Abstract and Keywords

The modern world is a multitasking world: In task domains ranging from office work to driving to sports to music, people frequently juggle and perform multiple tasks at the same time. This chapter examines human multitasking along a continuum of behavior that includes highly concurrent task performance (such as talking while driving) and more sequential interleaving of one task with another (as occurs after an interruption). The empirical literature is beginning to form a solid base on which to understand multitasking in both basic laboratory tasks and applied real-world tasks, and an associated theoretical literature has been evolving to better explain the empirical results in terms of general aspects of human cognition. This chapter highlights these empirical and theoretical developments, as well as the practical and societal implications that arise from this work.

**Keywords:** dual-task performance, driving, distraction, task switching, interruption, human-computer interaction
Introduction

Multitasking arises in almost every part of a person’s daily routine, from eating breakfast while reading news, to listening to the radio while driving to work, to answering phones while typing information, to talking to children while helping them to bed. The central nature of multitasking in human behavior has generated a great deal of interest from researchers interested in how people can attend to and perform multiple tasks at the same time. The scientific exploration of how people multitask has important implications for practical development of real-world systems (such as the design of complex interfaces for human users and operators) and for societal issues more generally (such as the potential dangers of multitasking while driving, or the potential stresses of increasingly multitask lifestyles).

Research on multitasking has appeared under a variety of guises, perhaps most notably in relation to broader ideas about human attention. Around the dawn of the study of psychology, James (1890) discussed attention as a form of focusing on one of “several simultaneously possible … trains of thought” (p. 403). Later research on attention (e.g., Kahneman, 1973; Moray, 1959; Posner & Petersen, 1990; Treisman, 1969; see also Wickens, this Handbook) extended this understanding often with an emphasis on perceptual (visual and aural) attention. Related work on cognitive control (Cohen, Dunbar, & McClelland, 1990; Cooper & Shallice, 2000; Logan, 1985; Norman & Shallice, 1986; see also Goodrich, this Handbook) focused on the act of maintaining attention on particular task in the context of routine activities (such as making coffee or tea). Multitasking can be thought of as conceptual cousins to attention and cognitive control, but with a primary emphasis on the execution of multiple tasks, the interaction of
cognitive, perceptual, and motor processes involved in these tasks, and the potential interference between processes that may result from this interaction.

In parallel with the above efforts based in the psychological laboratory, a number of applied research areas have explored multitasking in the context of particular real-world domains. Research in aviation (e.g., Dismukes & Nowinski, 2007; Kantowitz & Casper, 1988; Wickens, 2002-b) has investigated issues of multitask attention, workload, and error in pilots and air-traffic controllers. Research in driving has examined multitasking both for the driving task itself (such as navigational planning while driving: Tijerina et al., 2000; Tsimhoni, Smith, & Green, 2004) and for driving combined with various secondary tasks (such as dialing a phone: Alm & Nilsson, 1994; Brookhuis, De Vries, & De Waard, 1991; Reed & Green, 1999). Research in human-computer interaction has studied how computer users are frequently interrupted in their work and the effects of interruption on their behavior (e.g., Adamczyk & Bailey, 2004; Czerwinski, Cutrell, & Horvitz, 2000). When combined with basic psychological research, applied research such as these examples help to form a more complete picture of how fundamental limitations of the human system can concretely affect behavior in everyday tasks (see also Kramer, Wiegmann, & Kirlik, 2007; Wickens & McCarley, 2007).

There are many ways in which one could organize and describe the increasingly bountiful literature on human multitasking. One useful way of conceptualizing the space of multitasking behavior is in terms of a multitasking continuum (Salvucci & Taatgen, 2011) shown in Figure 1. One can place a pair of tasks along this continuum by noting the typical time spent on one task before switching to the other. Toward the left side of the continuum are tasks that involve more concurrent multitasking, or frequent task switching roughly every one second or less. Toward the right side of the continuum are tasks that involve more sequential multitasking, in which a person does one task for many
seconds to minutes or hours before switching tasks. As the continuum implies, there is no hard-and-fast threshold for concurrent versus sequential multitasking. In fact, some combinations can be more concurrent or more sequential depending on the context; for example, two people watching a baseball game might talk to each other continually during the game (switching tasks every second), or might talk to each other only between innings (switching tasks every few minutes). Nevertheless, much of the research in multitasking has fallen under the umbrella of primarily concurrent or primarily sequential multitasking, and thus the distinction will serve as a convenient way in which to break down and discuss human multitasking in the next two sections.

<< Figure 1 >>

<h1>Concurrent Multitasking</h1>

Concurrent multitasking embodies, in essence, the problem of doing multiple tasks at the same time. Research on concurrent multitasking, both basic and applied, has traditionally focused on the potential interference effects of one task on another—that is, how normal performance in the single-task case may degrade in the presence of a second concurrent task. Interference is often characterized in terms of the processing resources inherent in the human system, namely the various perceptual, motor, and cognitive resources required to produce behavior (Navon & Gopher, 1979; Salvucci & Taatgen, 2008; Wickens, 2002, 2008). In particular, interference occurs when two or more concurrent tasks need the same resource at the same time, creating a resource conflict that requires one or both tasks to wait for the resource and incur a penalty in overall performance.
Perceptual and Motor Interference

Perhaps the most obvious forms of interference arise in the perceptual and motor resources: When two tasks need the same perceptual resource, such as vision or audition, or the same motor resource, such as the hands and fingers, it is not difficult to imagine that these tasks can and often do interfere with each other. Consider, for example, the demands on a pilot flying an aircraft while managing various relevant secondary tasks. Wickens et al. (2003) investigated pilot performance when receiving traffic and flight information through either auditory or visual channels. They found that at low traffic levels, pilot performance for both conditions were virtually identical. However, at higher traffic levels, performance on vertical tracking was worse for the visual condition, suggesting that the visual demands of receiving information interfered with pilots’ ability to maintain the desired altitude. (Interestingly, redundant communication using both auditory and visual modalities resulted in overall worse performance than communication using only one modality.) The results nicely illustrate not only how one visual task may interfere with another when performed concurrently, but also how these interference effects may be mitigated by other issues such as overall workload demands (in the low-versus high-traffic conditions).

Similarly, consider the highly publicized issue of dialing a cellular phone while driving. Driving is of course a highly visual task, and any secondary concurrent task that requires vision is likely to produce at least some interference with the primary driving task. There have been numerous studies showing that phone dialing has significant effects on driver performance, both in terms of maintaining a central lane position and responding to an external event such as a lead vehicle braking (e.g., Alm & Nilsson, 1994; Brookhuis, De Vries, & De Waard, 1991; Reed & Green, 1999; Salvucci & Macuga, 2002). For example, Salvucci (2001) tested four methods of dialing, two that
involved manual dialing and two that involved voice dialing. For each of manual and voice dialing, one method required dialing a full 7-digit number while the other only required dialing a single digit or speaking a short phrase. Both manual-dialing methods resulted in a significantly higher lateral deviation (error computed from lateral distance to lane center) than that for normal driving. However, both voice-dialing methods resulted in approximately the same deviation as normal driving.

Similar effects of driver distraction have been found for a range of other secondary devices, including navigation devices (Tijerina et al., 2000; Tsimhoni, Smith, & Green, 2004), radios (e.g., Sodhi, Reimer, & Llamazares, 2002), voice-based email systems (Lee et al., 2001), and portable music players (Salvucci, Markley, Zuber, & Brumby, 2007). In all these cases, multitasking in these cases involves both vision and manual interaction, and thus one might wonder what is the primary source of multitasking interference. A partial answer to this question comes from the several studies that have compared potential distraction from handheld versus hands-free phones (e.g., Strayer & Johnston, 2001; Horrey & Wickens, 2006): These studies have generally found that both handheld and hands-free phones lead to similar significant effects on driver performance, suggesting that the visual demands of dialing, rather than the motor demands of holding the phone, are the primary source of the distraction effect.

There are many other domains, however, in which motor conflicts are the central factor in multitasking performance and interference. As one example, a chef trying to make several dishes continually experiences these kinds of motor conflicts: practically speaking, the chef’s two hands can only manage one task at a time (mixing, chopping, and so on), and thus the chef must interleave the multiple tasks in a balanced way to ultimately complete the dishes. As another example, in modern computer interfaces, it is very common to have several concurrent tasks visible in different windows, sometimes
both demanding the user’s attention—for instance, a chat or email application notifying a user of a new message while the user is typing a document. Ignoring the cognitive issues for now (to be discussed shortly), the computer’s input devices, namely a keyboard and mouse, can only be focused on one application at a time; concurrent applications thus share the user’s motor processes (the hands operating the keyboard and mouse), and user input to one application forces the other application to wait for its own input.

<h2>Cognitive Interference</h2>

Whereas perceptual and/or motor interference is often apparent when examining the component tasks in a multitasking scenario, cognitive interference—conflicts between the cognitive aspects of two or more tasks—is often more subtle and difficult to ascertain. Beginning in the early- to mid-1900s, researchers have explored the cognitive limitations of multitasking in highly controlled laboratory paradigms (e.g., Telford, 1931; Welford, 1952). The most common of these paradigms involves concurrent simple choice tasks in which a person, for example, responds to a visual stimulus with a manual response (a “visual-manual” choice task) while responding to an aural stimulus with a vocal response (an “aural-vocal” choice task). Even when the perceptual and motor modalities for the tasks have no conflicts (as in the visual-manual and aural-vocal tasks), interference often occurs in the cognitive processing needed for both tasks (see, e.g., Rubinstein, Meyer, & Evans, 2001; Schumacher et al., 2001); this so-called “psychological refractory period” (PRP) effect arises in that one task experiences a slowdown in choice response time when performed concurrently with the other task.

While the basic psychological literature has made clear that cognitive processing can be a central bottleneck in multitasking performance, the translation of these simple laboratory paradigms to real-world domains has proven difficult. Nevertheless, in what
may be viewed as a parallel line of research, many efforts have investigated multitasking behavior as it appears in particular applied task domains. In the domain of driving, a number of studies have demonstrated the effects of cognitive interference caused by conversations or other mental workload (e.g., Drews, Pasupathi, & Strayer, 2008; Strayer & Johnston, 2001). Alm and Nilsson (1994) used a memory-span task in which drivers listened to sentences, judged the plausibility of each sentence, and also memorized the last word of each sentence (up to five sentences). This intense mental task significantly affected to brake in response to the braking of a lead vehicle: The response time of younger drivers slowed down by roughly a half second compared to single-task conditions, and that of older drivers slowed down by more than one second. While such experiments create cognitive load using controlled psychological tasks, other experiments have found similar effects arising from realistic natural conversation (e.g., Strayer & Drews, 2004). In fact, a recent meta-analysis (Horrey & Wickens, 2006) concluded that there are “clear costs to driver performance” for drivers engaged in conversations or similar cognitive tasks.

In most work on cognitive interference in multitasking, the secondary task is primarily, instead of exclusively, cognitive; for example, the above examples of conversation and related tasks are primarily cognitive but also incorporate some (albeit smaller) amounts of perceptual and motor processing (i.e., listening and talking). A recent experiment (Salvucci & Beltowska, 2008) isolated the cognitive aspects of interference by having people learn a list of numbers and then drive only during a 20-second rehearsal stage; that is, the only secondary task while driving was mental rehearsal of the list, with no listening, speaking, or other perceptual-motor components. Even this purely cognitive task produced interference that affected both lane-keeping performance and brake response to a braking lead vehicle. The effects were small—for instance, a roughly 50-ms
increase in brake response time—but statistically significant, again demonstrating the presence of a cognitive bottleneck in multitasking behavior.

Just as the perceptual and motor systems have distinct resources (e.g., perception through visual, auditory, and tactile senses; movement of the hands, feet, etc.), cognition has its own various resources associated with different types of processing, and each resource can be considered a potential bottleneck when multitasking. Multiple resource theory (Wickens, 2002, 2008) posits different resources for processing spatial information versus processing verbal or linguistic information. The theory thus states that a task requiring spatial processing will experience greater interference from another task requiring spatial processing, and likewise for verbal processing. Threaded cognition (Salvucci & Taatgen, 2008, 2010) borrows from the more general ACT-R theory (Anderson, 2007) in differentiating between the declarative resource, representing memory processes, and the procedural resource, representing cognitive skill. In this framework, all tasks require procedural processing and can experience interference on this resource, though this interference is often small; however, two tasks that rely heavily on memory processes are likely to experience conflicts for the declarative memory resource. These and other more recent theories (e.g., Liu, Feyen, & Tsimhoni, 2006) are also related to earlier formulations of cognitive resources as limited-capacity processes (e.g., Navon & Gopher, 1979; Norman & Bobrow, 1975).

There is also evidence that multitasking performance changes over time with learning and practice. Spelke, Hirst, and Neisser (1976) asked participants to write dictated words (blindly) while reading text for comprehension. After several weeks of practice, the two participants were able to successfully perform the dictation task while reading at normal speeds. A later experiment using dual-choice tasks (Schumacher et al., 2001) found that at least some participants could, with practice, achieve perfect time-
sharing—that is, could perform both choice tasks concurrently just as fast as performing them individually. The effects of learning on multitasking behavior could be explained, according to one hypothesis, as the acquisition and adaptation of “customized executive processes” tuned to particular task combinations (Kieras et al., 2000). However, a more recent interpretation is that multitask learning is heavily driven by more general aspects of cognitive learning and skill acquisition; for example, the gradual compilation of memorized instructions to procedural skills (Taatgen & Lee, 2003) can reduce memory resource conflicts and alleviate, or even eliminate, the effects of dual-task interference (Anderson, Taatgen, & Byrne, 2005).

<h1>Sequential Multitasking</h1>

As the interval between task switches grows longer than a few seconds, multitasking can better be characterized as sequential multitasking: a user performs one task for a period of time, switches to another task for a time, and so on. While sequential multitasking simply denotes a range along the multitasking continuum, this type of behavior has been studied in its own right because of its many characteristics that distinguish it from concurrent multitasking. One useful way to view sequential multitasking is in terms of the trigger that results in task switching, namely the interruption that ends one task to begin another. The subsequent sections break down sequential multitasking into three rough categories of behavior—forced, deferrable, and self-initiated interruptions—and outline the empirical literature as well as the current theoretical developments for each category.
<h2>Forced Interruptions</h2>

There are many situations in which an external event interrupts someone, and the person must deal with the interruption immediately or very quickly; a phone ringing, a coworker entering one’s cubicle, or a computer out of battery power all require a response within a few seconds of time. Figure 2 shows a typical timeline of an interruption (based on Trafton et al., 2003). Sometimes an interruption can be immediate (like a power outage), but sometimes a warning may alert the person to the imminent interruption (like the ringing phone or the computer battery message). The time between a warning and the actual start of the interrupting task is known as the interruption lag. The interruption then forces the person to begin an interrupting task that takes them away from a primary task. When the interruption concludes, there is often a resumption lag, or time between the end of the interruption and the first observable action in the primary task. These two lag measures have been often used in both laboratory and applied studies of interruption, and in particular, resumption lag has arisen as the most frequently measured indicator of performance—that is, the time needed to recover from, or resume, the primary task.

<< Figure 2 >>

The research literature on forced interruptions has become fairly extensive over the past decade. Some of the most important studies and findings have examined the effects of when the interruption occurs on the ability to recover from the interruption. Several experiments (e.g., Adamczyk & Bailey, 2004; Bailey & Iqbal, 2008; Czerwinski, Cutrell, & Horvitz, 2000; Iqbal et al., 2005) have noted that as mental workload varies in the performance of the primary task, interruptions at points of higher workload are more disruptive than at points of lower workload. For example, in an experiment by Monk,
Boehm-Davis, and Trafton (2004), participants programmed a video-recording device but were interrupted for short durations (5 seconds) at two possible points in the programming task: between subtasks or within a subtask (where subtask boundaries were determined through task analysis). Monk et al. found that resumption lag increased significantly by roughly 200-300 ms when the interruption occurred within a subtask.

As another example, Iqbal and Bailey (2005) studied three primary tasks—route planning, document editing, and email filing—with an interrupting task that involved reading a news article and deciding on a title for the article. As in the Monk et al. (2004) study, the interruptions occurred either within a subtask or between subtasks. For all three primary tasks, experiment participants were slower to resume the primary task when the interruption occurred within a subtask. Their effects were much larger than those found by Monk et al. (2004): the increase in resumption lag ranged from 1 to 6 seconds for the three primary tasks, suggesting that although the overall trend matched those in Monk et al. (2004), other mechanisms may have been at work in generating larger effect sizes (to be discussed shortly).

The type of interrupting task—that is, the work performed during the interruption—can also affect recovery time. Monk, Trafton, and Boehm-Davis (2008) used the same video-recording task as Monk et al. (2004) above, but used three different interrupting tasks: a high-paced manual-tracking task, a memory-intensive task called the N-back task, and a no-task condition (simply waiting for the end of the interruption). The manual-tracking interruption resulted in a higher resumption lag than the no-task condition. For the memory-intensive task, not only was the resumption lag larger than the no-task condition, but it increased more rapidly for longer interruption times (from 3 to 13 seconds). In other words, the memory-intensive interruption led to a disproportionally higher resumption lag than even the manual-tracking interruption.
Cutrell, Czerwinski, and Horvitz (2000; see also Czerwinski, Cutrell, & Horvitz, 2000) also found an effect of interrupting-task type on resumption, but focusing instead on the relevance of the interrupting task to the primary task. In particular, they found that when an interrupting instant message was related to the primary task (information search), participants were faster in two ways: they more quickly processed the interruption (reading and responding to the message) and they more quickly resumed the primary task after completion of the interruption.

Other studies have focused on the effects of a warning or alert before an interruption. Trafton et al. (2003) tested participants on two tasks modeled after real-world military tasks, the primary task involving resource allocation and the interrupting task involving tactical assessment of aircraft. In their experiment, participants in a warning condition received an alert 8 seconds before an interruption, whereas those in no-warning condition were transported immediately to the interrupting task with no alert. They found that participants in the warning condition were roughly 4 seconds faster in resuming the primary task than those in the no-warning condition. Interestingly, they also found that this effect reduced with practice and practically disappeared after roughly an hour of time performing both tasks.

Not only can an interruption affect primary-task performance, there is also some evidence that an interruption can affect performance on the interrupting task itself—that is, performance on the task is degraded as a result of being used as an interrupting task. The Monk et al. (2008) data illustrated this effect: for the manual-tracking interruption, participants exhibited an increased tracking error in the first 3 seconds, even when excluding the first second to account for task-switching effects; their results suggest that its context as an interrupting task produced some interference with the tracking task. However, performance in the $N$-back task performance was not affected. In addition,
Trafton et al. (2003) did not find such an effect with respect to their interrupting task—30 seconds of tactical assessment on a radar display. Thus, it seems that effects on interrupting-task performance may be observable only for high-paced tasks (such as manual tracking) and only early in the interruption (the first few seconds).

Recent work has aimed to understand and explain these phenomena under a more unified theoretical framework. One influential theory, known as memory for goals (Altmann & Trafton, 2002), centers on a memory-based account of interruption and recovery. The theory posits that upon interruption, a person rehearses information relevant to the current task for a few seconds, and upon recovery, the person retrieves this information and resumes the primary task. Memory for goals nicely accounts for several phenomena, including increased resumption lag for longer interruptions (Monk et al., 2008), since memory decays over the course of the interruption; facilitation of resumption after a warning (Trafton et al., 2003), since the warning cues better rehearsal of task information; and effects of task relevance (Cutrell, Czerwinski, & Horvitz, 2000), since relevant context aids both rehearsal and retrieval processes.

Threaded cognition theory (Salvucci & Taatgen, 2011) builds on memory for goals in representing the rehearsal process as a concurrent multitasking phenomenon: under this view, rehearsal itself is just another “cognitive thread,” and thus can be performed concurrently with another task, specifically the interrupting task. This account helps to explain the occasional degradation in interrupting-task performance. For example, the slight increase in manual-tracking error during an interruption (Monk et al., 2008) is due to interference caused by the rehearsal process during the first few seconds of interruption (Salvucci & Taatgen, 2011). Similarly, memory-intensive interruptions are even more disruptive than other types of tasks (Monk et al., 2008) because any memory
usage by the interrupting task interferes with the memory processing required for rehearsal.

What information is actually being rehearsed and retrieved in the memory-for-goals process? Borst and colleagues (e.g., Borst, Taatgen, & van Rijn, in press; Borst et al., 2009) have described this information in terms of a task’s problem state, or temporary information used in service of task information processing. Specifically, their experiments have shown that problem-state information, associated with the brain’s parietal region (Anderson, 2007), can be a central bottleneck in multitasking behavior; in essence, the brain can only handle context information for a single task at a time, and this information must be swapped in and out when switching tasks. This view, combined with memory for goals, helps to explain why people tend to switch between subtasks rather than within subtasks: between subtasks, there may be little to no information to carry over to the next subtask, greatly facilitating recovery after an interruption. Experiments have, to this point, focused on relatively small chunks of information (e.g., a few numbers or letters); one might expect that a large mental context (such as for a complex physics problem or term paper) poses an even greater challenge in maintaining robust problem-state information.

<h2>Deferrable Interruptions</h2>

In some situations, an external event notifies someone of an interruption, but the interruption is not forced upon the person—rather, the person can delay the interruption for a short time and freely decide when to deal with the interruption. This type of deferrable interruption is commonplace in many settings; for example, a computer user notified of an incoming email may choose to read the email at whatever time is most convenient. Although there are many similarities between forced and deferrable
interruptions, much less research has addressed the latter. It seems reasonable that many of the disruptive factors outlined earlier for forced interruptions would also apply to deferrable interruptions, assuming that a person switches immediately (or very quickly) to the interrupting task. Nevertheless, the fact that a person controls the switching point changes the central issue: Whereas the study of forced interruptions focuses on an interruption’s effect on resumption, the study of deferrable interruptions focuses on when people defer an interruption versus actively switch to the interruption.

Several recent studies have made strides at addressing this question. Iqbal and Horvitz (2007), in a study of interruptions in naturalistic work settings, reported that computer users “prefer to complete conceptual and/or motor subtasks before switching and do so quickly before responding to an alert.” Cutrell, Czerwinski, and Horvitz (2000) found that users exhibited a “tendency to delay switching to another task until completion of a subtask.” In both cases, we can characterize behavior as attempting to minimize problem-state information before switching tasks: because task context must be carried over from before the interruption to after the interruption, it makes sense to minimize or even eliminate this context.

Salvucci and Bogunovich (2010) tested this explicitly using a primary task involving responding to email, and an interrupting task involving receiving and responding to chat messages. The primary task included a task interface in which a simple piece of information (e.g., a product name or price) had to be remembered between certain steps but not between others—thus formalizing the precise information being encoded as the current problem state. The experimental results showed that participants were much more likely (94%) to respond to chat messages when no information needed to be maintained across task steps.
The above results support the notion of problem state as a central bottleneck in multitasking performance, though in this case, the bottleneck delays processing of an interruption rather than hindering recovery after the interruption. Another theoretical viewpoint places deferrable interruptions in the context of prospective memory—that is, remembering to perform an action at some future time. Dismukes and Nowinski (2007) argue that prospective memory is critical for deferred actions in general and for deferred attention to interruptions in particular. In their view, prospective memory of actions is related to memory for goals in that actions must be explicitly rehearsed, and that interruptions can interfere with this rehearsal. In addition, environmental cues can help to recall prospective-memory actions, but at the same time, people may come to rely on such cues and may fail to recall actions when the cues are not available. This view of prospective memory and interruption was found to account well for a number of real-world incidents related to aircraft pilots and air-traffic controllers (see Dismukes, 2006; Dismukes & Nowinski, 2007; Dismukes, Young, & Sumwalt, 1998).

<h2>Self-Interruptions</h2>

It has been estimated that approximately half of all interruptions are not externally triggered, but rather are internally triggered self-interruptions (Gonzalez & Mark, 2004). Self-interruptions may include actions such as initiating a phone call or email or leaving a workstation. Self-interruptions have been the least studied of the three categories, perhaps in part because of the challenges of controlling self-interruptions for the sake of experimentation. However, given their prevalence in real environments, they remain a critical area of study.

There are many potential reasons behind internally triggered interruptions. Jin and Dabbish (2009) listed seven common categories of self-interruption specific to typical
computer use: changing the environment to increase productivity (Adjustment), switching because of frustration or fatigue (Break), seeking information to assist in the primary task (Inquiry), remembering the need to perform another task (Recollection), performing a task out of habit (Routine), starting a task triggered by some cue (Trigger), and performing a task simply to fill time (Wait). Three of these categories (Break, Recollection, and Routine) are purely internal or fully self-initiated. The other four (Adjustment, Inquiry, Trigger, and Wait) are still internally triggered but rely, to some extent, on some condition of the primary task and/or environment; for instance, Inquiry is initiated because the primary task lacks some information, and Wait occurs when the primary task is stalled for whatever reason. This type of taxonomy of self-interruption causes and behaviors are critical to both experimental work, in focusing on particular conditions, and theoretical work, in focusing on the root causes of the internal triggers and their consequences for performance.

Given the sparseness of empirical work in this area, it is perhaps not surprising that theoretical work on self-interruption has also lagged behind that for other types of interruptions. The variations in types of self-interruption make it likely that very different cognitive mechanisms underlie the different types. For example, an Adjustment interruption requires a complex set of cognitive behaviors—not only basic task knowledge, but also metacognitive knowledge in recognizing the inefficiency of a particular task strategy, and further higher-level reasoning about how to adapt the environment to improve efficiency. A Break interruption, on the other hand, is less a matter of higher-level reasoning and more a matter of emotional or physiological factors and their interplay with higher-order cognition. Thus, we might expect that as theoretical work for self-interruption evolves, the development of more unified theories of
phenomena may present a more significant challenge than the analogous development for external interruptions.

**Conclusion**

The multitasking continuum is a straightforward representation of the range of multitasking activities, yet the intricacies of human behavior at various points along the continuum offer a serious challenge to both researchers and practitioners. This chapter has focused on concurrent and sequential multitasking as important ranges along the continuum that have been emphasized by recent research. Nevertheless, as suggested by this review, the multitasking continuum is only one dimension with which we can characterize multitasking behavior. For concurrent multitasking, the types of interference offer a separate dimension to view behavior: perceptual or motor interference can be severe but is often apparent in the structure of the tasks, whereas cognitive interference tends to be pervasive but typically has smaller (or even unobservable) effects with respect to task performance. In sequential multitasking, the types of interruption can be viewed along at least two separate dimensions. Along one dimension, tasks can be more externally triggered or more internally triggered; as described, even external interruptions allow for internal adaptation of the interruption timing (e.g., in deferrable interruptions), and even self-interruptions can involve or be cued by aspects of the environment. Along a second dimension, tasks can be more or less time-constrained—that is, can allow for more or less time before the person needs to respond to the interruption.

All along the multitasking continuum, empirical evidence suggests a trend that primary-task performance is generally negatively affected in a multitask setting. This trend speaks more to negative effects that are statistically significant in controlled experiments. A more poignant question, however, is whether such negative effects are
significant in a real-world sense—a question that can only be answered in the context of the domain of interest. For example, the Salvucci & Beltowska (2008) study found a 50-ms increase in brake reaction time while rehearsing a long list of numbers; this result contributes to psychological research on cognitive multitasking, but is a 50-ms delay significant for real-world driving? For many daily tasks, a 50-ms delay would go completely unnoticed, whereas for driving, such a delay may not be important at all times but may be critical in particular situations (e.g., braking at highway speeds, at which a vehicle can travel 5 feet in 50 ms: Salvucci & Beltowska, 2008). The translation of laboratory research to applied contexts, such as the mentioned work on aviation (Dismukes & Nowinski, 2007), will help to steer research to future studies that are of interest to both the research community and the general public at large.

<h1>Future Directions</h1>

Some important open questions in the study of multitasking offer interesting challenges for future research, including:

(1) How do people recover from interruptions when memory-based recovery is not feasible? This chapter has outlined several theories that posit the centrality of memory processes in interruption behavior. However, as interruptions become longer (e.g., many minutes to hours), and/or the task context associated with the primary task becomes more complex, memory alone will likely not suffice for recovery; instead, people need to reconstruct the task context using the currently perceivable environment (see Salvucci, 2010). The processes involved in reconstruction, and the interplay of reconstruction with memory-based recovery, remains an open issue.
(2) How does a person’s internal sense of time affect multitasking? Recent integrated theories of time perception and estimation (e.g., Taatgen, van Rijn, & Anderson, 2007) have examined how people track time in the course of normal cognitive processing and task behavior, and such theories have important implications for multitasking—specifically our understanding of how a person monitors the temporal demands of each task and uses this information for task switching. These theories, however, currently account for shorter time intervals up to a few minutes; beyond this range, time estimation may be performed in very different ways, such as using explicit indicators (e.g., clocks), implicit indicators (e.g., the sun’s position), or even internal physical indicators (e.g., hunger). While there is clearly a conceptual link between time and multitasking, much more work is needed in order to flesh out our understanding of how these aspects of behavior work together in various ranges along the multitasking continuum (see, e.g., DeKeyser, 1995).

(3) How do emotional or physiological factors affect multitasking performance, and just as importantly, how does multitasking affect a person’s emotional or physiological well-being? This issue was mentioned briefly in the context of self-interruption, but is a critical concern at all points along the multitasking continuum. There is evidence, for example, that people sometimes compensate for multitasking and interruptions by working faster, but with a price: they experience more stress and frustration and feel more time pressure than in a non-multitask scenario (Mark, Gudith, & Klocke, 2008). Studies that address this question can greatly facilitate the translation of laboratory experiments and theory into their relevant in applied contexts (see, e.g., Lee, 2006; Meyer and Lee, this Handbook).
References


Figure Captions

Figure 1: The multitasking continuum.

Figure 2: Timeline for a typical task interruption.
Figures

Figure 1.

- driving & talking
- listening & note-taking
- watching game & talking to friend
- writing paper & reading email
- cooking & reading book

Time before Switching Tasks

seconds

minutes

hours
Figure 2.

- (sometimes) Interruption Warning
- Begin Interrupting Task
- End Interrupting Task
- Resume Primary Task

Primary Task

Interruption

Interruption Lag

Resumption Lag

Primary Task