CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2008 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-13: 978-0-8058-5983-6 (Softcover)

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

No part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (http://www.copyright.com/) or contact the Copyright Clearance Center, Inc. (CCC) 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Wickens, Christopher D.
Applied attention theory / authors, Christopher D. Wickens, Jason S. McCarley.
p. ; cm.
Includes bibliographical references and index.
ISBN 978-0-8058-5983-6 (hardcover : alk. paper)
1. Attention--Physiological aspects. 2. Cognitive neuroscience. I. McCarley, Jason S. II. Title.
[DNLM: 1. Attention--physiology. 2. Cognitive Science--methods. 3. Psychological Theory. BF 321 W636a 2007]

QP405.W55 2007
612.8'2331532--dc22 2007030245

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contents

Conclusion

In conclusion, executive control and task management play the dominant role in multiple-task performance, when parallel processing is no longer possible and when serial processing predominates. This parallels the role of the resource-allocation policy, discussed in parallel processing in the previous two chapters. There is some convergence in results describing these task-management processes when we look at the three domains of research covered here: (1) basic attention switching; (2) more complex interruption management; and (3) the complex level of real-world task and interruption management. However, more research in the third domain is certainly needed to better understand task-management strategies here. All three domains point to the costs of attention switching and interleaving compared with staying on a single, uninterrupted task. All point to the role of strategies and working memory in managing these multiple tasks well.

Also emerging from the literature are findings that certain task- and display-related factors *drive* task management in nonoptimal ways, analogous to the nuisance properties of salience and effort in the SEEV model discussed in chapter 4, whereas other, more optimal, top-down properties can be achieved by the well-calibrated task manager. More optimal task management is possible to the extent that the operator has the information and knowledge available to know things like calibrated task importance, expected value (risk of failing to do the task), duration, and arrival time. This knowledge is analogous to the E and V properties of the SEEV model. In particular, this latter class of top-down knowledge-driven factors in task management points to the possible role of attention and task-management training in improvement of multitasking, resource allocation, and interruption management (Dismukes 2001; Gopher 1992; Hess and Detweiller 1994), an issue addressed in the next chapter.

10

Individual Differences in Attention

Introduction

It has become somewhat of a cliché that we have entered the information age, but it is certainly true that that many of us find ourselves in an age of information overload in which we are bombarded by computer messages, cell-phone calls, PDA messages, and so forth—in which we are constantly multitasking. Some have speculated that such constant exposure to multiple electronic channels improves our overall multitasking ability through practice and experience, and others speculate that younger generations, growing up within such an environment, may possess an improved ability, almost as if it is a trait (Lohr 2007; *Time* 2006). Anecdotal evidence seems to support this speculation. Everyone has some acquaintances who seem to be talking, texting, and listening all at once and all the time and others who have trouble dealing with more than one task at a time.

The current chapter deals with three aspects of these individual differences in attention. First, consideration is given to how differences are created through training and experience. What makes the expert seemingly more proficient at dual tasking than the novice, and can such a skill be explicitly trained to create a shortcut to this important aspect of expertise? Next is addressed the differences between people unrelated to practice and, hence, more attributable to innate individual differences, analogous to verbal and spatial ability differences. What is the evidence for stable traits in the various manifestations of attention we have described, how are these traits assessed, and what differences do these assessments predict? Finally, an examination is given in detail of one very important form of individual difference contributing to attentional performance: biological age, an issue of increasing importance as our aging population strives to remain active and independent on the road and in their homes (Fisk and Rogers 2007; Fisk et al. 2004).

Attention as a Skill

When observing a skilled operator perform a complex task—whether juggling, taking dictation, flying an aircraft, or inspecting products off an assembly line—the novice is often awed at the ease with which the expert time shares multiple activities. Such performance differences between novices and experts could result from any one or more of four bases: (1) single-task skill level; (2) skill automatization; (3) task-specific time-sharing skills; and (4) domain general time-sharing skills. We consider evidence for each of these factors herein.

Single-Task Skill and Automaticity

It is well established that continued practice on a dual task leads to improved performance (Spelke, Hirst, and Neisser 1976). Naturally, some component of this gain could result simply from an improvement in the single-task component skills. Furthermore, the development of automaticity may improve dual-task performance even when no changes in single-task performance are evident. Within the framework of automaticity discussed in chapters 2 and 7 (Figure 7.4), practice that reduces single-task resource demands will free resources to be allocated to a secondary task, thus improving dual-task efficiency (Schneider 1985; Schneider and Detweiler 1988). This may not entail an observable improvement in single-task performance, but only an increase in the data-limited region of a performance resource function (PRF) that asymptotes at the same level (Figure 7.4). As noted already, automaticity develops with extended practice on tasks with consistently mapped components: repeated perceptual elements, co-occurring cues, or stimuli or categories that are consistently mapped to response classes and to physical responses.

Because this form of improvement does not reflect the acquisition of a time-sharing skill but rather a reduction in single-task resource demands, it can be achieved through single-task practice. Such a mechanism explains the automatic processing of familiar perceptual stimuli such as letters (LaBerge 1973), consistently mapped targets (Schneider and Fisk 1982; Schneider and Shiffrin 1977), and repeated sequences of stimuli and events (Bahrick and Shelley 1958; Bahrick, Noble, and Fitts 1954) as well as the automatic performance of habitual motor acts such as signing one's own name, tying a shoe, or logging onto e-mail. When discussing response execution, this automaticity of performance is referred to as the *motor program* (Keele 1973; Summers 1989). Differences in time sharing capabilities between flight instructors and student pilots (Damos 1978) can easily be explained by the greater automaticity with which the former carry out many aspects of their task.

Specific Time-Sharing Skills

In contrast to automaticity, strong evidence for the existence of time-sharing skills falls from the following logical arguments:

(1) Single-task automaticity develops best when full resources are allocated to learning the components (Lintern and Wickens 1991; Nissen and Bullemer 1980).

(2) If single-task automaticity were the only element underlying the high time-sharing, or divided-attention, competence following practice, then single-task practice of components—which in training research is called part-task training, or fractionation (Wightman and Lintern 1985)—would be the most efficient way of improving time-sharing performance.

(3) A review of the literature on part-task training suggests that such training is often no better and sometimes worse than whole-task training on a dual-task combination (Damos and Wickens 1980; Fabiani et al. 1989; Lintern and Wickens 1991) in spite of the fact that whole-task conditions hamper the development of automaticity. Hence, the existence of a learned time-sharing skill is revealed.

The revelation of a time-sharing skill leads to the next question: What does such a skill consist of? Research has suggested at least four possibilities, all tied to the general notion that the expert learns to strategically allocate attention.

First, time sharing is facilitated by the development of visual scanning strategies in multitask situations. For example, expert pilots learn scanning patterns necessary to control all three axes of flight (i.e., triple tasking) (Bellenkes, Wickens, and Kramer 1997). Skilled vehicle drivers learn to scan farther down the highway (Mourant and Rockwell 1972) and to orient toward sources of potential hazards (Fisher and Pollatsek 2007). As noted in chapter 4, many of these aspects of skills can be associated with a selective attention-scanning strategy that adheres to the expected value component of the SEEV model—that is, a calibrated mental model (Moray 1986). Thus, Wickens, McCarley, et al. (2007) found that superior performers in a multitask flight simulation had scanning strategies that approximated those prescribed by the optimum expected value model, unlike the participants who fared more poorly.

Given that scanning differences underlie proficiency differences in dual-task performance, one can ask if such differences can be explicitly trained. Here the research of Pollatsek et al. (2006), which was described in chapter 4, is promising. This work trained novice drivers to better scan to high-risk areas in the forward field, thus allowing better performance on the dual tasks of lane keeping and hazard monitoring.

A second source of time-sharing skill can be understood within the framework of the task-switching and interruption literature described in the previous chapter. There, mechanisms were discussed that improve task and interruption management; in particular, an experiment was noted by Dodhia and Dismukes (2003) and Dismukes and Nowinski (2007), which demonstrated that resumption of an ongoing task following interruption was easiest if (1) there was a delay allowed between the interruption and the suspension of the ongoing task, allowing the performer to choose a convenient leaving place and perhaps to place reminders of where to return to the ongoing task; and (2) when the interrupting task was completed there was some salient reminder existed to return to the ongoing task, perhaps one planted in (1).

It seems reasonable that such strategies—as well as others (McFarlane 2000; McFarlane and Latorella 2002) such as being aware of when interruptions are particularly insidious (McDaniel and Einstein 2007)—could be taught as a way to improve task management. To date, little data exist regarding the value of such explicit training in transfer to new tasks. Nevertheless, at least one study (Hess and Deitweiler 1994) established the value of mere exposure to interruptions as a way of developing interruption-handling skills, whereas Cades, Trafton, and Boehm-Davis (2005) found that explicit training on the interruption–resumption interval could produce improved performance above and beyond simple performance on the tasks themselves. Dismukes (2001) advocated such interruption management training for pilots.

A third source of evidence for time-sharing skill comes from the success of training fairly specific resource-allocation strategies, in which resources are considered in the context of chapters 7 and 8. Strong evidence has supported the success of what is termed *variable priority training* (Gopher 1992, 2007), suggesting that attentional flexibility is indeed an important time-sharing skill. Gopher and Brickner (1980) observed that subjects who were trained in a time-sharing regime that successively emphasized different resource-allocation policies became more efficient time sharers in general than did a group trained only with equal priorities. The former group was also better able to adjust performance in response to changes in dual-task difficulty. Fabiani et al. (1989) and Gopher, Weil, and Siegel (1989) found that training that emphasizes attention control leads to better transfer to a complex multitask video game, and further evidence suggests that similar training benefits later performance in the attention-challenging task of flying military aircraft (Gopher, Weil, and Bareketi 1994). As discussed following, Kramer, Larish, and Strayer (1995) found that variable priority training could offset some of the deficits in time sharing shown by older adults and that this skill in learning how to flexibly allocate resources could transfer between different dual-task combinations. Schneider and Fisk (1982) found that subjects could time share automatic and resource-demanding letter-detection tasks with perfect efficiency if they were instructed to allocate their attention away from the automatic task. In the absence of this training, subjects allocated resources in a nonoptimal fashion by providing more resources to the automatic task than it needed, compromising performance of the resource-limited task. Thus, clearly, resource allocation can be trained, and such training leads to better multitasking.

A fourth indication of what may underlie time-sharing skills comes from the research of Damos and Wickens (1980), who had subjects practice extensively on dual-task pairs involving both tracking and discrete digit processing. Fine-grained analysis of dual-task performance revealed that practiced subjects engaged in more parallel processing of the stimuli rather than discrete switching. Thus, it is possible that more proficient time sharing involved either developing knowledge that greater efficiency can be gained by parallel processing or that the actual capacity, or size of the resource pool, increases.

The success that researchers have had in training attentional scanning (Fisher and Pollatsek 2007; Pollatsek et al. 2006), visual search (Gramopadhye, Drury, and Prabhu 1997), and task prioritization (Gopher 2007) parallels other efforts to inculcate attentional skills. Walker and Fisk (1995) designed a computer game to train football quarterbacks to reading the defense and were successful enough that their technique was adopted by the Atlanta Falcons. A similar intervention that emphasized attentional flexibility has been employed with success in training college and professional basketball players (Gopher 2007). Navarro et al. (2003) developed a tool to help children divide visual attention between different elements to be compared in complex visual scenes (e.g., "One of these faces is not like the other") and found that benefits from training on this task transferred to improved performance on other cognitive tests that depended on attention. Green and Bavelier (2003) observed that habitual video-game players performed better on tests of attention measuring the useful field of view (UFOV) (i.e., attentional breadth) than did nonplayers. The investigators then assessed whether the UFOV could be expanded for nonplayers by having them practice for eight sessions on the video game, and they found that it could.

Evidence for such things as a broadened UFOV or a practice-induced increase of attentional flexibility suggests that some aspect of dual-task proficiency may be general in nature, applicable not only in the specific task-sharing context in which it was acquired but in other multitask combinations as well. For example, practicing cell-phone talking while driving might transfer to a qualitatively different time-sharing task combination (e.g., rehearsing a lecture while cooking). To date, however, evidence for such general time-sharing skill, learned through training, is slight but still positive. Thus, Damos and Wickens (1980) found that a transfer from dual-axis tracking to dual-digit processing—and vice versa—was positive, suggesting that the earlier dual-task training does, in fact, develop a generalizable multitasking skill. Kramer, Larish, and Strayer (1995) found that, particularly for older individuals, variable priority training on one dual-task combination led to positive transfer on a very different task combination. A related finding is that bilingual children who are raised in a household where attention must often be switched between languages show a pattern of more proficient executive control than children raised in a monlingual household (Bialystok 1999). These pieces of positive evidence notwithstanding, it is probably the case that the greatest component of time-sharing skills lies in learning the effective resource-allocation skills and strategies for a specific dual-task pair. Other more enduring and general differences across task combinations are probably more attributable to stable individual differences—traits of attention—an issue to which we now turn.

Attention as an Ability

As distinct from a skill, which is the result of practice, we consider here the role of ability in attention, in which ability is assumed to be a more innate and permanent cognitive characteristic, akin to the stable differences between people in verbal and spatial abilities. Such individual differences in attentional capability are important because of their potential role in selection of workers to carry out complex attention-demanding jobs, like piloting an aircraft or managing an office. For example, if reliable tests of attention can be shown to correlate with performance on the flight deck, then it should be possible to screen applicants for a highly competitive piloting job on the basis of their test scores (Caretta and Ree 2003; Hunter and Burke 1995; Pohlman and Fletcher 1999). To address the issue of attention abilities, we consider two broad classes of studies: (1) those that have examined stable individual differences in attentional components; and (2) those that have examined overall differences in time-sharing ability (Brookings and Damos 1991). Within each class, researchers' interests have been focused on correlational measures indicating that people who do well on one particular attention test also do well on another or on some complex skill requiring heavy attentional support (Hunt and Lansman 1981).

Attentional Components

Attention switching has received a fair amount of research as an ability component. Much of this research was stimulated by the early findings of Gopher and Kahneman (1971), Gopher (1982), and Kahneman, Ben-Ishae, and Lotan (1973) that measures of auditory attention-switching speed derived from the dichotic listening task discussed in chapter 2 could be used to predict the success rates of student pilots and the accident rates of bus drivers. This test measured how quickly operators could switch their attention on cue from one ear to the other. Research by Lansman, Poltrock, and Hunt (1983) also identified an abilities component related to attention switching. However, the degree of generality of such a component remains uncertain. Lansman and colleagues, for example, found that there were separate components within each the auditory and visual modalities. Correspondingly, Braune and Wickens (1986) failed to find that measures of auditory attention switching correlated with a variety of visual attention-switching measures.

Still, a review of research carried out by Hunt, Pellegrino, and Yee (1989, p. 308) on attention switching both between dual tasks and between components within a single task concluded that there does appear to be "an ability to coordinate information from several sources that is independent of the ability to process information from one of these sources alone." The role of attention control in this process is further supported by the research of North and Gopher (1976), who found that individual differences in the ability to modulate resources to primary and secondary tasks were both uncorrelated with single-task performance and independently predictive of success in flight training. This role of attention control as an ability appears to be closely related to the capacity of working memory, as discussed later in this chapter.

A somewhat related line of research has focused on an emerging distinction between two qualitatively different dual-task processing styles, characterized as parallel processing versus serial processing. The parallel processor, for example, might continue steering while performing a discrete task in the automobile, whereas the serial processor would pause the steering task while dealing with the discrete task or might postpone the discrete task until steering requirements have stopped. This dichotomy, paralleling the contrast between chapters 7 and 8 on the one hand and chapter 9 on the other, seems to distinguish two different classes of people given a dual-task challenge (Braune and Wickens 1986; Damos, Smist, and Bittner 1983). Importantly, it is not always the case that parallel processors show better dual-task performance. As intuition tells us, sometimes it is better to try to do two tasks sequentially and perfectly than to attempt to time share them, suffering decrements on one or both. That is, parallel processing does not necessarily imply perfect performance.

Chapter 5 discussed the UFOV as an important component of visual attention related to visual search. Here Owsley et al. (1998) found that this component can be reliably measured and is predictive of differences in driving safety. They made a compelling case that its assessment should be included in tests of driving competence or selective screening for driver's licenses.

Time-Sharing Ability

An alternative approach to measuring the attention components that often underlie dual-task performance is to directly assess individual differences in dual-task decrements and the extent to which these are stable across people. Of course, here the same care must be exercised as was discussed in the section on attention training. If one person has a smaller dual-task decrement than another, it may simply be because that person possesses greater automaticity on one or more of the component tasks, a difference unrelated to a time-sharing ability. To examine these issues, researchers have tried to disentangle differences in the resources demanded by a component task (i.e., the shape of the PRF) from differences in the resources available (i.e., the size of the resource pool) for performance of concurrent tasks (Lansman and Hunt 1982). If some people have more resources than others, then they should be able to perform better in dual-task circumstances than other people, but their performance loss in going from single- to dual-task conditions should be equivalent. This equivalence results because the demand for a particular task on those resources (i.e., automaticity level) will not differ. Thus, a low or zero correlation is predicted between dual-task decrement and single-task performance, and data have supported this lack of relationship (Braune and Wickens 1986; Lansman and Hunt 1982; Wickens and Weingartner 1985). Fogarty and Stankov (1982) reported that the degree of independence of the component of dual-task performance from single-task skills grows stronger as a component task is made secondary, or is deemphasized—a fact that again implicates the resource capacity metaphor to represent time-sharing ability.

These data, along with others (e.g., Fogarty and Stankov 1982, 1988; Hunt and Lansman 1981; Jennings and Chiles 1977; Stankov 1983, 1988; Sverko 1977; Wickens, Mountford, and Schreiner 1981), seem to establish that people differ in their time-sharing capabilities in ways that cannot be predicted only from their skill level on the component tasks, or automaticity. However, this conclusion has led to a further question regarding the extent to which such abilities are general, characterizing performance on a wide variety of qualitatively different dual-task pairs rather than specific to particular types of pairs (e.g., two visual tasks). It turns out that this conclusion of generality, paralleling that discussed in the context of time-sharing skill and attention switching, is extremely difficult to prove because of various statistical and methodological considerations (Ackerman, Schneider, and Wickens 1984). At best, the evidence is mixed. Wickens, Mountford, and Schreiner (1981), for example, examined differences in time-sharing ability of forty subjects performing four different tasks in nine different pairwise combinations. Although there were substantial individual differences in the efficiency of time sharing a given task pair, they did not correlate highly across the different dual-task combinations. On the other hand, Ackerman, Schneider, and Wickens (1984) examined the same data with a confirmatory factor analysis and concluded that there was some evidence for a general time-sharing ability.

Finally, given the possibility of a general time-sharing skill, it is appropriate to ask what its nature might be. Here at least three possibilities avail themselves, and they are not mutually exclusive. One is that it may relate to motivational effects, reflecting a cognitive continuum of low to high energetic arousal (Matthews and Davies 2001). High-energy people can better sustain the high resource demands of dual tasking. A second possibility is that such general ability is resident in the central executive—as discussed in chapter 9—as a means for flexibly deploying attention in demanding dual-task circumstances. This is consistent with the view of Hunt, Pellegrino, and Yee (1989) that such differences are due to attention control and coordination. A third possibility is that such differences relate to the capacity of working memory, as described following. These two components—working memory and executive control—are clearly related: Both are necessary for good multitasking, and both relate to the concept of fluid intelligence and general intelligence manifest in IQ, the single ability most predictive of success in complex multitask domains (Borman, Hanson, and Hedge 1997; Caretta and Ree 2003; Catell 1987; Hunt et al. 1983; Stankov 1987; Ree and Caretta 1996).

Attention and Working Memory

Another cognitive measure closely linked to attentional performance as well as individual differences is working memory capacity (Baddeley and Hitch 1974), a concept that can be best understood by comparison to the familiar notion of short-term memory (STM) (Atkinson and Shiffrin 1968; Miller 1956). STM, as traditionally conceived, is a cognitive system used to hold information over relatively brief periods of time. WM, in contrast, is more complex, "allowing the temporary storage and manipulation of information necessary for such complex tasks as comprehension, learning, and reasoning" (Baddeley 2000, p. 418). Thus, the WM system comprises not just the STM buffers needed to hold information but also a set of attentional control mechanisms used to regulate the flow of information into and out of STM and to transform the information stored. The influential WM model of Baddeley and Hitch (1974) and Baddeley (1986), for example, comprises a pair of short-term buffers for holding verbal and visual information, respectively, along with a central executive mechanism—as discussed in chapter 9—responsible for controlling the buffers' activity.

As befits its inclusion in the current chapter, large stable and meaningful individual differences in working memory have been well documented (Engle 2002). WM capacity can be measured with what is known as a complex span task. Various forms of complex span exist (Conway et al. 2005; Daneman and Carpenter 1980; Turner and Engle 1989), but all share the critical characteristic that they require subjects to hold information in STM while performing some additional information processing task—that is, under conditions of divided attention. In an operation span task (Turner and Engle 1989), for example, the subject is presented a series of true or false mathematical equations (e.g., $8 \times 2 - 5 = 9$), each followed by an unrelated word. The subject's task is to judge the truth of each equation while storing the words for recall at the end of the series. The task therefore demands that information be maintained in STM while additional information processing operations, which are needed to solve the equations, are performed. This can be compared with a traditional simple span task in which information is stored in STM but no additional task is performed.

Although the STM and WM systems are closely linked (Cowan 1995; Engle et al. 1999), STM and WM span scores differ dramatically in their relationship to other performance measures. STM capacity, contrary to the early expectations of many researchers, is at best weakly correlated with measures of performance on more complex tasks such as reading (Daneman and Carpenter 1980; Perfetti and Lesgold 1977). WM capacity, on the other hand, is a good predictor of many high-level cognitive abilities and traits, including reading comprehension (Daneman and Carpenter 1980), retrieval of information from long-term memory (Rosen and Engle 1997), and fluid intelligence (Engle et al. 1999). WM span scores also correlate highly with measures of various real-world skills, including proficiency in tasks such as following directions (Engle, Carullo, and Collins 1991), taking lecture notes (Kiewra and Benton 1988), learning a computer programming language (Shute 1991), and even judging the safety of a left-hand turn across lanes of oncoming traffic (Guerrier, Manivannan, and Nair 1999) (for a review see Engle 2002).

Data also show strong relationships, finally, between WM span and various lab-based measures of attentional processing. Proficiency in a selective listening task (e.g. Cherry 1953; Moray 1959; also see chapter 2 in this volume), for example, increases with WM capacity. Thus, when asked to shadow a stream of speech played to one ear and ignore a distracting voice in the other, listeners with a high WM span are less likely to notice their name in the to-be-ignored ear (Conway, Cowan, and Bunting 2001). Subjects with a high WM span also tend to suffer less Stroop interference than those with a low span (Kane and Engle 2003) and are better able to suppress capture of attention by a sudden visual transient (Kane et al. 2001). Thus, WM capacity correlates with the ability to focus attention. Furthermore, those with higher span are more flexible in distributing covert attentional resources, showing a greater ability to divide the mental spotlight of attention between noncontiguous areas of the visual field (Bleckley et al. 2003).

What makes WM span such a good predictor of performance on so many tasks, both in the lab and in real-world settings? Engle and colleagues (Engle 2002; Engle et al. 1999) argued that WM capacity predicts performance on attention-demanding tasks because the complex span task itself is a test of attentional function. As noted, the WM system includes the buffers needed to temporarily hold information and a central executive mechanism responsible for controlling the buffers' activity. Simple span tasks place little demand on the central executive mechanism because they do nothing to distract attention from information in the buffers. The complex span tasks used to measure WM capacity, however, tax the central executive heavily, requiring it to hold information in the memory buffers and protect it from interference while the focus of processing is repeatedly diverted to a concurrent task. WM capacity is a measure of how proficiently this attentional information juggling is performed; subjects with good attention control skills will better be able to maintain the information stored in short-term buffers while contending with the distracting task. WM span is a good predictor of performance in a variety of laboratory and real-world tasks, moreover, precisely because those tasks rely on the same attentional control mechanisms (Engle 2002).

Attention and Aging

Advancing age in adulthood brings a gradual but widespread decline in perceptual and cognitive performance (Fisk et al. 2004; Park 2000; Schroeder and Salthouse 2004), and it is no surprise that this includes a loss in some attentional abilities. The consequences of aging for attentional function, however, go beyond the direct effects of these losses themselves. Of perhaps equal importance is that everyday demands on attention increase with age as a result of declining sensorimotor function. As we move into middle and late adulthood, diminishing attentional resources are thus met with proliferating attentional needs. Fortunately, though, it is possible to compensate, at least in part, for these changes, through the wise application of attentional and the appropriate design of displays and tasks (Fisk and Rogers 2007; Fisk et al. 2004).

Declining Attentional Function

Notably, a number of attentional processes are spared with age. Visual search slopes for salient feature targets, for example, remain close to zero (Plude and Doussard-Roosevelt 1989), and the ability to selectively guide visual search on the basis of stimulus features remains largely or fully intact (Humphrey and Kramer 1997; Scialfa et al. 2000). Similarly, the ability to exploit both central and peripheral attentional cues in a spatial cuing task is uncompromised by healthy aging (Greenwood, Parasuraman, and Haxby 1993; Wiegmann et al. 2006), at least so long as the perceptibility of the cues themselves is matched across age groups (Gottlob and Madden 1998). Aging also appears to have little influence on processes that are highly overlearned or automatic (Hasher and Zacks 1979; Jennings and Jacoby 1993), though older adults may have difficulty achieving automatization of some new tasks (Fisk and Rogers 1991).

Other forms of attentional processing, however, are less robust across the lifespan. Some declines in attentional performance are equivalent to what is expected based on the general slowdown in perceptual and cognitive processes that occurs with advancing age (Salthouse 1996; Verhaegen 2000). As measured by differences in raw RTs, for example, older adults show greater Stroop interference and larger task-switching costs than young adults. As a proportion of baseline RTs, however, the effects are roughly the same size across young and older adult age groups (Verhaegen and Cerella 2002). In other words, advancing age seems to have no specific effects on these processes. Performance is apparently degraded only as a consequence of very broad declines in processing speed.

Other attentional mechanisms are harder hit by age, showing specific age-related losses. As one example, adults often experience particular difficulty focusing attention on task-relevant information in the presence of auditory or visual noise. Tun and Wingfield (1999), for instance, tested older and younger adults' ability to listen to and remember a stream of target speech with and without a distractor voice in the background. Memory for the target speech was compromised by the distractor for both age groups, but the effects were substantially greater for the older listeners. Age-related losses were larger still, moreover, when the distractor speech was meaningful than when it was nonmeaningful (Tun, O'Kane, and Wingfield 2002), confirming that the age difference was not simply a consequence of older listeners' sensory losses. Other data suggest similarly that older observers have difficulty processing visual information embedded among distractor items—whether those distractors are interspersed with the target spatially (e.g., Carlson et al. 1995) or temporally (Gazzaley et al. 2005)—and that the effects of visual distractors are especially pronounced when targets and distractor items do not appear in predictable locations (e.g., grouped into separate columns) (Carlson et al. 1995). These results appear, at least in part, to be the result of a deficit in top-down attentional suppression of the unwanted info (Gazzaley et al. 2005; Hasher and Zacks 1979; for caveats see Kramer et al. 1994). A related visual effect is that the visual lobe—the window of attention surrounding the point of fixation—becomes narrower with age, especially when the visual field is cluttered (Scialfa, Kline, and Lyman, 1987). The result of such attentional narrowing for older drivers is an increased risk of accident (Owsley et al. 1998). Together, these findings argue for the importance of minimizing noise levels and of ensuring clean, well-organized visual displays when designing for older users (Fisk et al. 2004).

Another form of attention strongly compromised with age is the capacity for multitasking; a large body of literature has demonstrated substantial deficits in multiple-task performance among older adults (for review see Craik 1977; Kramer, Larish, and Strayer 1995; Verhaeghen et al. 2003). In Sit and Fisk (1999), for example, young and older adult participants performed an array of four memory and perceptual judgment tasks that required them to attend to multiple visual and auditory display channels. Not surprisingly, performance for both age groups declined in the multitask condition as compared with single-task control conditions. Performance losses were disproportionately large, however, for the older adults. Similar results have been reported with task combinations ranging from walking and memorizing word lists (Li et al. 2001; Lindenberger, Marsiske, and Baltes 2000) to driving and talking on a cell phone (Alm and Nilsson 1995).

One apparent reason for the difficulty that older adults have in multitasking is that multiple-task conditions are simply more complex than single-task conditions (McDowd and Craik 1988). A second contributing factor appears to be a deficit in executive attentional control. Research has found, for instance, that older adults are less adept than their young adult counterparts in flexibly trading off attention between component tasks in a multiple-task environment (Sit and Fisk 1999; Tsang and Shaner 1998), an effect implying a loss of attentional flexibility and task coordination skills. Other findings indicate that older adults may have difficulty in simultaneously holding multiple task sets active in working memory (De Jong 2001). This conclusion is consistent with the more general finding of working memory losses in older adults (e.g., Dobbs and Rule 1989) and is bolstered by findings that in the task-switching paradigm, older adults show trial-to-trial switch costs proportionate to those of young adults but show inordinately large task-mixing costs (Bojko, Kramer, and Peterson 2004; Kray and Lindenberger 2000). Recall from Figure 9.2 that mixing costs are differences in mean RT for mixed- and pure-task blocks of trials that remain after trial-to-trial switch costs have been accounted for. They reflect the demands of keeping multiple task sets in working memory.

Increasing Attentional Demands

These reviewed findings confirm that aspects of attentional processing become less effective as we age. Evidence also indicates, unfortunately, that much of our behavior simultaneously becomes more dependent on attention. More particularly, findings show that age-related losses in sensory and physical function increase the attentional demands of everyday behavior, bringing about, in the phrasing of Lindenberger, Marsiske, and Baltes (2000, p. 434), a "permeation of behavior with cognition." Although it is common to ridicule the clumsy for their metaphorical inability to walk and chew gum at the same time, dual-task studies show that the control of posture and gait is attention demanding, particularly in the elderly (Woollacot and Shumway-Cook 2002). Thus, for older adults even the performance of relatively simple cognitive tasks—judging the pitch of a tone, detecting the onset of a light, memorizing a list of words, counting backwards by threes—can significantly compromise the ability to maintain posture and gait, to step over an obstacle, or to recover stability following a disruption of balance (e.g., Chen et al. 1996). Reciprocally, the resource demands of maintaining and recovering balance can degrade performance on secondary cognitive tasks (e.g., Lindenberger, Marsiske, and Baltes 2000). These effects are sometimes evident in the performance of young adults but are invariably larger for older adults. Why? Lindenberger et al.) speculate that as we age, "sensory and motor aspects of performance are increasingly in need of cognitive control and supervision because of frailty, sensory losses, and lower level problems in sensorimotor integration and coordination." That is, the tasks of maintaining posture and gait become more difficult as we get older, increasing their attentional requirements.

A similar phenomenon is seen at work in a connection between hearing loss and poor short-term memory. Though it is not obvious that the quality of our hearing and the capacity of our short-term memory should be related, data reveal that memory span for spoken words lists is smaller for older listeners with some hearing loss than for those with good hearing, even when the words are presented loudly enough to be heard by both groups (McCoy et al. 2005; Rabbitt 1991). The reason, theorists have concluded, is that listeners with poor hearing have to invest more effort to understand the spoken words, diverting attentional resources that could otherwise be used to keep the words active in working memory (Wingfield, Tun, and McCoy 2005). In other words, attentional resources are needed to overcome hearing losses. Consistent with this interpretation, young adults with normal hearing show lower memory spans for spoken words that are masked by noise than for words that are presented clearly (Rabbitt 1968).

Coping with Age-Related Attentional Changes

Happily, data indicate that age-related declines in cognitive performance do not translate invariably into functional everyday losses (Park and Gutchess

2000). As we age, rather, we appear to develop a variety of compensatory strategies for minimizing the consequences of our ebbing information-processing skills. One way this is accomplished in multiple task circumstances is by prioritizing the tasks that are most urgent or consequential and deemphasizing those that are less significant, optimizing the allocation of resources. Consider, for example, a study that asked young and old adults to memorize lists of words while walking a track (Li et al. 2001). As noted already, the maintenance of posture and gait is more demanding of attention in older than in younger adults. The researchers thus hypothesized that compared with single-task conditions, performance in dual-task conditions—as measured by the ability to remember the studied words and to walk without veering or stumbling—would be compromised more for older participants than for their younger counterparts. More importantly, the authors also speculated that the pattern of dual-task interference would be different across age groups. Because the consequences of stumbling and falling are worse for older than for younger adults, the authors reasoned, the older adults should be more likely to sacrifice memory performance under dual-task conditions to protect walking performance. This was exactly what the data revealed: Though dual-task costs for the walking task were similar across age groups, dual-tasks costs for the memory task were higher for older adults—in the context of chapters 7 and 8, a resource-allocation effect.

An equally important strategy for contending with age-related losses is through the use of environmental support—compensatory aids of various forms that allow operators to offload memory demands onto cues or reminders in the outside world (Baltes and Baltes 1990; Craik and Byrd 1982; Park and Gutchess 2000). The ability to exploit mechanisms of environmental support is a component of skilled performance generally and can dramatically attenuate age-related differences in cognitive performance (Fisk et al. 2004). A study by Morrow et al. (2003), for instance, compared the performance of young, middle-aged, and older pilots on a task that required participants to listen to, read back, and mentally integrate a series of simulated air-traffic commands. Subjects sometimes were allowed to take written notes while receiving their messages and sometimes were not. The results indicated that read-back accuracy declined with age only when note-taking was forbidden. When notes were allowed, accuracy was uniformly high across age groups. A follow-up study (Morrow et al. in press) found that the opportunity to take notes also reduced age-related differences in dual-task costs when operators were required to divide attention between the read-back task and piloting a flight simulator. Note-taking thus served as a form of environmental support to mitigate age-related performance losses. Interestingly, the effective use of notes as environmental support was apparently a skill that developed with experience, as note-taking failed to reduce age-related losses in a control group of nonpilot participants. Nonetheless, these results and others like them confirm that the use of environmental support can indeed help to minimize the real-world consequences of the age-related losses seen in simple laboratory measures of cognition. Li et al. (2001, p. 236) concluded, "In old age, individuals address declining abilities by prioritizing what should be preserved, and then maintaining prior performance levels by using compensatory means."

The consequences of attentional losses also can be mitigated through appropriate task design and operator training. In accordance with the predictions of multiple resource theory, research has found that age-related dual-task losses are attenuated when the paired tasks employ different response modalities (e.g., manual and vocal) rather than a single modality (e.g., manual alone) (Brouwer et al. 1991; Tsang and Shaner 1998) and, similarly, when display information is distributed over multiple input modalities. Dingus et al. (1997), for instance, demonstrated that in-vehicle displays presenting navigational information aurally rather than visually reduced demands on the visual resources needed for lane maintenance and roadway monitoring, and were especially beneficial for older drivers. These findings imply that older adults' multitasking difficulty can be reduced to the extent that processing demands are distributed across multiple attentional resource pools. The conclusion that age impairs task-set maintenance, furthermore, implies that older adults' multitask performance will be improved by environmental reminders and attentional cues that signal what tasks are to be performed and when. Indeed, the ability to exploit such mechanisms of environmental support appears to be an important component of successful aging in general (e.g., Baltes and Baltes 1990; Craik and Byrd 1982; Park and Gutchess 2000).

Finally, in accordance with the findings on attentional skill development discussed already, evidence suggests that older adults can be trained to multitask more efficiently, learning to strategically shift attention between tasks more flexibly (Sit and Fisk 1999; Tsang and Shaner 1998). Varied-priority training in particular appears to produce large gains in older adults' multitasking skills, reducing age-related differences in multiple task performance and encouraging the development of attentional control skills that generalize to novel task combinations (Kramer, Larish, and Strayer 1995; Kramer et al. 1999).

Conclusions

This chapter has considered three sources of individual differences in attentional capabilities: (1) practice, skills, and expertise; (2) traits and stable abilities; and (3) advancing age. Certainly there are other sources not treated here, including those due to clinical conditions like attention deficit disorder (Huang-Pollack and Nigg 2003); those due to young age, such as attention development across infancy and childhood (Wickens and Benel 1982); and possibly those due to cross-cultural differences. Such topics, though fascinating, are beyond the scope of the current book.

Three main themes emerge from our treatment herein. First, in understanding differences in multitask performance, it is critical to understand differences in performance of the single-task components to which attention is deployed. Second, individual differences observed in multitask performance are often largely specific to the particular task pair or task situation under consideration and are less the result of a generic skill or ability, applicable across all task combinations. This gives reason to doubt claims that the multitasking of the electronic generation will lead to substantial changes in their overall dual-tasking ability. Finally, the amalgamated combination of executive control, task management, and attention-switching capabilities—as discussed in chapter 9 and as represented so well in tests of working memory—appears to represent the most logical candidate that might underlie that which is general in attention skill and ability. The final chapter considers some of the physiological brain mechanisms that might be responsible for these and other attentional functions.

11

Cognitive Neurosciences and Neuroergonomics

Introduction

Having discussed research extending back to the work of William James (1890), it is useful to close by considering developments that portend the future of applied attention research: the convergence of human factors and neuroscience. Applied attention researchers have traditionally employed behavioral measures of performance as their primary window on mental processes. How quickly can the operator make a judgment, for example, or how much does accuracy suffer when the operator is asked to perform two tasks simultaneously? This reliance on behavioral data has been in large part for two practical reasons. First, behavioral data can usually be collected easily and with little cost, sometimes without even use of a computer. Second, performance measures such as speed and accuracy are typically the very phenomena that applied attention researchers wish to predict and control. Behavioral data are of direct and immediate interest to the topics that concern human factors scientists.

However, human factors researchers have also long held an interest in brain function (e.g., Sem-Jacobson 1959; Sem-Jacobson and Sem-Jacobson 1963). Indeed, much of the earliest research on workload was aimed at delineating the fundamental relationship between task demand and physiological measures of autonomic nervous system activity (Hockey, Coles, and Gailliard 1997; Kahneman 1973; Kalsbeek and Sykes 1967; Kramer 1987). As technological and theoretical advances have allowed cognitive neuroscience to elucidate the relationship between mental and neural processes in ever more detail, engineering psychology has gained further insights into real-world human performance. Recognizing the increasing value of brain research to applied cognitive psychology, Parasuraman (2003, p. 5) has even coined the term *neuroergonomics* to denote "the study of brain and behavior at work," the intersection of neuroscience and human factors. Of what value is neuroscience to applied psychology? Kramer and Parasuraman (2007) note possibilities. First, neuroergonomic measures may sometimes be more valid or reliable indices of psychological phenomena (e.g., effort and mental workload level) than more traditional behavioral or subjective measures. Second, neuroergonomic methods might allow measurement of psychological processes that are inaccessible to behavioral or subjective measures.