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The Effects of Interruptions, Task Complexity, and Information Presentation on Computer-Supported Decision-Making Performance

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ABSTRACT

Interruptions are a frequent occurrence in the work life of most decision makers. This paper investigated the influence of interruptions on different types of decision-making tasks and the ability of information presentation formats, an aspect of information systems design, to alleviate them. Results from the experimental study indicate that interruptions facilitate performance on simple tasks, while inhibiting performance on more complex tasks. Interruptions also influenced the relationship between information presentation format and the type of task performed: spatial presentation formats were able to mitigate the effects of interruptions while symbolic formats were not. The paper presents a broad conceptualization of interruptions and interprets the ramifications of the experimental findings within this conceptualization to develop a program for future research.

Subject Areas: Decision Making, Interruptions, and Information Presentation Formats.

INTRODUCTION

You are sitting at your desk working on a financial analysis or marketing report that is due tomorrow, when the phone rings. After taking the call, you return to your project only to discover that three e-mails have come in while you were on the phone and one is marked a priority. Will these interruptions affect the quality of your project deliverables? If so, are there features that can be designed into information systems that mitigate interruption effects?

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Both the academic and popular presses have concluded that interruptions permeate knowledge-worker environments (Mintzberg, 1973; Markels, 1997; Schmandt, Marmasse, Marti, Sawhney, & Sheeler, 2000). Knowledge workers perform a stream of disjointed activities (Carlson, 1951; Guest, 1956; Stewart, 1967) that occur at an unrelenting pace (Kurke & Aldrich, 1983; Mintzberg, 1973). Carlson (1951), examining the work life of managers, stated "All they knew was that they scarcely had time to start on a new task or sit down . . . before they were interrupted by a visitor or a telephone call" (pp. 73–74).

More recent studies continue to highlight the relationship between interruptions and knowledge-worker activities. For example, telephone interruptions and drop-in visitors have been identified as significant corporate time-wasters (Dahms, 1988), which knowledge workers often allow to take precedence over other activities (Jones & McLeod, 1986; Watson, Rainier, & Koh, 1991). E-mail interruptions may be more prevalent than phone and human interruptions, with studies reporting that knowledge workers in the United States send and receive an average of 204 emails per day (Pitney Bowes, 2000) and experience an average of six interruptions per hour in a typical work day (Pitney Bowes, 1998). Other evidence demonstrates that managers spend 10 minutes of every working hour responding to interruptions and do not return to their initial task 41% of the time (O'Conaill & Frolich, 1995). Thus, an interrupted work environment is commonplace for a typical knowledge worker.

Information systems are used increasingly to support knowledge-worker decision-making tasks, particularly when solving complex problems (Panko, 1992). These complex tasks typically involve high cognitive loads that require significant mental attention and effort and might therefore be susceptible to interference from interruptions (Baecker, Grudin, Buxton, & Greenberg, 1995). Further, "productivity" tools used in many organizations can actually instigate task interruptions—that is, e-mail or instant messaging services (Markels, 1997). Similarly, the spread of mobile telephones has brought with it the potential for continual interruptions from unwanted or ill-timed phone calls (Schmandt et al., 2000).

Given the detrimental influence of task complexity on computer-based decision making (Robinson & Swink, 1994; Crossland, Wynne, & Perkins, 1995; Swink & Robinson, 1997) and the likely negative influence of interruptions (Cellier & Eyrolle, 1992; Shiffman & Griest-Bousquet, 1992; Schuh, 1978), an important question is whether information systems can be designed to mitigate these effects (Rouncefield, Viller, Hughes, & Rodden, 1995). Prior research has identified information presentation as a factor affecting decision performance (DeSanctis, 1984; Tan & Benbasat, 1990; Vessey, 1991). Given the ease of changing presentation formats in most productivity-enhancing software packages, we focus on information presentation as a mechanism to help overcome these challenges. Understanding if and how information presentation formats can mitigate interruptions is therefore important to both designers and users of packaged software.

THEORY DEVELOPMENT AND HYPOTHESES

Interruptions have been defined as uncontrollable, unpredictable stressors that produce information overload, requiring additional decision-maker effort (Cohen, 1980). In addition, interruptions typically "require immediate attention" and "insist on action" (Covey, 1989, pp. 150–152). Thus, another person, object, or event creates an interruption, the timing of which is beyond a decision maker's control. Furthermore, an interruption breaks a decision maker's attention on a primary task and forces the decision maker to turn his or her attention toward the interruption—if only temporarily.

Prior Research Related to Interruptions

First we examine the research that has been conducted to date involving interruptions. We then describe interruptions in the context of both complex tasks and varying information presentation formats.

Distinction between interruptions and distractions

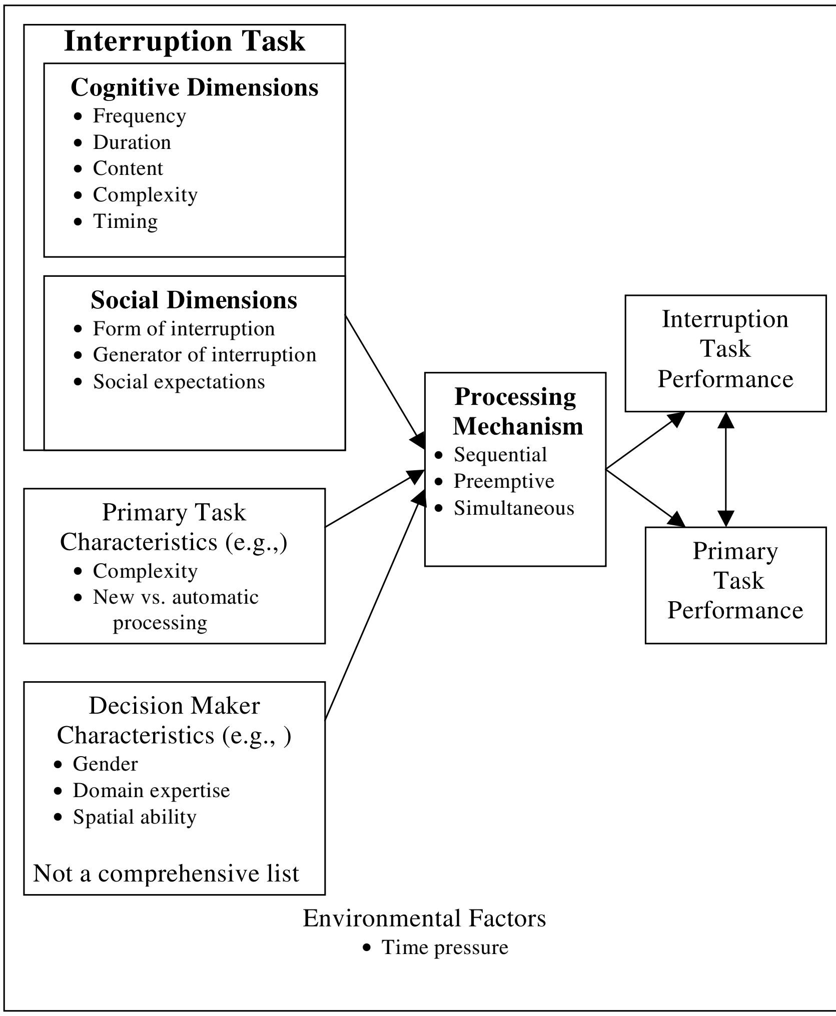
While there is limited prior research examining the influence of interruptions on decision performance, distraction conflict theory (DCT) describes a research stream investigating the influence of distractions (e.g., industrial noise or background music; see Eschenbrenner, 1971; Woodhead, 1965) on decision performance (Baron, 1986). The results from this literature form the basis for building the interruption/decision-making theory presented. First, however, we differentiate between distractions and interruptions and then present a framework of interruption characteristics.

In distinguishing between distractions and interruptions, we do so with reference to a primary activity; for example, a decision maker might examine a set of financial statements, write a report, and so on, that is the primary focus of his or her attention. Distractions and interruptions are similar in that they can both occur while a decision maker is performing a primary task. However, the manner in which distractions and interruptions are detected by sensory channels differs: distractions are detected by a different sensory channel from those of the primary task and may be ignored or processed concurrently with a primary task (Cohen, 1980; Groff, Baron & Moore, 1983); interruptions, however, use the same sensory channel for both the interruption and the primary task. Thus, decision makers cannot choose to ignore interruption cues, resulting in both capacity and structural interference (Kahneman, 1973). Capacity interference occurs when the number of incoming cues is greater than a decision maker can process. Structural interference occurs when a decision maker must attend to two inputs that require the same physiological mechanisms (e.g., attending to two different visual signals—a computer screen and a colleague entering an office). Thus, a decision maker must attend to and respond to interruptions while performing some other activity. These circumstances can place greater demands on cognitive processing resources than those available (Norman & Bobrow, 1975). In such cases, interruptions are likely to lead to loss of memory contents or confusion among information cues residing in memory, negatively influencing performance (Laird, Laird, & Fruehling, 1983).

Model of interruptions

Interruptions come in various types and forms and it is unlikely that all interruptions are equivalent in influencing decision making. There has been little research

Figure 1: Interruption framework.



formalizing interruptions (Moray, 1993). To better position the type of interruption we investigated here, an interruption framework (see Figure 1) was developed to differentiate interruptions along three dimensions: (1) cognitive processing characteristics such as the frequency, duration, content, complexity, and timing of the interruption (Czerwinski, Cutrell, & Horvitz, 2000; Eschenbrenner, 1971; Gillie & Broadbent, 1989; Speier, Valacich, & Vessey, 1999); (2) social characteristics of the interruption, which might affect how the decision maker responds to the interruption, including the form of the interruption (in-person versus phone), the person or object generating the interruption (level in the hierarchy), and social expectations that exist due to organizational or regional culture (Bond & Titus, 1983; Perlow, 1999; Robbins & DeNisi, 1994); and (3) processing mechanisms including sequential (process all events in order), preemptive (process interruptions as they occur and defer primary activity), and simultaneous (tries to attend to both activities simultaneously) (Kirmeyer, 1998). Although our focus is on interruptions, characteristics of the individual and the primary task, and the interaction of these factors, will also likely influence performance outcomes (DeSanctis, 1984).

These different interruption characteristics may result in the use of different processing mechanisms or varying degrees of cognitive disruption. For example, an urgent face-to-face interruption generated by a superior might disrupt cognitive processing of an ongoing task far more severely than when one's superior places a phone call to accomplish the same task. In this research study, our focus is on computer-generated interruptions (e.g., e-mail or instant messages) that require an immediate response.

Theoretical basis for interruptions

Distraction conflict theory (DCT) suggests that distractions facilitate performance on simple tasks and inhibit performance on complex tasks (Baron, 1986). The underlying premise behind DCT is that as distractions occur during simple tasks, stress increases and attention narrows, resulting in the possible dismissal or exclusion of irrelevant information cues, thus facilitating decision performance. However, as the number of information cues (i.e., complexity) increases (Payne, 1982; Wood, 1986), a decision maker's excess cognitive capacity decreases. The consequent narrowing of attention likely results in a decision maker processing fewer information cues, some of which may be relevant to completing the task successfully, which results in deteriorating performance. Finally, because interruptions use the same sensory channels as the primary task, interruptions may also result in the loss of working memory contents or confusion between cues in memory, which further inhibits decision performance (Norman & Bobrow, 1975). Empirical support for DCT has been demonstrated for distractions (Boggs & Simon, 1968; Hockey, 1970) and interruptions (Speier et al., 1999).

Interruptions and Task Complexity

The different effects of distractions and therefore interruptions on simple and complex tasks may be the result of the differing number of cues that must be processed and the number and the complexity of the individual processes required (Wood, 1986). Simple tasks require processing fewer cues (pieces of data) than complex tasks (Payne, 1982). Therefore, decision makers have ample cognitive resources to process simple tasks when interruptions occur and therefore do not need to change the way in which they process information. On the other hand, when processing complex tasks, decision makers minimize their expenditure of scarce cognitive resources, uncritically examining both relevant and irrelevant cues (Baron, 1986).

In addition to the degree of task complexity, tasks can also be characterized based on the type of cognitive processing needed to reach a solution: decision-making tasks require either manipulating discrete sets of symbols (symbolic tasks) or establishing relationships among those discrete sets of symbols (spatial tasks). We introduce the concept of symbolic and spatial tasks here to more fully articulate our hypotheses; the concepts themselves are explored more fully in a subsequent section. The crucial point here is that problem solvers/decision makers will seek to conserve resources when solving complex symbolic tasks, which otherwise consume large volumes of cognitive resources. We believe therefore that while interruptions will affect simple tasks, whether symbolic and spatial, in a similar manner, they will differentially influence symbolic and spatial complex tasks.

Effects of interruptions on simple tasks

Past research on simple tasks has found that when distractions occur, stress increases, causing decision makers to focus their attention on relatively few information cues. The focusing that results leads to more accurate solutions and faster task completion (Baron, 1986; Janis & Mann, 1977). This effect should occur regardless of the type of simple task performed. Therefore, we state the following hypotheses:

> H1a: For simple-symbolic tasks, decision accuracy will be higher when the task is interrupted compared to when the task is not interrupted.
>
> H1b: For simple-symbolic tasks, decision time will be faster when the task is interrupted compared to when the task is not interrupted.
>
> H2a: For simple-spatial tasks, decision accuracy will be higher when the task is interrupted compared to when the task is not interrupted.
>
> H2b: For simple-spatial tasks, decision time will be faster when the task is interrupted compared to when the task is not interrupted.

Effects of interruptions on complex tasks

Past research suggests that when interruptions occur, a decision maker's attention narrows and, as a result, processes fewer information cues. Complex tasks typically contain more information cues than simple tasks, with these cues being highly dependent on other cues and processes (Wood, 1986). Given the increased number and interdependence of these cues, narrowing one's attention, and therefore not processing some of the information cues that may be necessary for successful task completion, may result in deterioration of task performance. In addition to reducing the number of cues attended to, interruptions may encourage decision makers to use heuristics or opt for a satisfying decision, resulting in lower decision accuracy or, if heuristics are not used, longer decision time (Baron, 1986). Thus, as task complexity increases, interruptions increase perceived workload and stress (French, Caplan, & Harrison, 1982; Kirmeyer, 1988) and inhibit performance (Baron, 1986). Thus, we state:

> H3a: For complex-symbolic tasks, decision accuracy will be lower when the task is interrupted compared to when the task is not interrupted.
>
> H3b: For complex-symbolic tasks, decision time will be slower when the task is interrupted compared to when the task is not interrupted.

H4a: For complex-spatial tasks, decision accuracy will be lower when the task is interrupted compared to when the task is not interrupted.

H4b: For complex-spatial tasks, decision time will be slower when the task is interrupted compared to when the task is not interrupted.

Interruptions and Presentation Format

Prior research has identified information presentation format as a feature of information systems that influences decision performance (Bettman & Kakkar, 1977; DeSanctis, 1984; Vessey, 1991). The effects of information presentation format on decision making have led to the widely shared belief that the effectiveness of a specific presentation format depends on the task performed (Benbasat, Dexter, & Todd, 1986; DeSanctis, 1984; Jarvenpaa & Dickson, 1988; Tan & Benbasat, 1990; Vessey, 1991).

The theory of cognitive fit (CFT) provides a theoretical basis for understanding how information presentation formats support decision-making tasks (Vessey, 1991). A match or cognitive fit occurs when the information emphasized in a particular presentation format (symbolic or spatial) matches that required to most easily complete the task (symbolic or spatial). Tables (i.e., symbolic formats) are most appropriate for presenting discrete sets of symbols (e.g., a table of transportation departure and arrival times), while graphs (i.e., spatial formats) are most appropriate for depicting relationships among discrete sets of symbols (e.g., change in GDP over time, or the relationship among the performances of a number of sales regions).

Cognitive fit facilitates decision making because the problem-solving processes used to act on the problem representation are similar to those needed to solve the problem. Analytical processes (e.g., calculations) are used most effectively to act on symbolic formats and tasks, while perceptual processes (e.g., visual comparisons) are used most effectively on spatial formats and tasks (Vessey, 1991). Alternatively, when the information presentation format does not match the task, the decision maker must exert greater cognitive effort to transform the information into a form suitable for solving that particular type of problem (Vessey, 1994). This increased effort will result in decreased performance (i.e., decreased decision accuracy, increased decision time, or both).

Effects of information presentation format and interruptions on simple tasks

Prior research has demonstrated that decision makers narrow their attention to focus on relevant cues and are more likely to focus on “conspicuous” information when cognitive processing demands are high (Berlyne, 1970; Rabbit, 1964). How does this affect the processing of simple-spatial and simple-symbolic tasks? Simple-symbolic tasks are best supported with symbolic formats and analytical processing. Interruptions may lead to decision makers’ examining either fewer information cues or the most conspicuous ones. However, because decision makers have excess cognitive capacity when performing simple tasks, analytical processes can still be used effectively and decision makers should have ample cognitive resources to find and process the appropriate information cues. Symbolic data should continue, therefore, to provide the most accurate and efficient support when processing a simple-symbolic task even when interruptions occur.

Without interruptions, simple-spatial tasks are best supported by spatial information formats and perceptual processing, and this should also be true when interruptions occur. Using one's perceptual processes to focus on conspicuous information such as that easily identified in graphs should result in spatial information continuing to best support spatial tasks. We state the following hypotheses:

H5a: H5a: For simple-symbolic tasks, symbolic information presentation formats result in higher decision accuracy than spatial formats whether or not interruptions occur.

H5b: H5b: For simple-symbolic tasks, symbolic information presentation formats result in shorter decision time than spatial formats whether or not interruptions occur.

H6a: H6a: For simple-spatial tasks, spatial information presentation formats result in higher decision accuracy than symbolic formats whether or not interruptions occur.

H6b: H6b: For simple-spatial tasks, spatial information presentation formats result in shorter decision time than symbolic formats whether or not interruptions occur.

Effects of information presentation format and interruptions on complex tasks

As task complexity increases, decision makers experience higher cognitive loads and trade off decision accuracy against the time required to make the decision (Johnson & Payne, 1985). Decision makers typically seek to reduce effort (Beach & Mitchell, 1978), often by relying on perceptual processes, which consume less time, but are likely to result in reduced accuracy (Payne, Bettman, & Johnson, 1988; Vessey, 1994). Decision makers must evaluate the strategy they use to reach the desired outcome against their desire to reduce processing effort (e.g., determining the importance of 100% versus 90% accuracy when 90% accuracy can be determined in a fraction of the time). This choice influences the way in which decision makers process information.

As the complexity of a symbolic task increases, a point is reached at which decision makers can no longer use analytical processes regardless of the accuracy desired. This juncture occurs when the cognitive load is so high that decision makers do not have sufficient capacity to process information cues analytically. Complex tasks of this nature are known as limiting tasks (Johnson & Payne, 1985). The decision maker then uses perceptual problem-solving processes, which are best supported by spatial formats (Vessey, 1994).

In summary, a complex symbolic task at "moderate" levels of complexity should be more accurately and more quickly solved using tables rather than graphs. As task complexity increases, we expect that a level of complexity will be reached at which tables and graphs perform equally well, followed by a level at which graphs outperform tables as decision makers find it increasingly difficult to use symbolic processes and, as a result, seek to conserve effort at the expense of accuracy. Hence there is a crossover point at which more complex symbolic tasks are better supported by graphs than by tables. A further level of complexity is apparent in limiting tasks, which cannot be solved using analytical processes.

While complexity in and of itself can induce a crossover point that favors perceptual processing, environmental stresses such as interruptions and time pressure are likely to exacerbate the situation resulting in crossover at lower levels of task complexity. For example, when time pressure occurs during complex symbolic tasks, decision makers experience increased stress, resulting in more narrow information acquisition and selective use of information (Baron, 1986; Janis & Mann, 1977).

Prior research on the influence of time constraints and information presentation formats across different task environments has produced somewhat equivocal outcomes. Benbasat and Dexter (1985), for example, found that symbolic and spatial formats resulted in equivalent accuracy on a moderately complex task when time was constrained. In more complex tasks, individuals experience greater difficulty finding and processing information under time pressure, and use of symbolic formats results in decreased decision accuracy (Coury & Boulette, 1992). Similarly, Schwartz and Howell (1985) report that graphical data outperformed numeric data when time was constrained, whereas graphical and numeric data resulted in equivalent performance without time constraints. It is clear, therefore, that restricting the time available induces a performance constraint that influences decision processing and ultimately, decision performance.

We believe that it is likely that interruptions will create similar effects on decision-maker performance as time pressure. Both time pressure and interruptions increase the perceived stress (Baron, 1986; Payne, 1982) experienced by the decision maker, resulting in the processing of fewer information cues and performance deterioration (Barron, 1986; Speier et al., 1999). By analogy, the higher cognitive load induced by interruptions pushes a task potentially solvable using analytical processes into a region where perceptual processes may result in more desirable outcomes than analytical processes. A complex symbolic task that is best solved using analytical processes, and is therefore best supported using tables, may be solved equally well with tables or graphs, or it may be solved better with graphs, depending on the complexity of the task per se and the severity of the interruptions. We state the following hypothesis:

H7a: For complex-symbolic tasks, spatial information presentation formats result in lower decision accuracy than symbolic formats without interruptions and comparable or higher decision accuracy when interruptions occur.

H7b: For complex-symbolic tasks, spatial information presentation formats result in longer decision time than symbolic formats without interruptions and comparable or faster decision time when interruptions occur.

When interruptions occur on complex spatial tasks, decision makers have no reason to change processing strategies because perceptual processes facilitate information processing under high cognitive load (i.e., Coury & Boulette, 1992; Vessey, 1994). Spatial information presentation formats therefore result in higher decision accuracy and lower decision time than symbolic information presentation formats, irrespective of task complexity and interruptions in the work environment. The expected outcome is therefore similar whether decision making is interrupted or not, (i.e., we expect that there will be no interaction effects between interruptions and information presentation format on complex spatial tasks). We state the following hypotheses:

H8a: On complex-spatial tasks, spatial information presentation formats result in higher decision accuracy than symbolic formats whether or not interruptions occur.

H8b: On complex-spatial tasks, spatial information presentation formats result in longer decision time than symbolic formats whether or not interruptions occur.

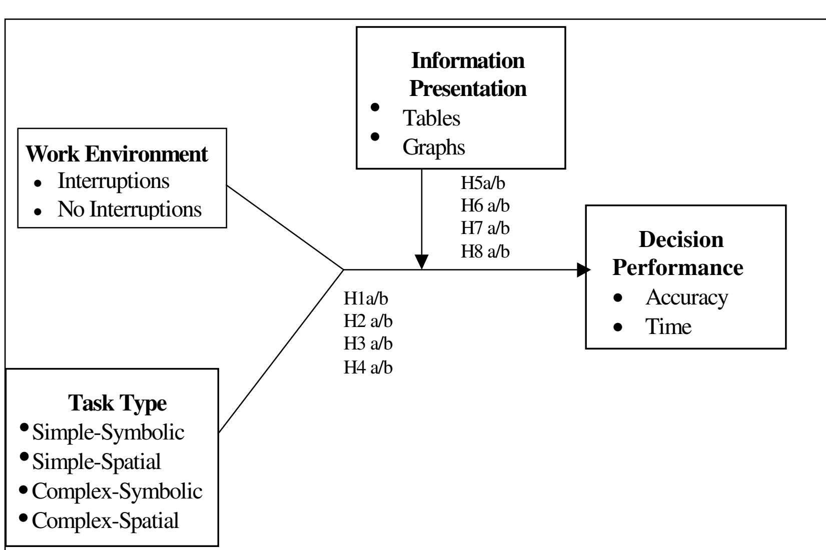
METHOD

A laboratory experiment was conducted to investigate the hypotheses articulated in the second section and illustrated in Figure 2.

Experimental Design

A 2 × 2 × 2 × 2 experimental design, with two between-subjects factors and two within-subjects factors, was used to test the hypotheses. The between-subject

Figure 2: Research model and hypotheses.



factors were *Work Environment* at two levels (interruptions, no interruptions) and *Information Presentation Format* at two levels (tables, graphs). The within-subject factors were *Task Type* (symbolic, spatial) and *Task Complexity* (simple, complex). Therefore, all subjects performed four tasks—simple-symbolic, simple-spatial, complex-symbolic, and complex-spatial. The task presentation order was counterbalanced within treatments. Subjects were given unlimited time to complete the tasks.

Subjects

Subjects were 136 undergraduate students enrolled in an introductory production management (PM) course who were randomly assigned to one of the four treatments. There were no significant differences across treatments with respect to gender, age, year in school, major, and prior PM experience. All subjects were volunteers and received 1% credit toward their final course grade for participating in the experiment. To encourage subjects to work both quickly and accurately, cash incentives (up to $10) were awarded to the highest-performing subjects as measured by decision accuracy per unit time. Over seventy percent of the subjects were awarded cash rewards with the average payoff equal to $6.50.

Factors Investigated

Pilot studies were implemented to test and validate the experimental procedures and operationalize levels of the independent and dependent variables. In addition, the pilot studies indicated that subjects had sufficient expertise to perform the tasks and found the tasks engaging.

Task type and task complexity

Tasks were drawn from the PM domain so that prior exposure to all tasks could be embedded into the subjects' course work, increasing the domain knowledge of the subject pool. Examples of each task are provided in Appendix A. Simple tasks were defined as tasks that required information acquisition only or information acquisition and some simple calculations. The problem area for simple tasks involved capacity planning over a six-month time horizon (see Umanath, Scamell, & Das, 1990). Each simple task consisted of six questions presented as separate screens within a computer simulation. Using Wood's (1986) definition, these simple tasks involved examining two–eight cues followed by one–four calculations. The simple-symbolic task required subjects to obtain specific data by directly extracting values or performing routine addition or subtraction calculations. In contrast, the simple-spatial task required subjects to identify trends in the data.

According to Wood (1986), complex tasks require significantly more processing of information cues (where the cues are typically interrelated) than the simple tasks. The two complex tasks consisted of a facility location task (the complex-symbolic task) (Buffa, 1990), and an aggregate planning task (the complex-spatial task) (Holt, Modigliani, Muth, & Simon, 1960; Davis & Kotterman 1994; Remus, 1984, 1987). In the facility location task, subjects were asked to rank order the location options from least to highest cost. Using Wood's (1986) definition, this task involves examination of up to 30 information cues and 18 calculations. In addition, subjects rank ordered their potential solutions, thus creating interrelated outcomes.

In the aggregate planning task (spatial), subjects determined the production levels of four different products based on a three-period demand forecast, work-force size, and inventory levels (i.e., 27 information cues). Based on the potential solutions generated, a subject received feedback regarding the overall cost of his or her solution as well as component costs (e.g., inventory charges, employee hiring/firing). Using “what if” capabilities, subjects could modify their solution using this cost information with the goal of obtaining the lowest cost solution. Therefore, each iteration involved the examination of the 27 information cues as well as required participants to remember prior outcomes. Furthermore, the factors associated with the task were highly interrelated, which added to the overall complexity of determining the lowest-cost production plan.

The work environment

Work environment was manipulated by introducing interruptions while subjects were performing the tasks. Interruptions consisted of four simple information acquisition tasks (both spatial and symbolic) that occurred during each of the four experimental tasks (e.g., task 1 start, 4 interruptions during task 1, task 1 end; task 2 start, etc.). These interruptions were timed to occur 7–15 seconds into the tasks. The interruptions were unpredictable (e.g., they did not occur after each subtask) and subjects could not anticipate when or if an interruption would occur (nor where they told that interruptions might occur). Interruptions were created by inserting a screen on the PC monitor announcing that the subject’s manager wanted him or her to complete a task immediately. The task appeared on the screen and once the subject completed the task, control returned automatically to the experimental task.

To control for fatigue and order effects, subjects in the no-interruption treatment also performed all interruption tasks—completing the interruption tasks either before or after the experimental tasks.

Information presentation format

Two types of information presentation format were examined: tables and graphs. Each experimental task used either graphs or tables, while the interruption tasks that occurred during each experimental task were constructed so that 50% used tables and 50% used graphs.

Performance Variables

The dependent variables were decision accuracy and decision time. Each of the four task types were intellective tasks and therefore had optimal solutions. The answers for simple-symbolic, complex-symbolic, and complex-spatial were all numeric and each answer was compared to the optimal solution. The simple-spatial task involved nonnumeric answers and subjects were awarded 1 point for a correct answer and 0 for an incorrect answer (for six subtasks). Scores for all tasks were calculated as the percent of optimal achieved. Therefore, a higher mean represents higher decision accuracy. Decision time (seconds) was calculated as the time required to perform the decision task, less the time needed to respond to any interruption tasks.

Controlled Variables

Three individual factors thought to influence decision performance either directly or indirectly were controlled statistically. They were domain expertise, spatial ability, and gender. Both domain expertise (Mackay & Elam, 1992; Ramamurthy, King, & Premkumar, 1992) and spatial abilities when performing spatial tasks (Loy, 1991) can improve decision performance. Domain expertise was measured as performance on production management examination questions relevant to the tasks performed in the experiment, while spatial ability was measured using the kit of factor referenced cognitive tests (Ekstrom, French, Harmon, & Dermen, 1976). Gender (measured via self-report) was included as a control variable because past research found that females are more easily distracted than males when performing complex tasks (Silverman, 1970). In addition to the individual difference characteristics, decision accuracy and time data for the *interruption tasks* was also collected and controlled statistically when necessary.

RESULTS

We used *SPSS*-based repeated-measures Multivariate Analysis of Covariance (MANCOVA) to analyze the data using task type and task complexity as within-subject factors and work environment and information presentation format as between-subject factors. The effects of the three covariates (domain expertise, spatial ability, and gender) were significant in most but not all of the statistical tests. Given that these variables influenced decision performance most of the time and that they represent enduring characteristics of the subject pool, they were included as covariates in all tests.

Consistent with expectations, all of the main effects were significant. The work environment main effect was explicitly hypothesized and is discussed in the following section. In addition, the main effects for information presentation ($F = 3.97$ (1, 134), $p = .02$), task type ($F = 40.17$ (1, 134), $p = .00$), and task complexity ($F = 3.30$ (1, 134), $p = .04$) were all statistically significant and in the expected directions, adding legitimacy to the operationalizations of the variables in this study.

The repeated-measures MANCOVA assesses the effects of the between- and within-subject variables on an aggregated measure of decision accuracy and time across each treatment (e.g., interruptions are significant for a combined effect on decision accuracy and decision time). Therefore, to test each of the hypotheses, decision accuracy and decision time for each of the four tasks (e.g., all four within-subject combinations) were assessed using parameter estimates. Parameter estimates are the planned contrasts used to differentiate among each of the dependent variables investigated and are reported using a t-value, transformed from univariate F tests (SPSS, Inc., 1990).

Table 1 presents the results for the main effects hypothesized (H1a–H4b), while Table 2 presents the results for the interaction effects hypothesized (H5a–H8b).

Table 1: Results of testing interruption main effects.

Hypothesis	Task Complexity	Task Type	Dependent Variable	No Interruption Mean (SD)	Interruption Mean (SD)	t statistic (dof)	P-value
H1a	Simple	Symbolic	Accuracy	.737 (.12)	.772 (.08)	1.299 (1, 134)	.196
H1b	Simple	Symbolic	Time	165.529 (36.77)	138.882 (43.14)	−2.580 (1, 134)	.011
H2a	Simple	Spatial	Accuracy	.726 (.21)	.803 (.11)	2.566 (1, 134)	.011
H2b	Simple	Spatial	Time	55.853 (18.79)	42.897 (10.10)	−3.685 (1, 134)	.001
H3a	Complex	Symbolic	Accuracy	.756 (.16)	.702 (.15)	−4.488 (1, 134)	.001
H3b	Complex	Symbolic	Time	1311.794 (340.81)	1307.064 (416.00)	−.166 (1, 134)	.868
H4a	Complex	Spatial	Accuracy	.549 (.254)	.441 (.273)	2.336 (1, 134)	.032
H4b	Complex	Spatial	Time	1442.882 (607.35)	1774.721 (446.16)	−2.216 (1, 134)	.028

Table 2: Results of testing interruption and information presentation format interaction effects.

Hypothesis	Task Complexity	Task Type	Dependent Variable	Presentation Format	No Interruption Mean (SD)	Interruption Mean (SD)	t statistic (dof)	P-value
H5a	Simple	Symbolic	Accuracy	Table	.754 (.11)	.789 (.08)	−.126 (1, 134)	.900
				Graph	.719 (.13)	.755 (.09)		
H5b	Simple	Symbolic	Time	Table	175.914 (37.95)	148.657 (48.21)	−.045 (1, 134)	.964
				Graph	154.515 (32.53)	128.515 (34.81)		
H6a	Simple	Spatial	Accuracy	Table	.662 (.25)	.779 (.11)	−1.380 (1, 134)	.170
				Graph	.793 (.11)	.828 (.11)		
H6b	Simple	Spatial	Time	Table	60.286 (19.41)	46.857 (8.68)	.078 (1, 134)	.938
				Graph	51.152 (17.16)	38.697 (9.92)		
H7a	Complex	Symbolic	Accuracy	Table	.829 (.17)	.677 (.17)	3.853 (1, 134)	.001
				Graph	.679 (12)	.729 (.12)		
H7b	Complex	Symbolic	Time	Table	1343.714 (174.59)	1316.667 (170.74)	.062 (1, 134)	.950
				Graph	1277.939 (141.82)	1296.879 (130.17)		
H8a	Complex	Spatial	Accuracy	Table	.503 (.32)	.400 (.27)	.023 (1, 134)	.982
				Graph	.598 (.16)	.484 (.28)		
H8b	Complex	Spatial	Time	Table	1573.514 (596.87)	1821.857 (455.63)	1.179 (1, 134)	.240
				Graph	1304.333 (596.07)	1724.727 (437.26)		

Work Environment Main Effects

Hypotheses 1a and 1b state that interruptions result in increased decision accuracy and decreased decision time on simple-symbolic tasks. Although decision accuracy with interruptions (.77) was higher than without interruptions (.74), the difference is not significant ($t(1, 134) = 1.30$; $p = .20$). Decision makers experiencing interruptions while solving simple-symbolic tasks took significantly less time (138.88 seconds) than those without interruptions (165.53 seconds) ($t(1, 134) = -2.580$, $p = .01$). Therefore, H1a was not supported, while H1b was supported.

Hypotheses 2a and 2b state that interruptions result in increased decision accuracy and decreased decision time on simple-spatial tasks. Decision makers experiencing interruptions while solving simple-spatial tasks had significantly higher accuracy (.80) than those without interruptions (.73) ($t(1, 134) = 2.57$, $p = .01$). Similarly, decision makers experiencing interruptions while solving simple-spatial tasks took significantly less time (42.90 seconds) than those without interruptions (55.85 seconds) ($t(1, 134) = -3.69$, $p = .00$). H2a and H2b were therefore both supported.

Hypotheses 3a and 3b state that interruptions result in lower decision accuracy and increased decision time on complex-symbolic tasks. Decision makers who did not experience interruptions made significantly more accurate decisions (.76) than those who experienced interruptions (.70) ($t(1, 134) = -4.49$, $p = .00$). There was, however, no significant difference in decision time between decision makers experiencing interruptions (1307.06 seconds) and those without interruptions (1311.79 seconds) ($t(1, 134) = -.17$, $p = .87$). Therefore, H3a was supported, while H3b was not supported.

Hypotheses 4a and 4b state that interruptions result in decreased decision accuracy and increased decision time on complex-spatial tasks. Decision makers experiencing interruptions had significantly lower accuracy (.44) than those without interruptions (.55) ($t(1, 134) = 2.14$, $p = .03$). Similarly, decision makers experiencing interruptions took significantly more time (1774.72 seconds) than those without interruptions (1442.88 seconds) ($t(1, 134) = -2.22$, $p = .03$). Therefore, H4a and H4b were both supported.

Work Environment and Information Presentation Interaction Effects

Hypotheses 5a and 5b state that there is no interaction between work environment and information presentation format for either decision accuracy or decision time on simple-symbolic tasks (i.e., tables provide the best support for solving simple-symbolic tasks whether or not interruptions occur). Statistical tests support H5a and H5b: there was no interaction effect for decision accuracy ($t(1, 134) = -.13$, $p = .90$) or for decision time ($t(1, 134) = -.05$, $p = .96$).

Hypotheses 6a and 6b state that there is no interaction between work environment and information presentation format for either decision accuracy or decision time on simple-spatial tasks. Statistical tests support H6a and H6b: there was no interaction effect for decision accuracy ($t(1, 134) = -1.38$, $p = .17$) or for decision time ($t(1, 134) = .08$, $p = .94$).

Hypotheses 7a and 7b state that there is an interaction between work environment and information presentation format on complex-symbolic tasks. The interaction effect was significant for decision accuracy ($t(1, 134) = 3.85$, $p = .000$), but not for decision time ($t(1, 134) = .06$, $p = .95$). Without interruptions, tables resulted in higher accuracy than graphs (mean = .83 compared with .68); with interruptions, tables and graphs resulted in decisions of comparable accuracy (mean = .68; compared with .73). With respect to decision time, graphs (no interruption: 1278 sec; interruption: 1297) resulted in faster decision making over tables (no interruption: 1394 sec; interruption: 1317) with and without interruptions. Hence, H7a is supported, while H7b is not.

Hypotheses 8a and 8b state that spatial formats will best support complex-spatial tasks with and without interruptions. Statistical tests support H8a and H8b: the interaction effect for decision accuracy ($t(1, 134) = .02$, $p = .98$) and decision time ($t(1, 134) = 1.18$, $p = .24$) were not significant.

Post-Hoc Perceptions

In addition to the objective decision performance measures, data was also collected to better understand subject perceptions regarding the complex-symbolic task (e.g., crossover effect). Data was collected on the following constructs: amount of information that makes a problem more difficult (Bailey & Pearson, 1983) and perception of performance quality (Spurrier, Topi, & Valacich, 1994). Factor analysis and reliability coefficients indicated that the measures had suitable psychometric properties: (Amount of information: factor loadings of 0.830, 0.798, 0.779 with Cronbach alpha = 0.680; and Perception of performance quality: factor loadings of 0.687, 0.817, 0.727 by Cronbach alpha = 0.788).

Empirical results reveal that for three of the four tasks (all but complex spatial), subjects experiencing interruptions had more negative perceptions regarding their performance than those who did not experience interruptions (Simple Symbolic: 3.02 vs. 3.59 ($F(1, 135) = 15.115$, $p < .001$); Simple Spatial: 3.09 vs. 3.58 ($F(1, 105) = 8.597$, $p < .004$); Complex Symbolic: 3.15 vs. 3.58 ($F(1, 135) = 6.471$, $p < .005$)).

Perceptions regarding the amount of information provide some support for some type of crossover effect. MANCOVA results indicate a significant interaction effect between interruptions and information presentation ($F(2, 135) = 3.191$, $p = .026$). Results indicate that subjects in the interruption/table condition found the amount of information more overwhelming (3.80) than any of the other conditions: interruptions/graphs (3.14); no interruptions/tables (3.12); no interruptions/graphs (3.21).

Finally, of the three control variables identified at the outset (gender, domain expertise, and spatial orientation ability), only domain expertise was significant in explaining differences in decision accuracy ($F(1, 132) = 11.657$, $p = .001$) and decision time ($F(1, 132) = 2.315$, $p = .031$). Those subjects with greater domain expertise performed the task more accurately and faster than those with less expertise.

DISCUSSION AND CONCLUSIONS

This section discusses the research findings, the limitations of the study, and the implications of the findings for future research and for practice.

Discussion

The primary goal of this research was to investigate the effectiveness of information presentation formats mitigating the negative influence of interruptions on complex decision-making tasks. We hypothesized a crossover effect for performance with tables on complex symbolic tasks: we expected that performance would be better with tables when there were no interruptions and better with graphs when there were.

The results of this study, specifically the significant interaction effect between interruptions and information presentation formats for complex symbolic tasks (H7a), demonstrate that interruptions do influence the manner in which information is processed. The effect of interruptions on complex-symbolic tasks is manifested in decision accuracy (H7a is supported), but not in time (H7b is not supported). Without interruptions, tables resulted in significantly greater accuracy than graphs on complex symbolic tasks; with interruptions, tables and graphs resulted in comparable accuracy. Hence, there is a crossover effect for symbolic tasks as the cognitive complexity of the task is increased by factors such as interruptions. This finding suggests that interruptions influence the manner in which problem solvers perceive and process information when performing complex intellective decision tasks. That spatial tasks are always best addressed using spatial formats was also confirmed in this research.

For simple tasks, interruptions focus a decision maker's attention on important cues resulting, in general, in both increased decision accuracy and shorter decision time. The only exception in the findings of this study is that, although accuracy on simple symbolic tasks improved with interruptions, the difference was not significant. (H1b, H2a, and H2b were supported, while H1a was not.)

Limitations of the Study

The meaningfulness of the findings from any study must be assessed in light of the study's limitations. For this study, the increased control afforded by a laboratory experiment must be traded off against the inherent limitations of the approach, primarily that of generalizability. Limitations in generalizability in this study involve the use of student subjects, the nature of the tasks, and the operationalization of the interruptions.

While the task experience and motivation of student subjects is a concern, we mitigated these concerns by ensuring that the students had considerable experience in the task area and by providing performance incentives. The generalizabilty of the findings is limited to where information is retrieved and calculations performed to develop an optimal solution. Finally, the interruptions operationalized in this study were devoid of social characteristics (e.g., status of the interrupter) and thus the type of interruptions used should be taken into account before generalizing these results across work environments.

Implications of the Findings

This paper shows that interrupted work environments lead to lower-quality decisions and reduced speed on complex intellective tasks. Furthermore, as indicated in the post-hoc results, even "helpful" interruptions (e.g., those that facilitated completion of simple tasks) were perceived negatively by decision makers. This negative perception may well manifest itself in more traditional work-related areas such as stress and job satisfaction. For example, prior research demonstrates that work hassles and interruptions result in more negative moods and increased fatigue (Schonpflug & Battman, 1988; Zohar, 1999). Further, Perlow (1999) describes how engineers lost time and were distracted just dreading interruptions that were sure to happen. Our results contribute to this area of research by demonstrating that the interruption itself creates negative perceptions even when the interruption itself does not impede effective and efficient completion of work.

Although the results for simple tasks (i.e., that interruptions result in both improved time and accuracy) are consistent with theory, for many, the notion that interruptions can actually improve performance is counterintuitive. In addition to the cognition/stress perspective conveyed by distraction conflict theory, there may be additional explanations for these performance effects. When performing simple tasks, individuals may perceive that the task "is too easy" and therefore do not dedicate their full attention and processing capabilities to performing the task at hand. Instead, they may think about other work-related (e.g., creative problem-solving on another task, creating a mental "to do" list) or personal issues.

From the perspective of cognitive fit, this study represents the first empirical test of the theoretical extensions of cognitive fit to complex tasks (Vessey, 1994) and provides support for those extensions: interruptions, like time constraints, moderate the relationship between information presentation format and task type for complex symbolic tasks. A more complete understanding of how interruptions influence information acquisition and processing will facilitate the design of more effective systems. In addition, our findings support the notion that interruptions have cognitively similar effects to distractions and support the use of distraction conflict theory as the foundation for this research.

Similarly, the results of this research enhance our understanding of complex task decision making, particularly the idea of a crossover point induced by the cognitive complexity of the task and its environment. In the context of the study, decision makers using analytical processes consciously or subconsciously traded off performance to ease the cognitive load associated with the symbolic task when interruptions occurred. Future research should explore both technological and managerial interventions to minimize performance degradation (e.g., reduce effort or provide incentives for accuracy) (Todd & Benbasat, 1999) on tasks of this nature where the individual or organization requires determining optimal, as opposed to satisfying solutions.

While this research provides evidence of a crossover point where analytical and perceptual processing is equivalent, the point at which perceptual processes result in better performance is still to be determined. Future research should examine this issue by looking at tasks that are more complex than those used in this study or by examining environmental stressors (e.g., interruptions or time pressure) that involve greater use of cognitive capacity (or a combination of the two).

The interaction effect between interruptions and information presentation format demonstrates that features of the information system can influence the manner in which interruptions are processed and that the effects of interruptions can therefore be mitigated using features of information systems. Presenting information in ways that enhance the use of perceptual processes (e.g., greater use of icons or pictures) facilitates the acquisition and processing of complex information. Organizational decision support and information systems can therefore use graphical formats to minimize the effect of interruptions on complex decision-making tasks (both symbolic and spatial).

Future Research Directions

Our findings suggest a number of avenues for future research. First, the results of this research hold promise that systems builders will be able to design features into information systems to mitigate the effects of at least some interruptions. Future research could therefore examine features of information systems that could be implemented as mechanisms to aid in recovery from interruptions (e.g., annotating tools, graphics, backtracking, and so on). Second, future research could focus on a broader range of interruption characteristics to understand those that have particularly deleterious effects (e.g., frequency, duration, and so on). A broad conceptualization of interruptions was presented in Figure 1 and very little systematic research examining these different cognitive and social factors has been conducted to date.

Third, research could also be conducted to better understand interruptions across different task domains and problem types. For example, conventional wisdom encourages programmers to "take a break" when they cannot solve a logical error while coding (a creative problem). Hence, it may be important to understand differences in problem types if we are to build more effective systems to support a range of knowledge worker activities.

Fourth, individuals and organizations could implement a variety of strategies to manage interruptions more effectively, all of which could be addressed in future research. For example, preventive strategies such as forwarding phone messages directly to e-mail or coming in early/staying late to get uninterrupted blocks of time could be embedded into the workday. However, some phone calls might require urgent response and coworkers would still need to be accessible during "normal" work hours, making preventive strategies effective for only brief periods of time throughout the workday. The answer to this dilemma might be found in interruption management strategies based on job/organization redesign and/or information technology.

Fifth, given the role of information technology as a possible "generator" of interruptions, we also need to understand more fully the effect of technologies on decision-making performance so that we can design more effective technologies. For example, electronic mail systems have been implemented widely within organizations as tools for more effective communication. The findings from the current research suggest, however, that the instant notification feature be disabled in some instances so as not to exacerbate the number of interruptions decision makers experience. Similarly, the organizational adoption of instant messaging (*Computerworld*, 2000) and push technologies such as Pointcast (now Infogate) (Pointcast Team, 1999) should be carefully evaluated from an interruption, and therefore an information overload, as well as a task-related standpoint, prior to implementing these technologies organization-wide.

Similarly, new organizational structures may also generate more interruptions into work environments. Many organizations are moving to new organizational forms such as self-organizing teams and open workflows to better support the flexibility, responsiveness, and global nature of today's business environment (see, for example, Miles & Snow, 1995). These organizational forms are likely to increase the frequency of interruptions experienced by an individual, exacerbating the (negative) influence of interruptions. One way to address the number of interruptions in both traditional and new organizational forms is to institute "quiet time," whereby an interruption-free work period is provided during the day, which has been shown to result in productivity increases (see, for example, Perlow, 1999).

Conclusions

Our research determined that decision makers who are interrupted when solving complex symbolic problems are better supported by graphs than by tables. This finding points the way to a possible solution to the dilemma of a work environment characterized by frequent interruptions: presentation format can be used to mitigate the deleterious effect of interruptions on the quality of decision making. A more thorough understanding of the design and delivery of existing information systems contributing to and recovery from interruptions would be beneficial. Clearly, much research must be undertaken to enhance our knowledge of interruptions and the methods that can be implemented to mitigate their influence on decision-making performance on complex tasks. [Received: January 2002. Accepted: May 2003.]

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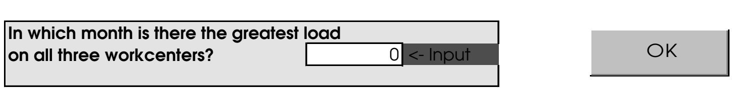
APPENDIX A

Examples of Experimental Tasks

Simple-Spatial Task with a Tabular Information Presentation Format

Work Center Load Profiles

	May	June	July	August	September	October
Work Center A						
Capacity (hours)	380	380	380	380	380	380
Load (hours)	400	380	440	360	280	300
Work Center B						
Capacity (hours)	330	330	330	330	330	330
Load (hours)	360	320	400	280	300	330
Work Center C						
Capacity (hours)	360	360	360	360	360	360
Load (hours)	420	300	400	340	320	360



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