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Attention and preattention in theories of automaticity

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The theoretical relation between preattentive processes and automatic processes is different in different approaches to attention and automaticity. In the modal view, automatic and preattentive processes are one and the same; automatic processing is preattentive. In recent views that treat automaticity as a memory phenomenon, automatic processing is postattentive. These views are described and evidence for them is discussed. Two experiments are reported that test whether the training that makes processing automatic also makes it preattentive. The data suggest a dissociation between automatic and preattentive processes that is more consistent with the memory view of automaticity than with the modal view.

Automatic processes and preattentive processes are similar in many respects, both theoretically and empirically. They are often defined in terms of attention, and they have played important roles in the development of current theories of attention. They are fast and effortless, capable of execution while the subject is engaged in another task. However, these similarities do not imply identity. There are important differences between them that suggest they should be distinguished theoretically and can be distinguished empirically. This article describes the similarities and differences between automatic and preattentive processes, proposes a theoretical distinction between them, and reports experiments that distinguish them empirically.

Preattentive Processes

Preattentive processes provide the informational basis for attentional selection. They are temporally prior to attention (hence *preattentive*) because attentional selection depends on the results of their computations; selection cannot occur until their computations are finished. Preattentive processes are independent of attention. They are driven by stimulus presentation, performing obligatory computations in parallel over the entire sensory field. Elementary feature

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detection and gestalt grouping by similarity and proximity are prominent examples of preattentive processes in vision (see, e.g., Treisman, 1985).

Many people consider preattentive processes to be automatic. If automaticity is defined as processing without attention (e.g., LaBerge & Samuels, 1974; Posner & Snyder, 1975), then preattentive processing is automatic by definition. We shall see in a moment that there are other ways of defining automaticity that do not lead to this conclusion. However, these other ways of defining automaticity are relatively recent contributions. There is a long history, dating back to Broadbent (1958) and Neisser (1967), in which preattentive processing and automatic processing were thought to be one and the same.

Early versus late selection

The debate on early versus late selection, which began in the 1950s and continues today, is an important part of that history. The locus of selection is defined in terms of the level of processing that can be reached without attention, in terms of the depth of preattentive processing. Advocates of early selection argue that only elementary physical features can be processed without attention, so attentional selection must occur early in the processing chain (e.g., Broadbent, 1958, 1982; Kahneman & Treisman, 1984). Advocates of late selection argue that semantic features and meaning can be processed without attention, so attentional selection occurs late in the chain, when processing is nearly complete (e.g., Deutsch & Deutsch, 1963; Norman, 1968). Others take an intermediate position, arguing that selection can occur at any level, early or late, with costs and consequences varying with the level of selection (e.g., Bundesen, 1990; Johnston & Heinz, 1978).[1]

The debate is fraught with methodological difficulties. Experimenters try to determine what can be processed without attention by presenting stimuli outside the focus of attention. The problem is that it is nearly impossible to prove that the so-called unattended stimuli were in fact unattended. It is exceedingly difficult to rule out the possibility that subjects paid attention to the unattended stimuli, however briefly (see Hollender, 1986; Kahneman & Treisman, 1984; Zbrodoff & Logan, 1986). Consequently, much of the evidence is not easily interpretable.

The effects of unattended stimuli are typically small. It is not clear whether they reflect consistent small effects that occur on every trial, as would be the case if they reflected preattentive processing, or occasional large effects, due to lapses of attention, that become small by averaging with a majority of trials in which there is no effect. Moreover, researchers interpret their data inappropriately. The data allow researchers to reject the null hypothesis of no effect of unattended stimuli, but they often go beyond that and accept the null hypothesis of no difference in the processing of attended and unattended material. It could easily be the case that unattended material is processed but not to the same extent as attended material, which is not consistent with late selection (Kahneman & Treisman, 1984; Zbrodoff & Logan, 1986).

Participants in the debate on early versus late selection generally do not distinguish between preattentive and automatic processing, and that may lead to some of the confusion. They interpret evidence that processing is automatic as evidence that processing is preattentive, and that may not be a valid inference. Very brief attention to irrelevant materials may be sufficient to evoke an automatic process that would not have been evoked had the material not been attended (see Bargh, 1989, 1992). Postattentive automatic processing may be mistaken for preattentive, attention-free processing.

Early visual processing

A more recent literature on early vision also considers preattentive processes to be automatic (see Treisman, 1985; Treisman & Gormican, 1988). Preattentive processing is processing without attention, and processing without attention is automatic. Preattentive processing is parallel, whereas attentional processing is serial (Treisman, 1985; Ullman, 1984). Evidence of parallel processing comes primarily from two tasks, *search* and *texture segregation* (see e.g., Treisman & Gelade, 1980). In search tasks, the time to detect a target typically increases linearly with the number of distractors presented, and the increase is taken as an index of the difficulty of search. A large slope suggests serial processing. Sometimes distractors have no effect—the search slope is zero. This is taken as evidence of parallel processing, which in turn is taken as evidence that processing is preattentive. In texture-segregation tasks, subjects are presented with large arrays of stimuli and asked to detect boundaries that divide the array into subgroups. Rapid detection of the boundary suggests parallel, preattentive processing; slow, effortful detection suggests serial, attentive processing (Julesz, 1984). Often, results from texture-segregation tasks agree with results from search tasks (Treisman, 1985).

Furthermore, most of the evidence suggests that only elementary physical features can be processed preattentively. Arbitrary conjunctions of elementary features are generally not processed preattentively (Treisman & Gelade, 1980), though some recent research has revealed a few exceptions (see McLeod, Driver, & Crisp, 1988; Nakayama &

Silverman, 1986; Triesman & Sato, 1990). These results seem more consistent with early than with late selection.

The literature on early vision considers preattentive processing to be automatic in the sense that preattentive processing is independent of attention. However, automaticity is a side issue in that literature. The main goal is to distinguish between preattentive and attentional processing. There is no attempt to explain the acquisition of automaticity through training or manifestations of automaticity in other domains beyond early vision. Thus, there is no necessary connection between preattentive processes in early vision and broader conceptions of automaticity.

Automatic Processing

The modal view

Automaticity is often defined as processing without attention. Attention is necessary to support initial performance, but gradually with practice, the need for attention diminishes, until ultimately performance can proceed without attention (LaBerge & Samuels, 1974; Logan, 1978; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). In this view, preattentive processing is automatic because it occurs without attention. However, the modal view does not equate preattentive processing with automatic processing. Automatic processing is processing without attention, and there can be several kinds of automatic processing that are not preattentive. Automatic processes need not precede attention as preattentive processes do. They can follow attention, as processes involved in motor control often do (e.g., Salthouse, 1986). Automatic processes can also bypass attention. Indeed, the modal conception of automatization is the development of the ability to bypass attention (LaBerge & Samuels, 1974; Logan, 1978; Shiffrin & Schneider, 1977).

There are serious problems with the modal view, which I have documented elsewhere (Logan, 1988, 1991). Most of them stem from two sources: First, the modal view defines what automaticity is not, rather than what automaticity is. It defines automaticity as processing without attention, without saying how processing is possible with or without attention. More recent theories (see below) focus on what automaticity is, rather than what it is not. Second, the modal view does not specify a learning mechanism. The modal view claims that attention is gradually withdrawn from processing as practice progresses, without providing a theory that explains how attention is withdrawn or how attention can be withdrawn. More recent theories focus on learning mechanisms.

These problems undermine the modal conception of the relation between automatic and preattentive processing. Essentially, the relation is that neither kind of processing involves attention. That is not much of a constraint. There are logical and computational considerations that constrain the nature of preattentive processes (i.e., they must provide an informational basis for attentional selection) quite apart from their independence from attention. The modal view offers no such considerations for automatic processes.

Automaticity as memory

A number of recent theories construe automaticity as a memory phenomenon, governed by the theoretical and empirical principles that govern memory. They claim that novice (nonautomatic) performance is based on a general algorithm for solving the problems the task presents, whereas automatic performance is based on single-step, direct-access retrieval of past solutions from memory (Anderson, 1982; Logan, 1988; Newell & Rosenbloom, 1981; Schneider, 1985). Automatic processing has the properties of well-practiced memory retrieval. It is fast and effortless (for further discussion, see Logan, 1991).

From this perspective, automatic processing is not processing without attention. Instead, it is processing that involves a different way of attending (Logan, 1985; Neumann, 1984; Vallacher & Wegner, 1987). Whereas novice performers attend to the various steps of the algorithm they execute to produce a solution, automatic performers attend to the solutions that memory provides. Automatic processing is intricately dependent on attention, not independent of it. In my instance theory (Logan, 1988), subjects must attend to a stimulus to retrieve the solutions that were associated with it, and retrieval of past solutions depends on how subjects attend to the stimulus. Adopting a different task set, for example, can block retrieval (Logan, 1990).

Vallacher and Wegner (1987) provide a nice conception of one way in which automaticity could involve attending differently: They argue that the same activity can be described at many different levels of organization. For example, one may be pressing buttons, dialing a phone, calling a friend, maintaining social contacts, or searching for meaning in life. Vallacher and Wegner propose that people attend to one of these levels, and all levels beneath it are performed automatically. Two counteracting factors determine the level of organization that people attend to: On the one hand, people attend to the highest level that allows the task to be completed without shifting to lower levels. Performance at lower levels is entailed by attention to the higher level. It follows as an inevitable consequence of attention to the higher level, and in that sense, it is automatic. On the other hand, errors, equipment failures, unusual circumstances, or the lack of available procedures force attention to lower levels (e.g., we think of dialing a number, not pressing buttons, when we use a phone, but we would shift attention to button pressing if one of the buttons did not work properly). The development of automaticity in this scheme involves attending to progressively higher levels of task organization. Attention is not withdrawn from performance—indeed, the act remains largely the same. Instead, attention is shifted to a different level of organization.

Automaticity-as-memory theories in general and the Vallacher and Wegner view of automaticity in particular suggest a different relation between automatic and preattentive processes than the modal view. They suggest that automatic processing is *post*attentive rather than *pre*attentive: Attention must be directed to the stimulus for it to retrieve past solutions from memory. Thus, automatic processing is not at all the same as preattentive processing. It is similar in that it is fast and effortless, but it is fundamentally different. Automatic processing depends on attention, whereas preattentive processing does not.

Acquisition of Automatic and Preattentive Processes

An important characteristic of automaticity from any view is that it can be learned. Abundant evidence documents this fact, dating back to Bryan and Harter (1899) and William James (1890). The question is whether preattentive processes share this characteristic with automaticity.

Preattentive processes

Research on preattentive processes carried out in the debate over early versus late selection suggests that preattentive processes can be learned, and therefore, that automatization makes processing preattentive. Evidence of late selection is essentially evidence that subjects can pick up acquired meanings of arbitrary symbols presented outside the focus of attention. Presumably, people could not process these symbols preattentively before they learned them; automatizing the response to the symbols made them preattentive. However, as noted earlier, this evidence is inconclusive because subjects may have paid attention to so-called unattended material (Hollender, 1986; Kahneman & Treisman, 1984; Zbrodoff & Logan, 1986). Even brief attention to unattended material may be sufficient to instigate an automatic process (Bargh, 1989, 1992).

Most of the preattentive processes studied by early vision researchers are either innate or learned early in life. Attempts to make attentive processes preattentive by training adult subjects have been mostly unsuccessful. Treisman and Gelade (1980) were unable to automatize conjunction search. As seen in the present volume, Treisman, Vieira, and Hayes (1992) were able to flatten the slope of the search function in a task that required apprehension of spatial relations between features, which is suggestive of automaticity, but the learning did not transfer well to other tests of preattentive processing. Learning did not make processing preattentive.

Automatic processes

Many of the early theories of automaticity said little about learning and so do not speak directly to the issue. However, Shiffrin and Schneider (1977) took a stand that they appear to defend today (Schneider, 1985; Shiffrin & Czerwinski, 1988). They argued that through training, automatic processes became preattentive. Their position contrasts with automaticity-as-memory theories, such as Logan's (1988), which assume that automaticity is postattentive and cannot become preattentive through learning.

Automaticity is preattentive. Shiffrin and Schneider (1977) argued that two kinds of learning underlie automaticity: *association learning* and *priority learning*. Association learning developed the ability of a stimulus to evoke a response without attention, that is, the ability of a stimulus to proceed along a mental pathway without support from the attentional system. Association learning is not controversial; it is part of most other approaches to automaticity, past and present (e.g., Cohen, Dunbar, & McClelland, 1990; LaBerge & Samuels, 1974; Logan, 1988; Posner & Snyder, 1975). Priority learning is more controversial. It involves the development of the ability of a stimulus to attract attention automatically (what Shiffrin and Schneider called the *automatic attention response*). Priority learning is important in the present context because it represents a mechanism by which automatic processing can become preattentive. Schneider (1985) and Shiffrin and Czerwinski (1988) provided formal descriptions of learning mechanisms that could underlie priority learning.

Shiffrin and Schneider (1977) presented two main pieces of evidence for the automatic attention response and, hence, for the priority learning that produced it: Flattened slopes in search tasks, and the effects of familiar stimuli presented outside the focus of attention.

They argued that the automatic attention response pulled attention directly to the target item, so there was no need to search the display. The number of items in the display no longer mattered, so the search function flattened.

In this issue, Czerwinski, Lightfoot, and Shiffrin (1992) offer alternative interpretations for these results, arguing that most of the reduction in slope is due to the memory search component of the task. Indeed, many of their experiments involved both memory search and visual search (searching for several targets in displays of several items). Most of the evidence that slopes become flat with practice comes from memory search rather than visual search. The display may contain several items, but their number typically remains constant while the number of items in the memory set varies (see Shiffrin & Schneider, 1977). Thus, the slope reflects the number of memory comparisons—memory search, not visual search. The extensions of basic results with letter and digit search to words and categories used a similar procedure, holding constant the number of display items while varying the number of memory items (e.g., Fisk & Schneider, 1983; Schneider & Fisk, 1984). They, too, focus primarily on memory search. Thus, flattened slopes may not indicate priority learning (also see Logan & Stadler, 1991).

Shiffrin and Schneider (1977) also showed that familiar stimuli presented outside the focus of attention disrupted performance. They interpreted this result as an effect of the automatic attention response. Familiar targets attracted attention, diverting it from the task at hand, and therefore disrupted performance. However, these effects are subject to the interpretive difficulties mentioned earlier: They may reflect the effects of brief attention to irrelevant locations rather than automatic attraction of attention.

Automaticity is postattentive. Logan (1988) was most explicit in assuming that automaticity is postattentive. His instance theory rests on three assumptions: (a) *obligatory encoding*—attention to an object or event is sufficient to encode it into memory; (b) *obligatory retrieval*—attention to an object or event causes all that was associated with it to be retrieved from memory; and (c) *instance representation*—each encounter with an object or event is encoded, stored, and retrieved separately. Together, these assumptions imply a learning mechanism: Obligatory encoding builds memory strength for familiar situations, and obligatory retrieval makes past learning available for present problems. The more that was learned, the more that is made available. Logan (1988) showed how these assumptions and the assumption of instance representation can account for the power law of learning and extend it to distributions of reaction times. For the present, the important point comes from the assumption of obligatory retrieval: Attention is necessary to invoke the retrieval process. Memory is accessed postattentively, not preattentively. So far, this is a theoretical claim. The evidence against it (i.e., the evidence for priority learning) is weak, and there is no evidence that uniquely supports it. The experiments reported here were conducted to gather such evidence.

The Experiments

Two experiments were conducted to determine whether automatization would make processing preattentive. In the first experiment, subjects were trained to detect words that were presented alone (*focused attention*) or in the context of two unpronounceable nonwords (*divided attention*). Previous research has shown that automaticity can develop with as few as 16 presentations of words by themselves (Logan, 1988, 1990). The question here was whether priority learning would accompany the automatization. Priority learning would be evidenced by a reduction of the difference in reaction time (RT) between focused attention and divided attention conditions. Priority learning should have no effect in the focused attention condition because the single word presented by itself should have sufficient priority (i.e., a single word presented alone should attract attention regardless of its history; there are no competing stimuli to draw attention away from it). By contrast, priority learning should benefit performance in the divided attention condition because it would cause attention to be drawn to the target position and away from the nontarget positions. With sufficient practice (i.e., at asymptote), divided attention targets should attract attention as strongly as focused attention targets, and so should be responded to just as rapidly.

The second experiment was a replication of the first, substituting a *selective attention* condition for the focused attention condition. In the selective attention condition, two nonwords were presented along with the word, just as in the divided attention condition. However, the target was colored red or green, and the distractors were white. Subjects were told that the word would be colored, and if the colored item was not a word, there would be no word in the display (i.e., the cue was perfectly valid). The predictions were the same as in the first experiment: Priority learning should confer no advantage in the selective attention condition because the difference in color between targets and distractors should give the target priority. But priority learning should facilitate performance in the divided attention condition and eventually produce performance that is as fast and accurate as performance in the selective attention condition.

EXPERIMENT 1

METHOD

Subjects

Twenty-four students from an introductory psychology course served to fulfill course requirements.

Apparatus and stimuli

The stimuli were displayed on Amdek Model 722 color monitors controlled by IBM XT and AT computers. The stimuli were words, pronounceable nonwords, and consonant strings, all five characters in length, presented in lowercase.

On focused attention trials, only one stimulus was presented. It was a word (target) or a pronounceable nonword (nontarget). On divided attention trials, two consonant strings appeared with the target or nontarget. Targets and nontargets appeared in one of three rows (Row 12, 13, or 14 on a standard 24-row × 80-column screen) centered on the computer screen (leftmost letter appearing in Column 33). On focused attention trials, the other two rows were blank. On divided attention trials, the other two rows contained consonant strings.

Targets were words from a sample of 340 common nouns drawn from the Kucera and Francis (1967) norms. They ranged in frequency from 8 to 787 per million with a mean of 75.27. Nontargets were constructed by substituting letters for each of the words to create 340 pronounceable nonwords.

Each trial began with a fixation display exposed for 500 ms. It consisted of two rows of seven dashes (one in Row 11 and one in Row 15) centered on the computer screen (the leftmost dash in each row began in Column 32). When the fixation display terminated, it was replaced immediately with the one- or three-string stimulus display, which was exposed for 500 ms. After termination of the stimulus display, the screen remained blank for a 2,000-ms intertrial interval.

Subjects responded by pressing the *z* key or the / key. These keys were the leftmost and rightmost keys on the bottom row of the AT keyboard and nearly so on the XT keyboard. Reaction times were measured in milliseconds. The computer recorded the first response after the stimulus display appeared. If no response occurred during stimulus exposure, a response could be registered during the intertrial interval.

Procedure

Each subject completed 384 focused attention trials and 384 divided attention trials. Half of the subjects completed the focused attention trials before the divided attention trials, and half did the opposite. The 384 trials in each condition were made up of 16 blocks of 24 trials. Within each block of 24 trials, 12 different word targets and 12 different pronounceable nonword targets were presented in random order. The same 12 words and 12 nonwords were presented in each of the 16 blocks, though the order of stimuli changed between blocks. One set of 12 words and 12 nonwords was used in the focused attention condition, and another set was used in the divided attention condition. The words and nonwords used in each condition were selected randomly without replacement from the 340 words and 340 pronounceable nonwords. The only constraint on selection was that none of the nonwords was derived from any of the 12 target words. A different set was selected for each subject.

Each trial began with a fixation display, which was extinguished and replaced by the stimulus display. Subjects were told to make one response if the stimulus display contained a word and another response if it did not. They were told to respond as quickly as possible without making too many errors. They were given short breaks every 128 trials. Half of the subjects pressed the *z* key for words and the / key for nonwords, and half did the opposite. Assignment of these mapping conditions was orthogonal to assignment to the order of focused and divided attention conditions.

RESULTS

The mean RTs for words and nonwords in focused and divided attention conditions are presented in Figure 1 as a function of the

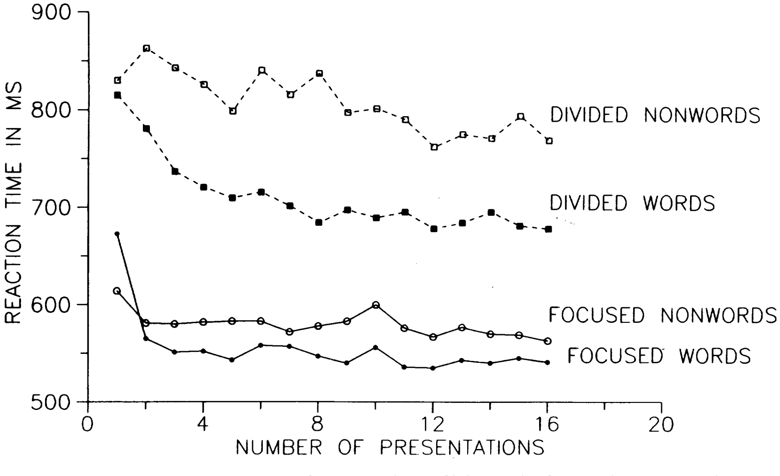

Figure 1. Mean reaction time for words (solid symbols) and nonwords (open symbols) in focused (solid lines and circles) and divided (dashed lines and squares) attention conditions as a function of the number of presentations in Experiment 1

number of presentations. Reaction time decreased as the number of presentations increased, replicating past research (Logan, 1988, 1990), though in these data the reduction was greater for words than for nonwords. Focusing attention on a single item reduced RT substantially, relative to dividing attention between three items (mean reduction = 192 ms). It is important to note that the effect of focusing attention was not reduced by practice: The effect was 179 ms on the 1st presentation and 173 ms on the 16th.

These conclusions were supported by a 2 (Order of Attention Conditions) × 2 (Mapping Rule) × 2 (Word vs. Nonword) × 2 (Focused vs. Divided Attention) × 16 (Presentations) analysis of variance (ANOVA) on the RTs. There was a significant main effects of presentations, $F(15, 300) = 11.82$, $p < .01$, $MS_e = 4{,}857.47$; word vs. nonword, $F(1, 20) = 73.29$, $p < .01$, $MS_e = 19{,}428.89$; and focused vs. divided attention, $F(1, 20) = 191.19$, $p < .01$, $MS_e = 73{,}749.07$. There was a significant interaction between attention conditions and lexical status, $F(1, 20) = 48.05$, $p < .01$, $MS_e = 10{,}463.86$, reflecting a larger effect of dividing attention with nonwords than with words (see Figure 1). There was a significant interaction between lexical status and presentations, $F(15, 300) = 8.99$, $p < .01$, $MS_e = 1{,}579.20$, reflecting greater learning with words than with nonwords (see Figure 1). There was a significant interaction between attention conditions and presentations, $F(15, 300) = 2.56$, $p < .05$, $MS_e = 4{,}552.01$, reflecting a somewhat slower approach to asymptote in divided attention than in focused attention. After the fifth presentation, for words at least, the functions are essentially parallel.

In addition to these effects, there were significant interactions between lexical status, presentations, and order of attention conditions, $F(15, 300) = 2.43$, $p < .01$ $MS_e = 1{,}579.20$, and between lexical status, presentations, order of attention conditions, and focused vs. divided attention, $F(15, 300) = 2.24$, $p < .01$, $MS_e = 1{,}841.32$, which did not compromise conclusions drawn from the main results.

The accuracy data for words and nonwords in focused and divided attention conditions are presented as a function of number of presentations in Table 1. Nothing in the accuracy data compromises the interpretation of the RTs.

DISCUSSION

This experiment provided evidence of automatization in that RTs decreased considerably over presentations and approached asymptote (cf. Logan, 1988, 1990). At the same time, there was no clear evidence of priority learning. The advantage of focused attention over divided

Table 1. Percent correct for words and nonwords in focused and divided attention in Experiment 1, as a function of the number of presentations

No. of presentations	Focused		Divided	
	Word	Nonword	Word	Nonword
1	95	99	62	94
2	96	99	84	98
3	98	99	81	97
4	96	100	86	96
5	98	98	82	97
6	98	97	90	91
7	98	97	91	93
8	97	96	89	97
9	98	99	90	96
10	99	99	90	96
11	97	96	87	95
12	99	95	91	97
13	97	97	95	96
14	99	98	91	97
15	97	99	94	97
16	97	97	96	99

attention persisted undiminished as automaticity was attained, especially after the first few presentations. This suggests a dissociation between automaticity and preattentive processing, in that one can be obtained without the other. The dissociation is consistent with memory-based theories of automaticity, such as Logan's (1988), which assume that automaticity is postattentive. The dissociation is inconsistent with the modal view and with the priority learning mechanisms of Schneider (1985) and Shiffrin and Czerwinski (1988), which assume that automatic processing becomes preattentive.

These conclusions may be mitigated somewhat by the relatively low levels of practice used in the experiment (but see Logan, 1988; Logan & Klapp, 1991). However, the results may be extrapolated to higher levels of practice by fitting power functions to the data and comparing the asymptotes of the functions. The hypothesis that automatic processing becomes preattentive predicts identical asymptotes in focused and divided attention conditions; the hypothesis that automatic processing is postattentive predicts a lower asymptote in focused attention than in divided attention. Power functions were fit to the data for words and nonwords in both attention conditions. The fits to the nonwords were poor (r^2 = .55 for focused and divided attention), so they will not be considered.

The fits for words were excellent. In focused attention, r^2 was .96 and the root-mean-squared deviation (*rmsd*) between observed and predicted values was 6.6 ms. The asymptote of the fitted function was 544 ms, the exponent was −2.502, and the multiplicative parameter, reflecting the difference between initial and asymptotic performance, was 128 ms. In divided attention, r^2 was .96 as well and *rmsd* was 8.2 ms. The asymptote was 636 ms, the exponent was −.516, and the multiplicative parameter was 184 ms.

The issue at hand is whether the asymptotes are equal or the asymptote is lower in focused than in divided attention. The asymptotes differed by 92 ms, which makes it hard to accept the null hypothesis of no difference. However, the fitting routine provides no estimate of the standard error of the fitted parameters, so the significance of the difference cannot be assessed. I tried fitting power functions to data of individual subjects and comparing asymptote parameters, but the individual data were so noisy that several subjects did not produce significant fits and statistical analyses of asymptotes from subjects with significant fits were not significant. One way to assess the significance of the difference in asymptotes is to compare it against the mean squared error for the interaction of presentations, lexical status, and attention conditions in the ANOVA on the RTs. That comparison yielded a highly significant difference, $F(1, 300) = 55.16$, $p < .01$, $MS_e = 1{,}841.32$.

EXPERIMENT 2

Experiment 2 was a replication of Experiment 1, except that the focused attention condition was replaced by a selective attention condition. Subjects were shown three-item displays in all conditions. In the selective attention condition, the target item was colored differently from the distractors. In the divided attention condition, the target was the same color as the distractors. The same hypotheses were tested. The hypothesis that automatic processing becomes preattentive predicts a reduction in the difference between selective and divided attention conditions with practice. The hypothesis that automatic processing is postattentive predicts no such reduction.

METHOD

Subjects

Twenty-four students from an introductory psychology course received course credit for participating. None of the subjects was color blind, as assessed by the Ishihara (1987) colorblindness test.

Apparatus and stimuli

These were the same as in the divided attention condition of Experiment 1 with the following exceptions: In the selective attention condition, half the targets were colored red (IBM 12) and half were colored green (IBM 10), and the consonant-string distractors were colored white (IBM 15). Similarly, half of the pronounceable nonword nontargets were colored red and half green. In the divided attention condition, targets and distractors were all colored red or all colored green. Half of the targets were red and half were green; similarly for nontargets.

Procedure

This was the same as in Experiment 1.

RESULTS

The mean RTs for words and nonwords in the selective and divided attention conditions appear in Figure 2 as a function of the number of presentations. As in Experiment 1, RT decreased as the number of presentations increased, and the reduction was greater for words than for nonwords. Selective attention reduced RT relative to divided attention (mean difference = 44 ms). The difference appeared to grow somewhat with presentations, averaging 6 ms on the 1st presentation and 68 ms on the 16th. Selective attention and divided

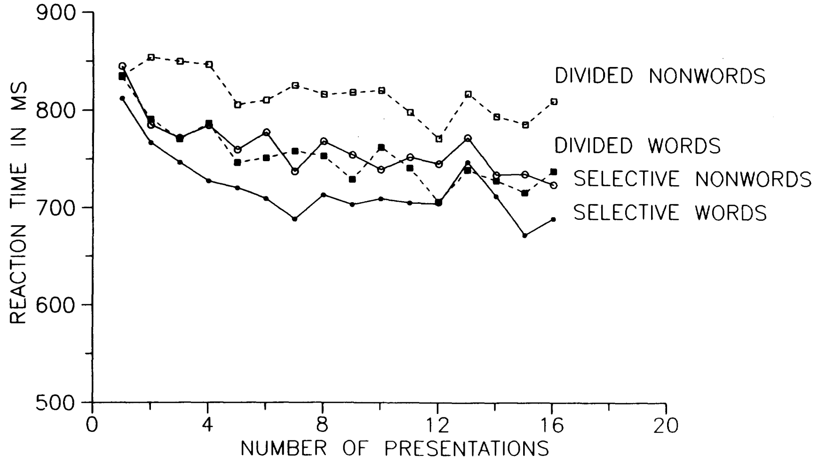

Figure 2. Mean reaction time for words (solid symbols) and nonwords (open symbols) in selective (solid lines and circles) and divided (dashed lines and squares) attention conditions as a function of the number of presentations in Experiment 2

attention were nearly identical for words on the 12th, 13th, and 14th presentations, but the difference emerged again on the 15th and 16th presentations, suggesting that the functions were not converging with practice.

These conclusions were supported by a 2 (Order of Attention Conditions) × 2 (Mapping Rule) × 2 (Word vs. Nonword) × 2 (Selective vs. Divided Attention) × 16 (Presentations) ANOVA on the RTs. There was a significant main effects of presentations, $F(15, 300) = 8.83$, $p < .01$, $MS_e = 7{,}645.18$; word vs. nonword, $F(1, 20) = 65.12$, $p < .01$, $MS_e = 15{,}964.72$; and selective vs. divided attention, $F(1, 20) = 16.51$, $p < .01$, $MS_e = 44{,}271.98$. There was a significant interaction between attention conditions and lexical status, $F(1,20) = 5.96$, $p < .05$, $MS_e = 7{,}633.31$, reflecting a larger effect of dividing attention with nonwords than with words (see Figure 2).

The accuracy data for words and nonwords in selective and divided attention conditions are presented as a function of number of presentations in Table 2. Nothing in the accuracy data compromises the interpretation of the RTs.

DISCUSSION

This experiment replicated the first one. It provided further evidence of automatization with no evidence of priority learning. The advantage of selective attention over divided attention was maintained as automaticity was attained. This result is consistent with the hypothesis that automaticity is postattentive and is inconsistent with the hypothesis that automatic processing becomes preattentive with practice.

Power functions were fitted to the data to extrapolate the results to higher levels of practice. Once again, the fits to the nonwords were poor, so only word data will be reported. The fits for words were reasonable. In selective attention r^2 was.78 and *rmsd* was 15.5 ms. The asymptote of the fitted function was 685 ms, the exponent was −.777, and the multiplicative parameter was 130 ms. In divided attention, r^2 was .82 and *rmsd* was 12.9 ms. The asymptote was 674 ms, the exponent was −.382, and the multiplicative parameter was 158 ms. The important comparison is between the asymptotes. Here, the asymptote for divided attention was numerically smaller than the asymptote for selective attention, which suggests that the advantage of selective over divided attention disappeared at asymptote. This suggests that priority learning may develop with sufficient practice.

It is possible that these results do not indicate priority learning. The effect of selective attention (44 ms) was small compared with the

Table 2. Percent correct for words and nonwords in selective and divided attention in Experiment 2, as a function of the number of presentations

No. of presentations	Selective		Divided	
	Word	Nonword	Word	Nonword
1	92	91	76	98
2	98	95	84	98
3	97	95	86	98
4	96	95	91	97
5	94	99	91	99
6	97	98	90	99
7	94	98	94	97
8	93	98	92	98
9	97	98	95	99
10	97	98	93	98
11	94	97	92	98
12	97	98	93	97
13	94	99	93	99
14	97	97	94	99
15	95	98	94	97
16	96	98	93	99

effect of focusing attention on a single item in Experiment 1 (192 ms). The difference in effect size was largely due to the contrast between the selective and focused attention conditions; divided attention RTs were about the same in the two experiments (760 ms in Experiment 1; 786 ms in Experiment 2). Perhaps coloring the targets was not a very effective way to draw attention to them. One possibility is that subjects learned similar strategies to detect targets in selective and divided attention conditions: Only targets and pronounceable nonword nontargets contained vowels; distractors contained only consonants. Thus, subjects could have learned to search for vowels to find the position of the target or nontarget and evaluate only that position. Vowels may have been easier to detect than colors, so this strategy may have been useful even in the selective attention condition. If subjects used the same strategy in both conditions, the asymptotes of the learning curves would have been the same, as was observed. Note, however, that the strategies do not involve priority learning. Subjects need not learn to detect vowels preattentively.

Even if the results are interpreted as evidence for priority learning, they nevertheless show a dissociation between priority learning and automatization. There was evidence of automatization without priority learning in the initial 16 training trials. Evidence of priority learning comes only when performance is extrapolated to asymptote. Thus, automatization may require less practice than priority learning (also see Logan & Klapp, 1991).

GENERAL DISCUSSION

The experiments provided no evidence that training modulated the effects produced by focusing attention (Experiment 1) and attending selectively (Experiment 2). At best, there was some indication that the selective attention effect may be eliminated at asymptote, but there was no clear reduction in the effect at the levels of practice experienced in the current experiments. Those same levels of practice produced substantial automatization, as reflected by the power-function speed-up in RT in both experiments. These results are consistent with the hypothesis that the effects of automaticity occur after the effects of attention—with the hypothesis that automaticity is postattentive. The results show little evidence of the development of an automatic attention response; they are inconsistent with the hypothesis that automaticity is preattentive.

The results and conclusions appear contrary to common interpretations of the literature. It is often assumed that practice will reduce the slope of search functions, and the contrast between divided and focused attention provides two points on a search function. As mentioned earlier, many of the studies that are interpreted as providing evidence that visual search slopes flatten with practice may show instead that memory search slopes flatten with practice (also see Czerwinski et al., 1992).

Moreover, most of the previous studies involved search for letters or digits that come from relatively small sets, whereas the present experiments involved search for words, which are combinations of letters that came from a large set (340 words in the experiment; potentially 500,000 words in the language). It may be that the principles that govern visual search for single letters do not generalize to visual search for words (cf. Fisk & Schneider, 1983). It may be that automatic attention responses can be developed to single letters or digits but not to words.

There are reasons to expect that different principles govern word search and letter search. Words may be viewed as conjunctions of elementary features (i.e., letters), and the slope of conjunction search functions typically does not flatten much with practice (Treisman & Gelade, 1980). (When conjunction slopes do flatten with practice, transfer to other tests of preattentive processing is poor; see Treisman et al., 1992). Compared with words, letters are fairly simple stimuli. Search for letters appears to be governed largely by similarity between targets and distractors and similarity among the distractors themselves (Duncan & Humphreys, 1989).

These reasons need to be evaluated, and the results of the evaluation need to be incorporated into theories of automatization. Schneider (1985), for example, used a category search task to illustrate his theory and argued that an automatic attention response would develop to words that are members of the target category. That aspect of his theory may need revision.

Similarly, different principles may govern memory for words and for displays of random letters. Words have semantic content, whereas random letter arrays do not. Words have pronunciations, whereas random letter arrays do not. Semantic contents and pronunciations may provide ways of encoding and retrieving words that are simply not available to random letter strings. Thus, words may be easier to encode and easier to retrieve than random letter strings and therefore automatize faster. (This may explain why there was less learning for nonwords than for words in both experiments, but see Logan, 1988, 1990.)

These possibilities need to be evaluated as well, and the results of the evaluation need to be incorporated into theories of automatization. Logan (1988), for example, says nothing about how instances are encoded, nothing about how different orienting tasks affect retrieval, and nothing about how materials that afford different encoding and retrieval routes will manifest different learning curves. That aspect of the theory needs to be developed.

Varieties of automaticity

A critical reader may challenge the conclusions I have drawn here, arguing that I have distinguished between two legitimate meanings of the term *automaticity* and reserved the term itself for only one of its meanings. Might there be more than one kind of automaticity, one that depends on attention and one that is independent of it? Bargh (1989, 1992), for example, takes a position that suggests a positive answer. He distinguishes between *preconscious* automaticity that is independent of attention and intention, *postconscious* automaticity that is independent of intention but not attention, and *goal-dependent* automaticity that depends on both attention and intention. At first glance, preconscious automaticity appears similar to preattentive automaticity. On further reflection, however, preconscious automaticity may be postattentive: The examples Bargh provides to illustrate preconscious automaticity often require the subject to pay attention to the stimulus that evokes the automatic process. In my terms, such automaticity would be postattentive, not preattentive.

I believe there may be many kinds of automaticity, but all of them depend on attention. I believe that preattentive processing is automatic in a different sense than postattentive processing is automatic. Preattentive processing is automatic only in the sense that it is independent of attention; postattentive processing is clearly not automatic in that sense. The conventional view that automatic processing is independent of attention would lead to the unhappy conclusion that much of automaticity is not automatic. To escape this contradiction in terms, automaticity must be defined in some way other than independence from attention (also see Logan, 1988; Logan & Klapp, 1991).

Perhaps the clearest distinction between preattentive and postattentive automaticity lies in the computations they perform. According to Ullman (1984), preattentive processes appear to perform computations that can be done by local parallel processing. Apparently, computations that require spatial indexing and computations that require interactions between sources of information in arbitrarily different regions of the visual field cannot be done preattentively. Attention is required. According to Logan (1988), postattentive automatic processes appear to perform computations that can be done by single-step direct-access memory retrieval (table look-up, association, etc.). Computations that require information that is not readily available in memory cannot be performed automatically. Some general-purpose or special algorithm must be invoked.

Local parallel processing imposes very different computational constraints than single-step direct-access memory retrieval does. The class of computations that can be performed by local parallel processing is very different from the class of computations that can be performed by single-step direct-access memory retrieval. For example, representations that are output from a spatial indexing process, and thus cannot have been produced by preattentive processing, may serve as input to the memory retrieval process, and therefore initiate automatic processing.

The computational perspective provides a meaningful distinction between preattentive and postattentive automaticity, but it does not resolve the terminological issue: Should the term *automaticity* be reserved for postattentive automaticity? I would argue that it should. On the one hand, preattentive processing is automatic only in the sense that it is independent of attention. It should be possible to capture this property with the words "independent of attention" instead of the word "automaticity." On the other hand, postattentive automaticity is a phenomenon in itself, closely related to skill acquisition, implicit memory, and volition but identical to none of them (Logan, 1985, 1991; Vallacher & Wegner, 1987; Zbrodoff & Logan, 1986). It seems reasonable to give the phenomenon a name of its own. Until a better term comes along, it may be best to honor history and call the phenomenon automaticity.

Notes

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1. I am grateful to Anne Treisman for reminding me that early selection theorists, such as Broadbent (1958) and herself (e.g., Treisman, 1969), always thought late selection was possible. Indeed, Broadbent's (1971) revision of his theory distinguished between *filtering* and *pigeonholing*, which corresponded directly to early and late selection, respectively. For these theorists, the question was not whether there was only early selection. Rather, they assumed late selection and asked whether early selection was possible.

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