total trial time of 85.2 seconds with high access cost (SD=15.5s), compared to 73.1 seconds with low access cost (SD=12.55s).

Resumption lag

Resumption lag was measured by the time duration between the end of an interruption and the first mouse click. This corresponds to the time spent to "collect one's thoughts" (E. Altmann, 2004) and answer the questions "where am I?" and "What was I doing?". The mean resumption lag was 2.39 seconds (SD =1.52s). A longer resumption lag for high information cost (M=2.57, SD=1.63s) compared to low information access cost (M=2.21, SD=1.41s) can be noted; however this difference carries an insignificant weight. $F(1,14)=0.65$.

Contrary to expectations, the level of difficulty of the interruption a very little impact on the time it took participant to return to the primary task. The resumption lags are extremely close between an easy interruption (M=2.472, SD=1.93s) and a hard interruption (M=2.309, SD=1.1s).

The main effects on interruption lags can be found when observing mixed conditions. When measured across the different levels of interruption demands, the effect of placekeeping cues accentuates to reach significance, $F(1,14)=4.01$, $p=.06$. Placekeeping cues had a considerable impact in high demand interruptions, generating a much longer resumption lag when present (M=2.6, SD=1.21s) than when they were not on the interface (M=2.02s, SD=0.99s). This may indicate that participants were overwhelmed by the amount of information on the screen upon resuming from a hard interruption, and suggests a “clutter effect”.

Placekeeping elements had a reverse effect in the presence of low demand interruptions, greatly reducing the resumption lag when present (M=2.04, SD=0.8s) by nearly a second compared to when they were not present on the interface (M=2.91s, SD=3.06s). These results are consistent across different levels of information access-cost.

Instruction visit counts

Participants visited the instruction screen an average of 2.17 times (SD=0.71) over all the measured trials. The access cost to information was the main effect on the number of times the instruction was visited $F(1,14)=21.54$. With a reduced cost of access, participants accessed the information significantly more (M=2.79, SD= 0.95) compared to high cost (M=1.57, SD= 0.47) with a factor of 1.78.

The complexity of interruptions had very little impact on the instruction visit count, with 2.23 visits in the case of high demand interruptions (SD=0.74) and 2.125 visits when the trial was interrupted by an easy interruption (SD=0.7). Placekeeping elements had no significant impact either, with very little difference between the presence of their presence (M=2.17, SD=0.69) or their absence (M=2.19, SD=0.74).

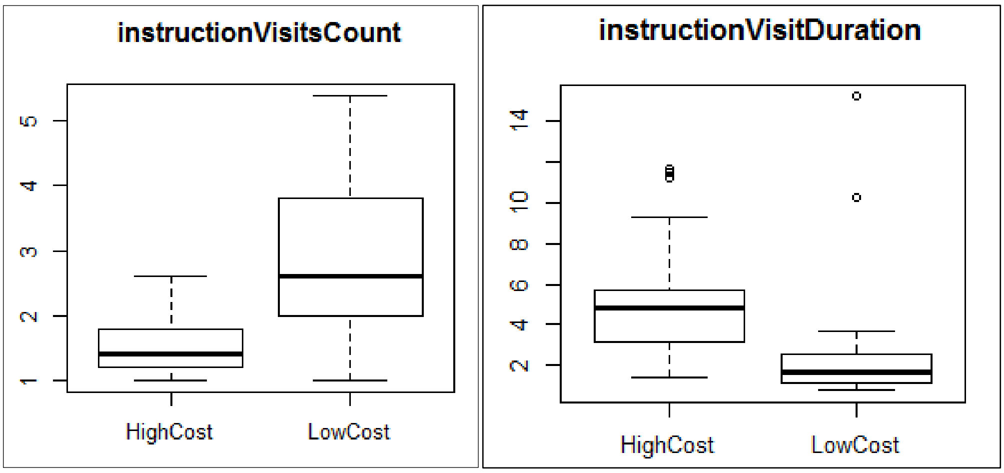

Figure 3.6 Charts showing the impact of Information access cost on instruction visit counts and instruction visit duration

	HighCost	LowCost	Ratio	
Visit counts	1.57 visits	2.79 visits	0.56	Half as many visits
Visit duration	5.05 seconds/visit	2.46 seconds/visit	2.05	Twice as long
Total time	**7.92 seconds**	**6.86 seconds**		

Table 3.2. Comparison of instruction visits depending on information access cost.

Instruction visit duration

The average visit to the instruction screen lasted 3.75 seconds (SD=1.57). On average, participants spent nearly twice as much time on the instruction sheet when the access cost was high (M=5.05s, SD=2.17s), when visits to easy-access information lasted 2.46 seconds (SD=0.97s). This constitutes the strongest effect on instruction visit duration, with high significance. $F(1,14)=35.37$, $p<.05$.

Interruption complexity had an insignificant impact on the duration of instruction visits with 3.77 seconds per visit (SD=1.72s) for high demand interruptions, and 3.74 seconds (SD=1.42s) for low demand interruptions. Placekeeping elements did not influence the amount of time spent visiting instructions, with an average visit of 3.67 seconds (SD=1.63s) when PK elements were visible, and 3.83 seconds (SD=XXs) hen PK elements where invisible.

When comparing information access cost and placekeeping information factors, and interesting phenomenon occurred. In a situation of higher mental workload, the presence of placekeeping elements did not mitigate the high cost, but in fact increased the duration by 1.02 seconds (SD=2.55s). The reverse effect occurred when information was easily accessible, placekeeping elements contributed to a decreased in the instruction visit duration of 1.34 seconds, (SD=0.71s). This mixed effect is significant at *F*(1,14)=7.36, *p*=.017.

	Total task time			Instruction visit counts			Instruction visit duration			Resumption lag	
Source	MSE	F		MSE	F		MSE	F		MSE	F
Information Access cost (IAC)	4041	35.36**		23.77	21.54**		107.33	35.37**		0.06	0.003
Placekeeping elements (PK)	1684.6	1.803		0.006	0.002		0.41	0.02		689	16.52**
IAC x PK	36	0.58		0.6	0.54		22.35	7.36**		0.063	0.003
**p>.01.											

Table 3.3 Means and significance of results for dependant variables.

Error rates

Measuring errors was another way of assessing the impact of UI elements on primary task and interruptions. Overall, 1.17 errors were made per trial (SD=0.31). Participants made 50% more errors in a high information cost condition (M=1.41, SD=0.33) than with low cost of information (M=0.938, SD=0.29). However, the significance of this effect is above the threshold, *F*(1,14)=0.39. Easy interruptions yielded more errors (M=1.25, SD=0.34) than harder ones (M=1.09, SD=0.28), *F*(1,14)=0.33.

Placekeeping cues had an effect of similar magnitude, *F*(1,14)=0.76, reducing the amount of errors to 0.84 (SD=0.2) when visible, compared to 1.5 errors per trial (SD=0.42) when invisible on the interface. This effect was consistent across the different levels of Information access-cost, the stronger effect being when information was harder to access, with an error rate going from 1.88 errors per trial (SD=0.41) with no placekeeping elements and high information cost, to 0.94 errors per trial (SD=0.25) with placekeeping elements visible.

Number of subtasks revisits

Subtasks revisits counts the number of times a participant re-accessed the lower level of the menu to verify or change an item of the order. On the whole, subtasks were revisited an average of 4.3 times per trial (SD=0.86).

The presence of placekeeping elements greatly affected this variable *F*(1,14)=16.52, *p*<.01. As one might have expected, placekeeping elements made a clear impact on the number of task revisits, with less than 1 revisit per trial with PK elements visible (M=0.94, SD=0.23) for 7.5 revisits per trial with PK elements invisible (M=7.5, SD=1.49).

Task strategy

We present here a breakdown of time spent on each screen of the interface, and the impact of our variables on this allocation of attention. The goal of this measure was to observe the amount of time spent on the main screen and on the instructions screen.

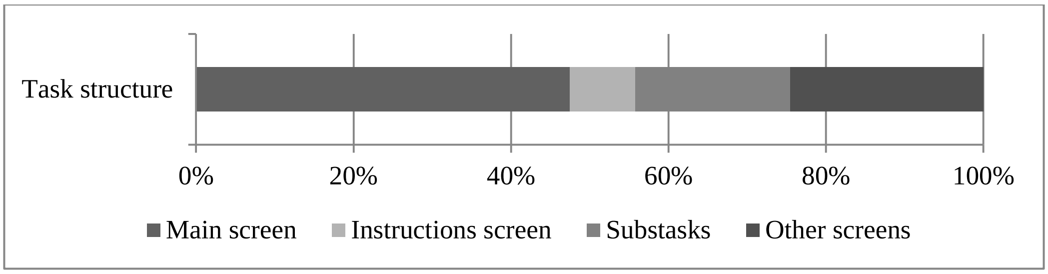

Figure 3.7 Breakdown of time spent on each screen during trials.

On average, Participants spent 37.45 seconds on the main screen (SD=11.16s). The biggest effect on this duration is the cost of access to information. Our independent variables both had significant effects on the time spent on each screen.

The information access cost significantly shifted this time allocation. When information was harder to access, participants spent less time on the main task (M=34.7s, SD=13.15s) $F(1,14)=5.03$, $p<.05$ and more time on instructions (M=7.55, SD=0.82s) than with easy access, with an average of 40.1 seconds spent on the main screen (SD=9.17s) and 5.49 seconds on the instruction screen (SD= 1.01s).

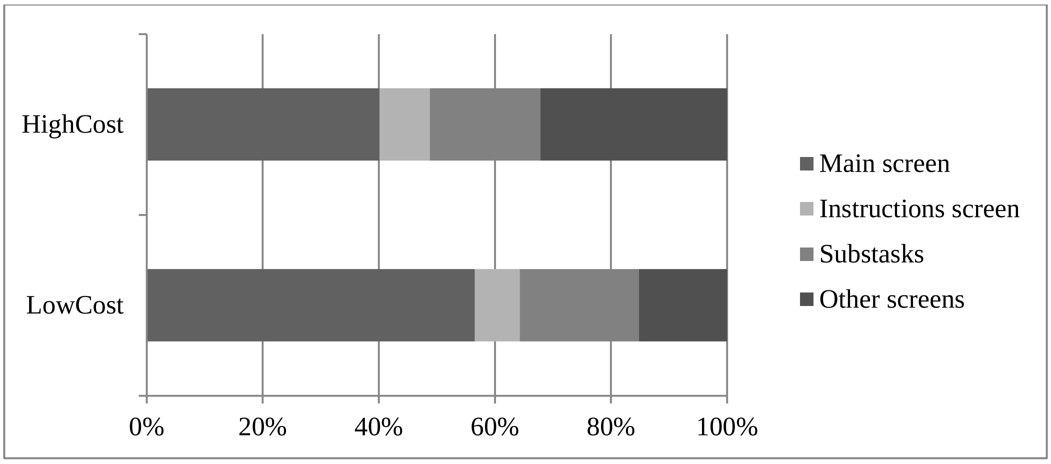

Figure 3.8 Impact of information access cost on time spent on each screen during trials.

The difficulty of interruption also changed the allocation of time between the main screen and the instructions. A harder interruption incurred a shorter time on the main screen (M=33.3s, SD=11.19s) compared to easy interruptions (M=41.5s, SD=11.13s). The impact of interruption demand on the time spent on the main screen is significant at $F(1,14)=8.56, p<.05$. Placekeeping elements also improved the time spent on the main task screen; however, these results did not reach statistical significance.

Post resumption behaviour

Interruptions were triggered at random moments during a trial. It is therefore impractical to compare such data in terms of time duration. However, in our quest to investigate the moment of interruption, we can report the results of what actions were taken directly after the end of an interruption. In order to analyse the post-resumption behaviour, we dissected the number and nature of events happening between the end of an interruption and the end of the trial. To assess the impact of the presence of place-keeping cues and information access cost memory, we isolated elements that dealt with information retrieval and memory, such as the next visit to the instruction sheet, and other actions taken immediately after interruptions. Concretely, this was measured by the number of actions taken between the "End_Interruption" event and the "loading_InstructionVisit" event.

Overall, participants re-accessed the instruction sheet immediately after the end of an interruption in 42% of the trials. There was an effect if interruption demand on the occurrence of immediate re-access. With low demand interruptions, the instruction sheet was visited immediately in 37% of trials, and in 48% of the trials after hard interruptions. This difference of 11% confirms the possibility of memory decay in the case of a higher working memory load, present in the memory for goals framework (E. Altmann, 2002), and the functional decay theory (E. M. Altmann & Gray, 2000). In the event of an easy interruption (0-back) participants were 34% likely to consult the instruction sheet immediately after the end of an interruption.

In summary, time allocation and performance were greatly influenced by information access cost, and we have seen the presence of a trade-off with regards to instruction visit and visit duration. Placekeeping elements were instrumental in mitigating interruption effects and reducing the error-prone memory-based strategy.

DISCUSSION

Increasing the cost to access information generally encouraged a memory-based strategy, but resulted in negative effects on nearly all performance measures. It seems that in the case of higher information access-cost, participants increased the attention given to this information, spending more time accessing it, memorizing it, paying a considerable cost in their performance. A higher information cost led to more time spent on the instruction screen (excluding loading time) of roughly 16%. In this regard, our results confirm that an increased IAC encourages a more memory-based strategy and less reliance on the display (Duggan & Payne, 2001; W. D. Gray & Fu, 2001). However, a more memory-based strategy had detrimental effects on task performance, with longer total completion times, and a much higher error rate (50% higher). These findings are in line with results from other studies on the impact of IAC (W. Gray, 2000; W. D. Gray, 2004; P. Morgan & Patrick, 2009). We can confirm the presence of temporal cost-benefit trade-off (W. D. Gray et al., 2006), with the amount of visits being less than half in the high access cost condition, yet lasting nearly twice longer. While the decision to pursue a more memory based strategy is apparent, this did not result in better recall as suggested by Waldron (2007), and the soft-constraints hypothesis (P. L. Morgan & Patrick, 2010a). It seems that the effort to memorize and rehearse the goal had negative consequences on the performance in the task, with increased error rates and number of subtask redone. These results are consistent with the necessity of rehearsing and activating goals stipulated by the memory-for-goals framework (E. Altmann, 2002).

Our results strongly confirm the essential role of placekeeping elements to help resuming after an interruption. Globally, these elements mitigated the reliance on memory thus resulting in fewer errors on the primary task. These results provide novel empirical evidence of their positive role, in complement to studies already suggesting the reduction in post-completion errors when such cues are present (Chen, Ratwani, & Trafton, 2010b), providing help to users in making fewer errors, and spending less time revisiting the instruction screen.

Considering these results with the soft constraints hypothesis, we can suggest several things. Firstly, a memory-based strategy in navigation has a negative impact on performance, as we can see that the number of subtasks revisited is more than double when these environmental cues are absent. Furthermore, the number of errors made was also significantly higher in the absence of these cues. These findings suggest that placekeeping elements and environmental cues should not be considered for use in soft constraints, as their presence provides vital help in situations of high mental workload. In our study, global placekeeping elements provided explicit links to the task environment, and confirmed their priming roles, as suggested by the memory-for-goals framework and empirical studies (E. Altmann, 2002; Trafton et al., 2003).

While they did contribute to fewer errors, the resumption lag was increased when global placekeeping elements were present. This may suggest that as participants were relying on the interface to help them resume, and as they adopted more display-based strategies, they might have experienced an overwhelming amount of environmental cues, and perhaps a sense of clutter. These mixed effects partly confirm the necessity of environmental cues on interfaces, but at the same time, provide support for the soft constraints hypothesis (W. D. Gray et al., 2006), seeing how the absence of placekeeping elements reduced resumption lags. In our case, reducing cues could avoid clutter when users face high demand interruptions.

The analysis of time allocated on each screen highlights the increased attention given to information when it is not easily available. The decision to make fewer visits and spend more time on each visit is clearly a poorer strategy as it resulted in longer total completion times and more errors. These results corroborate previous findings linking higher information access cost to poorer task performance (P L Morgan et al., 2009).

Looking at performance metrics, we note that overall, the level of complexity of the interruption had very little impact, with similar times in total task time, similar error rates and interruption lags, contrary to previous findings (D M Cades et al., 2007; D. M. Cades et al., 2008). No significant differences in task performance were noted either. Our findings concur with other works suggesting little impact of interruption complexity on total task time (Zijlstra, Roe, Leonora, & Krediet, 1999) and little resumption time difference between different levels of difficulty in n-back memory tasks (Lovett et al., 2000). The level of significance of these results does not qualify them to be main findings. Manipulating interruption complexity helped us highlight and verify the general effects of our other variables. Using a harder interruption showed that information access and placekeeping elements greatly increased or mitigated error rates. In interruptions of high demand, visible placekeeping elements completely neutralized the higher cost of information, and thus compensated for priming goal state.

Limitations

We discuss here the potential issues with our study. We consider the implications of each issue and how they relate to theory and the practical validity of our results.

The chosen high information cost of 10 seconds is clearly very high compared to the real-world situations it was supposed to mimic. Page loading times, task switching and other lockouts rarely last this long, but considering that switching from one task to another also depends on the skill level of a user and hardware capacity, this loading time is not entirely unrealistic. Choosing such a loading time prevented us from exploring the suggested benefits of soft constraints (P. L. Morgan & Patrick, 2010b) as these fall in a much smaller scale (less than half a second). We also realize that a cost of 10 seconds to access information may have overpowered other factors. What we argue is that such a high cost still holds a level of ecological validity, and helped in the experimental observations, in accentuating the consequence of such cost, and highlight the behaviour strategies employed by the participants. We do recognize the unrealistic nature of the chosen cost, yet we defend that it was the right choice to explore the impact in behaviour in an experimental context.

A second concern of this study was the clear establishment of goals in the experiment. The only clear goal for participants was to get the order right. They were free to revisit the instruction screen as many times as needed, and could restart the primary task until they got the order right. Similarly, no performance goal was attached to the interruptions. We chose not to associate a performance objective to the interruption because the objective of this interrupting task was simply to load the working memory of the participants, in order to observe the impact of interface elements on their behaviour. The ANOVAS on other variables did not indicate any confounding effect, but oral testimonies from participants indicated a feeling of struggle and frustration when faced with high demand interruption. As we saw however, this feeling did not translate into significantly poorer task performance.

We realize that the literature and the current environment point to the fact that most interruptions in the day of an office worker come from an external device (Karlson, Iqbal, Meyers, & Ramos, 2010; Oulasvirta et al., 2005). However, interruptions stemming from the same device as the primary task are very frequent, and furthermore, the convergence of technology and multi-use devices are increasing the frequency of primary tasks and interruptions taking place on the same device. We believe that setting the interruption to come from the same device as the primary task does not infringe on the ecological validity of our research, and it allows for far greater precision in our measurements.

Implications and future directions

The results of this study show that individuals were able to adapt their strategy in response to different conditions; we must insist that being locked out of a piece of information had a great impact on task performance. The tendency for full screen and more immersive layouts increases the cost to access information, and interface designers must be aware that accessing information on other screens must be kept relatively easy, otherwise task times are likely to build up, and so will user frustration. Our findings also suggest that a memory-based strategy will contribute to a loss of focus on the primary task. This informs us that by making peripheral information easily accessible; a person can spend more time on the primary task. This finding carries implication for interface design for small screen devices such as phones and tablets, where the compromise between primary task controls and relevant information should be considered. Furthermore, in context where the primary task requires constant attention, such as driving or monitoring activities, designers should focus on maintaining the user present on the main screen, rather than spending time accessing other information.

In situations of increased memory load, placekeeping cues contribute to the construction of valid mental models and helpful in-the-world elements. Yet, designers must beware of the level of cognitive loading as to not create an overwhelming number of cues, in turn detrimental to resumption. We have seen how much interruptions can take the focus away from the primary task (time allocation and error level). Since interruptions are inevitable with modern devices, it is of paramount importance that users can rely on environmental cues on the interface to resume smoothly to their primary tasks.

Further research should be performed to investigate the impact of placekeeping elements on the trade-off between speed and accuracy. We recognize that the interruption performance in our primary task had very little weight on the overall results, and it may be of interest to link the two to identify a possible shift in the memory allocation trade-off.

CONCLUSION

A study was conducted to investigate the effects of information access cost and placekeeping information on behaviour. Participants were asked to perform trials of a primary task with varying levels of information access-cost and were interrupted regularly by secondary tasks, also varying in complexity. For some participants, environmental cues were present on the interface while others did not have these elements present.

The results of this study suggest that high information access cost has a negative impact on general task performance, and that placekeeping information are essential to keep a user on track with a primary task. When interrupted however, these elements may also generate clutter and lead to slower resumption. Providing the results of a controlled lab study, findings highlight the importance of placekeeping elements on an interface. We believe that in the light of current interface innovations, our research provides empirical guidance to design safer and more user-friendly systems.

REFERENCES

Alm, H., & Nilsson, L. (1995). The effects of a mobile telephone task on driver behaviour in a car following situation. *Accident analysis and prevention*, *27*(5), 707–715. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8579701

Altmann, E. (2002). Memory for goals: An activation-based model. *Cognitive science*, *26*, 39–83. Retrieved from http://www.sciencedirect.com/science/article/pii/S0364021301000581

Altmann, E. (2004). Task interruption: Resumption lag and the role of cues. *Proceedings of the 26th Annual Conference of the Cognitive Science Society* (pp. 43–48). Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA480333

Altmann, E. (2007). Timecourse of recovery from task interruption: Data and a model. *Psychonomic Bulletin & Review*, *14*(6), 1079–1084. Retrieved from http://www.springerlink.com/index/83R21171873H7236.pdf

Altmann, E. M., & Gray, W. D. (2000). Managing attention by preparing to forget. *Proceedings of the Human Factors and Ergonomics Society*. Retrieved from http://pro.sagepub.com/content/44/1/152.short

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. (2004). *An integrated theory of the mind. Psychological Review* (Vol. 111, pp. 1036–1060). American Psychological Association. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15482072

Anderson, J. R., & Lebiere, C. (1998). *The atomic components of thought*. (John Robert Anderson & C. Lebiere, Eds.)*Trends in Cognitive Sciences* (Vol. 3, p. 490). Erlbaum. doi:10.1016/S1364-6613(98)01250-9

Andrews, A. E., Ratwani, R. M., & Trafton, J. G. (2009). The Effect of Alert Type to an Interruption on Primary Task Resumption. *Proceedings of the Human Factors and Ergonomics Society 53rd Annual Meeting (HFES'09)*.

Avrahami, D. (2007). *Enhancing Technology-Mediated Communication: Tools, Analyses, and Predictive Models*. Carnegie Mellon University. Retrieved from http://reports-archive.adm.cs.cmu.edu/anon/anon/home/ftp/hcii/CMU-HCII-07-102.pdf

Back, J., Brumby, D. P., & Cox, A. L. (2010). Locked-out : Investigating the Effectiveness of System Lockouts to Reduce Errors in Routine Tasks. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*.

Band, G., Jolicœur, P., Akyürek, E., & Memelink, J. (2006). Integrative views on dual-task costs. *European Journal of Cognitive Psychology*, *18*(4), 481–492. doi:10.1080/09541440500422675

Baron, R. S. (1986). Distraction-Conflict Theory: Progress and Problems. (Psychology, Ed.)*Advances in Experimental Social Psychology*, *19*(1), 1–40. doi:10.1016/S0065-2601(08)60211-7

Baxter-Reynolds, M. (2012). Windows 8 means the era of overlapping windows is on the way out. *The Guardian*. Retrieved from http://www.guardian.co.uk/technology/blog/2012/jul/06/windows-8-overlapping-windows-out

Bloom, B. S. (1984). *Taxonomy of Educational Objectives Book 1: Cognitive Domain*. Addison Wesley Publishing Company. Retrieved from http://www.amazon.com/Taxonomy-Educational-Objectives-Book-Cognitive/dp/0582280109

Cades, D M, Trafton, J. G., Davis, B., Boehm-Davis, D. A., & Monk, C. A. (2007). Does the Difficulty of an Interruption Affect our Ability to Resume? *Human Factors and Ergonomics Society Annual Meeting Proceedings* (Vol. 51, pp. 1–5). Human Factors and Ergonomics Society. Retrieved from http://www.ingentaconnect.com/content/hfes/hfproc/2007/00000051/00000004/art00019

Cades, D. M., Werner, N., Boehm-Davis, D. a., Trafton, J. G., & Monk, C. a. (2008). Dealing with Interruptions can be Complex, but does Interruption Complexity Matter: A Mental Resources Approach to Quantifying Disruptions. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 52, pp. 398–402). doi:10.1177/154193120805200442

Carroll, J. M. (2003). *HCI Models, Theories, and Frameworks: Toward a Multidisciplinary Science (Interactive Technologies)* (p. 576). Morgan Kaufmann. Retrieved from http://www.amazon.co.uk/HCI-Models-Theories-Frameworks-Multidisciplinary/dp/1558608087

Chen, J. M., Ratwani, R. M., & Trafton, J. G. (2010a). The Effect of Interruptions and Global Placekeeping on Postcompletion Error Rates. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *54*(4), 463–467. doi:10.1177/154193121005400440

Chen, J. M., Ratwani, R. M., & Trafton, J. G. (2010b). The Effect of Interruptions and Global Placekeeping on Postcompletion Error Rates. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *54*(4), 463–467. doi:10.1177/154193121005400440

Coiera, E. (2012). The science of interruption. *BMJ quality & safety*, (March). doi:10.1136/bmjqs-2012-000783

Cutrell, E., Czerwinski, M., & Horvitz, E. (2001). Notification, Disruption, and Memory: Effects of Messaging Interruptions on Memory and Performance. In M. Hirose (Ed.), *Proceeding of 8th International Conference on HumanComputer Interactions INTEHumanComputer Interactions INTE* (Vol. Tokyo, Jap, pp. 263–269). IOS Press. Retrieved from http://eprints.kfupm.edu.sa/53531/

Czerwinski, M., Horvitz, E., & Wilhite, S. (2004). A diary study of task switching and interruptions. *Proceedings of the 2004 conference on Human factors in computing systems - CHI ’04* (Vol. 6, pp. 175–182). New York, New York, USA: ACM Press. doi:10.1145/985692.985715

Dismukes, K., & Nowinski, J. (1996). Prospective Memory , Concurrent Task Management , and Pilot Error. (A. Kramer, D. Wiegmann, & A. Kirlik, Eds.)*Field Studies*, 225–236. Retrieved from http://books.google.com/books?hl=en&lr=&id=wEUi-bEaqWcC&oi=fnd&pg=PA225&dq=maylor+1996+prospective+memory&ots=50Kl_1IL2u&sig=8C5zwoZQZK2nP9r05ojx67Ffe48

Dror, I., & Harnad, S. (2008). Offloading Cognition onto Cognitive Technology. In I. E. Dror & S. R. Harnad (Eds.), *Cognition* (pp. 1–23). John Benjamins. Retrieved from http://eprints.soton.ac.uk/59246/

Duggan, G. B., & Payne, S. J. (2001). Interleaving reading and acting while following procedural instructions. *Journal of experimental psychology Applied*, *7*(4), 297–307. Retrieved from http://dx.doi.org/10.1037/1076-898X.7.4.297

Edwards, M. B., & Gronlund, S. D. (1998). Task Interruption and its Effects on Memory. *Memory*, *6*(6), 665–687. Retrieved from http://interruptions.net/literature/Edwards-Memory98.pdf

Gillie, T., & Broadbent, D. (1989). What makes interruptions disruptive? A study of length, similarity, and complexity. *Psychological Research*, *50*(4), 243–250. doi:10.1007/BF00309260

Gray, W. (2000). The nature and processing of errors in interactive behavior. *Cognitive Science*, *24*(2), 205–248. doi:10.1016/S0364-0213(00)00022-7

Gray, W. D. (2004). Soft Constraints in Interactive Behavior: The Case of Ignoring Perfect Knowledge In-The-World for Imperfect Knowledge In-The-Head. *Cognitive Science*, *28*(3), 359–382. doi:10.1016/j.cogsci.2003.12.001

Gray, W. D., & Fu, W. (2001). Ignoring Perfect Knowledge In-The-World for Imperfect Knowledge In-The-Head : Implications of Rational Analysis for Interface Design. *CHI Letters*, *3*(3), 112–119. doi:10.1145/365024.365061

Gray, W. D., Sims, C. R., Fu, W.-T., & Schoelles, M. J. (2006). The soft constraints hypothesis: a rational analysis approach to resource allocation for interactive behavior. *Psychological review*, *113*(3), 461–82. doi:10.1037/0033-295X.113.3.461

Ho, C.-Y., Nikolic, M. I., Waters, M. J., & Sarter, N. B. (2004). Not Now! Supporting Interruption Management by Indicating the Modality and Urgency of Pending Tasks. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *46*(3), 399–409. doi:10.1518/hfes.46.3.399.50397

Hodgetts, H M, & Jones, D. M. (2005). Interrupting problem solving: Effects of interruption position and complexity. *Past Reflections Future Directions Proceedings of the 40th Australian Psychological Society Annual Conference Melbourne Australia* (pp. 128–132). Citeseer. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.80.2608&rep=rep1&type=pdf

Hodgetts, Helen M, & Jones, D. M. (2006). Interruption of the Tower of London task: support for a goal-activation approach. *Journal of experimental psychology General*, *135*(1), 103–115. doi:10.1037/0096-3445.135.1.103

Iqbal, S. (2007). Disruption and recovery of computing tasks: field study, analysis, and directions. *SIGCHI conference on Human factors in computing*, 677–686. Retrieved from http://dl.acm.org/citation.cfm?id=1240624.1240730

Iqbal, S. T., & Horvitz, E. (2007). Disruption and Recovery of Computing Tasks : Field Study , Analysis , and Directions, 677–686.

Jacob, R. J. K., Girouard, A., Hirshfield, L. M., Horn, M. S., Shaer, O., Solovey, E. T., & Zigelbaum, J. (2008). Reality-based interaction: a framework for post-WIMP interfaces. (M. Burnett, M. F. Costabile, T. Catarci, B. De Ruyter, D. Tan, M. Czerwinski, & A. Lund, Eds.)*Generations Journal Of The American Society On Aging*, *301*(2), 201–210. doi:10.1145/1357054.1357089

Jetter, C., Gerken, J., & Reiterer, H. (2011). Natural user interfaces: Why we need better model-worlds, not better gestures. *CHI '11: Proceedings of the 2011 annual conference on Human factors in computing systems* (pp. 1–4). Retrieved from http://kops.ub.uni-konstanz.de/handle/urn:nbn:de:bsz:352-136527

Kaber, D. B., Alexander, A. L., Stelzer, E. M., Kim, S.-H., Kaufmann, K., & Hsiang, S. (2008). Perceived clutter in advanced cockpit displays: measurement and modeling with experienced pilots. *Aviation space and environmental medicine*, *79*(11), 1007–1018. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18998481

Karlson, A., Iqbal, S., Meyers, B., & Ramos, G. (2010). Mobile taskflow in context: a screenshot study of smartphone usage. *Proceedings of the 28th international conference on Human factors in computing systems* (pp. 2009–2018). Retrieved from http://dl.acm.org/citation.cfm?id=1753631

Lovett, M. C., Daily, L. Z., & Reder, L. M. (2000). A source activation theory of working memory: cross-task prediction of performance in ACT-R. *Cognitive Systems Research*, *1*(2), 99–118. doi:10.1016/S1389-0417(99)00012-1

McKnight, A. J., & McKnight, A. S. (1993). The effect of cellular phone use upon driver attention. *Accident analysis and prevention*, *25*(3), 259–265. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8323660

Miyata, Y., & Norman, D. A. (1986). Psychological issues in support of multiple activities. (D. A. Norman & Draper, Eds.)*User centered system design*, 265–284. Retrieved from http://interruptions.net/literature/Miyata-Norman-86.pdf

Monk, C A. (2004). The effect of frequent versus infrequent interruptions on primary task resumption. *Human Factors and Ergonomics Society Annual Meeting Proceedings*, *48*(3), 295–299. doi:10.1177/154193120404800304

Monk, Christopher A, Boehm-Davis, D. A., & Trafton, J. G. (2004). Recovering from interruptions: implications for driver distraction research. *Human Factors*, *46*(4), 650–663. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15709327

Morgan, P L, Patrick, J., Waldron, S. M., King, S. L., & Patrick, T. (2009). Improving memory after interruption: exploiting soft constraints and manipulating information access cost. *Journal of experimental psychology. Applied*, *15*(4), 291–306. doi:10.1037/a0018008

Morgan, P. L., & Patrick, J. (2010a). Designing Interfaces that Encourage a More Effortful Cognitive Strategy. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *54*(4), 408–412. doi:10.1177/154193121005400429

Morgan, P. L., & Patrick, J. (2010b). Designing Interfaces that Encourage a More Effortful Cognitive Strategy. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *54*(4), 408–412. doi:10.1177/154193121005400429

Morgan, P., & Patrick, J. (2009). Increasing Information Access Cost to Protect Against Interruption Effects during Problem Solving. *csjarchive.cogsci.rpi.edu*, 949–954. Retrieved from http://csjarchive.cogsci.rpi.edu/proceedings/2010/papers/0304/paper0304.pdf

Norman, D. A. (1986). Cognitive Engineering. In D. A. Norman & S. W. Draper (Eds.), *User Centered System Design: New Perspectives on Human-Computer Interaction* (pp. 31–61). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Norman, D. A. (2010). Natural User Interfaces Are Not Natural. *interactions*, *17*(3), 6–10. doi:10.1145/1744161.1744163

Oulasvirta, A., Tamminen, S., & Roto, V. (2005). Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI. *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 919–928). Retrieved from http://dl.acm.org/citation.cfm?id=1055101

Robertson, T. J., Prabhakararao, S., Burnett, M., Cook, C., Ruthruff, J. R., Beckwith, L., & Phalgune, A. (2004). Impact of interruption style on end-user debugging. *Proceedings of the 2004 conference on Human factors in computing systems CHI 04*, *6*(1), 287–294. doi:10.1145/985692.985729

Rosenholtz, R., Li, Y., Mansfield, J., & Jin, Z. (2005). Feature congestion: a measure of display clutter. *CHI Conference Proceedings* (pp. 761–770). {ACM} Press. doi:10.1145/1054972.1055078

Rudzka, K., Arif, A. M., & Berreau, L. M. (2000). Impact of Information Presentation Modes on Online Shopping: An Empirical Evaluation of a Broadband Interactive Shopping Service. *Journal of Organizational Computing Electronic Commerce*, *10*(1), 1. Retrieved from http://search.ebscohost.com.abc.cardiff.ac.uk/login.aspx?direct=true&db=buh&AN=3320048&site=ehost-live

Salvucci, D. D., & Bogunovich, P. (2010). Multitasking and monotasking: the effects of mental workload on deferred task interruptions. *Proceedings of the 28th international conference on Human factors in computing systems* (pp. 85–88). ACM. Retrieved from http://dl.acm.org/citation.cfm?id=1753340

Speier, C., & Vessey, I. (2003). The Effects of Interruptions, Task Complexity, and Information Presentation on Computer-Supported Decision-Making Performance. *Decision Sciences*, *34*(4), 771–798. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1540-5414.2003.02292.x/full

Trafton, J. G., Altmann, E. M., Brock, D. P., & Mintz, F. E. (2003). Preparing to resume an interrupted task: effects of prospective goal encoding and retrospective rehearsal. *International Journal of Human-Computer Studies*, *58*(5), 583–603. doi:10.1016/S1071-5819(03)00023-5

Tuddenham, P., Kirk, D., & Izadi, S. (2010). Graspables Revisited : Multi-Touch vs . Tangible Input for Tabletop Displays in Acquisition and Manipulation Tasks. (E. D. Mynatt, D. Schoner, G. Fitzpatrick, S. E. Hudson, W. K. Edwards, & T. Rodden, Eds.)*Design*, 2223–2232. doi:10.1145/1753326.1753662

Waldron, S. M., Patrick, J., Morgan, P. L., & King, S. (2007). Influencing Cognitive Strategy by Manipulating Information Access. *The Computer Journal*, *50*(6), 694–702. doi:10.1093/comjnl/bxm064

Wigdor, D., & Wixon, D. (2011). *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture*. *Brave NUI World Designing Natural User Interfaces for Touch and Gesture* (p. 253). Morgan Kaufmann. doi:10.1016/B978-0-12-382231-4.X0001-9

Zijlstra, F. R. H., Roe, R. A., Leonora, A. B., & Krediet, I. (1999). Temporal factors in mental work: Effects of interrupted activities. *Journal of Occupational and Organizational Psychology*, *72*(2), 163–185. doi:10.1348/096317999166581