Multitasking

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Abstract

Multitasking has become increasingly prevalent, especially as we continue to incorporate more and more new media technologies into our daily activities. This essay first identifies trends in the availability and use of media devices in daily life and multitasking behaviors related to such trends. Second, given the general consensus that multitasking impairs performance outcomes, recent multitasking trends call for greater research attention to the subject. We outline the historical perspectives on cognitive structures and processes related to a human's general ability to multitask, culminating with the more recent threaded cognition theory. Third, we present two new research directions on multitasking. One is the exploration of long-term consequences of multitasking behaviors, such as their impacts on cognitive functions, and dynamic changes in individuals' needs and multitasking behavioral changes over time; the other is a cognitive dimensional framework for defining multitasking, which may offer a means to reconcile findings across various multitasking research paradigms, and also to guide designs of multitasking technologies and environments. Finally, looking to the future, we propose several ways to advance the research on multitasking.

INTRODUCTION

Multitasking refers to doing two things at the same time. More precisely, it is when a person simultaneously manages more than one goal, attends to more than one set of stimuli, and generates more than one set of cognitive or behavioral responses. Although even simple activities—such as in the idiomatic expression "walking and chewing gum"—are instances of multitasking; multitasking research has focused on situations that place high cognitive demands on the individual, such as distracted driving (e.g., Levy, Pashler, & Boer, 2006) and reading while watching television (e.g., Armstrong & Chung, 2000).

Although multitasking research can be traced back to at least two centuries ago (e.g., Hamilton, 1859), the term *multitasking* originated relatively recently in reference to a computer's ability to run multiple programs concurrently (e.g., Havender, 1968). Cognitive psychologists interested in finding how humans process information often use the computer as an analogy for

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the mind and brain, making the adoption of such a word in the context of human cognition understandable. Such phrasing hints at the general perspective taken by many multitasking researchers. Much like with a computer, the human brain is said to use specific processes and resources that allow for—and place limits upon—its ability to perform several tasks at once. Understanding the relationships between cognitive processes and resources, and the resulting human capabilities and limitations, is central to multitasking research.

Major technological advances and the increasing prevalence of multitasking in recent years have attracted more research interest in multitasking. In both personal and professional settings, people are constantly surrounded by multiple technologies. Such devices allow for, and in fact encourage, multitasking in two ways. On the one hand, improved device mobility makes it easier to act on-the-go while performing other tasks; on the other hand, the devices by themselves facilitate multiple (possibly unrelated) tasks at once, such as writing, talking, viewing images, and searching for information.

In this essay, first, we will review the trends and prevalence of multitasking, especially media multitasking behaviors. Then we will describe major cognitive theories that have been used to account for performance consequences of multitasking, followed by a review of a recently developed multitasking theory, threaded cognition. Finally, new trends in multitasking research will be reviewed and future research directions will be discussed.

Multitasking Behaviors and Contributing Factors

Increases in multitasking behaviors are directly affected by growing media accessibility and consumption. Rideout, Foehr, and Roberts (2010) surveyed 702 American children and adolescents between 8 and 18 years old as part of a series of surveys conducted every 5 years. They found that on average, a home has 3.8 televisions, 2.5 radios, 2.0 computers, and 2.3 video game consoles. These figures have risen consistently since these studies began in 1999, with the exception of radio. This translates to heavy media consumption, including multitasking. These children reported 7.5 h of media use per day in 2009 and were multitasking with media sources 29% of that time, averaging 10.75 h of media exposure in a day.

These recent changes in media environments are reflected in generational differences in multitasking as well. Carrier, Cheever, Rosen, Benitez, and Chang (2009) measured media use combinations (e.g., television and e-mail) in Baby Boomers (born 1946–1964), Gen Xers (1965–1978), and Net Geners (after 1978). Baby Boomers averaged 23.2 combinations out of 66 possibilities, Gen Xers 32.4, and Net Geners 37.5. Research indicates that multitasking has become a way of life for many children and adolescents. A majority of

Americans aged 8–18 multitask "most" or "some" of the time while listening to music (73% of respondents), using a computer (66%), watching TV (68%), and reading (53%) (Rideout *et al.*, 2010). Similar multitasking trends are reported for other countries (e.g., Svoen, 2007).

In addition to increasing media accessibility, a number of other factors have been found to relate to multitasking. For instance, Jeong and Fishbein (2007) found that for teenagers aged 14 to 16, media multitasking behaviors are predicted by having televisions in the bedroom, supporting the argument that media accessibility is a contributing factor. However, they also found that high sensation seeking, a psychological construct of a person's need for novel or exciting experiences, is a predictor of multitasking behaviors. Intriguingly, Sanbonmatsu, Strayer, Medeiros-Ward, and Watson (2013) found that those most likely to multitask—people who are impulsive, sensation-seekers, and/or have weak executive control—are actually the worst at multitasking performance. Such alarming findings warrant further study. Other individual differences that impact multitasking tendencies and performance include extraversion and neuroticism (Oswald, Hambrick, & Jones, 2007; Wang & Tchernev, 2012), attentional styles (Hawkins *et al.*, 2005), and expertise (Lin, Robertson, & Lee, 2009).

Beyond individual differences, the needs and wants that drive multitasking behaviors have been examined. On the basis of survey data, Zhang and Zhang (2012) described how different types of gratifications (e.g., goal-oriented/work and emotional/social) are sought by different types of computer multitasking. Using longitudinal experience sampling method over 4 weeks and time series analysis, Wang and Tchernev (2012) further identified reciprocal causal relationships between media multitasking behaviors, needs, and gratifications obtained. They found that among the college students sampled, cognitive needs (e.g., homework, information) drive their media multitasking behaviors but are not satisfied by the behaviors. Instead, emotional gratifications (e.g., relaxation, entertainment) are obtained despite not being actively sought. In addition, habitual gratifications (e.g., daily routines) and the behavioral system's endogenous influences (i.e., self-causing or self-maintaining influences) predict media multitasking behaviors. They suggest that these are partially the reasons why multitasking behaviors are persistent, and pursued at the cost of cognitive productivity.

FOUNDATIONAL RESEARCH

Major Cognitive Theories of Multitasking

Before the term multitasking had come into common use, the presence of new devices in daily life was noteworthy to scholars. Consider the anecdote that Cantril and Allport (1935) use in speculating about the effect of radios, and then a relatively new technology, as background sound in homes:

The story is told of a French mathematician who in the war selected a ruined house within sound of guns at the front because he found that his attention to his problems became sharper. Inattention to one stimulus always means attention to some other; inhibition of one response requires concentration on another. The stronger the potential distraction, the greater is the compensatory attention (p. 25).

The suggestion here is that background distractors, such as a radio, can actually improve performance on the primary task at hand.

Unfortunately, contemporary studies of multitasking so far generally suggest otherwise. Existing laboratory experimental research has consistently found that multitasking harms task performance (e.g., Bowman, Levine, Waite, & Gendron, 2010; Wang *et al.*, 2012), though this depends on, to some extent, how performance is defined (e.g., "efficiency" versus "accuracy," Adler & Benbunan-Fich, 2012). In fact, the negative consequences of multitasking extend beyond inefficiencies and can potentially be life-threatening, such as the dangerously high cognitive demands placed on pilots and drivers (e.g., McCartt, Hellinga, & Bratiman, 2006). In recent years, research in this vein has garnered interest and concern from the mainstream press, as attested to by articles and books with titles such as *The Autumn of the Multitaskers* (Kirn, 2007), *Distracted* (Jackson, 2008), and *The Dumbest Generation* (Bauerlein, 2008). For researchers, explaining such worrisome findings with models and theories has become the goal as a means to better understand, predict, and perhaps recommend useful policies for multitasking behavior. A number of cognitive theoretical perspectives have helped in this regard.

CENTRAL BOTTLENECK THEORIES

Central bottleneck theories originate in earlier research on the single-channel hypothesis (Welford, 1967). As both phrases suggest, these theories posit that cognition is limited by a "central" or "single-channel" structure that constrains information processing. The information modality of the stimuli does not matter (e.g., one task could involve audio and the other images), as all activities are ultimately handled by a singular cognitive structure that cannot operate on two processes at the same time (Marois & Ivanoff, 2005). Such a structural limitation would account for declining performance while multitasking as it requires a person to process multiple tasks one at a time.

The concept of a central bottleneck provides a parsimonious (i.e., simple; technically, requiring fewer parameters if in a formal model) way to account for declines in performance while multitasking. It is often used to explain findings within the psychological refractory period (PRP) research paradigm, in which participants are generally found to take longer to respond to a second task if they are still processing a prior task. Further, its plausibility is supported by evidence of a neural network in the brain that may act as a central bottleneck. Researchers using functional magnetic resonance imaging (fMRI) found activity in the posterior lateral prefrontal cortex and the superior medial frontal cortex after inducing a PRP, suggesting that these regions may act as the structures predicted by central bottleneck theories (Dux, Ivanoff, Asplund, & Marois, 2006).

Intriguingly, if the cognitive system is truly only capable of fully processing one set of stimuli at a time as central bottleneck theories predict, this would suggest that multitasking is in essence a process of *sequentially* managing tasks (i.e., first this, then that) rather than *concurrently* processing them (i.e., both this and that simultaneously). Multitasking would then seem better described as a process of rapid task switches, rather than doing two things at once.

Some critics of central bottleneck theories have suggested alternative cognitive structures. For example, early research by Allport, Antonis, and Reynolds (1972) found little to no loss in performance efficiency in a series of "divided attention" experiments. As an alternative to the single channel hypothesis, they suggest the mind may actually have multiple channels that allow for such multitasking. In this way, there may still be interference between two tasks, but only if they share the same cognitive channels. More recently, Townsend and colleagues have accumulated experimental evidence showing that certain elementary psychological processes can be categorized as parallel, instead of serial, processing, and developed mathematical models and tools to differentiate parallel versus serial (e.g., Townsend, 1990; Townsend & Wenger, 2004). It should be instrumental to apply their approach to test cognitive processing during multitasking.

LIMITED CAPACITY THEORIES

Rather than focusing on the cognitive structure in information processing, limited capacity theories focus on cognitive resources. A pioneer on this question is philosopher, Sir William Hamilton. As reported by a posthumous book in 1859, he experimented with visual attention using marbles scattered on the floor, and concluded that on average, visual attention span is limited to six to seven items. A century later, similar findings were reported by Miller (1956) in his well-known article on "the magical number seven, plus or minus two." Kahneman (1973) lays out the foundational arguments by suggesting that cognitive capacity, or "attention," is limited, divisible, and can be automatically elicited and consciously controlled. Thus, such theories suggest a person may successfully process two or more tasks simultaneously as long as cognitive demands divided among tasks do not exceed her/his total capacity. That is, multitasking as traditionally conceived—"doing two things at once"—is indeed possible.

Expanding on this, information processing is said to occur in subprocesses, such as encoding, storage, and retrieval (Lang, 2000). From this perspective, deficiencies in performance while multitasking are caused by a lack of available resources to allocate to one or more subprocesses, rather than a cognitive structure that always operates in a sequential fashion. Resource allocation problems may happen to any of the subprocesses. For example, though attention can be consciously controlled, external stimuli (e.g., sound effects from movies, emotional images) may also elicit orienting responses that automatically allocate attentional resources toward the stimuli. This explains deficient performance while multitasking, such as why people retain less information from reading while watching television (e.g., Armstrong & Chung, 2000). As a person tries to read, her/his resources may be distracted from encoding and storing textual information to encoding auditory or visual cues from the television.

MULTIPLE RESOURCES THEORIES

As a variation on the concept of a shared resource pool in limited capacity theories, multiple resources theories argue that there are distinct resources available for different cognitive operations. Navon and Gopher (1979) argue that cognition is divided across *multiple channels* and that these channels have *their own resource pools* to draw upon. Channels can serve different modalities (e.g., visual processing, auditory processing), process stages (e.g., perceiving, responding), visual channels (e.g., focal, ambient), and codes (e.g., verbal, spatial) (Wickens, 2002). In terms of multitasking, the more overlap between two tasks, the more likely they are to share resource pools and interfere with one another. Conversely, this suggests that two or more tasks could be successfully performed simultaneously as long as they draw primarily from separate resource pools.

Going back to the context of television, multiple resources theories help reveal the complex nature of simply comprehending information while watching a show. Not only are there separate resources and pathways required for perceiving the visual and auditory information from television, but also still more distinct resources are next drawn upon for cognitive processing, and again for storing such information in memory (Basil, 1994). Identifying such distinctions makes more refined predictions about possible multitasking outcomes, such as what task combinations are more harmful or benign (e.g., Wang *et al*., 2012). To use an example, reading and watching television might be seen as a generally more difficult task combination than reading and listening to music, because of the higher degree of shared modality between reading and television.

Threaded Cognition

Threaded cognition (Salvucci & Taatgen, 2008) is a multiple resources theory aiming to explain cognitive processes and outcomes of multitasking behaviors. It is based on ACT-R (Adaptive Control of Thought-Rational), a computational model of the mind's architecture that attempts to identify and represent fundamental structures and processes (Anderson *et al.*, 2004).

Threaded cognition argues there are different resource pools for different cognitive processes, including a central pool for procedural memory (i.e., how tasks are done) and peripheral pools for perception, motor abilities, and declarative memory. While multitasking, each task is organized around the person's specific goals as an autonomous cognitive "thread" (or multiple threads for complex tasks). When a goal is established, it triggers a series of rules—drawing from the central procedural resource pool—that guide cognitive subprocesses and the use of resources from other pools for the achievement of the goal. Consider a simple situation: a person is walking down a hallway and talking with a friend. There are two distinct goals (walking and talking) with established cognitive rules for each. The rules are triggered in procedural memory; and necessary perceptual, motor, or declarative memory processes involved in performing each task are incorporated into cognitive threads (e.g., monitoring the environment, moving legs, generating utterances).

Most important, only one thread can actively draw upon a given resource pool at once. This is unlike the general limited capacity or multiple resources theories described earlier, in which the limiting factor is the amount of resources available in a pool (e.g., Wickens, 2002). Instead, if a resource pool is engaging with a process from one thread, then a process from another thread is delayed. In the example of walking and talking, there may not be a great degree of overlap in resources between the various subprocesses. This allows for both goals to be executed concurrently. In more complex tasks, there may be greater overlap between resources, producing bottlenecks or interference between tasks.

Resolving such bottlenecks between tasks requires that resources are somehow managed and eventually assigned to each thread. By what process does this happen? Threaded cognition attempts to explain this process without positing centralized executive structures in the mind. By doing so, it avoids the problem of a homunculus ("little man"), or using circular reasoning suggesting the mind itself has a mind-like structure that makes decisions. As stated by Salvucci and Taatgen (2008):

> We believe that humans have a basic ability to perform multiple concurrent tasks, and that this ability does not require supervisory or executive processes. Instead, this ability is best represented by a general, domain-independent, parsimonious mechanism that allows for concurrent processing and provides basic resource conflict resolution. (p. 102)

This mechanism is fairly straightforward. First, threads are conceptualized as both "greedy" and "polite" (Salvucci & Taatgen, 2008). "Greedy" implies that if resources are available for a thread to proceed, the thread will take immediate advantage of the resources. "Polite" implies that a thread will free up resources for another thread as soon as possible. In this manner, a process is completed as quickly and efficiently as possible if resources are free. However, in multitasking situations where more than one thread requires the same resource, a bottleneck occurs. If there is only one thread waiting to access this resource pool, it will "greedily" acquire the resources as soon as the preceding thread "politely" makes it available. If there are multiple threads waiting for the same resource pool, the cognitive system attempts to balance processing times by giving privilege to the longest cued thread (i.e., on a first-come, first-serve basis).

CUTTING-EDGE RESEARCH

A large body of research has estimated the prevalence of multitasking using survey methods and assessed performance impairment of multitasking behaviors using laboratory experiments. In recent times, a couple of new research directions have emerged. First, given the increasing prevalence of multitasking, researchers have started to explore the long-term consequences of multitasking behaviors, such as the impacts of chronic multitasking on cognitive functions, and dynamic changes in individuals' needs and multitasking behavioral changes over time. Second, researchers are trying to understand how people adaptively select certain multitasking behaviors over others to more "optimally" achieve their multiple goals under the constraints of the environment and their own cognitive systems. They hope to understand how multitasking media technologies and task designs can be improved to help mitigate negative influences of multitasking and possibly even produce positive outcomes. In order to achieve these goals, a dimensional approach to multitasking has been proposed.

Long-Term Effects of Multitasking

Ophir, Nass, and Wagner (2009) developed the media multitasking index (MMI) to identify individuals as light versus heavy media multitaskers

(LMMs vs HMMs) based on the amount of media they reported using simultaneously. They then performed a series of experiments comparing the cognitive control exhibited by these two groups. HMMs found it more difficult to filter out irrelevant stimuli, ignore irrelevant information in memory, and showed an increase in switch costs as they alternated between two tasks. The finding that HMMs show greater switching cost is perhaps the most surprising; one might expect people are better able to switch between tasks the more they multitask. The authors suggest that these findings demonstrate that HMMs have breadth-biased cognitive control, meaning that they are more likely to respond to new and irrelevant stimuli from the environment at cost to performance on a single task. Interestingly, a follow-up study by Alzahabi and Becker (2013) found contradictory evidence. In two experiments, they found that HMMs actually performed better at task switching than LMMs, while there were no differences between the two groups at dual-tasks (i.e., when they perform two tasks simultaneously).

These discrepant findings suggest there is much to be learned about the long-term cognitive effects of multitasking. One potential direction is to test the causal relationship between personal differences (in cognitive functions, in needs and motives, in personality traits, etc.) and multitasking behaviors. One such exploration is by Wang and Tchernev (2012). They found evidence of dynamic mutual causal influences between media multitasking behaviors, and individuals' various needs and gratifications, which are further moderated by neuroticism. Their findings suggest that different multitasking behavioral patterns can be formed as a result of motivational and cognitive differences in individuals, which in turn, are further cultivated by these behaviors over time.

Dimensional Frameworks of Multitasking

On the basis of information processing and resource allocation research described earlier, multiple cognitive dimensions can be identified to help assess the cognitive demands of a given multitasking combination. This dimensional framework can help predict the prevalence of certain multitasking behaviors. Indeed, new evidence shows that as expected, people typically avoid more cognitive demanding task combinations and favor easier ones (Wang, Irwin, Cooper, & Srivastava, 2014). This suggests that, instead of being labeled as "maladaptive" (because of performance deterioration), increasing multitasking behaviors in daily life may be adaptive to our media-saturated environments. In addition, a dimensional framework of multitasking can help better pinpoint the underlying concepts being tested across multitasking experiments or surveys to help synthesize findings.

Two such frameworks have been proposed. Oswald *et al*. (2007) considered various dimensions of tasks and individual differences (e.g., ability, personality, motivation). They propose a total of 17 task dimensions related to five categories: task characteristics, task structure, task timing, task control, and task outcomes. Alternatively, Wang *et al*., 2014 propose a dimensional framework specifically for media multitasking (i.e., multitasking with at least one media device), which could potentially be applied to general multitasking situations. They identified 11 cognitive dimensions in four categories: task relations, task inputs, task outputs, and individual differences, which are summarized in the following text.

The task relations category includes five dimensions regarding how tasks in a multitasking situation relate to each other. (i) *Task hierarchy* refers to whether a task is considered primary and the others secondary, or if tasks are relatively equal in significance to the person. Research has shown that more cognitive resources are allocated to more important tasks, such that a person performs better by focusing on a primary task over a peripheral task than if both are treated equally (Dijksterhuis & Aarts, 2010; Lin *et al*., 2009). (ii) *Task switch* is the degree of control a person has in switching between tasks, that is, whether task switches are intentional or externally controlled. Some tasks allow for greater control over when they are engaged, while others may force attention switches (Wang *et al*., 2012). (iii) *Task relevance* refers to the relatedness of the goals in each task—are they ultimately done for the same or different ends? While multitasking research often examines tasks with unrelated goals (e.g., Adler & Benbunan-Fich, 2012), studies have shown that task performance may improve if tasks are highly related (e.g., Levy & Pashler, 2008). (iv) *Modality variation* is the degree to which sensory modalities engaged by each task overlap or are distinct. A multitasking behavior should be less demanding when tasks are spread across multiple modalities (Moreno & Mayer, 1999; Salvucci & Taatgen, 2008; Wang *et al*., 2012). (v) Finally, *task contiguity* assesses the physical proximity of the multiple tasks, including task stimuli responses. Relevant tasks benefit from physical proximity as task switch costs are reduced, while there may be greater interference between irrelevant tasks in close proximity (e.g., Mayer & Moreno, 2002).

The task inputs category includes three dimensions of the format and content of incoming stimuli. (i) *Information modality* refers to the type and number of modalities engaged by each task. Threaded cognition theory suggests that the more sensory modalities engaged, the more likely that interference will occur between tasks that share a common resource pool and a greater burden on the central procedural pool (Salvucci & Taatgen, 2008). (ii) *Informational flow* can range from static information (e.g., stories in print newspapers) to transitory, dynamic information that requires immediate attention (e.g., moving images and sound). The limited capacity research applied to media processing (Lang, 2000, 2006) emphasizes that the video and audio content of media can elicit attention in a dynamic manner distinct from activities such as reading. Although processing of a media task may benefit from increased attention, too many information changes can overwhelm the cognitive system—especially if cognitive resources are split between two tasks. (iii) Lastly, *emotional content* refers to the valence and intensity of stimuli that can motivate resource allocation. Positive or negative emotional content can trigger activation of the appetitive and/or aversive systems, allocating cognitive resources toward or away from the content depending on the level of intensity (Wang, Lang, & Busemeyer, 2011).

The third category is task outputs, consisting of two dimensions. (i) *Behavioral responses* distinguish tasks that require a person to provide behavioral responses (e.g., making statements during a conversation) from those that are primarily cognitive (e.g., processing information while watching television). Tasks that require behavioral responses demand not only motor resources, but also additional cognitive resources to make decisions. (ii) *Time pressure* refers to the context when such behavioral responses are required. Does a person need to act within a set time period?

Finally, a number of individual differences have been identified that can influence multitasking performance, such as sensation seeking (Sanbonmatsu *et al*., 2013), neuroticism (Wang & Tchernev, 2012), and expertise (Lin *et al*., 2009). These variables can help predict both the likelihood that a person will opt to multitask and performance outcomes.

KEY ISSUES FOR FUTURE RESEARCH

Much more effort is still needed to explore the two new research directions described above. First, it is important to further understand the long-term impacts of chronic multitasking behavior. We have seen evidence of the persistence of multitasking behaviors and intricate dynamic reciprocal impacts between the behaviors and individuals' needs and gratifications (Wang & Tchernev, 2012) and their potential influences on cognitive functions (Alzahabi & Becker, 2013; Ophir *et al*., 2009). These studies need to be replicated, especially when contrastive evidence is presented. Meanwhile, new measures and methods should be used to further explore these questions. For example, multitasking behaviors potentially can shape the underlying neurocognitive architecture that controls future behavior (La Cerra & Bingham, 1998). On the basis of extensive neuroscientific evidence, particularly the extraordinary functional plasticity of the neocortex of mammals, including humans, it is argued that flexible cortical representational networks are modified and constructed through adaptive interactions with the environment (La Cerra & Bingham, 1998), including a mediated environment. Considering the incessant expansion of our information environment facilitated by media technologies, it is critical to carefully examine the long-term mutual influences between media multitasking, cognitive functions, neural substrates, and personal traits from a dynamic and developmental perspective.

Second, the dimensional framework of multitasking can be used to compare and synthesize existing research on multitasking. In addition, it can be used to guide designs of more efficient and friendly multitasking technologies and environments. For example, as threaded cognition theory and multiple resources theories indicate, we can employ different modalities for different tasks to reduce competition between threads for the same modality resource.

Third, related to the dimension of individual differences, we may design training programs to develop better multitasking capabilities. For example, as threaded cognition theory suggests, as tasks become more routinized, they shift from depending on declarative (i.e., memorized, informational) to procedural (i.e., how to perform an action) memory (Salvucci & Taatgen, 2008). As this process occurs, tasks become less cognitively demanding and multitasking becomes easier. In addition, media multitasking literacy should be integrated into media literacy education to help mitigate negative influences of multitasking, such as potentially dangerous overestimation of one's own multitasking capabilities (Wang *et al*., 2012).

Finally, more advanced approaches, such as dynamic methods and analysis, and computational models, will help advance this research agenda. Prominently, these include the formal computational models of threaded cognition and Townsend's response time models to identify series versus parallel cognitive processes in the context of complex multitasking.

REFERENCES

Adler, R. F., & Benbunan-Fich, R. (2012). Juggling on a high wire: Multitasking effects on performance. *International Journal of Human-Computer Studies*, *70*, 156–168.

Allport, D. A., Antonis, B., & Reynolds, P. (1972). On the division of attention: A disproof of the single channel hypothesis. *Quarterly Journal of Experimental Psychology*, *24*, 225–235.

Alzahabi, R., & Becker, M. W. (2013, February 11). The association between media multitasking, task-switching, and dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance* Advance online publication. doi:10.1037/a0031208

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. (2004). An integrated theory of the mind. *Psychological Review*, *111*, 1036–1060.

Armstrong, G. B., & Chung, L. (2000). Background television and reading memory in context. *Communication Research*, *27*, 327–352.

Basil, M. D. (1994). Multiple resource theory I: Application to television viewing. *Communication Research*, *21*, 177–207.

Bauerlein, M. (2008). *The dumbest generation: How the digital age stupefies young Americans and jeopardizes our future*. New York, NY: Jeremy P. Tarcher/Penguin Group.

Bowman, L. L., Levine, L. E., Waite, B. M., & Gendron, M. (2010). Can students really multitask? An experimental study of instant messaging while reading. *Computers & Education*, *54*, 927–931.

Cantril, H., & Allport, G. W. (1935). *The psychology of radio* (pp. 19–35). New York, NY: Harper & Brothers.

Carrier, L. M., Cheever, N. A., Rosen, L. D., Benitez, S., & Chang, J. (2009). Multitasking across generations: Multitasking choices and difficulty ratings in three generations of Americans. *Computers in Human Behavior*, *25*, 483–489.

Dijksterhuis, A., & Aarts, H. (2010). Goals, attention, and (un)consciousness. *Annual Review of Psychology*, *61*, 467–490.

Dux, P. E., Ivanoff, J. G., Asplund, C. L., & Marois, R. (2006). Isolation of a central bottleneck of information processing with time-resolved fMRI. *Neuron*, *52*, 1109–1120.

Hamilton, J. (1859). *Lectures on metaphysics and logic*. Edinburgh, UK: Blackwood.

Havender, J. W. (1968). Avoiding deadlock in multitasking systems. *IBM Systems Journal*, *7*, 74–84.

Hawkins, R. P., Pingree, S., Hitchon, J., Radler, B., Gorham, B. W., Kahlor, L., & Kolbeins, G. H. (2005). What produces television attention and attention style? *Human Communication Research*, *31*, 162–187.

Jackson, M. (2008). *Distracted: The erosion of attention and the coming dark age*. New York, NY: Prometheus Books.

Jeong, S. H., & Fishbein, M. (2007). Predictors of multitasking with media: Media factors and audience factors. *Journal of Media Psychology*, *10*, 364–384.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.

Kirn, W. (2007) (November). The autumn of the multitaskers. *The Atlantic.* Retrieved from http://www.theatlantic.com/magazine/toc/2007/11.

La Cerra, P., & Bingham, R. (1998). The adaptive nature of the human neurocognitive architecture: An alternative model. *Proceedings of the National Academy of Sciences*, *95*, 11290–11294.

Lang, A. (2000). The limited capacity model of mediated message processing. *Journal of Communication*, *50*, 46–70.

Lang, A. (2006). Using the limited capacity model of motivated mediated message processing to design effective cancer communication messages. *Journal of Communication*, *56*, S57–S80.

Levy, J., & Pashler, H. (2008). Task prioritization in multitasking during driving: Opportunity to abort a concurrent task does not insulate braking responses from dual-task slowing. *Applied Cognitive Psychology*, *22*, 507–525.

Levy, J., Pashler, H., & Boer, E. (2006). Central interference in driving: Is there any stopping the psychological refractory period? *Psychological Science*, *17*, 228–235.

Lin, L., Robertson, T., & Lee, J. (2009). Reading performances between novices and experts in different media multitasking environments. *Computers in the Schools*, *26*, 169–186.

Marois, R., & Ivanoff, J. (2005). Capacity limits of information processing in the brain. *Trends in Cognitive Sciences*, *9*, 296–305.

Mayer, R. E., & Moreno, R. (2002). Animation as an aid to multimedia learning. *Educational Psychology Review*, *14*, 87–99.

McCartt, A. T., Hellinga, L. A., & Bratiman, K. A. (2006). Cell phones and driving: Review of research. *Traffic Injury Prevention*, *7*(2), 89–106.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 81–97.

Moreno, R., & Mayer, R. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology*, *91*, 358–368.

Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. *Psychological Review*, *86*, 214–255.

Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences*, *106*, 15583–15587.

Oswald, F. L., Hambrick, D. Z., & Jones, L. A. (2007). Keeping all the plates spinning: Understanding and predicting multitasking performance. In D. H. Jonassen (Ed.), *Learning to solve complex scientific problems* (pp. 77–97). Mahwah, NJ: Erlbaum.

Rideout, V. J., Foehr, U. G., & Roberts, D. F. (2010). *Generation M^2: Media in the lives of 8- to 18-year-olds*. Retrieved from the Henry J. Kaiser Family Foundation: http://kff.org/other/event/generation-m2-media-in-the-lives-of/.

Salvucci, D. D., & Taatgen, N. A. (2008). Threaded cognition: An integrated theory of concurrent multitasking. *Psychological Review*, *115*, 101–130.

Sanbonmatsu, D. M., Strayer, D. L., Medeiros-Ward, N., & Watson, J. M. (2013). Who multi-tasks and why? Multi-tasking ability, perceived multi-tasking ability, impulsivity, and sensation seeking. *PLoS ONE*, *8*, e54402.

Svoen, B. (2007). Consumers, participants, and creators: Young people's diverse use of television and new media. *ACM Computers in Entertainment*, *5*(2), 1–16.

Townsend, J. T. (1990). Serial vs. parallel processing: Sometimes they look like tweedledum and tweedledee but they can (and should) be distinguished. *Psychological Science*, *1*, 46–54.

Townsend, J. T., & Wenger, M. J. (2004). A theory of interactive parallel processing: New capacity measures and predictions for a response time inequality series. *Psychological Review*, *111*, 1003–1035.

Wang, Z., David, P., Srivastava, J., Powers, S., Brady, C., D'Angelo, J., & Moreland, J. (2012). Behavioral performance and visual attention in communication multitasking: A comparison between instant messaging and online voice chat. *Computers in Human Behavior*, *28*, 968–975.

Wang, Z., Irwin, M., Cooper, C., & Srivastava, J. (2014). Multidimensions of media multitasking and adaptive media selection. *Human Communication Research*, Advance online publication. doi:10.1111/hcre.12042

Wang, Z., Lang, A., & Busemeyer, J. R. (2011). Motivational processing and choice behavior during television viewing: An integrative dynamic approach. *Journal of Communication*, *61*, 71–93.

Wang, Z., & Tchernev, J. M. (2012). The "myth" of media multitasking: Reciprocal dynamics of media multitasking, personal needs, and gratifications. *Journal of Communication*, *62*, 493–513.

Welford, A. T. (1967). Single-channel operation in the brain. *Acta Psychologica*, *27*, 5–22.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, *3*, 159–177.

Zhang, W., & Zhang, L. (2012). Explicating multitasking with computers: Gratifications and situations. *Computers in Human Behavior*, *28*, 1883–1891.

FURTHER READING

Meyer, D. E., & Kieras, E. (1997). A computational theory of executive cognitive processes and multiple-task performance. *Psychological Review*, *104*, 3–65.

Moreno, M. A., Jelenchick, L., Koff, R., Eikoff, J., Diermyer, C., & Christakis, D. A. (2012). Internet use and multitasking among older adolescents: An experience sampling approach. *Computers in Human Behavior*, *28*, 1097–1102.

Nielsen Company (2012). State of the media: Cross-platform report quarter 2, 2012—US. Available from the Nielsen Company, http://www.nielsen.com/us/en/reports/2012/state-of-the-media–cross-platform-report-q2-2012.html.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin*, *116*, 220–244.

Pool, M. M., Koolstra, C. M., & van der Voort, T. (2003). The impact of background radio and television on high school students' homework performance. *Journal of Communication*, *53*, 74–87.

Schumacher, E. H., Seymour, T. L., Glass, J. M., Fencsik, D. E., Lauber, E. J., Kieras, D. E., & Meyer, D. E. (2001). Virtually perfect time sharing in dual-task performance: Uncorking the central cognitive bottleneck. *Psychological Science*, *12*, 101–108.

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