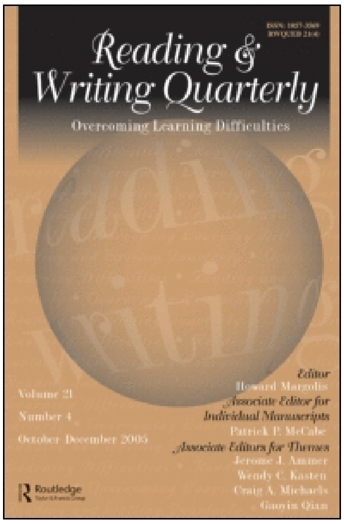

Reading & Writing Quarterly
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713775334

AUTOMATICITY AND READING: PERSPECTIVES FROM THE INSTANCE THEORY OF AUTOMATIZATION

Gordon D. Logan[a]
[a] University of Illinois, Champaign, Illinois, USA

To cite this Article Logan, Gordon D.(1997) 'AUTOMATICITY AND READING: PERSPECTIVES FROM THE INSTANCE THEORY OF AUTOMATIZATION', Reading & Writing Quarterly, 13: 2, 123 — 146

To link to this Article: DOI: 10.1080/1057356970130203

URL: http://dx.doi.org/10.1080/1057356970130203

AUTOMATICITY AND READING: PERSPECTIVES FROM THE INSTANCE THEORY OF AUTOMATIZATION

Gordon D. Logan
University of Illinois, Champaign, Illinois, USA

The ability to process information automatically is an important aspect of many everyday skills, including reading. This article reviews the literature on automaticity and relates it to issues in reading. The main focus of the review is on the instance theory of automaticity (Logan, 1988b, 1990, 1992), because it offers a unique perspective on automatization and has special relevance to reading.

Automaticity is a familiar concept in everyday life. We characterize well-practiced skills and deeply ingrained habits as automatic because we perform them easily, with little effort and little conscious thought. Perceptual-motor tasks, such as riding a bicycle or shifting gears in a manual transmission, are common examples of automatic processing. We also recognize that certain cognitive tasks can be performed automatically as well. Reading is a prominent example: we look at a page and "see" its meaning without much effort or conscious awareness of the processes that derive meaning from print.

Over the last century and especially in the last 20 years, automaticity has become a familiar concept in experimental psychology, playing a central role in the characterization of skill acquisition and the development of expertise. The early work focused on perceptual-motor skills, like telegraphy (Bryan & Harter, 1899) and tracking (Fitts & Posner, 1967). In the mid-1970s, the focus shifted to cognitive skills, and reading took center stage. LaBerge and Samuels (1974) presented a general theory of automatic information processing in reading; Posner (1978) and his colleagues addressed letter recognition (Posner & Snyder, 1975) and lexical access (Neely, 1977); and Shiffrin and Schneider (1977) addressed a large literature on visual search and memory search for letters and words.

Since the mid-1970s, cognitive skills have remained the central focus of research on automaticity. The first 10 years of this research were devoted to characterizing the properties of automatic processing in

This research was supported by grant no. SBR 94-10406 from the National Science Foundation. I would like to thank Tom Carr for his help in thinking through the ideas expressed in this article.

Address correspondence to Gordon D. Logan, Department of Psychology, University of Illinois, 603 East Daniel Street, Champaign, IL 61820, USA. E-mail: GLOGAN@S.PSYCH.UIUC.EDU.

1057-3569/97 $12.00 + .00

terms of experimental procedures, and distinguishing them from the properties of non-automatic (*controlled, effortful,* or *strategic*) processing (for reviews, see LaBerge, 1981; Logan, 1985; Schneider, Dumais & Shiffrin, 1984; Shiffrin & Dumais, 1981). The last 10 years have been devoted to understanding the mechanisms that underlie automatic processing and relating them to mechanisms in other areas of cognitive psychology, such as memory and attention (see, e.g., Logan, 1988a, 1991).

The purpose of this article is to review the recent literature on automaticity, defining the criteria that distinguish automatic processing from non-automatic processing, and describing modern theories of the underlying mechanisms. Wherever possible, the review will focus on evidence from studies of reading and will draw implications from theory and data for practical issues in teaching reading.

CRITERIA FOR AUTOMATICITY

From the mid-1970s to the mid-1980s, much of the research on automaticity focused on criteria that distinguish automatic processing from non-automatic processing. The general strategy was to find a list of properties that could be used to define and diagnose automaticity, so that processes, tasks, or performances that possessed those properties could be designated "automatic," and processes, tasks, and performances that did not possess them could be designated "non-automatic." Several researchers proposed lists of properties, and the number of properties varied from list to list. The shortest list, proposed by Posner and Snyder (1975), contained three properties. The longest, proposed by Schneider et al. (1984), contained twelve. For the purposes of this review, we will consider a list of four properties: *speed, effortlessness, autonomy,* and *lack of conscious awareness.* These properties are common to most lists and prominent in definitions of automaticity (see, e.g., Hasher & Zacks, 1979; LaBerge & Samuels, 1974; Logan, 1978, 1980; Shiffrin & Schneider, 1977).

Speed

Automatic processing is fast. Non-automatic processing is slow. It is difficult to defend an absolute criterion for how fast a process must be in order to be considered automatic, because speed varies continuously, especially over practice (see Logan, 1992; Newell & Rosenbloom, 1981).

Speed is an important criterion for automaticity because an increase in speed—a decrease in reaction time—is characteristic of the development of automaticity. In virtually every task that can be automatized, performance gets faster with practice. The form of the learning curve is the same from study to study even though materials, tasks, and subject populations change, following a *power law* (Logan, 1988b, 1992; Newell & Rosenbloom, 1981). The power law states that reaction time decreases as a function of practice until some irreducible limit is reached. Speed increases throughout practice, but the gains are largest early on and diminish with further practice. The first few trials often show dramatic improvement. With extended practice, many trials are required to produce a noticeable change in speed.

The power law is important because it makes it clear that the speed criterion for automaticity is relative. Performance is faster after 10 trials than after 1, and therefore it is more automatic. Performance is also faster after 100 trials than after 10, and therefore more automatic. The relativity of automaticity is important both practically and theoretically, as we shall see below. The power law clearly applies to the automatization of reading. High-frequency words, which by definition are more practiced, are read more rapidly than low-frequency words (Seidenberg & McClelland, 1989).

Effortlessness

Automatic processing is effortless. Non-automatic processing is effortful. In everyday life, the effortless of automatic processing is apparent first as a sense of ease and second as the ability to do another task while performing an automatic one. For example, we can carry on a conversation while driving, or sing while riding a bike. If two tasks can be done at once without interference; then at least one of them must be automatic (Logan, 1978, 1979; Posner & Boies, 1971; Schneider & Fisk, 1982a, 1982b, 1984).

Several studies suggest that skilled reading is automatic by the effortlessness criterion. Posner and Boies (1971) used dual-task interference to argue that letter encoding was automatic (but see Paap & Ogden, 1981). Becker (1976) and Herdman (1992) used dual-task interference to argue that lexical access was more automatic for high-frequency words than for low-frequency words. And Spelke, Hirst, and Neisser (1976) and Hirst, Spelke, Reaves, Caharack, and Neisser (1980) showed that subjects could read prose and take dictation concurrently if they were given sufficient practice.

Autonomy

Automatic processing is autonomous, in that it begins and runs on to completion without intention. Non-automatic processing is deliberate, in that it cannot begin and end without intention (Zbrodoff & Logan, 1986). The most common example of the autonomy of automatic processing is the Stroop effect (Stroop, 1935; for a review, see MacLeod, 1991), in which subjects who are instructed to name the color of the ink in which words are written apparently cannot stop themselves from reading the words. Subjects are much slower to name the ink color if the word spells the name of a different color (e.g., RED written in green) than if it spells the name of the same color (e.g., GREEN written in green) or if the colored object is not a word at all (e.g., a bar colored green). This is interpreted as evidence of autonomous processing because it is in the subject's interest to stop reading the word and therefore avoid the interference it produces when it is incongruent with the ink color.

There is evidence that Stroop and Stroop-like interferences develop with practice, as automaticity should. Schiller (1966) found that first-grade children just learning to read showed less interference than second-grade children with better reading skills (see also MacLeod & Dunbar, 1988). Tzelgov, Henik, and Leiser (1990) showed that strategic modulation of Stroop interference develops with practice. Testing bilinguals, they found that subjects could modulate Stroop interference in their first language, which was highly automatic, but not in their second language, which was less automatic. So far, there are no serious challenges to the idea that Stroop interference reflects the autonomy associated with automatic processing (for theoretical accounts in terms of automaticity, see Cohen, Dunbar & McClelland, 1990; Logan, 1980).

Consciousness

Automatic processing is not available to consciousness; non-automatic processing is. This claim rests primarily on phenomenal experience. We shift gears, type, and read words without much awareness of the processing involved in doing so, at least if we are well-practiced. As novices, we may be painfully aware of the steps, executing them slowly with considerable effort. These intuitions have been hard to capture in the laboratory. Many researchers have tried to show that automatic processing is unconscious (or does not give rise to conscious awareness), but their work has been highly controversial. Serious methodological and theoretical criticisms have been raised, sometimes so strenuously that it seems that researchers either believe or disbelieve in the phenomena and their beliefs cannot be shaken by evidence (see e.g., Hollender, 1986, and the accompanying commentary). Nevertheless, the experiments are interesting and are well worth relating.

The main evidence has come from semantic priming paradigms in which the presentation of a prime (e.g., "DOCTOR") speeds responses to a target (e.g., "NURSE"; Meyer & Schvaneveldt, 1971). The effect is quite robust under normal presentation conditions. Interestingly, the priming effect can be obtained even if the prime is presented briefly and is masked so that the subject cannot report it (Carr, McCauley, Sperber & Parmalee, 1982; Marcel, 1983). In a related paradigm, Cheesman and Merikle (1986) showed that strategic effects in the Stroop task could be eliminated by masking the color word, but the basic Stroop effect itself could not be.

These data suggest that automatic processes—semantic priming and Stroop interference—are unconscious in that they can occur without the subject being aware of the stimulus that produced them. The theoretical controversy surrounding these effects centers on the assumption that something that cannot be reported is truly unconscious. The empirical controversy centers on the evidence that the primes were truly not reportable, with critics arguing that the procedures for setting thresholds were inadequate so that subjects could actually see the primes on some of the trials (see Hollender, 1986, and commentary). In either case, the masked priming paradigm seems somewhat removed from the everyday situations in which we process fully visible stimuli automatically yet have little awareness of what we do with them.

CO-OCCURRENCE OF PROPERTIES

The property-list approach defines automaticity in terms of a list of binary-opposite properties, one value of which is possessed by automatic processes and the other value by non-automatic processes. This view has suggested to some that automatic processes should share all of the properties associated with automaticity (i.e., they should be fast, effortless, autonomous, and unconscious) and non-automatic processes should share all of the properties associated with the lack of automaticity (i.e., they should be slow, effortful, deliberate, and conscious). In other words, the properties associated with automaticity should *co-occur* in examples of automatic processing.

In the early 1980s, several researchers tested the co-occurrence of properties and generally found exceptions. Paap and Ogden (1981), Regan (1981), and Kahneman and Henik (1981) found that obligatory processes were effortful, not effortless. This led some researchers to challenge the very concept of automaticity, arguing that the violations of co-occurrence meant that the concept was not internally consistent (e.g., Regan, 1981).

Soon afterward, other researchers pointed out that the violations of co-occurrence challenged the implicit assumption that automaticity was dichotomous rather than the explicit assumption that automatic processes shared certain properties (e.g., Logan, 1985; MacLeod & Dunbar, 1988). Automaticity is viewed by many as a continuum rather than a dichotomy, so that one process may be more automatic than another but less automatic than a third. If that is the case, then one would expect co-occurrence of properties at the beginning and the end of the continuum but not in the middle. Thus, novice performance may be slow, effortful, deliberate, and conscious, and highly practiced performance may be fast, effortful, autonomous, and unconscious. However, performance after an intermediate amount of practice may be somewhat fast, somewhat effortful, somewhat autonomous, and partially unconscious. There is evidence (reviewed above; also see Logan, 1985) that all of the properties of automatic processing change more or less continuously with practice, and it may be that different properties change at different rates. If autonomy develops before effortlessness, then it may be easy to find cases of effortful autonomous processes, like those observed by Paap and Ogden (1981), Regan (1981), and Kahneman and Henik (1981).

The upshot of the controversy over the co-occurrence of properties of automaticity was to shift emphasis from defining automaticity in terms of property lists to investigating practice effects and the acquisition of automaticity. If automaticity was a continuum and the properties of automatic processes changed continuously with practice, it seemed reasonable and appropriate to examine practice itself.

ACQUISITION OF AUTOMATICITY

Determinants of Acquisition

Even before William James (1890), people knew that automaticity was produced by practice. James (1890) wrote about automaticity in his chapter on habit, and Bryan and Harter (1899) wrote about the acquisition of telegraphy skill, with automaticity figuring prominently in their account. Acquisition was an important issue when automaticity hit center stage in cognitive psychology in the mid-1970s. LaBerge and Samuels (1974) suggested that automaticity limited the rate at which reading skill was acquired, arguing that letter encoding had to be automatized before word reading could be automatized. Shiffrin and Schneider (1977; Schneider & Shiffrin, 1977) examined how the amount of consistent practice influenced the degree of automaticity. By the end of the 1970s, it was clear that automaticity and the properties associated with it developed with practice in consistent environments (e.g., Logan, 1978, 1979; Shiffrin & Schneider, 1977). Consistency was essential. Automaticity did not develop in inconsistent tasks, and the degree of automaticity depended on the amount of consistency (Schneider & Fisk, 1982b).

Until the 1980s, most of the work on acquisition was descriptive rather than explanatory. Researchers were interested in the conditions that were necessary to produce automaticity and the extent to which the properties of automaticity developed with practice, but no one proposed a theory of the mechanism underlying the acquisition of automaticity. That became a major theme of research in the 1980s. Following Newell and Rosenbloom (1981; also see Rosenbloom & Newell, 1986), Anderson (1982, 1987, 1992), MacKay (1982), Schneider (1985), Logan (1988b, 1992), and Cohen, Dunbar, and McClelland (1990) proposed theories that explained how automaticity was acquired.

Theories of Acquisition

Strength theories

Theories of the acquisition of automaticity include a variety of mechanisms. The most common and most straightforward, anticipated in the theories of LaBerge and Samuels (1974) and Shiffrin and Schneider (1977), is strengthening of connections between "stimulus" and "response" elements. Strengthening connections is the only learning mechanism in MacKay's (1982) theory and Cohen et al.'s (1990), one of two mechanisms in Schneider's (1985) theory, and one of several mechanisms in Anderson's (1982, 1987) theory. The algorithms that compute the change in strength from trial to trial differ between theories, but the end result is the same: practice makes connections stronger, and consequently, performance is faster and less effortful.

Chunking theories

Anderson (1982, 1987) and Newell and Rosenbloom (1981; Rosenbloom & Newell, 1986) proposed broader theories that border on artificial intelligence and include learning mechanisms that reduce the number of steps involved in performing a task. Anderson's mechanisms work directly on the procedure for doing the task, collapsing several steps into one single step. Newell and Rosenbloom's mechanisms "chunk" stimulus and response elements so that complex stimuli are perceived and responded to as single units in a single processing step (cf. LaBerge & Samuels, 1974). Performance is faster and less effortful because the number of steps is reduced.

Instance theory

Logan (1988b, 1990, 1992) proposed a theory of automatization in which the learning mechanism was *episodic memory* (i.e., the same sort of memory used in everyday life). He argued that each experience with a task lays down a separate memory trace or *instance representation* that can be retrieved when the task repeats itself. The number of instances in memory grows with the number of practice trials, building up a task-relevant knowledge base. Logan argued that performance is automatic when it is based on retrieval of past instances—memories of past solutions to task-relevant problems—rather than algorithmic computation (i.e., producing a solution by thinking or reasoning) and that automatic performance was more likely the greater the number of task-relevant instances in memory. When the knowledge base became large enough and reliable enough, performance could be based entirely on memory retrieval, and the algorithm that supported initial, novice performance could be abandoned entirely. According to instance theory, automatic performance is fast and effortless because memory retrieval is faster than algorithmic performance and involves fewer steps.

Relevance to reading

Each of the learning mechanisms has relevance to reading. LaBerge and Samuels (1974) noted the relevance of strengthening to automatization of reading, arguing that weak connections (e.g., between letters and the words they form) required support from costly attentional processing, whereas strong connections could pass activation from letters to words even if attention were distracted. The chunking mechanisms discussed by Anderson (1982, 1987) and Newell and Rosenbloom (1981; Rosenbloom & Newell, 1986) could be responsible for the *unitization* phenomenon in reading, in which words that were perceived initially as strings of separate letters come to be seen as single units. The instance learning mechanism in Logan's (1988b, 1990) theory could be responsible for speeding up several different levels of the reading process and so may be broader in scope than the other mechanisms, at least when applied to reading. Consequently, the remainder of this article will explore the implications of Logan's theory.

INSTANCE THEORY OF AUTOMATICITY

The instance theory rests on three main assumptions: *obligatory encoding,* which says that attention to an object or event is sufficient to cause it to be encoded into memory, *obligatory retrieval,* which says that attention to an object or event is sufficient to cause things that were associated with it in the past to be retrieved from memory, and *instance representation,* which says that each trace of past objects and events is encoded, stored, and retrieved separately, even if the object or event has been experienced before (Logan, 1988b, 1990).

The obligatory encoding assumption provides the learning mechanism. Attention to objects and events in the course of performing a task causes a task-relevant knowledge base to be built up in memory. There is considerable support in the literature for the obligatory encoding assumption (for reviews, see Logan, 1988b; Logan & Etherton, 1994). The main evidence for it is the equivalence of incidental and intentional learning when attention is equated between conditions (e.g., Craik & Tulving, 1975). The intention to learn appears to have no effect on learning, except that it guarantees attention to the things to be learned. Put differently, there appears to be no "store" or "write to disk" instruction in the mind's programming language. Learning and storing seem to be a side effect of attending.

The obligatory retrieval assumption is responsible for the expression of automaticity in performance. Attention to objects in a familiar task environment causes retrieval of the relevant knowledge. The more knowledge there is available, the more is retrieved. The response from memory becomes strong enough to support performance, so performance can be automatic (i.e., based on memory retrieval). There is considerable support in the literature for obligatory retrieval (for reviews, see Logan, 1988b; Logan, Taylor & Etherton, 1996). The main evidence for it is the ubiquitous Stroop effect described earlier as evidence for the autonomy of automatic processing (Stroop, 1935; for a review, see MacLeod, 1991). People appear unable to "turn off" reading even when it is in their best interests to do so. The instance theory interprets the Stroop effect as a retrieval phenomenon: a familiar word at the focus of attention retrieves things associated with it in the past, like its meaning and the motor program for pronouncing it. The motor program interferes with the motor program for pronouncing the name of the color, and reaction time is prolonged as the interference is resolved.

From the perspective of the instance theory, automaticity is not so much a special topic in the study of attention but a central topic in cognitive psychology in general. Following the lead of instance theories in other domains (e.g., Hintzman, 1986, 1988; Kahneman & Miller, 1986; Medin & Schaffer, 1978; Nosofsky, 1986; Ross, 1984; Smith & Zaraté, 1992), the instance theory suggests that automaticity is a memory phenomenon governed by the theoretical and empirical principles that govern memory. These new connections to other domains outside the attention literature open up exciting possibilities for new directions in research and application.

The instance representation assumption is the most controversial because instance representation is not as well established as the phenomena underlying the other assumptions. The idea that each trace is encoded, stored, and retrieved separately seems counterintuitive to many people, and other hypotheses about representation abound (e.g., strength representations in the psychology of memory; prototype or schema representations in the psychology of concept learning; connectionist representations in psychology in general). However, the proof is in the pudding, or rather, the experimental laboratory and the theoretical armchair, and instance theories have fared very well in these testing grounds. Since the mid-1970s, it has been clear that instance (or *multiple trace*) theories provide better accounts of the data than do strength theories (for a review, see Hintzman, 1976), and since the early 1980s, instance theories have dominated prototype theories in accounting for the data on concept learning (see e.g., Hintzman, 1986; Medin & Ross, 1989; Ross & Makin, in press).

The instance representation assumption plays an important role in the formal development of the instance theory. The theory assumes that retrieval involves a race between the different traces in memory, such that the first trace to finish governs performance. Thus, when you are asked to produce the sum of 2 + 2, all of the different traces that represent 2 + 2 = 4 get retrieved, and you are able to respond as soon as the first one finishes. An important point is that the different traces are equivalent. You can respond correctly if you retrieve a trace of the first time you were taught the sum in grade school or the last time you used it to balance your checkbook.

The race between traces accounts for the speed-up in reaction time that characterizes the development of automaticity. The more traces there are in memory, the more likely it is that one trace will be retrieved exceptionally quickly. Practice increases the number of traces being retrieved, and this accounts for the speed-up. However, the speed-up will have diminishing returns. Adding one trace to 100 will have less of an impact on the race than adding one trace to 10 or one trace to 1. The fastest of 100 traces is likely to be pretty fast, and it is unlikely that the fastest of 101 traces will be much faster. This accounts for the negative acceleration of the power function.

Logan (1988b, 1992, 1995) developed these predictions mathematically, borrowing from the engineering literature on the statistics of extreme values. He was able to prove mathematically that the outcome of the race described above would follow the power law that characterizes the development of automaticity (Newell & Rosenbloom, 1981).

While the details are too technical to repeat here, they lead to specific quantitative predictions that have been confirmed readily in many experiments (see e.g., Logan, 1988b, 1992; Strayer & Kramer, 1990). This is an important strength of the instance theory, from the perspective of experimental psychology.

The instance theory represents a major shift in the conceptualization of automaticity. Earlier approaches identified automatization with a change in particular processes, so that things like letter identification (Posner & Boies, 1971), lexical access (Becker, 1976), and semantic access (Neely, 1977) could be automatized. The instance theory identifies automatization with a change to a particular kind of processing—memory retrieval—so that all examples of automaticity are based on the same kind of processing—memory retrieval. Thus, according to the instance theory, automaticity is not a property of a particular process, and automatization is not a change that a particular process goes through, as it was in earlier theories. Rather, automaticity is memory-based processing and automatization is a shift from algorithmic processing (which may be based on a variety of particular processes) to memory retrieval.

The shift in conceptualization may be mostly a matter of emphasis. The strongest interpretation is that all automatic processing relies on the same memory system, and that is a major shift in conceptualization. However, a weaker interpretation is that different memory systems may underlie different examples of automaticity (Logan, 1991), and that allows for different kinds of automaticity for different initial processes, which was the main idea underlying earlier conceptions of automaticity.

INSTANCE THEORY AND READING

The most provocative aspect of the instance theory of automaticity, from the perspective of reading, is the idea that learning can occur on a single exposure to an object or event. In essence, learning is all or none, and more often all than none. This means that automaticity can occur after a single trial. The theory assumes that automatic processing is processing based on memory retrieval, and that this retrieval can happen in a single trial if a person remembers the stimulus encountered on that trial when it appears again, and responds on the basis of that memory. Automaticity usually builds up gradually, as more and more traces are added to memory and the response of memory to a familiar situation becomes stronger and stronger, but in principle, it can occur in a single trial. Logan and Klapp (1991) showed that 15 minutes of memorization produced automaticity in an arithmetic analog task that was similar in many ways to the automaticity produced after 12 sessions of practice on the task itself. They went on to show that memorization was not more effective than practice on the task itself—subjects in the 12-session practice experiment had many more problems to learn than subjects in the 15-minute memorization experiment—but they made the point that extensive practice was not necessary to produce automaticity.

The possibility of single-trial automatization has important implications for reading. Reading involves several different levels of processing, from letter recognition to the apprehension of subtle aspects of meaning, and single-trial automatization makes it possible for automaticity to appear at every level. The main requirement is that the reader encodes the relevant structures in memory (e.g., letters, words, propositions, ideas) and retrieves them when they are encountered once again.

More traditional approaches to automaticity, such as those that involve strengthening as a learning mechanism, would not predict automatization at higher levels of processing, at least not so easily. Strengthening is a gradual process, and many repetitions are required to bring strength near its maximum. Thus, many repetitions are required for automatization. The problem is that the probability of repetition is lower the higher the level of processing is (Newell & Rosenbloom, 1981). There are only 26 letters (in English), so letters will repeat themselves often in a day's reading. There are several hundred thousand words, and although some repeat themselves more than others (i.e., high frequency vs. low frequency words), even the more common words repeat themselves less often than letters. The propositions that words are parts of repeat themselves even less often, and higher-order propositional structures may be repeated rarely. Thus, there is less opportunity for gradual strengthening at higher levels of processing.

The single-trial learning in the instance theory allows automatization to occur at every level. All that is required, in principle, is one repetition, and even high-level structures may repeat themselves once. Automaticity may never become particularly strong at higher levels because the low frequency of repetition limits the number of traces in memory, but initial gains are strongest, and some benefits of automaticity may be apparent at every level.

Repetition Priming and Automaticity

Repetition priming refers to changes in performance that result from repetition. The changes are usually beneficial; reaction time is faster, and accuracy is higher, though in some cases there may be costs. Repetition priming is usually considered to be a memory phenomenon, and much of the recent research on memory—especially the contrast between explicit and implicit memory—has focused on repetition priming (for reviews, see Richardson-Klavehn & Bjork, 1988; Roediger, 1990). Repetition priming is important to the instance theory because the instance theory considers automaticity to be the accumulation of repetition priming effects (Logan, 1990). Investigations of repetition priming in the memory literature usually focus on the effects of one or two presentations. The instance theory generalizes those results to several presentations—even hundreds—and argues that the effects are essentially the same regardless of the number of presentations: repetition priming and automaticity both depend on memory retrieval. Performance is primed or automatized if it is based on retrieval of past solutions instead of algorithmic computation.

The analogy between repetition priming and automaticity is important from the perspective of the instance theory, because repetition priming effects can occur after a single trial. This is consistent with the all-or-none learning assumption of the instance theory, which predicts single-trial automatization (in some situations). From the perspective of the instance theory, one can interpret single-trial repetition priming effects as evidence of automatization. That strategy is exploited in the remainder of this section, which reviews demonstrations of automaticity in letter-level, word-level, and text-level processing.

Letter-Level Automaticity

Kolers (e.g., 1975) developed an important strategy for studying automaticity in reading, by presenting adults with spatially transformed text (mirror reversed, rotated, reflected, etc.) and observing their performance change with practice on the task. The spatially transformed text puts adults in a position similar to that of beginning readers, in that they do not have automatized perceptual routines for reading such text. Kolers (1975) found a power-function speed-up in the time required to read transformed text, which he interpreted as evidence for automatization.

Kolers interpreted the speed-up as evidence for changes in the perceptual processes involved in reading. He thought it reflected the development of reading skill that should generalize to new materials. Masson (1986) questioned this conclusion, providing evidence that an instance account might explain the speed-up just as well. His view was an important alternative to Kolers' view, arguing that automaticity was based on memory retrieval rather than the tuning and adjustment of general reading procedures.

Word-Level Automaticity

Many studies have examined repetition priming at the word level, following Scarborough, Cortese, and Scarborough (1977). Logan (1990) related repetition priming to automaticity, interpreting automaticity as massive repetition priming. He showed that repetition priming and automaticity shared three important characteristics: they were both *item based,* depending on the specific items that appeared in training; they were both *associative,* depending on "connections" between items and interpretations or items and responses rather than on general strengthening of the items themselves; and they both showed the *power-function speed-up* that is characteristic of automaticity.

Logan (1988b, 1990) trained subjects on a lexical decision task (in which they decided whether or not a letter string was a word), comparing conditions in which they saw new words and nonwords on every trial with conditions in which the words and nonwords were repeated from trial to trial. The two conditions were equivalent initially but diverged with practice. The divergence is evidence of item-based repetition priming and automaticity. Performance improved for items that were repeated but not for novel items. The alternative, process-based improvement, would predict equivalent practice effects in the two conditions (cf. Kolers, 1975). Moreover, the speed-up in reaction time for the repeated items followed a power-function, which is characteristic of automaticity, supporting the idea that automaticity is just repetition priming taken to the extreme.

Further experiments demonstrated the associative basis. Logan (1988b, 1990) presented subjects with words (e.g., brat), pronounceable nonwords (e.g., blat), and unpronounceable nonwords (e.g., brjt), repeating them up to 16 times. There were two tasks: *lexical decision,* in which subjects decided whether or not a letter string was a word, thereby discriminating between words on the one hand and pronounceable nonwords and unpronounceable nonwords on the other, and *pronounceability decision,* in which subjects decided whether or not a letter string was pronounceable, thereby discriminating between words and pronounceable nonwords on the one hand and unpronounceable nonwords on the other.

Two groups of subjects were tested to determine whether the improvements from repetition were based on associations between items and interpretations. Both groups saw the same items for the same number of times during training, but one group performed the same task on the items each time they were presented (*consistent interpretation*), whereas the other group alternated between tasks, making lexical decisions on one presentation and pronounceability decisions on the next (*varied interpretation*). The consistent-interpretation group improved much more with practice than the varied-interpretation group, which Logan (1988b, 1990) interpreted as evidence that the repetition priming and automaticity effects were based on associations between items and interpretations (i.e., as words vs. nonwords or as pronounceable vs. unpronounceable strings). Performance depended on the number of times a stimulus was interpreted a particular way, not on the number of times the stimulus was presented.

Logan's (1988b, 1990) results are important because they build a bridge between repetition priming effects and automaticity that allows researchers (and consumers of research) to interpret repetition priming effects as evidence of automaticity. A single-trial repetition priming effect is the first step toward automaticity. Thus, the large literature on word-level repetition priming can be interpreted as evidence of word-level automaticity. The factors that affect word-level repetition priming effects may also affect word-level automaticity.

Text-Level Automaticity

When people read texts repeatedly, as in the pedagogical method of repeated reading, the time required to do so decreases as a function of the number of repetitions. The greatest decrease in reading time occurs in the first few readings, and with extended practice, the improvements are less dramatic (e.g., Levy, Di Persio & Hollingshead, 1992; Levy, Newell, Snyder & Timmins, 1986). The speed-up is suggestive of the power function that is characteristic of automaticity, although the number of points is typically too small for reasonable curve fitting (but see Kolers, 1975). Much of the research on text repetition effects concerns the level of processing that is responsible for the effects.

There is evidence that under some conditions, at least, text-level processing is responsible for the speed-up. The research strategy involves comparing speed-up with scrambled and coherent texts. Carr, Brown, and Charalambous (1989) found equivalent performance on the second reading of texts whether the first reading was scrambled or coherent, which led them to suggest that word-level factors were responsible for the speed-up. However, subsequent research by Carlson, Alejano, and Carr (1991) showed that this result happened because the task set conveyed in the instructions induced subjects to attend to words and ignore text-level structures. When Carlson et al. (1991) induced subjects to attend to the meanings of paragraphs, they found that the second reading was faster if the first were coherent than if it were scrambled, indicative of text-level automaticity.

Levy and Burns (1990) compared coherent texts with texts that were scrambled by reordering paragraphs, sentences, and words. Coherent texts showed a 12% improvement in reading time from the first presentation to the second. Reordered paragraphs produced a 13% benefit, whereas reordering sentences produced a 7% benefit and reordering words produced a 3% benefit. This suggests that paragraph-level text structures may not support automatic reading but sentence- and word-level structures may.

The contrast between scrambled and coherent texts addresses the importance of text-level processing directly. Another line of evidence addresses it indirectly, by asking whether low-level perceptual processes are responsible for the speed-up. The strategy here is to change the format from one presentation to another and measure the cost associated with the change. In some situations, dramatic changes in format have no effect on the speed-up. Carr et al. (1989) found that reading time was the same on the second presentation whether the first presentation was handwritten or typed, which is a huge change in format. Levy et al. (1986) used less dramatic differences in format and found no difference in speed-up between subjects who read the same text four times in the same format and subjects who read the same text four times in a different format each time. These results suggest that low-level (letter-level) processes are not important in the speed-up, and suggest, by inference, that text-level processes are important.

Brown and Carr (1993) found asymmetrical transfer between typewritten font and handwriting that suggests that low-level processes may contribute sometimes to rereading benefits. If the second reading involved a typewritten font, the benefit was the same whether the first reading involved a typewritten font or handwriting. However, if the second reading involved handwriting, the benefit was greater if the first reading also involved handwriting. Brown and Carr offered a typicality hypothesis to explain their results: if the font is typical (as typewritten fonts tend to be), it requires little attention, and so it is not encoded very strongly in the memory trace that supports repetition. However, if the font is atypical (as handwriting tends to be—especially mine), it requires much more attention and therefore is more likely to be encoded into memory. This interpretation is consistent with the instance theory of automaticity, which assumes that attention determines what is encoded (Logan & Etherton, 1994).

IMPLICATIONS FOR READING INSTRUCTION

Current research on automaticity has many implications for reading instruction. They would be articulated best by someone involved in research on reading instruction. Being interested primarily in basic issues in skill acquisition, I fall short of this ideal. Nevertheless, I can offer some suggestions and hope that practitioners may find them useful.

Practice and Repetition

The clearest message from automaticity research is that practice is necessary to develop skill. Repetition is a good. The research suggests that readers will benefit most from consistent practice. Fortunately, reading involves the kinds of consistencies that are essential to the development of automaticity. Vowels are always vowels and consonants are always consonants. Words have the same meaning each time they are read (polysemy notwithstanding).

Some variability in the practice regime is beneficial as well. Automaticity transfers to similar stimuli, so there should be some benefit in exposing readers to different materials. The research so far cannot suggest an optimal mixture of old and new. On the one hand, it is clear that transfer will be better the greater the proportion of old material. On the other hand, the greater the proportion of new material, the greater the opportunity to learn. In either case, it would be better to maximize the similarity of new and old material. When introducing new vocabulary, for example, it would help to have thematic or semantic relations among the new words, so that learning about one word draws on prior learning about other words and sets the stage for learning about future words.

Font Variation

Readers need to be able to decipher all sorts of fonts, from Century to squiggley handwriting. Research on font variation suggests that reading instructors do not have to worry much about this issue. Transfer among professionally printed fonts is excellent. Handwritten fonts sometimes show poor transfer, especially when the handwriting is unique and atypical. However, teachers' handwriting is usually clear and typical, and so should provide no problem. The natural variation in printed and handwritten fonts experienced in the first few years of reading instruction should prepare students reasonably well for the occasional atypical fonts they will experience later in life.

Oral Versus Silent Reading

The first few years of reading instruction usually involve oral reading. Students read aloud or follow the teacher reading aloud. In later years, silent reading predominates. What kind of transfer should we expect between oral and silent reading? Research on automaticity suggests that transfer should be excellent. Output or motoric factors appear to play a small role in the automatization of cognitive skills (Logan, 1990), and the main difficulties in reading are pre-motor (i.e., in mapping print onto meaning).

The normal course of reading instruction probably conspires to make transfer efficacious. Research tells us that transfer is a function of similarity, with more-similar tasks showing better transfer than less-similar ones. The progression from oral to silent reading likely involves three stages: oral reading, subvocal reading, and silent reading. Subvocal reading involves forming phonetic representations of the words that are read, using the same processes as oral reading but inhibiting the vocal output. Students with a moderate degree of skill at oral reading should be able to manage to read subvocally without much difficulty. After some practice with subvocal reading, the phonetic representations may become less prominent, and after extensive practice, they may drop out entirely.

Skilled readers may find it easier to comprehend things they read silently than things they read orally because silent reading is faster than oral reading and its pace is closer to the rate at which readers can think. This is not really an issue of transfer of automaticity; it is more an issue of compatibility between rates of processing.

Repeated Reading Methodology

About 20 years ago, Jay Samuels and Carol Chomsky independently developed a pedagogical method called *repeated reading* for training both good and poor readers. The method involves reading the same text repeatedly until a target reading rate of 80 words per minute is reached. At that point, a new text is introduced, and students read it repeatedly until they reach 80 words per minute. There is very little prosodic variation in the first few readings. Readers sometimes stumble over words, make false starts, and pause longer than they should at inappropriate places. After several repetitions, their reading becomes more fluent and normal prosody emerges. Repeated reading is an effective method for teaching students to read fluently, motivated in part by the LaBerge and Samuels (1974) theory of automaticity. The question for modern research is: why does it work?

Several factors likely contribute to the efficacy of repeated reading. The original LaBerge and Samuels (1974) idea was that automatizing lower-level components freed attentional capacity, which could then be allocated to higher-level processing. Modern research would endorse the broad conception of this explanation but would argue about the details. Most likely, automatization is going on concurrently at several different levels. Over repetitions, readers learn specific words and specific combinations of words as well as the meaning of the text. Learning specific words allows a kind of fluency, so that the reader does not have to stop to think about how to retrieve specific pronunciations or, worse, to work them out by applying phonological rules. Learning the text-level meaning helps to organize the prosody, suggesting what should go with what, what should be emphasized, and what should be de-emphasized. Word-level learning interacts with text-level learning; disfluent word-level processing disrupts text-level prosody—you can't read smoothly if you don't know what to say next.

Reading a text for meaning is a complex activity that requires integration of all of the different levels of processing. Emergent problems of coordination and control become important. Perhaps the most important effect of the repeated reading method is to teach readers how to solve these problems. Each repetition may allow them to solve a few of the problems of coordination and control. Multiple repetitions ensure that most of the problems get solved, for a particular text. Hopefully, there are some similarities among the solutions to these problems with different texts, so that the training can transfer.

CONCLUSIONS

Automaticity has been an important concept in psychology since the time of William James (1890). It has been a central concept in cognitive psychology for the last 20 years. Considerable progress has been made in that time. The conception of automaticity has changed and become more sophisticated. Initial research aimed at documenting its properties and the conditions under which it appeared evolved into modern efforts to understand the learning mechanisms that produce it. Recent theories have related automaticity to attention and memory, and to cognition in general.

Reading has always been an important topic in research on automaticity, and it has been especially important in the last 20 years. Modern approaches that focus on learning promise new insights into automaticity and reading. The instance theory of automaticity in particular has important implications, suggesting that automaticity may pervade all of the levels of processing involved in reading, and providing new ways to gather evidence about that automaticity.

REFERENCES

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89,* 369–406.

Anderson, J. R. (1987). Skill acquisition: Compilation of weak-method problem solutions. *Psychological Review, 94,* 192–210.

Anderson, J. R. (1992). Automaticity and the ACT* theory. *American Journal of Psychology, 105,* 165–180.

Becker, C. A. (1976). Allocation of attention during visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 556–566.

Brown, J. S., & Carr, T. H. (1993). Limits on perceptual abstraction in reading: Asymmetric transfer between surface forms differing in typicality. *Journal of Experimental Psychology: Learning, Memory and Cognition, 19,* 1277–1296.

Bryan, W. L., & Harter, N. (1899). Studies of the telegraphic language. The acquisition of a hierarchy of habits. *Psychological Review, 6,* 345–375.

Carlson, L. A., Alejano, A. R., & Carr, T. H. (1991). The level-of-focal-attention hypothesis in oral reading: Influences of strategies on the context specificity of lexical repetition effects. *Journal of Experimental Psychology: Learning, Memory and Cognition, 17,* 924–931.

Carr, T. H., Brown, J. S., & Charalambous, A. (1989). Repetition and reading: Perceptual encoding mechanisms are very abstract but not very interactive. *Journal of Experimental Psychology: Learning, Memory and Cognition, 15,* 763–778.

Carr, T. H., McCauley, C., Sperber, R. D., & Parmalee, C. M. (1982). Words, pictures, and priming: On semantic activation, conscious identification, and the automaticity of information processing. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 757–777.

Cheesman, J., & Merikle, P. M. (1986). Distinguishing conscious from unconscious perceptual processes. *Canadian Journal of Psychology, 40,* 343–367.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review, 97,* 332–361.

Craik, F. I. M., & Tulving, E. (1975). Depth of processing and retention of words in episodic memory. *Journal of Experimental Psychology: General, 104,* 268–294.

Fitts, P. M., & Posner, M. I. (1967). *Human performance.* Belmont, CA: Brooks Cole.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108,* 356–388.

Herdman, C. M. (1992). Attentional resource demands of visual word recognition in naming and lexical decisions. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 460–470.

Hintzman, D. L. (1976). Repetition and memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 47–91). New York: Academic Press.

Hintzman, D. L. (1986). "Schema abstraction" in a multiple-trace model. *Psychological Review, 93,* 411–428.

Hintzman, D. L. (1988). Judgments of frequency and recognition memory in a multiple-trace memory model. *Psychological Review, 95,* 528–551.

Hirst, W., Spelke, E. S., Reaves, C. C., Caharack, G., & Neisser, U. (1980). Dividing attention without alternation or automaticity. *Journal of Experimental Psychology: General, 109,* 98–117.

Hollender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking. *Brain and Behavioral Sciences, 9,* 1–23.

James, W. (1890). *Principles of psychology.* New York: Holt.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J. Pomerantz (Eds.), *Perceptual organization* (pp. 181–211). Hillsdale, NJ: Erlbaum.

Kahneman, D., & Miller, D. T. (1986). Norm theory: Comparing reality to its alternatives. *Psychological Review, 93,* 136–153.

Kolers, P. A. (1975). Memorial consequences of automatized encoding. *Journal of Experimental Psychology: Human Learning and Memory, 1,* 689–701.

LaBerge, D. (1981). Automatic information processing: A review. In J. Long & A. D. Baddeley (Eds.), *Attention and Performance IX* (pp. 173–186). Hillsdale, NJ: Erlbaum.

LaBerge, D., & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology, 6,* 293–323.

Levy, B. A., & Burns, K. I. (1990). Reprocessing text: Contributions from conceptually driven processes. *Canadian Journal of Psychology, 44,* 465–482.

Levy, B. A., Di Persio, R., & Hollingshead, A. (1992). Fluent rereading: Repetition, automaticity, and discrepancy. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18,* 957–971.

Levy, B. A., Newell, S., Snyder, J. & Timmins, K. (1986). Processing changes across reading encounters. *Journal of Experimental Psychology: Learning, Memory and Cognition, 12,* 467–478.

Logan, G. D. (1978). Attention in character classification: Evidence for the automaticity of component stages. *Journal of Experimental Psychology: General, 107,* 32–63.

Logan, G. D. (1979). On the use of a concurrent memory load to measure attention and automaticity. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 189–207.

Logan, G. D. (1980). Attention and automaticity in Stroop and priming tasks: Theory and data. *Cognitive Psychology, 12,* 523–553.

Logan, G. D. (1985). Skill and automaticity: Relations, implications, and future directions. *Canadian Journal of Psychology, 39,* 367–386.

Logan, G. D. (1988a). Automaticity, resources and memory: Theoretical controversies and practical implications. *Human Factors, 30,* 583–598.

Logan, G. D. (1988b). Toward an instance theory of automatization. *Psychological Review, 95,* 492–527.

Logan, G. D. (1990). Repetition priming and automaticity: Common underlying mechanisms? *Cognitive Psychology, 22,* 1–35.

Logan, G. D. (1991). Automaticity and memory. In W. Hockley & S. Lewandowsky (Eds.), *Relating theory and data: Essays on human memory in honor of Bennet B. Murdock.* Hillsdale, NJ: Erlbaum.

Logan, G. D. (1992). Shapes of reaction-time distributions and shapes of learning curves: A test of the instance theory of automaticity. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18,* 883–914.

Logan, G. D. (1995). The Weibull distribution, the power law, and the instance theory of automaticity. *Psychological Review, 102,* 751–756.

Logan, G. D., & Etherton, J. L. (1994). What is learned during automatization? The role of attention in constructing an instance. *Journal of Experimental Psychology: Learning, Memory and Cognition, 20,* 1022–1050.

Logan, G. D., & Klapp, S. T. (1991). Automatizing alphabet arithmetic: I. Is extended practice necessary to produce automaticity? *Journal of Experimental Psychology: Learning, Memory and Cognition, 17,* 179–195.

Logan, G. D., Taylor, S. E., & Etherton, J. L. (1996). Attention in the acquisition and expression of automaticity. *Journal of Experimental Psychology: Learning, Memory and Cognition, 22,* 620–638.

MacKay, D. G. (1982). The problem of flexibility, fluency, and speed-accuracy trade-off in skilled behavior. *Psychological Review, 89,* 483–506.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109,* 163–203.

MacLeod, C. M., & Dunbar, K. (1988). Training and Stroop-like interference: Evidence for a continuum of automaticity. *Journal of Experimental Psychology: Learning, Memory and Cognition, 14,* 126–135.

Marcel, A. J. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15,* 197–237.

Masson, M. E. J. (1986). Identification of typographically transformed words: Instance-based skill acquisition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 12,* 479–488.

Medin, D. L., & Ross, B. H. (1989). The specific character of abstract thought: Categorization, problem-solving, and induction. In R. Sternberg (Ed.). *Advances in the psychology of human intelligence, Vol. 5.* Hillsdale, NJ: Erlbaum.

Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review, 85,* 207–238.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90,* 227–234.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226–254.

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 1–55). Hillsdale, NJ: Erlbaum.

Nosofsky, R. M. (1986). Attention, similarity, and the identification-categorization relationship. *Journal of Experimental Psychology: General, 115,* 39–57.

Paap, K. R., & Ogden, W. C. (1981). Letter encoding is an obligatory but capacity-demanding operation. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 518–527.

Posner, M. I. (1978). *Chronometric explorations of mind.* Hillsdale, NJ: Erlbaum.

Posner, M. I., & Boies, S. J. (1971). Components of attention. *Psychological Review, 78,* 391–408.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Regan, J. E. (1981). Automaticity and learning: Effects of familiarity on naming letters. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 180–195.

Richardson-Klavehn, A., & Bjork, R. A. (1988). Measures of memory. *Annual Review of Psychology, 39,* 453–475.

Roediger, H. L. III. (1990). Implicit memory: Retention without remembering. *American Psychologist, 45,* 1043–1056.

Rosenbloom, P. S., & Newell, A. (1986). The chunking of goal hierarchies: A generalized model of practice. In R. S. Michalski, J. G. Carbonell, & T. M. Mitchell (Eds.), *Machine learning: An artificial intelligence approach* (Vol. 2, pp. 247–288). Los Altos, CA: Morgan Kaufmann.

Ross, B. H. (1984). Remindings and their effects in learning a cognitive skill. *Cognitive Psychology, 16,* 371–416.

Ross, B. H., & Makin, V. S. (in press). Prototypes versus exemplar models. In R. Sternberg (Ed.), *The concept of cognition.* Cambridge, MA: MIT Press.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 1–17.

Schiller, P. H. (1966). Developmental study of color-word interference. *Journal of Experimental Psychology, 72,* 105–108.

Schneider, W. (1985). Toward a model of attention and the development of automatic processing. In M. I. Posner & O. S. Marin (Eds.), *Attention and Performance XI* (pp. 475–492). Hillsdale, NJ: Erlbaum.

Schneider, W., Dumais, S. T., & Shiffrin, R. M. (1984). Automatic and control processing and attention. In R. Parasuraman & R. Davies (Eds.), *Varieties of attention* (pp. 1–27). New York: Academic Press.

Schneider, W., & Fisk, A. D. (1982a). Concurrent automatic and controlled visual search: Can processing occur without resource cost? *Journal of Experimental Psychology: Learning, Memory and Cognition, 8,* 261–278.

Schneider, W., & Fisk, A. D. (1982b). Degree of consistent training: Improvements in search performance and automatic process development. *Perception and Psychophysics, 31,* 160–168.

Schneider, W., & Fisk, A. D. (1984). Automatic category search and its trans-

fer. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10,* 1–15.
Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84,* 1–66.
Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96,* 523–568.
Shiffrin, R. M., & Dumais, S. T. (1981). The development of automatism. In J. Long & A. D. Baddeley (Eds.), *Attention and Performance IX* (pp. 111–140). Hillsdale, NJ: Erlbaum.
Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84,* 127–190.
Smith, E. R., & Zaraté, M. (1992). Exemplar-based model of social judgment. *Psychological Review, 99,* 3–21.
Spelke, E., Hirst, W., & Neisser, U. (1976). Skills of divided attention. *Cognition, 4,* 215–230.
Strayer, D. L., & Kramer, A. F. (1990). An analysis of memory-based theories of automaticity. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16,* 291–304.
Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662.
Tzelgov, J., Henik, A., & Leiser, D. (1990). Controlling Stroop interference: Evidence from a bilingual task. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16,* 760–771.
Zbrodoff, N. J., & Logan, G. D. (1986). On the autonomy of mental processes: A case study of arithmetic. *Journal of Experimental Psychology: General, 115,* 118–130.