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Constraints on Awareness, Attention, Processing, and Memory: Some Recent Investigations with Ignored Speech

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We discuss potential benefits of research in which attention is directed toward or away from a spoken channel and measures of the allocation of attention are used. This type of research is relevant to at least two basic, still-unresolved issues in cognitive psychology: (a) the extent to which unattended information is processed and (b) the extent to which unattended information that is processed can later be remembered. Four recent studies of this type that address these questions in various ways (Cowan, Lichty, & Grove, 1990; Wood & Cowan, 1995a,b; Wood, Stadler & Cowan, in press) are reviewed as illustrations. We conclude from these studies that (a) unattended information appears to be partially processed automatically, though attention enhances the processing considerably, and (b) the unattended information that is processed may not be retrievable in direct or many indirect memory tasks, though it remains possible that there is an automatically stored memory trace (e.g., one that could produce semantic priming).

The modern era of cognitive psychological research has lasted about 40 years. During that period, many topics have been explored, but from time to time investigators have returned to a few central questions that remain unanswered. One of the most important of these concerns the effects of attending to a stimulus to the point of becoming aware of it. One can ask, more specifically, to what extent attention and awareness affect (a) processing of the stimulus and (b) memory of the stimulus.

The specific issues of processing and memory often have been confounded because memory measures have been used to indicate awareness and processing. To separate these issues, both immediate and delayed indices are needed. In this paper, we review several of our recent studies of the processing and memory of attended and ignored stimuli, which include both immediate and delayed indices of processing (Cowan, Lichty, & Grove, 1990; Wood & Cowan, 1995a,b; Wood, Stadler, & Cowan, in press).

Often in cognitive psychology, flow diagrams of processing have been used to help clarify the concepts and issues. (The first such flow diagram within cognitive psychology, to our knowledge, was issued as a minor aside within a footnote of Broadbent's 1958 book.) However, the processing flow diagrams have not clearly separated the processing and memory issues, perhaps because of the confounding in how they are typically studied. How might these issues be separately represented?

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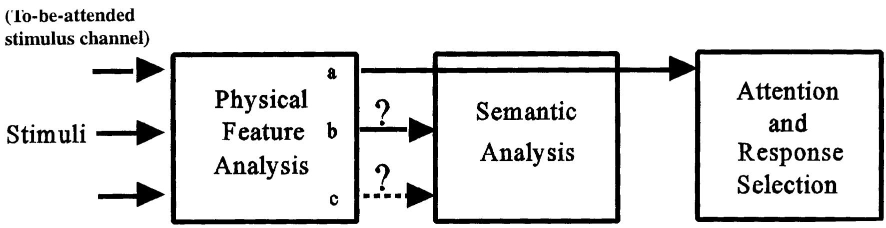

FIG. 1. A depiction of three steps in information processing for attended stimuli (long, solid-line arrow), and possibilities for the semantic processing of unattended stimuli according to the late filter theory (short, solid-line arrow) or the attenuation theory (short, dashed-line arrow), which would lead to only a partial semantic analysis.

THE QUESTION OF THE DEPTH OF ANALYSIS OF IGNORED STIMULI

Figure 1 represents the processing question and summarizes several alternative answers that appear in the literature. According to all models, some analysis of the physical features of all stimuli must automatically take place. This is depicted for three concurrent stimuli in the left-hand box of the figure. The assumption follows partly from a seminal selective listening study (Cherry, 1953) in which subjects shadowed (repeated) prose presented in one ear and ignored different prose presented in the other ear. Though subjects remembered little of the semantic content in the ignored channel, they easily and consistently noticed a change in that channel from one person's voice to another voice. This demonstrated that physical features of the voice must have been processed (and remembered for a short while) even though the channel in which it had been presented was ignored.

The middle panel of the figure is relevant to the further question of when semantic processing takes place. It is assumed by all theories that the attended stimulus is processed semantically. The theories differ as to what happens to an ignored stimulus. The ''early filter'' theory of Broadbent (1958) suggested that no semantic processing of such a stimulus would take place; its processing is filtered out early in the flow of information. This theory was based on studies such as that of Cherry (1953), who found that subjects could not report a change of the semantic content, or even of the language, of the message in the ignored channel in selective listening. In contrast, the ''late filter'' theory of Deutsch and Deutsch (1963) suggested that all stimuli are processed semantically, but that only the attended stimulus can go on to elicit a response from the subject. This is represented in the figure by the middle, solid arrow, which proceeds from physical feature processing to semantic processing but does not carry on to include response selection, in contrast to the attended stimulus. This sort of view was formulated in response to evidence that some semantic processing of seemingly ignored stimuli did take place. For example, Moray (1959) showed that subjects sometimes could recall hearing their own name when it was presented in an ignored channel in selective listening. Moray's finding, along with those of Cherry (1953), appear to form the original basis of what has become known as the ''cocktail party phenomenon,'' referring to the limitations and abilities in speech processing that one would encounter at a cocktail party in which many people were speaking at once and frequent choices had to be made about what information to process and what to ignore.

An intermediate theory was proposed by Treisman (1964). This ''attenuating filter'' theory stated that the ignored channels were not excluded from semantic processing, as in the early filter theory, but rather were processed to an extent that was attenuated in comparison to attended stimuli. This is represented by the dashed arrow leading from physical processing to semantic processing in Fig. 1. If the attenuated processing occurred for a stimulus that had a particularly low threshold of activation in memory, it would stand a reasonable chance of activating that information, recruiting attention to it, and bringing the stimulus into awareness. That theory can explain, among other things, why people sometimes notice their names in the ignored channel, as it is assumed that one's own name would have an especially low threshold of activation. Moray (1959) studied 12 subjects and found that 4 of them noticed their names. The attenuating filter theory seems more apt than the late filter theory for understanding why such an important stimulus as one's own name was detected only in a probabilistic manner. The amount of attenuation of the input name could vary from one subject to the next, depending on how intensely attention was focused, and people could differ in the importance they attach to their own names.

Further supporting this theory rather than a late filter theory in which all semantic processing is automatic, it is much less effortful to select one channel and ignore another on the basis of physical distinctions between them than it is on the basis of semantic distinctions, as measured by performance on a subsidiary reaction time task involving detection of a light (Johnston & Heinz, 1978). For reviews of other relevant evidence, see Cowan (1988, 1995) and Kahneman and Treisman (1984).

That is not the end of the controversy, though. Over the years subsequent to Treisman's (1964) account, views on both ends of the spectrum have been voiced. Reviving the possibility of an early filter, Holender (1986) reviewed relevant literature seeming to support semantic processing of ignored information and found that there were insufficient measures of the deployment of attention in most of the studies, so that the allegedly ignored stimuli may not have been ignored after all. On the other end of the spectrum, in keeping with a late filter view, Hirst, Spelke, Reaves, Caharack, and Neisser (1980) taught people to read and take dictation at the same time, and these researchers voiced the opinion that there is no general attentional resource, only the need for practice, in order to process both streams simultaneously in dual task situations. Banks and Zender (1984) took a similar stance. Some others (e.g., Wickens, 1984) similarly argued that there are specific processing resources but no attentional limit across all tasks.

Reviews by Cowan (1988, 1995) argued for a view like that of Treisman (1964) and showed how an attenuating filter might work. All stimuli would be processed to some extent, possibly including some semantic processing, but they would recruit attention only if they deviated from the subject's current neural model of the environment, thereby eliciting an attentional orienting response (Sokolov, 1963). Orienting would habituate in the absence of any such changes or especially significant stimuli. Cowan (1995) presented a detailed critique of the Hirst et al. study, suggesting that the dual task performance their subjects achieved (though it was interesting and remarkable) can be accounted for through attention shifting between tasks, attention sharing, or both, in contrast to what Hirst et al. argued. Despite all this, we will suggest that more information on the nature of attentional filtering is needed and will describe some work that begins to fill that need. First, though, we will describe the second, memory-related issue and a little more about research methods.

THE QUESTION OF MEMORY OF IGNORED STIMULI

This is the question that has so frequently been combined with the question of the level of attention, rather than considered separately. How much processing of a stimulus is necessary before that stimulus leaves a permanent record in the memory system?

There does not appear to be much controversy concerning attended stimuli. They can be remembered, subject only to various contextual and neural constraints on retrieval (the most compelling being, in our opinion, the concept of ‘‘encoding specificity’’ of Tulving & Thomson, 1973, or the ‘‘transfer-appropriate processing’’ of Morris, Bransford, & Franks, 1977). Information that is ignored at the time of its presentation is, without a doubt, more difficult to remember (all else being equal). It is still an open question as to why this difference in memory for attended and unattended information occurs. One hypothesis would be that attended information is recalled better because it is processed more completely, a view that would be in keeping with the ‘‘levels of processing’’ approach of Craik and Lockhart (1972). However, this would have to include situations in which new meaning is added for events that originally were meaningless. (For example, newly acquired vocabulary does not at first elicit a strong semantic meaning but can be entered into long-term memory.)

There is more controversy concerning a related question, that of how well ignored stimuli are recalled. According to either the attenuation theory or the late filter theory, totally ignored stimuli might be processed to a semantic level to some extent, but still not responded to. One possibility is that such stimuli leave a record in memory, and the alternative view is that they do not. This question is represented by the memory box in Fig. 2 that includes a question mark.

Most of the research studies of this issue compare relative amounts of attention but make no assertion about complete inattention. For example, Jacoby, Toth, and Yonelinas (1993) showed that dividing attention at the time of encoding or at the time of recall impaired memory for visually presented lists in a very interesting way, in a word stem completion task. A component of memory that was assumed to reflect conscious recollection was altered severely by dividing attention, whereas a component that was assumed to reflect automatic familiarity was not altered.

One often-cited study (Eich, 1984), however, did intend to address the quality of memory without attention. Eich used a selective attention task and presented critical word pairs in the ignored channel while subjects shadowed the other channel. An example of a critical word pair is ‘‘taxi fare.’’ What makes these words critical is that the second word is a homophone that is lexically specified (‘‘disambiguated’’) by the first word. Eich found in a subsequent recognition test that subjects could not remember that the critical homophonic words had been presented in the ignored channel; performance was not significantly above chance. Nevertheless, in a spelling test

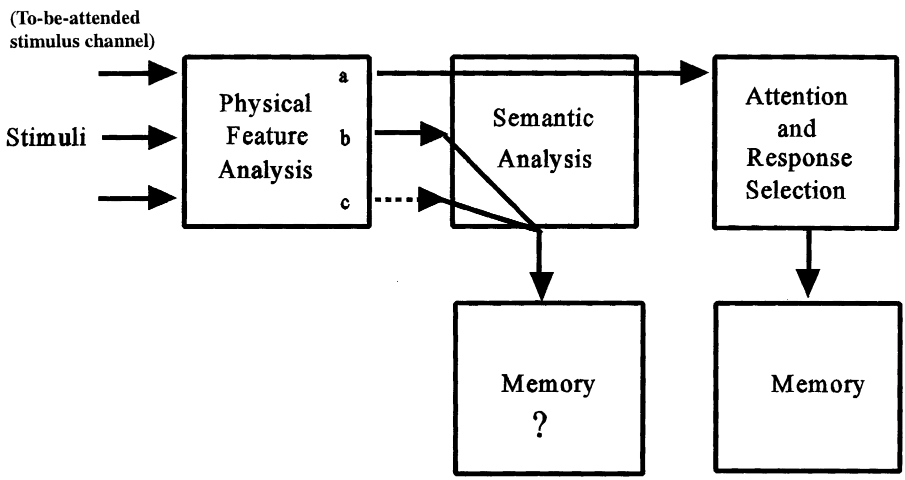

FIG. 2. A depiction of the issue of whether a long-term, semantically based memory is formed on the basis of unattended stimuli.

it was found that an acoustic presentation of the homophonic words resulted in a spelling that matched the presented version of the word (e.g., ''fare'' rather than ''fair'') more often than was found for control homophones that had not been presented.

Eich's (1984) study thus suggested that there was memory for unattended material as revealed in an indirect test (the spelling test), which made no explicit reference to the study session, even though there was no evidence of memory in a direct test (the recognition test), which did refer to what happened in the study session. Cowan (1995) argued, however, that the control of attention in Eich's study was insufficient to warrant these conclusions. We will discuss recent evidence supporting this point later on. In sum, it appears that the questions raised in Figs. 1 and 2 are not yet answered satisfactorily. In the next section, we make a case that auditory studies can be especially useful in addressing these questions.

DRAWBACKS AND ADVANTAGES OF THE FORSAKEN AUDITORY MODALITY IN ATTENTION RESEARCH

We have discussed the central questions illustrated in Figs. 1 and 2 mostly in terms of auditory studies. However, it seems clear that the field shifted, beginning perhaps in the middle 1960s, to the predominant use of visual materials in research on selective attention. The main reason for this shift may have to do with practical issues related to technology. It was easier and cheaper to produce visual stimuli with carefully controlled parameters (including precise stimulus timing) than it was to produce equally well-controlled acoustic stimuli. That difference in difficulty remains to some extent today, but recent advances in computer technology within the past 10 years have greatly diminished the difference.

Another possible drawback of the auditory modality is that it yields no obvious behavior indicating the allocation of attention. In the visual modality, attention usually follows the direction of the subject's gaze, but there are no comparable, observable ''ear movements'' in humans (though perhaps there are in rabbits).

These practical disadvantages of audition must be balanced, however, with several important advantages. First, by using earphones it is easy to stabilize the quality of the incoming sensory information. In the visual modality, a somewhat comparable technique is to start a trial only when the subject is looking at a fixation cross and to present the stimuli so quickly that there is no time for the eyes to wander, but that is a much more difficult technique to use.

Second, one can manipulate attention without changing the auditory sensory input. One simply asks the subject to attend to one ear and ignore the other. Similar attentional manipulations can be accomplished in the visual modality, but the stimuli have to be balanced in such a way as to prevent eye movements to the stimuli that are to be attended. Foveal vision involves better stimulus input quality than peripheral vision, so that tricky detail is essential in the visual modality. There is no such problem in audition.

Third, by sending separate signals to the left and right ears through headphones, it is easy to present the stimuli to different receptors and also have them perceived as originating from different spatial locations (with the left ear mediating a leftward spatial location and the right ear mediating a rightward spatial location). In contrast, in the visual modality, one can use special optical devices to present different materials to the two eyes, but the perceived locations of the stimuli in space still will overlap unless further steps are contrived (e.g., using only the left visual half-field for the left eye and using only the right visual half-field for the right eye).

Thus, there are advantages to the use of the auditory modality. Selective attention seems to be deployed on a spatial basis. In audition with headphones we know that that means attention to particular receptors (those of the left or right ears) rather than having to consider a more complex configuration of receptors. The stimuli presented to the attended and ignored receptors can be directly controlled.

What is needed to make the auditory modality useful, though, is an adequate measure of the deployment of attention. There are some examples in the literature in which errors and pauses in shadowing performance were used to examine the deployment of attention in auditory tasks (e.g., Barr & Kapadnis, 1986; Corteen & Wood, 1972; Dawson & Schell, 1982; Treisman & Geffen, 1967; Treisman, Squire, & Green, 1974; Yates & Thul, 1979). However, it is our contention that the technique was for the most part abandoned prematurely, in the face of easier-to-use visual techniques.

In the past few years, we have conducted several auditory studies in which attention was monitored in various ways. Each of them followed up on a classic result in the attention literature, typically because we considered those results important but inconclusive. Below, we describe these studies and discuss their implications for attention and memory, with reference to the issues depicted in Figs. 1 and 2.

COWAN, LICHTY, AND GROVE (1990): ACOUSTIC AND CATEGORICAL CODING OF ATTENDED AND IGNORED SPEECH

The main purpose of the research by Cowan et al. (1990) was to examine memory for acoustic and phonetic properties of ignored speech. This study adapted a technique previously used by Eriksen and Johnson (1964) to examine ignored tones. However, whereas Eriksen and Johnson relied on a single measure that indicated inattention to the tones, we used various methods of examining attention and explored the consequences of subtle differences in attentional allocation.

There were four main experiments in Cowan et al. (1990), each having several phases. In the first phase of an experiment, each subject donned headphones in a soundproof room and heard nine syllables in a male voice formed from combinations of the consonants [b], [d], and [g] (this last as in *go*) and the vowels [i] (as in *bee*), [I] (as in *bin*), and [E] (as in *bet*). In three of the experiments, the nine syllables were the consonant–vowel syllables [bi], [bI], [bE], [di], [dI], [dE], [gi], [gI], and [gE], whereas in one of the experiments, they were vowel–consonant syllables ([ib], [Ib], [Eb], and so on). Subjects listened to a tape recording in which the nine syllables occurred in a random order, separated by 1 to 13 s of silence. When the tape was stopped at random points, the subject was to identify the last syllable heard, which occurred about 1 s ago, by circling the correct syllable on a 3 × 3 matrix (with the items represented in ordinary English spelling, e.g., ‘‘bee,’’ ‘‘bih,’’ ‘‘beh,’’ and so on). This method allowed separate scoring of the acoustically simpler vowels and the acoustically more complex consonants, which can help to reveal the nature of the coding of information in memory. Performance levels in this phase of each experiment were very high, approximating 100% correct.

What happened next (in the main part of the experiment) changed from one experiment to the next. In Experiment 1, the subject was to ignore random sequences of the nine consonant–vowel syllables presented in the same irregular tempo as before, while silently reading a novel (*2001: A Space Odyssey*). However, when one of the room lights went off, which occurred only nine times in an hour, the subject was to put down the novel and identify the last syllable presented through the headphones. After that, the subject was to write a sentence reporting what was going on in the reading at the moment. This, along with knowledge that there would be a multiple-choice test on the reading material at the end of the session, served to discourage subjects from dividing attention between the reading and the auditory channel throughout the reading session. The silent retention interval between the last syllable and the time that the light was turned off (serving as a recall signal) was 1, 5, or 10 s.

The results of this experiment are shown for consonants and vowels separately in the top panel of Fig. 3. The isolated points show the excellent performance when the syllables were attended at the time of their presentation. The connected data lines show that performance for ignored speech was high with a 1-s test delay and declined dramatically with increases in delay, with more memory loss for consonants than for vowels. That pattern is as expected if the form of memory used was an acoustic form, inasmuch as the acoustic characteristics of the vowels were much simpler than those of the consonants.

An additional control experiment was conducted so that the possibility of attention-sharing between the reading and the speech sounds could be examined. In this control experiment, there were no sounds and the subjects attended fully to the reading. Their reading scores were equivalent to those of the subjects who did hear sounds and much better than subjects in another group who did not do the reading and only

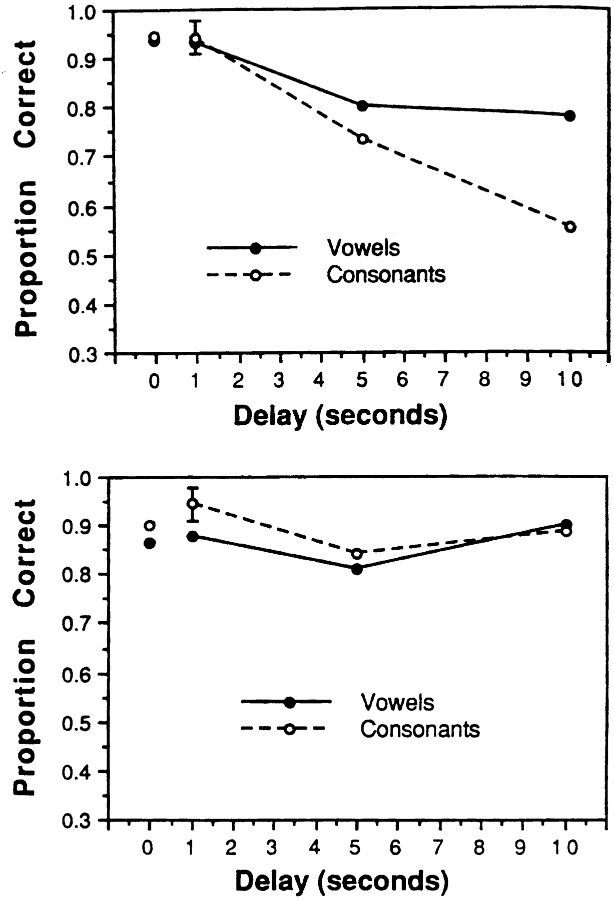

FIG. 3. Data from Cowan et al. (1990), from an experiment on memory for unattended spoken syllables (Experiment 1, top) and from an experiment in which attention was divided between a visual task and the spoken syllables (Experiment 3, bottom). *Note.* From ''Properties of memory for unattended spoken syllables,'' by N. Cowan, W. Lichty, and T. R. Grove, 1990, *Journal of Experimental Psychology: Learning Memory, and Cognition,* **16,** 258–269 (Fig. 1 from p. 260 and Fig. 3 from p. 263). Copyright © 1990 by the American Psychological Association. Reprinted with permission.

guessed at the multiple choice answers. These control experiments suggest that attention was focused for the most part on the reading, despite subjects' knowledge that there was an occasional test of memory for sounds.

In Experiment 2, the role of serial order of the phonemes within the syllables was examined in order to ensure that the consonant–vowel difference in performance was an acoustic effect, not simply a phoneme order effect. Specifically, the stimuli in this experiment were vowel–consonant syllables. There was little difference between consonant and vowel recall in this experiment, with a vowel advantage remaining though now nonsignificant. In this experiment, an advantage for the most recent phoneme in the syllable (the consonant) may have counteracted a vowel advantage. In the experiments with consonant–vowel stimuli, in contrast, these effects would have summated rather than counteracted one another. Thus, the vowel advantage in all of the experiments with unattended sounds can be viewed as based at least partly on a vowel advantage within sensory memory. A similar vowel advantage is not thought to occur in a more categorical form of memory, a point that is important for an understanding of Experiments 3 and 4, in which attention differentially enhanced consonant recall relative to the recall of consonants within unattended syllables.

Experiment 3 examined what would happen to memory if a little bit of attention was shifted to the auditory channel. In this experiment, the procedure was like Experiment 1 except that, while reading, the subject was to press a button whenever the syllable [dI] occurred in the auditory channel. Subjects detected the target syllable about 60% of the time. The final multiple choice test of the reading showed slightly lower comprehension than before and, unlike the other experiments, subjects found the dual task tedious. All of this indicated that attention was shared between the reading and the auditory detection task.

How did this sharing of attention affect the memory for the syllables? The memory results of this experiment are shown in the bottom panel of Fig. 3. The memory was not lost across 10 s as in Experiment 1.

One possible interpretation of this result is that attention to the auditory channel permitted a type of coding in Experiment 3 that was not carried out in the ignored speech situation of Experiment 1. Whereas acoustic memory is not as good for the acoustically complex initial consonants as it is for the acoustically simpler vowels, a categorical, abstract, phonemic memory should be equally good for consonant and vowel categories. Cowan et al. suggested that it is this phonemic memory that is formed only with the help of attention and that it lasts longer than the acoustic memory that is formed even in the absence of attention.

Further evidence regarding this interpretation came from Experiment 4, in which subjects whispered the reading into a microphone instead of reading silently. This procedure created only minimal acoustic interference with the sounds, but allowed an on-line measure of attention shifts, which could be recorded. It was assumed that a shift of attention away from the reading (and potentially toward the sounds) could result in a pause in the reading. Accordingly, trials in which there was no recorded reading either during a 1-s interval before the onset of the target sound or during a 1-s interval after that onset were separated from other trials. About 17% of the trials had such pauses.

It was not certain that pauses would reflect shifts in attention, and it was not certain that any shift in attention away from the reading task necessarily would indicate that the attention was reallocated to the auditory channel. However, an empirically observed change in auditory memory performance related to the pauses could be taken as reasonable evidence that at least some of the attention was, in fact, reallocated to the sounds on some trials.

Those trials with pauses in the reading did show less forgetting than the remaining trials. The result was clearest for consonants within trials that had a 1-s retention interval. For that retention interval, consonant performance was increased from 70% in trials with no evidence of attention shifting to 93% in trials with evidence of potential attention shifting. This result suggests once more that consonants are not well coded in short-term memory for syllables that are unattended, but that the consonants are coded much more adequately when a little bit of attention is free to assist in the coding.

The results of this study suggest that the perceptual analysis and short-term retention of speech are rather incomplete when there is little or no attention devoted to the perceptual process. It appears that acoustic, but not phonetic, coding is habitually carried out automatically. Even a quite subtle reallocation of attention to the sounds is enough to permit that phonetic coding to take place rather well, however.

The mapping of these results onto Fig. 1 is not quite clear. On one hand, phonemes are closely linked to their acoustic representations, so they might be considered physical features. On the other hand, we could consider phonetic coding to be semantic rather than physical in nature because the same phonetic categories are used to encode printed language, resulting in abstract categories with implications for word meaning. Therefore, we tentatively could interpret this study as showing that a basic type of fundamentally semantic coding is assisted by attention.

WOOD AND COWAN (1995A): ATTENTION AND MEMORY OF SPEECH EVENTS

This next study continued the examination of the role of attention in memory for speech, this time focusing on a longer-term form of memory. The study was a replication and extension of the original selective listening study by Cherry (1953). In that study, subjects ‘‘shadowed’’ or repeated speech presented to one ear and later were quizzed about events taking place in the other ear, which they had not been required to shadow. Cherry reported that people could not recall hearing a change in the topic of speech or even the language of speech presented in the nonselected ear. We were most interested, however, in a condition in which the nonselected stimuli changed from ordinary speech to backward speech. This change was detected by some of Cherry’s subjects but not others. It was interesting for us because we wished to learn of the difference in attentional allocation in subjects who noticed the change to backward speech and subjects who did not notice. Thus, we added an on-line measure of attention to Cherry’s (1953) backward speech condition.

Cherry (1953) was not very precise about the nature of his procedure or results. In our first two experiments, we worked on refining a method that would yield an intermediate level of memory for the backward speech. In the first experiment, the attended channel consisted of a passage from *The Grapes of Wrath* spoken in a female voice at 175 words per minute, presented to the right ear, and the channel to be ignored consisted of a passage from *2001: A Space Odyssey* spoken in the same voice, presented to the left ear. For separate groups of 24 subjects, the shadowing task lasted 1, 3, or 5 min before a change to backward speech occurred in the nonselected channel. A 30-s segment of backward speech was followed by 30 s more of forward speech, and then the subject was tested on memory for events that had taken place in the ignored channel.

The postshadowing questions we asked of subjects became increasingly specific. At first, the subject was to report whatever he or she could about the content of the nonselected channel. Then, the subject was asked if anything unusual had taken place in that channel and, if so, what. A subject was marked as having detected the backward speech if he or she agreed that something unusual had taken place and then went on to specify an appropriate unusual event (e.g., garbled speech or a foreign language, which could reasonably be a depiction of backward speech, as opposed to something like a simple change in loudness or a semantic characteristic, which could not be). Among subjects who shadowed for 1, 3, or 5 min before the change to backward speech, 16/24, 11/24, and 7/24 of them noticed the change. One interpretation of this finding is that the subjects' attention became fixed more firmly on the shadowing task as it continued.

The second experiment compared memory for backward speech in selective listening tasks with shadowing prose (this time in a male voice), shadowing unconnected words, and reading prose aloud as the primary tasks. The ignored channel was the same as before, in a female voice. Shadowing words or reading prose aloud resulted in nearly all subjects noticing the backward speech, as opposed to shadowing prose, which resulted in 50% of the subjects noticing. Control subjects who also had shadowed or read materials, but had not received backward speech, never reported anything that could be coded as hearing backward speech.

Experiment 3 applied what had been learned about the shadowing task to acquire an understanding of the relation between attention-shifting and memory. The stimuli basically were the same as in the prior experiment, but with certain modifications in the timing. In Condition A, there was no backward speech, whereas in Conditions B and C, backward speech occurred after 5 min of shadowing and lasted for 30 s. In Condition B, there were 3 min of forward speech following the backward speech segment and preceding the memory test, whereas in Condition C there was only 30 s of forward speech following the backward speech; then the memory test took place.

The number of subjects detecting the backward speech was 11/24 in Condition B and 9/24 in Condition C, whereas none of the control (Condition A) subjects reported anything similar. We looked at errors in shadowing as potential indications of shifts in attention. In all of the subjects, errors in shadowing were counted for the 30 s before the change to backward speech, the 30 s during backward speech, and the 30 s after it ended. These error scores were subdivided into 5-s bins.

Figure 4 shows the results, which were strikingly clear. The dashed lines reflect subjects in Groups B and C who, in the postshadowing questionnaire, gave evidence that they noticed the change to backward speech. Those subjects show a marked increase in shadowing errors from 15 s to 35 s after the onset of backward speech. No such increase in errors was observed in subjects in those same stimulus groups who did not go on to notice the backward speech or in control (Group A) subjects who had not received the backward speech.

This result shows that memory for a subtle acoustic/semantic change (the change to backward speech) can be observed only if the subject showed evidence of potential shifts of attention to the nonselected channel. The memory, when it is formed, seems relatively stable as it occurred similarly in both Conditions B and C, which differed in the duration of the retention interval for the memory of the backward speech.

These shifts of attention occurred only a short while after the onset of the change

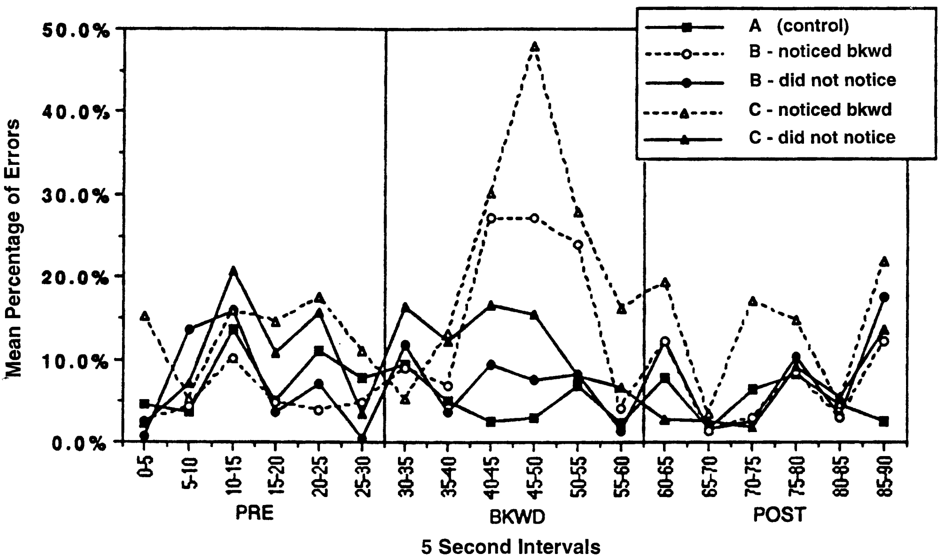

FIG. 4. Data on the percentage of errors in shadowing during 5-s intervals for the 30-s periods before, during, and after a change in the ignored channel from ordinary speech to backward speech. Only those subjects who later recalled hearing something unusual in the ignored channel that could reflect backward speech (dashed line) showed evidence of attention shifts during the backward speech. *Note.* From ''The cocktail party phenomenon revisited: Attention and memory in the classic selective listening procedure of Cherry, (1953),'' by N. Wood and N. Cowan, 1995, *Journal of Experimental Psychology: General,* **124,** 243–262 (Fig. 5 from p. 253). Copyright © 1995 by the American Psychological Association. Reprinted with permission.

to backward speech, not in the prechange period. Therefore, it appears that the change to backward speech automatically recruited attention in those subjects who went on to recall it, rather than the shift in attention being the result of intermittent monitoring of the nonselected channel. Some rather subtle aspects of the sound had to be processed automatically for this to occur, but the gradual nature of the attention shifts suggests that the processing was only partial and had to go on for some time (10–15 s) before the unusual nature of the backward speech was noticed.

In Experiment 4, memory for substantive aspects of ignored speech were examined. Subjects listened to one spoken channel and ignored another, and subjects then were given direct and indirect memory tests for the material in one channel. In one group, the subjects shadowed the attended channel and ignored the other, as in the previous experiment. The channel that they ignored was to become the target channel in the subsequent memory test. In a second group, however, subjects did not shadow either channel, but were told to listen to the channel that later would be used as the target for the memory tests.

In each trial within either memory test, a phrase from the target channel was paired with a phrase that had never been presented on either channel. Both phrases were presented acoustically, one at a time in either order, in the same voice that had been used for the target channel in selective listening. In the direct memory test, the task

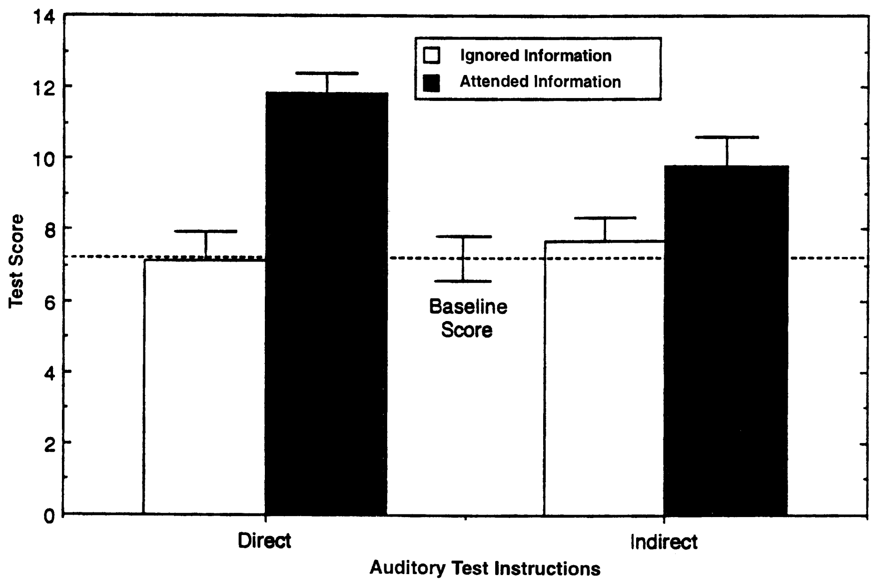

FIG. 5. Performance in direct and indirect tasks with auditory target stimuli reproduced from the ignored or the attended channel in selective listening. The baseline score comes from subjects who had not heard the target stimuli. *Note.* From ''The cocktail party phenomenon revisited: Attention and memory in the classic selective listening procedure of Cherry (1953),'' by N. Wood and N. Cowan, 1995, *Journal of Experimental Psychology: General,* **124,** 243–262 (Fig. 7 from p. 257). Copyright © 1995 by the American Psychological Association. Reprinted with permission.

was to indicate which phrase had been presented in the ignored channel, whereas in the indirect test, the task was to indicate which phrase was likely to come from a published story by a well-known author (when in fact both phrases in each pair did).

A final group of subjects completed these same memory tests without having carried out the selective listening task. This group's data provided a baseline for guessing in the memory tests.

The results are shown in Fig. 5. The subjects who ignored the target channel (white bars) did no better than the baseline control group in either type of test, whereas the subjects who attended to the target channels (black bars) did better than the baseline group on both types of test.

The results of this experiment show that only limited processing takes place without attention. Some subjects appear to process physical features automatically to an extent that allows them to notice the change to backward speech, which then recruits attention and permits recall of the backward speech. The higher-level semantic or lexical content of ignored speech is not retained, however, even to an extent that would show up on an indirect test. Thus, evidence of an increase in the familiarity of materials that are not fully attended, which has been obtained under divided attention conditions (e.g., Jacoby et al., 1993), may be more difficult to obtain for materials that are truly unattended at the time of their presentation.

WOOD AND COWAN (1995B): ATTENTION AND MEMORY OF ONE'S NAME PRESENTED IN AN IGNORED CHANNEL

The study described above (Wood & Cowan, 1995a) focused on a change from ordinary prose to backward speech, a gross change that involves distortions in the acoustics, a reversal of both intonation and phonemic order, and the cessation of semantic meaning. It served basically to establish the relation between on-line attention shifts and later memory for the event to which a shift did or did not occur. However, it does not fully address the question of whether complex semantic processing takes place in the absence of attention.

One of the most frequently cited studies suggesting that automatic semantic processing can take place is Moray's (1959) investigation, which showed that some subjects detected their own names when those were spoken in an ignored channel, as indicated by subjects' retrospective reports. However, Moray's famous study, much like that of Cherry (1953) discussed above, was conducted only in a rather preliminary nature. Textbook presentations notwithstanding, Moray actually examined 12 subjects and found that 4 of them recalled hearing their name in the ignored channel. We found no replications of this effect in the subsequent 40 years.

Wood and Cowan (1995b) endeavored to replicate this effect using a better method. Both the attended channel and the ignored channel consisted of monosyllabic words presented at a rate of 60 words per minute (WPM). This allowed the word presentations on the two channels to be synchronized, which minimized the chances that the subject's attention could be free when a word arrived in the channel to be ignored. These words were digitally recorded into a Macintosh computer, which allowed them to be synchronized. Subjects were asked to shadow the right channel and ignore the left one. Two monosyllabic words in the ignored channel, those occurring 4 and 5 min after the beginning of shadowing, were replaced with names.

In Moray's (1959) experiment, an acoustical click or pop where the name was dubbed in could have attracted the subject's attention to the name. In our experiment, however, digital recording allowed us to reduce that problem. More importantly, our subjects were run in yoked pairs that heard the same acoustic stimuli, including the first names of both of these subjects, one after 4 min and one after 5 min of shadowing. (Only subjects with monosyllabic names were included in the study.) The critical measure was how often subjects recalled hearing their own names in comparison to how often they recalled hearing the names of the yoked control subject.

After 5.5 min of shadowing, the sounds ended. Subjects had been told that when the sounds ended, they were to turn a questionnaire packet right side up and complete each page in sequential order. There was only one question per page in order to prevent subjects from looking ahead. Subjects were asked (1) to report any of the ignored channel content they could recall; (2) to note if anything unusual was heard therein; (3) to indicate if any names were presented therein; and (4) to indicate if they had heard their own name. Finally, it asked subjects to estimate how many times their attention had wandered and to indicate why this may have occurred.

Nine of 26 subjects who went through this procedure recalled hearing their own name (5 whose name was presented at 4 min and 4 whose name was presented at 5

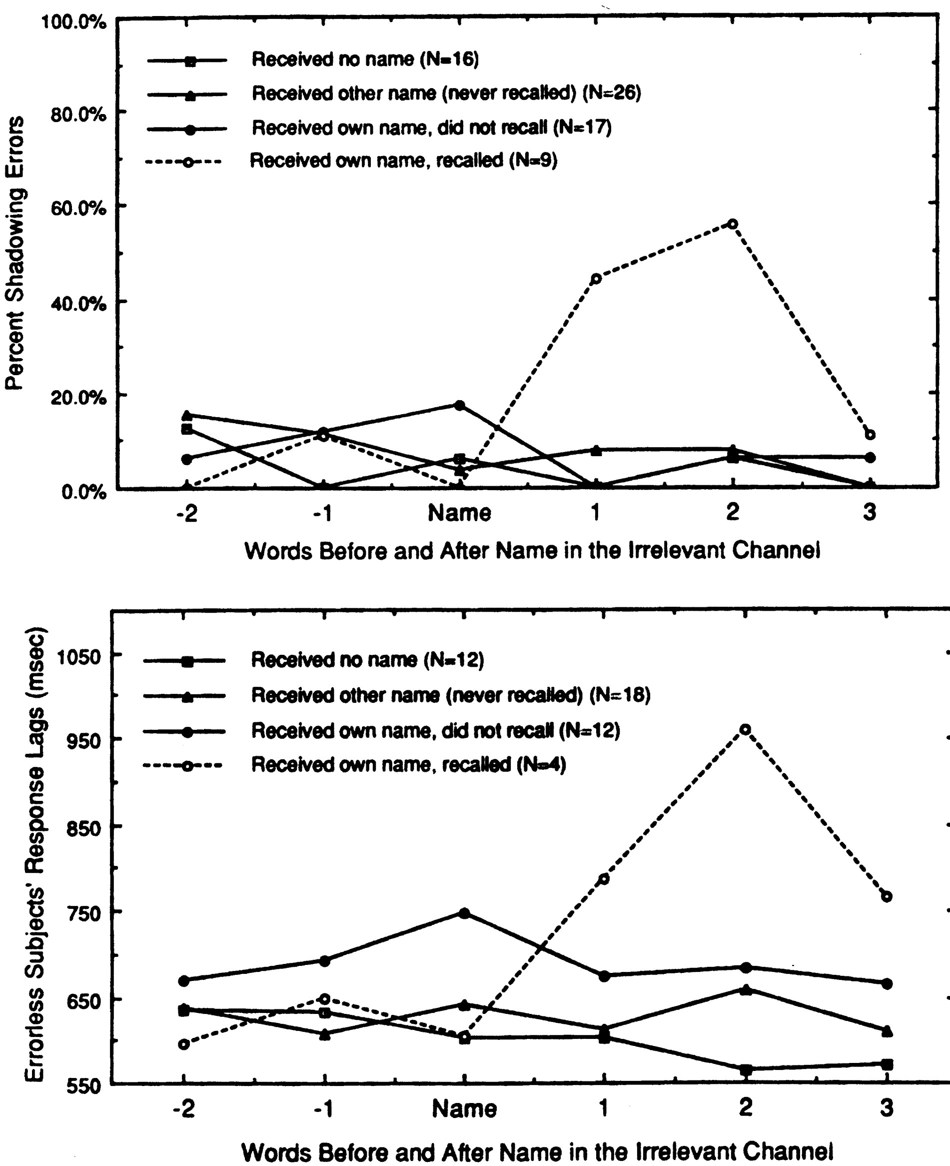

FIG. 6. Errors (top) and pauses for errorless subjects (bottom) within a shadowing response just before, during, or after a spoken name. Only subjects who later recalled hearing their name in the ignored channel (dashed line) showed evidence of attention shifts shortly after their name. *Note.* From ''The cocktail party phenomenon revisited: How frequent are attention shifts to one's name in an irrelevant auditory channel?,'' by N. Wood and N. Cowan, 1995, *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **21,** 255–260 (Fig. 1 from p. 258 and Fig. 2 from p. 259). Copyright © 1995 by the American Psychological Association. Reprinted with permission.

min). This is a 34.6% hit rate that is almost identical to the 33% rate that Moray (1959) observed for 12 subjects. In contrast, no subject recalled hearing the name of a yoked control subject. Eight other subjects received no names, and none of them recalled hearing any.

Regarding the other questions, 14.7% recalled hearing a specific word in the ignored channel, and 38.2% volunteered that the channel was presented in a male voice. There was no indication that any specific names were recalled more frequently than other names. Subjects estimated that they shifted attention an average of 3.7 times, typically because they ''lost their concentration,'' ''were distracted,'' or ''were curious about the other channel.'' Subjects who did versus those did not recall their name did not noticeably differ in any of these other responses.

Unlike Moray (1959), we recorded the shadowing responses and analyzed them for possible attention shifts immediately before or after the presentation of a name. The top panel of Fig. 6 shows errors in shadowing. It is clear that the subjects who later recalled hearing their name showed a marked increase in the percentage of errors in shadowing just following the presentation of their own name (dashed line). In contrast, there was no such increase in errors for subjects who received no name, for subjects shadowing at the point where the yoked control name was presented, or for subjects who did not recall hearing their own name, when shadowing at the point where their own name was presented (solid lines).

The coupling of attention and memory was even stronger than that, however. There were four subjects who recalled hearing their own names but still did not make errors in shadowing after their names. We examined these subjects' shadowing responses in more detail by using the computer to measure the time that elapsed from the presentation of each word to the beginning of the repetition of that word within the shadowing response. The four subjects who recalled hearing their names but made no errors surrounding their names showed a marked increase in response lags, as shown in the bottom panel of Fig. 6 (dashed line). In contrast, other errorless subjects showed no such increase in response lags following the name.

From these results it appears that at least some semantic analysis can take place without attention, though it is recalled only if attention is recruited to that stimulus. An alternative explanation would be that attention shifted before the name was presented, but the on-line measures of attention shifts provide no evidence that that happened. The amount of semantic analysis is probably limited, however, or else many more subjects would have shifted attention to their own names.

WOOD, STADLER, AND COWAN (IN PRESS): ATTENTION AND IMPLICIT MEMORY OF WORD SEQUENCES

The results of Wood and Cowan (1995a,b) suggest that in the absence of attentive processing, items are not processed in a manner that allows them to be recalled even 1 min later. Indeed, the results of Cowan et al. (1990) showed that memory for unattended items declines rapidly across a 10-s period, presumably as a sensory representation fades. As we mentioned above, we can think of only one study in which it is claimed that unattended information is remembered, and that is Eich's (1984) study. In this study, recall that subjects who had heard critical word pairs like ''taxi–fare'' in an ignored channel later used the spelling of the homophonic word that matched the presented item (e.g., ''fare'' rather than ''fair'') more often than did control subjects who had not heard that particular homophonic word. This spelling difference was observed even though subjects did not remember having heard the critical word, according to the results of a recognition test requiring a ''new'' (not previously presented in the ignored channel) versus ''old'' (previously presented) decision for each word.

Wood et al. (in press) were worried, though, that the control of attention was inadequate in Eich's (1984) study. The attended prose passage that he had subjects shadow was presented at 85 WPM, much slower than the usual rate of shadowing in selective listening studies of this nature (typically, about 120–150 WPM). This slow rate could have allowed attention to shift to the other channel between words in the shadowing response. Also, the channel to be ignored was presented at a rate of 1 word per second within a pair, with 2 s of silence between pairs. The long pauses between word pairs could have resulted in orienting responses to the onset of each pair (Cowan, 1988, 1995).

There also were some questions about Eich's (1984) counterbalancing scheme, which was incomplete. Therefore, Eich's procedure was repeated by Wood et al. (in press), but with improved counterbalancing and with four groups of subjects: (1) a group that basically replicated Eich's method; (2) a group in which the rate of presentation of the prose passage in the attended channel was 170 WPM, double the rate Eich used; (3) a group in which the rate of the attended channel was 85 WPM like Eich, but in which the rate of the channel to be ignored was double the rate Eich used (with 1.2–1.3 s per word pair complemented by 700–800 ms of silence between pairs, to produce a steady rate of 2 s per word pair); and (4) a group in which the double rates were used for both the attended and the ignored channels.

There was little effect of varying the speed of the ignored channel. However, there was an effect of varying the speed of the attended channel. In subjects who repeated a slow attended channel, as in Eich (1984), the target spelling of the homophone was chosen 7% more often for homophonic words that had been presented in the ignored channel than for control homophonic words (with a sensitivity d' of 0.22). In the subjects who repeated an attended channel twice that speed, however, the mean difference was −2%, not different from chance (with $d' = -0.06$). Thus, the memory effect disappeared entirely when attention was controlled adequately.

This study's results suggest that there may be no long-term memory for unattended spoken word pairs. It remains possible that there is memory for individual words presented in an unattended channel, as measured perhaps by semantic priming.

SUMMARY AND CONCLUSIONS

The story to be told is a relatively straightforward one, even if incomplete at this time. The first part of it pertains to Fig. 1. The question is whether semantic analysis takes place for stimuli that are not attended and, if it does, whether the analysis is complete (as shown by the shorter solid-line arrow) or partial (as shown by the short, dashed-line arrow). The answer appears to be that a partial semantic analysis takes place. The results of Wood and Cowan (1995a,b) showing that some people noticed a change to backward speech or noticed their own name in a channel to be ignored, with no evidence of attention shifts to that channel before the critical event (Fig. 4 and 6), suggest that some analysis does take place. However, the finding that many subjects did not notice these events (i.e., showed no attention shifting according to the on-line measure and did not recall these events later on) suggests that the analysis is only partial. Moreover, the finding by Cowan et al. (1990, Experiment 4) that there was a marked difference between vowel and consonant recall with inattention to the sounds, but that it was nearly eliminated when there was some evidence of attention-shifting, suggests that an abstract form of coding (phonemic rather than acoustic coding) depends on attention.

The second part of the story pertains to Fig. 2. The question here is whether the partly analyzed semantic information in an unattended channel can support long-term memory for this information. That remains possible, but we found no evidence of it. Cowan et al. (1990, Experiment 1) found a rapid decay of memory for unattended spoken syllables across a 10-s retention interval (Fig. 3, top), whereas Cowan et al. (1990, Experiment 3) found that dividing attention between the visual and the auditory channels was sufficient to prevent this decay across 10 s (Fig. 3, bottom). Wood and Cowan (1995a,b) found that memory of backward speech or the subject's name occurred in those who showed evidence of possible attention-shifting, but not in those who showed no such evidence. This was a rather clean empirical distinction (Figs. 4 and 6). Wood and Cowan (1995a) also found no evidence of memory for the content of ignored speech channels (Fig. 5). Finally, Wood et al. (in press) found no evidence of indirect memory for word pairs presented in an ignored channel when attention was adequately controlled.

It remains unclear if unattended speech could cause semantic priming, as some investigators have suggested (e.g., see Lewis, 1970; MacKay, 1973). If so, it would indicate that some semantic processing has, in fact, taken place without attention. However, Holender (1986) discussed the great difficulty that one might face in making this case because it could be argued that attention may have shifted to the channel that was to be ignored. For example, Treisman et al. (1974) obtained evidence that the effect observed by Lewis (1970) occurs only in the early trials, before attention is well focused on the target channel. The present methods for examining attention-shifting might be applied to this type of question in future studies.

Banks, Roberts, and Ciranni (1995) presented words in a male voice and a female voice simultaneously, the task being to repeat the female voice and ignore the male voice. Sometimes the male voice spoke the same word on Trial N-1 that the female voice would speak on a critical Trial N, and the result was negative priming. With several trials intervening between the male-voice prime and the female-voice, same-word target, the effect changed to positive priming. However, the words were presented at a slow rate of one simultaneous pair every 1.2 s, and it seems possible that some attention could have been devoted to processing the sensory memory of the male voice during the interstimulus interval (even if it was not enough attention to allow awareness of the prime–target relationship).

Finally, a brief discussion about theoretical modeling of attention and memory is in order. The models shown in Figs. 1 and 2 serve the purpose of explaining the logically necessary steps of information processing, but they do not address the under-

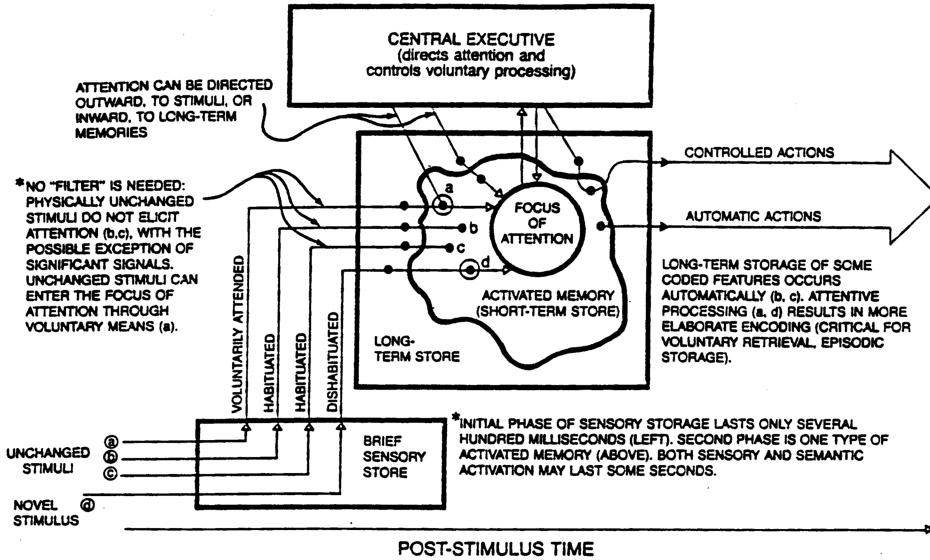

FIG. 7. A basic model of information processing. *Note.* From ''Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system,'' 1988, *Psychological Bulletin,* **104,** 163–191. Copyright © 1988 *by the American Psychological Association.* Reprinted with permission.

lying mechanisms. The information flow diagrams like those of Broadbent (1958) and Atkinson and Shiffrin (1968) did address underlying mechanisms (e.g., with the inclusion of an attentional filter), but there was no easy way to modify those flow diagrams to explain automatic semantic processing. For that kind of processing to occur, the incoming sensory information has to activate information in long-term memory directly, reaching a limited-capacity processor only if attention is recruited to the stimulus. Moreover, only in that case would a new episodic memory trace be laid down in long-term memory, so the processing flow would be somewhat circular between long- and short-term memory stores.

According to Treisman's (1964) attenuation theory, in which unattended information was said to be processed only incompletely, activation would take place for automatically processed information that made contact with information in memory having a relatively low threshold (such as one's own name). Treisman's model was not translated into a detailed diagrammatic representation including the limited-capacity process, and the nature of the attenuation process was left relatively unspecified.

Cowan (1988, 1995) described a processing model that is similar in spirit to the attenuation model, except with a more detailed description of the attenuating device and certain other fundamental processes. This model is shown in Fig. 7. Incoming information activates some features in long-term memory automatically, but they are predominantly the physical features. Semantic features are only partly activated. Either a change in the physical features of the stimulus stream or a semantic element activating a particularly significant item in long-term memory will cause an attentional orienting response (Sokolov, 1963) that recruits attention to that stimulus channel. These orienting responses, which are basically not under the subject's voluntary control, compete with (or summate with) the voluntary, effortful control of attention mediated by what has been called central executive processes.

Any items that become attended receive a more complete semantic analysis, and any perceptual analysis that has been completed becomes part of an ongoing neural model of the stimulus array that can be compared to the incoming stimulation, leading to an orienting response if it is found to differ from the model. Of course, only those aspects of the incoming stimulation that are processed can be compared to the neural model. Thus, even if semantic aspects of attended stimuli have contributed to the neural model, an unattended stimulus differing from the neural model in a semantic manner may not be noticed, given that its semantic qualities are not very well analyzed.

The issues about the completeness of semantic processing with and without attention, and the relation between attention and memory, have been examined within a supporting set of assumptions. These assumptions include the assumption that attention is a unitary construct in normal humans, not a specialized set of separate resources; that attention and awareness co-occur in normal humans; and that awareness and attention are needed for successful performance in direct memory tasks. These assumptions may break down in some cases of neurological impairment, and Cowan (1995) provides a lengthy discussion of the assumptions and evidence behind it. In the present article, the intent has been to show that the issue of the role of attention in perceptual processing can be separated from the issue of the relation between memory and attention, using measures of the potential allocation of attention along with retrospective reports and both direct and indirect memory tests. Our hope is that this summary helps stimulate additional research of a similar nature, and especially research with auditory stimuli, which in many ways are well suited to the issues.

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