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Probing the Automatic and Attentional Effects of Priming

by

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Abstract

The major consensus within the study of attention seems to be that our capacity to attend consciously is limited. Many studies have exposed our inability to handle simultaneous information from two task at once. Despite these constraints, some studies have shown that under certain conditions two tasks could be performed simultaneously (e.g., Shiffrin & Schneider, 1977) free of attentional capacity and independently of intentions (Posner, 1978). The term "automatic" has been used to describe the underlying processes that presumably mediate the absence of dual-task interference and unavoidable processes. Among these works, priming studies (e.g., Neely, 1977; Posner & Snyder, 1975; Warren, 1977) provide evidence of automatic priming of of stimulus pathways outside the conscious awareness of the subjects. In the present investigation subjects in two experiments performed a primed letter-matching task and an auditory discrimination task both separately and concurrently. Individual mean RTs and measures of accuracy were analyzed for costs and benefits. In both experiments, when letter matching was performed alone, cost-benefit analysis as a function of ISI revealed that costs began to accrue earlier than benefits, a reversal to what had been predicted by earlier studies of priming. However, when subjects performed the two tasks together it was found that costs in letter matching were removed and yet the benefits of priming were unaffected by the presence of the secondary attention demanding task suggesting that the benefits of priming were indeed automatic. In the second experiment an attempt was made to prime the two tasks simultaneously for if priming is automatic then two tasks could presumably be primed together in parallel as effectively as when each was primed alone. To test this a dual-priming method was introduced. The results demonstrated that subjects in a dual-task situation can process two primes simultaneously affecting each task in parallel rather serially. The relevance of these results to current theoretical accounts of human attention and automaticity is discussed.

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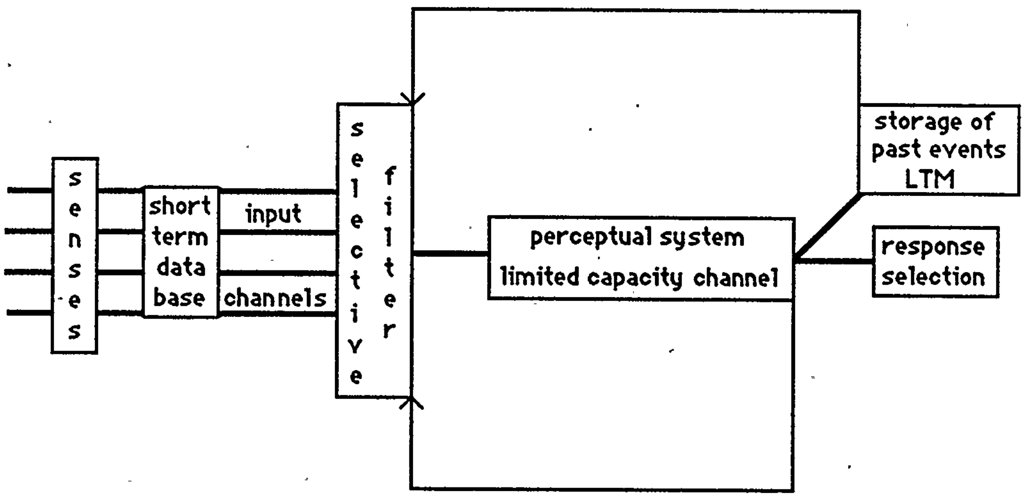
Introduction

A problem in psychology concerns the division of attention among competing sources of information. Early studies into this issue concentrated on observations of the ability of people to perform simultaneous tasks. Some studies found that people often performed several activities in parallel, such as driving a car and talking, apparently dividing attention between the two activities (Kahneman, 1973). Other studies, however, found that when subjects were presented with simultaneous messages only one of them was perceived, while the other was ignored completely (Broadbent, 1958). Similarly, if people were required to react to a second signal during the processing of a prior signal, responses to each source were made in succession rather than simultaneously (Welford, 1952). The evidence of delays and exclusions of information from a secondary source during the processing of a primary task suggested the idea of a bottleneck, a stage of central processing of limited capacity that could only transform one stimulus at a time. Attention theorists have sought to discover the location of this bottleneck in order to discover what stage of processing limits our ability to perceive, decide or respond to more than one input at a time. The research reviewed in this thesis looks at the issue of what limits our ability to process information.

Welford (1952, 1980) provided several lines of evidence suggesting that the limit in processing information was due to the fixed capacity of attention. He based his ideas on the finding that when subjects were presented with two signals in succession, each requiring a separate response, the response to the second one was delayed relative to when it was performed alone. Welford hypothesized that if two signals appear in succession the second must be held in storage until the central processor is finished with the first. Since central processing time was not observable directly, Welford developed the equation, RT2 = RT2n + RT1 - ISI, to estimate the delay in processing of the second signal. In this equation, RT1 symbolizes the RT to the first signal, which is an estimate of its central processing time and ISI is the inter-stimulus interval between the two signals. The RT to the second signal, RT2, is equal the central processing time of the first signal, minus ISI, plus the time to react to the second signal when it is presented alone (RT2n). This single-channel hypothesis predicts that any factor tending to lengthen or shorten RT1 should lengthen or shorten RT2 by the same amount. Results of this type imply that at some stage in the transformation of a signal to response there is a single-channel mechanism that can only process one input at a time and therefore attention could not be divided between two competing signals (Welford, 1980).

The first person to offer a complete attentional theory was Donald Broadbent (1958). His model mapped the passage of information through the mind much like a communication engineer or computer scientist may have. A simple schematic illustration of his model is given in Figure 1. As the diagram

Figure 1. Broadbent's model of the human information processing system.



shows, energy makes contact with the senses and in turn is passed to a 'short term store'. This memory store, or "icon" as it has been called, receives all the input from the senses. These data are then divided up into their most rudimentary physical features and held at the icon for only a short period of time awaiting selection. At this early stage of processing the nervous system can process all information simultaneously and in parallel. Behind the short term sensory store is a single-channel. This single-channel cannot process more than a limited amount of information during a given time. In theory, this limited capacity channel can process more than one message at one time as long as the combined stimulus information does not exceed the channel capacity (Broadbent, 1958). To prevent the single-channel from being overloaded, a selective filter that precedes the limited capacity channel selects information from the many channels at the short term sensory store. Selection is based on common features derived from sensory inputs by 'preattentive' analysis that distinguishes the salient physical properties that define a channel. This preattentive process distinguishes the 'relevant' from the irrelevant. That is, when several simultaneous inputs occur, a person may select those events possessing a particular physical feature (such as a particular location in space) enabling the person to cope with one event at the cost of knowing little about the remaining events (Broadbent, 1982). Filtering was conceived by Broadbent as a strategy that allowed adequate performance when a person was in risk of perceptual overload. Only that information that has been passed through the filter to the single-channel can affect the person's response or be sent to long-term memory (LTM).

The distinctive tenet of Broadbent's model is that the selective filter can be employed early in the flow of information processing whenever a person is confronted with an overwhelming amount of information. In an effort to adapt and avoid incoherence, the person must focus attention on one stimulus channel and filter out the surrounding noise. Those data arriving on other channels are filtered and are thus precluded from perceptual analysis. It follows from such a model that attention cannot be divided between two sources of information (Kahneman, 1973) because the single capacity channel allows no parallel processing past the short term sensory store. Any apparent evidence of divided attention between simultaneous messages is a result of our ability to have switched to alternative channels about every 300 to 500 ms (Broadbent, 1958). Taxing the system with two or more simultaneous stimuli implies that each stimulus source requires a fixed amount of time to be attended to before a second may be processed. Given that only one signal can be processed at a time, serial processing is therefore a necessary function in order to avoid perceptual overload. Research that followed in the next decade attempted to find results that could not be incorporated by Broadbent's early selection theory.

One of the first people to reject the idea of a static filter was Anne Treisman (1964). She found that information rejected on the irrelevant channel can make contact with LTM allowing the analysis of the meaning of the unattended message. Her study used French-English bilinguals in a dichotic-listening task. Subjects were employed to listen and repeat (shadow) a passage played in one ear while ignoring the message played in the other ear. The message in the unattended ear was the same passage but presented in the alternative language. The presentation time between the two messages was delayed. When the interval between the two messages was shortened, shadowing was disrupted and the subjects could no longer focus their attention on just one channel. Since the two messages were the same story it would appear that the semantic content of the unattended passage was being followed, at least when the two were presented almost simultaneously. Treisman concluded that the subjects' awareness that the messages were the same was based upon simultaneous semantic analysis of both messages rather than upon a comparison of the physical aspects of the messages.

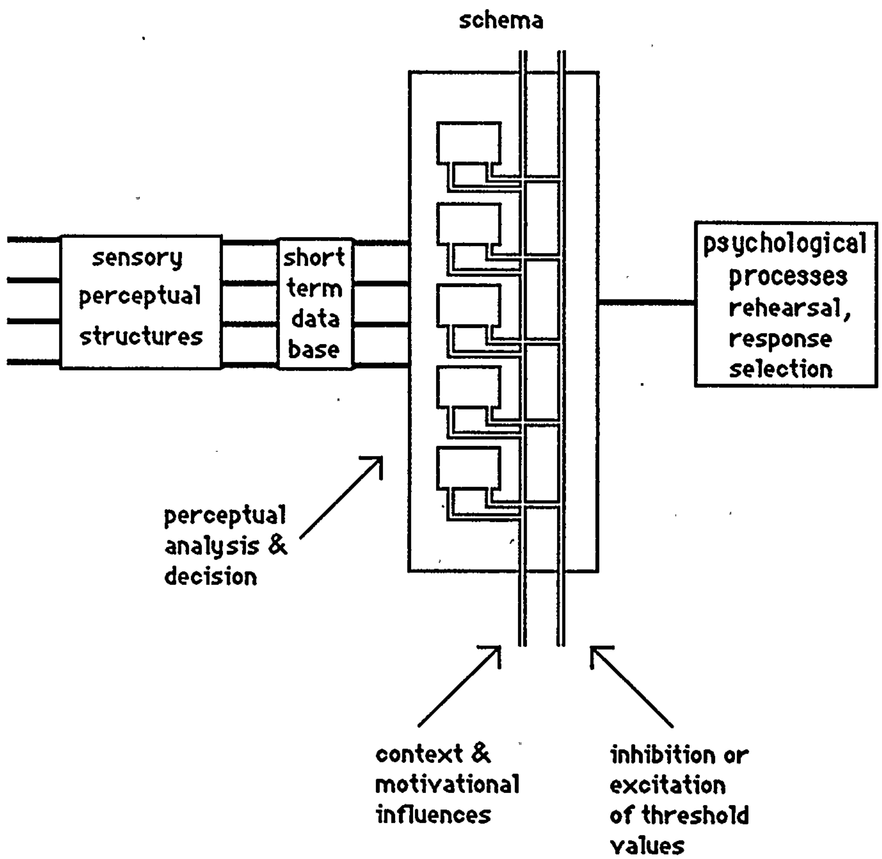
Early versus Late Selection

Treisman's study, and many others like her's (e.g., Lewis,1970; MacKay,1978) posed a problem for classical single-channel theory of early selection. Their results suggested that an unattended signal can attain semantic analysis in parallel with the transformation of another signal and therefore selection of unattended information did not necessarily occur early in the processing of information. In early selection models (e.g., Broadbent, 1982; Welford, 1980) unattended information was purported not to be processed past the filter. According to these serial or early selection models, in order for a signal to reach LTM a signal must pass through the single-channel. However, studies like Treisman's that showed that the meaning of the unattended signal can be extracted raised questions as to the idea of early selection, as it appeared that more than one signal had parallel access to signal related information stored in LTM (Keele & Neill, 1978). The question behind the controversy was at what level of processing was information destined for the single-channel selected, early, before it made contact with LTM or later, after semantic analysis?

One answer is based on an attenuation device, rather than a filter, that allows a certain degree of parallel processing (Treisman, 1969). This device still limits access early, between sensory and semantic processes, but it merely "tunes down" the unattended channel rather than filtering it out completely. When the context of the task creates considerable preview or anticipation, certain memorial representations (logogens) are sensitized or primed sufficiently to permit the leakage of some of the features of the unattended message. The break-through of some of the unattended information then gives the appearance that some parallel processing is taking place. However, Treisman was quick to point out that if a few features of a related message or highly probable message in the supposedly unattended channel are allowed to break through it does not mean, necessarily, that all stimuli that reach the senses are processed fully and selection is late.

Others, however, have proposed that all processes affected by central limitations of the single-channel occur relatively late after LTM receives all input from the senses (e.g., Deutsch & Deutsch, 1963; Keele, 1973; Norman, 1968). Accounts concerned with late selection also emphasized an early parallel system and a second limited system. However, in this first system all signals can contact their appropriate logogens, uncensored by any filter or attenuation device. As depicted in Figure 2, selection of stimuli for single-channel processing (e.g., rehearsal) occurs after parallel pattern recognition. Therefore, all impinging signals are allowed to make contact with information in LTM (i.e., encoded), unselectively and without capacity limitations. The function of attention, according to early-selection theorists, is to allow the limited resources of attention to select the most relevant information for perceptual processing. According to the second theory, if selection is late, occurring after perceptual encoding, attention is only limited when more than one response has to be initiated. The function of attention, therefore, is to select the appropriate response.

Figure 2. A rendition of a late selection model of human information processing.*



* adapted from Norman and Shallice, 1985

Automaticity

In the decade of the 1970's the study of attention moved to the exploration of automatic processes rather than attentional limits (Kahneman & Treisman, 1984). These studies focus on processes that supposedly do not use any of the limited capacity of the single-channel. Though these studies have offered different definitions of automaticity, most authors agree that a mental process is automatic if it occurs without intention, without conscious awareness and without producing interference with other ongoing mental activities, whereas attentional operations are seen as intentional, slow and serial in nature (LaBerge,1981; Logan, 1979; Posner, 1978; Shiffrin & Schneider, 1977). Given these defining conditions, each study tries to develop procedures that can distinguish whether or not a particular process is being accomplished automatically or in a conscious manner. Evidence of automatic processing has come from studies of Stroop, visual search, probing and priming.

Stroop

The Stroop task is considered a classic example of unintentionally processing unattended information (Keele, 1973; Posner & Snyder, 1975). In this task, people name the color of the ink that a word is printed in. Responses are delayed when the word is itself a name of a different color. It is assumed that each word, printed in colored ink, activates its node or logogen in LTM automatically. Reading and color naming occur in parallel with no interference until the form of the word and color naming elicit incompatible responses. For example, if a color word (e.g., BLUE) elicits a different response than the color of the ink (e.g., red) then interference with the color naming response will occur. Because it is the close semantic association between the form of the word and the ink color that seems to produce the delay, interference is considered due to response competition rather than perceptual competition. This would suggest that the two sources of information in a Stroop stimulus, the color and the form of the word, can be processed simultaneously automatically in spite of any intentions by the subject to ignore the word.

Visual Search

In a series of experiments, Shiffrin and Schneider (1977) reported that people could process simultaneous sources of information as well as they could with only one source. They stated that with considerable practice and consistency each source of information eventually makes automatic contact with LTM without the conscious control of the subject. Their ideas were based on the observation that under certain conditions, the RT to a single target no longer increased with an increase in the number of items in a visual field.

Each of their experiments used the same basic procedure. A trial consisted of the presentation of 20 frames in immediate succession. In each frame four elements were presented simultaneously. The elements were characters (digits or consonants) or dot patterns. At the beginning of each trial, the subject was given a memory set of one or several characters. The subject was required to detect a memory set item that appeared in the subsequent frames. A memory set item that appeared in a frame was called a target and other items were distractors. The experimenters manipulated the number of characters in each frame and the number of characters in the memory set. The subjects were trained using two different procedures. The method varied the relation between memory set items and distractors. In the consistent mapping procedure in all the trials the memory set items were never distractors. In addition, memory-set items were from one category (e.g., digits) and distractors were from the other (e.g., consonants). In the varied mapping procedure memory-set items and distractors were intermixed across trials and were from the same category.

In the varied mapping condition, RT increased by a constant amount every time that either a memory set item or frame item was added. When the targets and distractors were consistent from trial to trial the speed of the search did not depend on the number of items presented. Therefore, the authors concluded that with consistent mapping and vast amounts of practice all items can be processed in parallel, automatically without interference and without conscious control.

Probing

It has been stated that measures of dual-task interference provided evidence about the capacity of the central processor (Ells, 1973; Posner, 1978). The demands that a primary task place on the single-channel are inferred by the amount of delay to the second task . Interference is measured as a difference between the performance of the second task (the probe) when it is embedded within certain locations of the processing of the primary task and when it is presented alone (McLean & Shulman, 1978). If a mental process does not interfere with the probe it is considered automatic. Specifically, if a probe is not delayed in a dual-task situation, relative to when this probe was performed alone then the processing of a primary task is automatic because it does not require attention (Posner, 1978).

Using the probing technique Posner and Boies (1971) provided support for the idea that encoding does not require attentional capacity. The primary task was letter-matching. A warning signal was presented followed by a letter and 1000 ms later another letter. With one hand subjects indicated whether the two letters were the SAME or DIFFERENT. Using the other hand they responded to a burst of white noise (the probe) which was presented on half of the trials. Reaction times to the probes that were presented 50, 150, and 300 ms after the onset of the first letter were equal to the probe latencies when the probe was presented alone in the inter-trial interval (ITI). During the first 300 ms following the first letter, it was assumed that the subject was encoding the letter. Since there was no evidence of interference it was concluded that encoding can proceed in parallel with the processing of the probe.

Priming

In a typical priming paradigm two signals are presented in close succession. When the information from the first signal (prime) is related to the second signal (target), responses to the target are faster and more accurate relative to trials where the first and second signal are not related. This measure of facilitation or priming has been found when the two signals are semantically (e.g., Hines, Czerwinski, Sawyer & Dwyer, 1986), phonologically, (e.g., Slowiaczek, Nusbaum & Pisoni, 1987) or physically related (e.g., Flowers & Wilcox, 1982). Several methods have been used to investigate the processes that may mediate this priming effect.

In a cost-benefit method, developed by Posner and Snyder (1975), a visual prime preceded a pair of letters. On half of the trials the prime was a neutral plus sign, on the other half the prime was a letter. Subjects were instructed to treat the prime as a warning cue only and respond SAME when the pair of letters in the target were identical and DIFFERENT if they were not. Facilitation (benefit) is calculated by subtracting mean latencies to targets preceded by a matching letter pair (A/AA) from targets preceded by a neutral prime (+/AA). Inhibition (cost) is calculated as a difference in mean RT between trials where the prime letter does not match the target (B/AA) and neutral trials).

For their first experiment, three separate groups were run, with the probability that a letter prime matched the target being varied. On SAME trials where a letter prime was presented (1/4 of all trials), the probability that a prime would match the target (e.g., A/AA) was either 80%, 50% or 20%. When a prime could be used to validly predicted targets 80% of the time, calculation of cost and benefit revealed that SAME responses benefited in RT and accuracy but when the prime invalidly predicted the target 20% of the time (e.g.,A/BB), RTs and errors were increased. However, when the prime was uninformative, not providing any valid information about the upcoming target, matching the target 50% or only 20% of the time, benefits but no costs were found. The conclusion was that subjects do not attend to an uninformative prime since it does not contain any information about the identity of the subsequent target and therefore costs only occur when subjects are induced to attend to an informative prime.

In the second experiment of Posner and Snyder's, the time between the prime and the letter pair (ISI) was varied from 0 to 500 ms. Presenting an informative prime over five ISIs resulted in separate cost-benefit functions. Benefits began to accrue at 50 ms and reached asymptote thereafter. Costs appeared later at the 300 ms interval. The authors concluded that two separate processing mechanisms must be responsible for producing the different time course of cost and benefit.

Theory

Posner and Snyder (1975) used their study along with related evidence to provide an explanation of priming based on automatic processing and limited capacity attention. Theoretically, when a signal is first presented it automatically activates its psychological pathway. Psychological pathways are internal codes (e.g., logogens) representing the physical form, name and semantic content associated with a signal. As a signal is encoded, activation spreads to related pathways speeding the processing of any related signal that follows. Many pathways can be activated at the same time, in parallel with processes requiring attention. The parallel activation of automatic processing is different from the serial constraints imposed by active attention. Attention can intervene in the flow of information prior to the onset of a signal and activate its pathway in anticipation of a particular event or signal. If attention has sufficient time to be directed to a particular code, prior to the appearance of an expected signal, RT will benefit, but if an unexpected signal is presented, attention must switch from the activated pathway, to which it was committed, to a new pathway activated by the unanticipated target thereby causing a delay or cost in performance. Attending to a particular pathway does not prevent automatic processes from occurring, but it does reduce the availability of attention. Costs in RTs can therefore be used to indicate the reduced available capacity of attention (Posner, 1978).

Posner and Snyder (1975) use their results of letter-matching in particular to argue that benefits can result from both automatic and attentional factors whereas costs do not accrue automatically but are solely the product of selective attention. The results of the condition, where the subjects are not given an incentive to attend to the prime, revealed a facilitating effect even when the prime only matched a pair of identical letters on 20% of the trials with no inhibition when the prime mismatched the target. It appears that when the subject does not attend to the prime the prime still automatically activates its pathway, benefiting signals that follow. However, when the subjects are given an informative prime, both inhibition and facilitation occur but costs are late to appear. Benefits begin earlier because they are automatic. Later processing of the informative prime resulted in enhanced benefits and costs when the prime letter was different than the target. As long as processing is automatic then there will be no costs. Interference or delays appear only when the subject has an informative prime and only then after enough time has elapsed for the processes of encoding and selection for attention to have been completed.

A similar time course for cost and benefit to that of Posner and Snyder's was found in an experiment that required subjects to decide if a primed letter string was a word or not (Neely, 1977). Preceding the targets was either a neutral prime (XXX) or the name of a category in which a semantically unrelated target was highly likely to follow. For example, when the prime BUILDING was presented subjects were informed that there was a 67% chance that the name of a body part would follow (e.g., ARM). However, 33% of the targets were preceded with a prime that was semantically related (e.g., BUILDING/DOOR). In the condition where the prime correctly predicted the target (i.e.,67%) there was no semantic association between the target and the prime thus preventing any automatic facilitation. It was hypothesized, based on Posner and Snyder's (1975) two process model of priming, that any benefit in decision time should only occur if enough time has elapsed since the presentation of the prime to allow a person to expect consciously a particular word. Cost should appear at the same onset as benefits and only when an unexpected word appears (e.g., DOOR). However, if the interval between the prime and the target is too short to permit the person to attend to the prime, the prime will still automatically activate its LTM code facilitating any semantically related target that happens to follow. The result should be cost and benefit accruing asymmetrically with benefits appearing before costs as a function of ISI.

Neely's (1977) data confirmed these predictions. Compared to neutral primes, primes that were semantically related, appearing at very short ISIs, facilitated targets but created interference with the unexpected target at longer ISIs. At the longer interval, primes that correctly cued the target benefited decision latencies. These results show the same time course as Posner and Snyder's letter-matching data.

Since Neely's experiment, many studies have shown that the processing of a target (e.g., DOCTOR) can be facilitated when it follows a semantically related prime (e.g., NURSE). Semantic priming effects have been found even when the prime was a related picture (e.g., Carr, McCauly, Sperber & Parmelee, 1982) and when the prime was simply perceptually related (e.g., BALL/CHERRY), (e.g., Schreuder, Flores d' Arcais & Glazenberg, 1984), suggesting that the priming effect is the result of some combination of automatic and attentional processes.

Recent studies, however, are more interested in discovering what processes are actually automatic and what structures lie behind these proposed psychological pathways that lead to automatic lexical analysis. In a series of investigations, the procedure was to place a mask within the interval between the prime and target (e.g.,Fowler, Wolford, Slade & Tassinary, 1981; Marcel, 1983a). The mask was positioned closer to the prime until the subjects could no longer reliably report an awareness of the prime. The magnitude of the priming effect in the masked condition and the unmasked condition were the same, usually. Since the subject was unaware of the prime it was concluded that the effect can not be attributable to any conscious strategy or expectations that the subject may create. Moreover it was the meaning of the masked prime that produces the effect and thus the prime must automatically activate lexical entries in LTM facilitating related targets despite the person's intent (Marcel, 1983b).

However, Flowers et al. (1984) points out that there may be a major difference between lexical tasks and letter-matching tasks that require stimulus matching or classification. In a lexical experiment, the prime activates a lexical code that aids in the recognition of semantically related words. When that prime is a predictive cue, about a particular word category, the prime increases the probability that a target will be from a certain class of words which reduces stimulus uncertainty. The prime does not, however, reduce response uncertainty. In a task like letter-matching, the prime is directly related to the response (e.g., 80% chance SAME) which does reduce response uncertainty. Because the number of responses that can be executed at one time is limited, priming for a competing response will result in response inhibition or interference. The idea of direct response priming implies that inhibition is not the result of competing nodes in LTM but rather interference that begins at the beginning of response selection; a selection that occurs when the prime is presented and that may not await the complete encoding of the target. What priming may produce then is bias for a particular response not a particular pathway.

Flowers' et al. (1984) explanation of response priming accounts for the results of Posner and Snyder's letter-matching well. Making a prime a valid predictor of a target may have led the subjects to adopt a strategy of matching the prime letter to the letter in the target. As Posner and Snyder noted, using this strategy will lead to benefits when the prime matches both letters in the target (A/AA). When the prime mismatches one of the letters (A/BB), the subject may be inclined to respond

DIFFERENT creating costs in RT and accuracy. In their study reaction times were delayed and there was a 39% error rate where chance was 50%. More problematic were the DIFFERENT responses. Responses were quicker when the prime mismatched the different letters (A/BC) and RTs and errors were greater when the prime matched one of the letters (A/AC) in the target. Thus, Posner and Snyder's data are difficult to interpret, given such a high error rate and the strategy of the subjects tending to include the prime in the match. However this apparent confound does not explain away the asymmetry of costs and benefits and why there are still benefits and no costs when the prime was actually uninformative; that is, it could not be used to predict the upcoming target.

Results from different experiments suggest that prime utilization is automatic, free of the limited capacity of attention. These conclusions resemble the more general finding that attention can be divided between separate stimulus dimensions with no loss in performance (e.g., Allport, 1971; Treisman, 1969). "The generality of this conclusion with respect to cue utilization is important and warrants further investigation. In particular, it would be useful to determine the limits on the number of cues that can be used simultaneously and to discover the limits affecting the limit" (Logan, 1980 p 541).

The following experiments were designed to replicate the asymmetry of costs and benefits found in the Posner and Snyder

(1975) experiment and to investigate further the utility of priming. The first experiment was constructed in light of a possible response priming explanation of letter-matching. One block of trials were used in an attempt to replicate Posner and Snyder's letter-matching results while trying to hold the error rate at a reasonable level. Letter-matching was then coupled with a secondary or probe task. The probe was used to assess the demands placed on attention in the production of cost and benefits. The second experiment tested how well attention can be divided between separate dimensions of a prime in terms of its physical form and spatial location. If prime utilization is automatic then two tasks should be able to be primed simultaneously with attention divided between both dimensions of the prime.

EXPERIMENT 1

Posner and Snyder's two-process theory of priming predicts that automatic facilitation will yield to conscious influences as the ISI between the prime and the target is increased. They assume an initial stage of automatic priming that produces benefit data only followed by a later stage of greater facilitation and inhibition mediated by conscious expectancies that produce both costs and benefits. Specifically, benefits should begin to accrue at the short ISIs whenever the prime matches the target with no evidence of costs when it does not match the target. At longer ISIs benefits from priming should be increased due to informative priming, benefits that will be coupled with the onset of costs when, on occasion, the prime invalidly predicts the target. In the first experiment, a base-line measure of primed letter-matching was used to test directly Posner and Snyder's predictions. This block of letter-matching trials were then followed by a second condition of probed letter-matching. The probe was used to assess the amount of attention invested in letter-matching by measuring delays in probe performance relative to the probe task performed alone. Costs and benefits to probe RTs were also measured in relation to concurrent costs and benefits in letter-matching performance. During probing, according to the single-channel hypothesis, if the RTs to letter targets are benefited, concurrent probe latencies should show a similar decrease and costs in letter-matching should be mirrored by the same delay to probes. A secondary hypothesis was that costs, which are the result of conscious expectations, will be prevented by the distraction caused by the probe (McLean & Shulman, 1978). That is, if an expectancy requires attention, then the effects of this strategy should be reduced or eliminated by a simultaneous task that requires attention.

The probe in this experiment was a high or low frequency tone which required a choice vocal response. A tone does not supposedly compete perceptually with the visual targets (McLeod, 1977) nor does a vocal response compete with the manual response to the targets (Kantowitz, 1974). Therefore, it may be assumed that the secondary task (probe) only competed for the central attentional resources used by the primary task (letter-matching). To prevent subjects from grouping their responses, catch -trials were introduced in which the tone was omitted and in addition a choice response to the tones rather than a detection response was used (Welford, 1980). Grouping refers to a strategy that subjects adopt whereby they treat each of the two signals as a complex whole, trying to respond to both simultaneously rather than sequentially. If subjects adopt this type of behavior, RTs to probed targets will be lengthened significantly compared to RTs when letter-matching was performed alone.

EXPERIMENT 1

Method

Subjects

Twelve people with no previous experience in letter-matching experiments were recruited from the psychology subject pool at the University of Calgary. All persons were right-handed with an age-range of 20 to 27 years. Each person participated individually in two 90 minute sessions and was paid $9.00 for each session. Seven subjects had corrected-to-normal vision. Four subjects were males.

Apparatus and Stimuli

The experiment was controlled by a PDP 11/34 computer. Visual signals were presented on a Tektronix 620 oscilloscope using a P 30 phosphor. The visual stimuli were from a six letter set (A C P S T X) and a plus sign (+). All visual signals were foveal. Each signal subtended approximately 0.55 x .86 degrees of visual angle. The prime was either a single letter or a plus sign presented at the center of the screen. The target was a pair of letters presented 0.15 degrees of visual angle adjacent to the right of the prime. Each letter of the target was also separated by 0.15 degrees of visual angle. Four black lines perpendicular to and bisecting each side of the screen pointed to the center of the screen were used to help localize the spatial location of the prime. The luminance of the stimuli was 23.0 cd/m^2 and the background of the oscilloscope had a luminance of 5.1 cd/m^2. The auditory signal or probe was presented at at 71 dB over a Beyerdynamic DT 109 stereo headset. The probe signal was generated by a square waveform synthesizer presented binaurally at a frequency of either 1.575 kHz or 0.575 kHz. Vocal responses to the probe were recorded by a voice activated relay. Manual responses to the target were recorded when one of the two micro switches was depressed.

The letter-matching stimuli in this experiment were presented in basically the same way as they were in Posner and Snyder's second experiment. Subjects were given an informative prime that could be used to validly predict a subsequent target.Targets were physically identical on half of the total trials (e.g., AA). Half of all trials began with a plus sign (a neutral prime) and half began with a letter (informative prime). The prime was presented for 50 ms. At the offset of the prime the screen was blank for one of five time intervals (i.e., ISI) of 0 ms, 50 ms, 100 ms, 250 ms, or 450 ms after which a pair of letters appeared for 500 ms. The subjects were instructed to depress the key labeled "SAME" with their right index finger when the two letters in the target matched physically. On the other half of the trials the letter pairs did not match (e.g., AB) in which case the subjects were instructed to press the key labeled "DIFFERENT" with the left index finger. When the target was turned off there was a 1500 ms pause or inter-trial interval.

The probability that the letter prime matched one or both of the target letters was 70%. On trials requiring a SAME response, the prime was followed by an identical target (A/AA) 70% of the time (called valid priming) and by a different target (A/BB) 30% of the time (called invalid priming). For DIFFERENT trials 70% of the letter primes matched the first letter of the target (A/AB) and 30 % did not (A/BC). Seventy percent was used instead of the 80% validity used by Posner and Snyder so as to provide more observations of invalid or cost trials (A/BB). Subjects were instructed to attend to the information contained in the prime although the overall probability of a prime and the target being identical was only 0.175.

The design of prime type (valid, invalid and neutral) and ISI (0, 50, 100, 250, and 450 ms) were combined factorially to produce 15 different letter-matching trials that required a SAME response and 15 that required a DIFFERENT response. An example of the manner in which these 30 trials types were replicated for one block of trials can be seen in Figure 3.

Procedure

One thousand and seven hundred letter-matching trials were run in two sessions for each subject. These 1700 trials were broken into three blocks: 300 trials in Block 1, 600 trials in Block 2 and 800 trials in Block 3. Subjects performed Block 1 and 2 on the first day and then Block 3 on the following day. Subjects were given a short break after every 200 trials. A sample of 50 trials from each block served as practice trials. Subjects performed all blocks in the same order: Block 1, Block

Figure 3. Delineation of the type of trials in the second block.

Block 2.

Letter -Matching Trials

Total = 600

SAME → (300)

- (150) Informative (e.g., A/BB)
  - **70% Valid** (105) (e.g., A/AA) - 21 at each ISI
  - **30% Invalid** (45) (e.g, B/AA) - 9 at each ISI
- (150) Neutral (+/BB)

DIFFERENT → (300)

- (150) Informative (A/BC)
  - **70% Valid** (105) (e.g., A/AB) - 21 at each ISI
  - **30% Invalid** (45) (e.g, B/AT) - 9 at each ISI
- (150) Neutral (+/AB)

2 and Block 3. In Block 1 and in Block 3 the probe appeared simultaneously with the letter-matching targets.

Block 1 was comprised of a random presentation of 60 letter-matching trials at each of 0, 50, 100, 250, and 450 ms ISIs. On 80% of these letter-matching trials a high or low frequency tone was presented for 500 ms binaurally and simultaneously with the letter pair. Subjects were not required to respond to the letter pair but were to respond to the tone. When the high tone sounded subjects were asked to respond with the word "bye" (by) and when the low tone was presented they were to say "bow" (bo) into the microphone. When the tone was omitted they were instructed not to respond.

Block 2 was made up of the random presentation of 120 letter-matching trials at each of the five ISIs. There was no tone. Only the RTs to the 300 SAME letter pairs and the 300 DIFFERENT letter pairs were compiled. Upon returning the next day, subjects performed the 800 trials in Block 3. Subjects were asked to respond to letter pairs as well as to the tones. Letter-matching targets were presented on all trials and 80 % of the time either the high or low frequency tones sounded simultaneously with the target. Tones were randomly introduced with letter-matching at each of the five ISIs. On the occasion that the tone did not appear (i.e., 20% of the time) subjects were instructed to continue responding to the targets. The only difference in procedure between Block 3 and the other two blocks was that the subjects performed the two tasks together.

Instruction emphasized that letter-matching was primary and that accuracy and speed were very important. Subjects were told that the probe task was secondary and that they should respond to the letter pairs first and tones second.

Results

Because the distribution of the correct mean RTs was highly positively skewed the data were transformed to logarithmic RTs ($base_{10}$) (skew = .41, Z = 2.27, p < .01). The transformed measure was used in each analysis of variance (ANOVA) with cue (3) and ISI (5) as the main factors. Cost was calculated by subtracting the mean RT for SAME responses when a plus sign was the prime from the mean RT for SAME responses when the letter prime did not match the letter pair. Benefit was calculated by subtracting the mean RT for SAME responses when the the prime matched the letter pair from the mean RT for SAME responses when a plus sign preceded the target. Tables 1, 2, 3, and 4 present correct logarithmic RTs, mean RTs, percentage of errors and cost-benefit measured under the 15 combinations of SAME letter-matching conditions. Unless indicated otherwise, all tests were conducted at an alpha level of p <.05. Data from each block were treated separately.

SAME Responses

Probe task: Block 1.

The data in Table 1 represent the probe baseline measures from Block 1. Tone latencies and errors did not vary significantly under the presence of any of the 15 letter-matching conditions. The overall mean RT to the probes was 528 ms [2.70554].

Letter-matching: Block 2.

The main effects of cue , (F (2,22) = 103.22) and ISI, (F

Table 1

Correct Log RTs, Mean RTs [ ] and % Errors( ) For the Tones in Block 1 During the 15 Conditions of Letter-Matching For SAME Responses

(ISI)	A AA valid	+ AA neutral	A BB invalid	Benefit	Cost
0	2.71068 [533] (0.9)	2.72592 [553] (0.6)	2.68844 [528] (0.3)	0.01524 [20] (-0.3)	-0.03748 [-25] (-0.3)
50	2.71010 [534] (1.9)	2.70486 [523] (0.1)	2.68801 [511] (0.3)	-0.00524 [-11] (-1.8)	-0.01685 [-12] (0.2)
100	2.70246 [528] (1.9)	2.70237 [523] (0.1)	2.69178 [523] (0.3)	-0.00009 [-5] (-1.8)	-0.01059 [0] (-0.2)
250	2.70452 [535] (0.4)	2.70836 [527] (0.6)	2.68922 [505] (0.6)	-0.00384 [-8] (0.2)	-0.01914 [-22] (0)
450	2.68844 [511] (0.9)	2.70499 [527] (0.4)	2.73437 [559] (0.3)	0.01655 [-16] (-0.5)	0.02938 [32] (-0.1)
$\overline{X}$	2.70324 [528] (1.2)	2.70930 [530] (0.4)	2.69836 [525] (0.4)	0.00606 [2] (-0.8)	-0.01094 [-5] (0)

* $\underline{p} < .05$

(4,44) = 7.91) were both significant, as illustrated by mean RTs in Table 2, from Block 2. The two-way interaction, CUE X ISI, was also significant F (8,88) = 2.76. The interaction of CUE and ISI resulted from cost accruing earlier than benefit. Figure 4 shows that the cost function begins at the second interval (ISI 50) declines sharply at the next ISI and then flattens out over the last two intervals. The benefit function starts later, at the 100 ms ISI, then rises and declines over the last two ISIs. Newman-Keuls tests confirm that these costs and benefits were significant at these intervals, q (2,88) = .02110[1].

Analyzing the percentage of errors made during SAME letter-matching revealed a significant effect for cue only, F (2,22) = 13.88. Invalid primes produced a 7.1 % mean error rate as compared to valid priming, mean error rate of 1.3 %. Newman-Keuls comparisons substantiated this 5.8 % difference in error rate, q (3,22) = 2.9.

Letter-matching and probes: Block 3.

When the letter-matching task was accompanied by the probe task in Block 3, only main effects were evident. For SAME responses to the letters, effects of cue, F (2,22) = 17.24 and ISI F (4,44) = 7.22 were significant. As can be seen from the mean letter-matching RTs in Table 3, the mean of 37 ms [0.03276] for benefit was significant, q (2,22) = .01502, but the mean of 10

[1]The "q" value for the logarithmic RTs was derived by calculating q critical value times MSe.

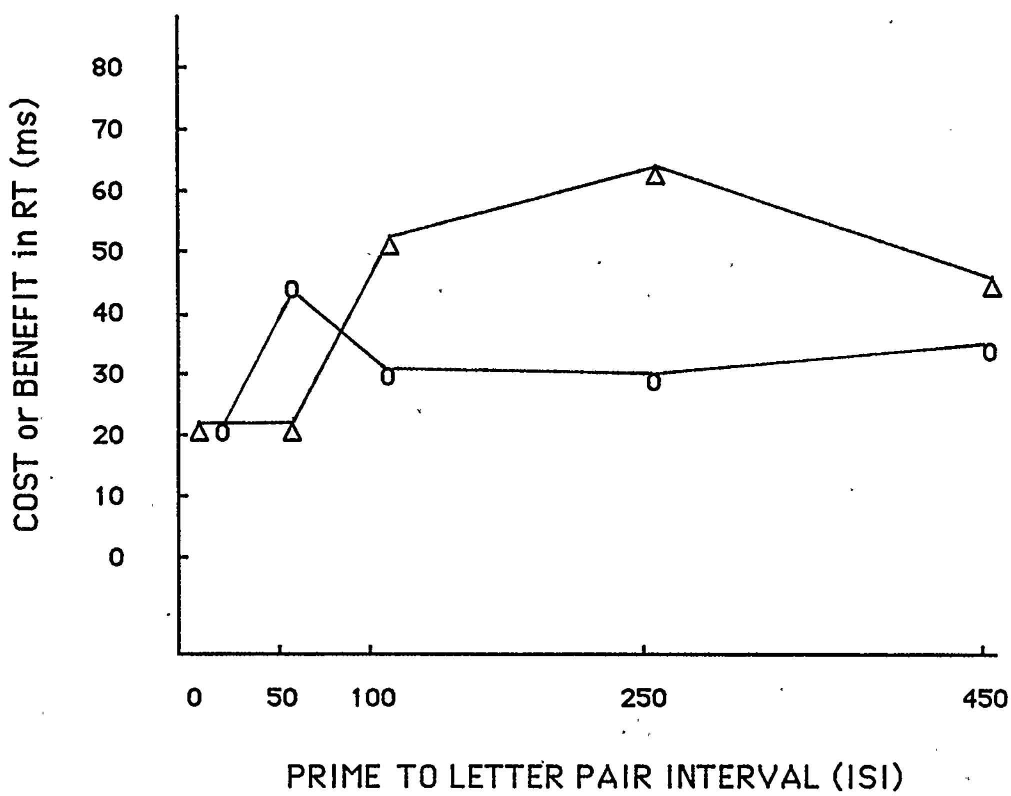
Table 2

Correct Log RTs, Mean RTs [ ] and % Errors ( ) To Letter Pairs For 15 Trial Types During Block 2 For SAME Responses

(ISI)	A AA valid	+ AA neutral	A BB invalid	Benefit	Cost
0	2.65103 [451] (0.8)	2.67120 [473] (2.5)	2.69228 [495] (5.4)	0.02017 [22] (1.7)	0.02108 [22] (1.9)
50	2.63573 [436] (0.8)	2.65547 [456] (1.7)	2.69615 [501] (4.3)	0.01974 [22] (1.9)	0.04068* [45] (3.6)
100	2.60093 [402] (2.9)	2.65156 [452] (2.5)	2.67936 [483] (7.4)	0.05063* [50] (-0.4)	0.02780* [31] (4.9)
250	2.58684 [390] (1.3)	2.65358 [453] (1.8)	2.67910 [482] (7.6)	0.06674* [63] (0.5)	0.02552* [29] (5.8)
450	2.58998 [394] (0.8)	2.63970 [440] (1.5)	2.67570 [476] (10.7)	0.04972* [46] (0.7)	0.03600* [36] (9.2)
$\bar{X}$	2.61270 [415] (1.3)	2.65430 [455] (2.0)	2.68452 [487] (7.0)	0.04160* [40] (0.7)	0.03022* [32] (5.0)

* $p < .05$

Figure 4. The time course of costs and benefits as a of function of the time between the prime and a matching letter pair from Block 2 SAME responses.



Δ = Benefit trials (e.g., A/AA)

o = Cost trials (e.g., A/BB)

Table 3

Correct Log RTs, Mean RTs [ ] and % Errors ( ) for Probed Letter-Matching During Block 3 For SAME Responses

(ISI)	A AA valid	+ AA neutral	A BB invalid	Benefit	Cost
0	2.68503 [490] (3.0)	2.70848 [520] (3.5)	2.70282 [530] (4.5)	0.02345 [30] (0.5)	0.00566 [10] (1)
50	2.67504 [481] (3.6)	2.68898 [496] (5.0)	2.70939 [520] (6.7)	0.01394 [15] (1.4)	0.02041 [24] (1.7)
100	2.65257 [455] (3.6)	2.68823 [491] (5.0)	2.68424 [492] (4.5)	0.03566 [36] (1.4)	-0.00399 [1] (-0.5)
250	2.62560 [427] (5.0)	2.67654 [483] (2.9)	2.70348 [506] (3.7)	0.05094 [56] (-2.1)	0.02694 [23] (0.8)
450	2.63576 [438] (3.3)	2.67555 [484] (4.2)	2.67049 [479] (2.2)	0.03979 [46] (0.9)	-0.00506 [5] (2.0)
$\overline{X}$	2.65480 [458] (3.8)	2.68756 [495] (4.1)	2.69408 [505] (4.3)	0.03276* [37] (0.3)	0.00653 [10] (0.2)

* $p < .05$

ms [0.00653] for cost was not. A similar pattern of results emerged for the probe RTs (see Table 4). The cue and ISI effects were significant, F (2,22) = 8.85 and F (4,44) = 4.43 but the interaction was not. Probe RTs, in general, benefited during validly primed letter-matching by 28 ms [0.01356], q (2,22) = .00854; however, the 5 ms [0.00245] of cost added to the probe RTs was not significant.

No significant costs and benefits in mean error rates were observed in probed letter-matching SAME trials nor were there significant costs and benefits in accuracy to the probe in Block 3.

Analysis of the letter-matching latencies and errors where the probe was omitted (20% of all the trials) in the third block did not reveal any significant effects in any conditions.

Baselines: Block 1, 2, and 3.

The data from Block 1, Block 2 and Block 3, where 20% of the targets were not probed serve as baselines against which differences in probed letter-matching and in processing the probe during letter-matching can be assessed. It can be seen from the differences between the means in Table 1 and Table 4 that probe latencies were increased when they were performed as the secondary task compared to when they were performed alone. The probe was delayed by an overall mean of 369 ms [0.24037] in the dual-task situation in Block 3 compared to its baseline in Block 1. Comparing the mean RTs to the letter-matching targets from Block 2 to those in Block 3 it appears

Table 4

Correct Log RTs, Mean RTs [ ] and % Errors ( ) to the Probes During the 15 Letter-Matching Conditions in Block 3 For SAME Resposnes

(ISI)	A AA valid	+ AA neutral	A BB invalid	Benefit	Cost
0	2.94735 [896] (0.4)	2.96603 [936] (0.3)	2.95824 [919] (0.0)	0.01868 [40] (-0.1)	-0.00779 [-17] (-0.3)
50	2.95234 [910] (0.4)	2.94765 [898] (0.8)	2.95996 [921] (1.8)	-0.00469 [-12] (0.4)	0.01231 [23] (1.0)
100	2.93384 [868] (0.8)	2.95017 [900] (1.0)	2.95982 [922] (0.9)	0.01633 [32] (0.2)	0.00965 [22] (-0.1)
250	2.91446 [830] (0.0)	2.94249 [888] (0.3)	2.95982 [901] (0.9)	0.02803 [58] (0.3)	0.01733 [13] (0.6)
450	2.93567 [872] (0.4)	2.94513 [894] (0.5)	2.93769 [879] (0.9)	0.00946 [22] (0.1)	-0.00744 [-15] (0.4)
$\bar{X}$	2.93673 [875] (0.4)	2.95029 [903] (0.6)	2.95275 [908] (0.9)	0.01356* [28] (0.2)	0.00245 [5] (0.3)

* $p < .05$

that probed letter-matching latencies were increased by an average of 30 ms [0.03343] during dual-task performance (refer to Table 2 and 3). However, this 30 ms [0.03343] difference was not statistically significant and therefore there is no statistical evidence to confirm that letter-matching was affected by the presentation of the probe. The same is true for a comparison of probed letter-matching mean RTs in Block 3 with the latencies where the probe was omitted in Block 3. Comparing error rates for the dual-task situation against blocks where the tasks were performed alone did not reveal any reliable differences in accuracy between conditions.

DIFFERENT Responses

Calculations for the correct DIFFERENT responses in Block 2 and 3 produced significant main effects for the ISI factor only, reflecting a general foreperiod effect. For Block 2 letter-matching, $\underline{F}$ (4,44) = 16.18, Block 3 letter-matching, $\underline{F}$ (4,44) = 5.92 and probe RTs $\underline{F}$ (4,44) = 2.81. Analysis of the errors from the DIFFERENT trials did not show any reliable statistical effects. The overall error rate was less than 5 % for all blocks. The correct logarithmic RTs, mean RTs and percentage of errors for the DIFFERENT responses can be seen in Tables 5, 6 and 7.

Table 5

Correct Log RTs, Mean RTs [ ] and % Errors ( ) To Letter Pairs For 15 Trial Types During Block 2 For DIFFERENT Responses

(ISI)	A AB valid	+ AB neutral	A CB invalid	Benefit	Cost
0	2.73560 [544] (3.8)	2.72428 [530] (2.7)	2.72428 [530] (6.7)	-0.01132 [-14] (-1.1)	0.00000 [0] (4.0)
50	2.71933 [524] (6.2)	2.72263 [528] (4.4)	2.73719 [546] (8.3)	0.00330 [4.0] (-1.8)	0.01456 [18] (3.9)
100	2.70757 [510] (5.4)	2.70243 [504] (4.9)	2.71181 [515] (5.0)	-0.00514 [-6] (-0.5)	0.00938 [11] (0.1)
250	2.70842 [511] (3.7)	2.69460 [495] (2.7)	2.68485 [484] (8.3)	-0.01381 [-16] (-1.0)	-0.00976 [-11] (5.6)
450	2.69984 [501] (3.3)	2.69108 [491] (2.7)	2.67943 [478] (8.3)	-0.00876 [-10] (-0.6)	-0.01165 [-13] (5.6)
$\overline{X}$	2.71433 [518] (4.5)	2.70757 [510] (3.5)	2.70842 [511] (7.3)	0.00676 [-8] (-1.0)	-0.00085 [1] (3.8)

* $p < .05$

Table 6

Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Probed Letter-Matching During Block 3 For DIFFERENT Responses

(ISI)	A AB valid	+ AB neutral	A CB invalid	Benefit	Cost
0	2.74741 [559] (6.9)	2.73159 [539] (4.9)	2.71933 [524] (10.3)	-0.01582 [-20] (-2.0)	-0.01226 [-15] (5.4)
50	2.72754 [534] (7.2)	2.72916 [536] (6.6)	2.78390 [608] (9.0)	0.00162 [2] (-0.6)	0.05474 [72] (2.4)
100	2.72672 [533] (6.3)	2.72263 [528] (2.1)	2.73480 [543] (5.5)	-0.00409 [-5] (4.2)	0.01216 [15] (3.4)
250	2.71181 [515] (3.0)	2.70672 [509] (2.5)	2.69636 [497] (10.3)	-0.00509 [-6] (-0.5)	-0.01036 [-12] (7.8)
450	2.71265 [516] (3.8)	2.70243 [504] (3.3)	2.70842 [511] (6.9)	-0.01022 [-12] (-0.5)	0.00599 [7] (3.6)
$\overline{X}$	2.72509 [531] (5.4)	2.71850 [523] (3.9)	2.72997 [537] (8.4)	-0.00659 [-8] (-1.5)	0.01147 [14] (4.5)

* $\underline{p} < .05$

Table 7

Correct Log RTs, Mean RTs [ ] and % Errors ( ) to the Probes During the 15 Letter-Matching Conditions in Block 3 For DIFFERENT Respones

(ISI)	A AB valid	+ AB neutral	A CB invalid	Benefit	Cost
0	2.98855 [974] (1.4)	2.98046 [956] (0.8)	2.97909 [953] (0.9)	-0.00810 [-18] (-0.6)	-0.00136 [-3] (0.1)
50	2.98000 [955] (1.1)	2.96894 [931] (0.3)	3.00689 [1016] (0.9)	-0.01105 [-24] (-0.8)	0.03794 [85] (0.6)
100	2.97128 [936] (1.1)	2.96237 [917] (1.8)	2.97451 [943] (0.0)	-0.00891 [-19] (-0.7)	0.01214 [26] (-1.8)
250	2.96708 [927] (1.4)	2.96047 [913] (1.8)	2.97127 [936] (0.0)	-0.00661 [-14] (0.4)	0.01080 [13] (-1.8)
450	2.96473 [922] (1.1)	2.97909 [953] (1.3)	2.96988 [933] (0.9)	0.01436 [31] (0.2)	-0.00921 [-20] (0.4)
$\overline{X}$	2.97451 [943] (1.2)	2.97035 [934] (1.2)	2.98046 [956] (0.5)	-0.00416 [-9] (0.0)	0.01011 [22] (-0.7)

* $p < .05$

Discussion

The first experiment revealed that the effects of inhibition, that are seen as costs in letter-matching RTs, can be found at very short ISIs while the benefits of priming accrue at longer ISIs. Coupling letter-matching with a second task to assess the attentional demands of costs and benefits led to the preclusion of costs, yet the probe did not hinder the accruement of benefits.

Letter-matching

The letter-matching results from the SAME responses in Block 2 showed that costs and benefits do develop at different ISIs but not at the time intervals predicted by Posner and Snyder's two-process model of priming. In this experiment costs began to accrue earlier than benefits. Significant evidence of costs first appeared at the 50 ms ISI or a stimulus onset asynchrony (SOA) of 100 ms and continued throughout the last 3 intervals. In contrast, benefits did not appear until the 100 ms ISI or 150 ms SOA (see figure 4). Measures of accuracy supported this pattern of costs and benefits rather than a speed accuracy trade-off. These functions reveal a pattern of costs and benefits that are a reversal to that which Posner and Snyder (1975) first discovered when they used primed letter-matching.

In Posner and Snyder's experiment, when subjects were presented with an informative prime (matching the targets on 0.8 of the SAME trials), benefits accrued almost immediately after the presentation of the prime (60 ms SOA). Costs, however, did not begin until an SOA of 310 ms. The authors concluded that early benefits are the result of automatic pathway activation that develop unintentionally whenever a target shares a pathway created by the prime. Costs, however, are an indication of the involvement of attention and thus, costs only occur if priming demands the limited capacity of attention.

Therefore, according to Posner and Snyder's (1975) definition of costs, it can either be argued that the subjects in this experiment could attend to a prime that preceded a target that did not match the target (A/BB) earlier than they could when it did match (A/AA) or that there is evidence of significant inhibition even when the ISI is too short to allow the subject to attend to the prime. The first explanation makes little sense since the primes in costs and benefits trials are the same initially and only after the target appears is there any difference between the two. Moreover, previous studies have stated that it takes approximately 200 to 500 ms to attend to a prime (e.g., Logan, 1980; Posner and Boies, 1971; Warren,1977) and therefore an ISI of 50 ms (SOA 60) would not allow enough time to encode the prime in order for attention to have an effect. The other conclusion is that inhibition can occur before a subject can attend to the prime, or in Posner's terms, costs occur automatically. The idea of automatic costs, however, contradicts the proposed operational definition of automaticity since automatic processes supposedly occur in parallel without interfering with operations that require attention. Automatic processes are also hypothesized to occur immediately upon presentation of the prime but there is no evidence from this experiment to support the idea of rapidly accruing automatic benefits that build before costs. In sum, the data from the second block did not reveal any benefits in priming without costs and thus these data do not provide an operational distinction between automatic and attentional operations which are thought to produce the priming effect.

An alternative explanation of priming has been based on a response strategy account (e.g., Becker, 1980; Flowers et al., 1984). It has been hypothesized that the benefits of priming have little to do with the proposed separate mechanisms of attention and automaticity. The reason for the benefits of priming may be that subjects include the prime with the target when they make their response. For example, in the cost condition, the prime does not match the target letters (A/BB) whereby subjects may be inclined to respond DIFFERENT. Compared to a neutral condition, this strategy would produce faster RTs when the targets matches the prime (A/AA), slower RTs with more errors to those that mismatch (A/BB) for the SAME responses and increased RTs and errors when the prime matches the first letter of the target (A/AB), with faster RTs when it does not (A/BC) for the DIFFERENT responses. It is apparent from much of the letter-matching data that response strategies can account for the costs and benefits of priming (Posner, 1978).

Posner (1978), however, has maintained that strategic factors cannot explain the asymmetry of costs and benefits first observed by Posner and Snyder and later confirmed by Neely (1977). The problem with this contention is that Posner and Snyder's error data for this condition are unavailable (Posner personal communication, 1987) in order to give a complete account of their results (they stated simply that errors were high). Antos (1979) points out that in the Neely study there is a problem of a speed accuracy trade-off. In Neely's data the conditions that show no costs in RT do show costs in terms of errors. For example, there were no costs in RT when the word prime invalidly cued the target (BIRD/arm) at the 250 ms SOA, as predicted, but there were costs in errors of 4.3%. It is possible that the reason there were no costs in RT was that the subjects were responding as quickly as they were in the neutral condition only at the expense of accuracy which would hide costs in RT. Measures of costs in accuracy are important because Neely and Posner claim that the existence of automatic processing is established only by finding evidence of inhibitionless or cost free data (Antos, 1979). Neely's data do not meet this criterion in light of an apparent problem of accuracy, and unless Posner and Snyder's error data is analyzed it is difficult to know if there was evidence of cost-free performance.

Despite problems of accuracy, the question that remains is why are these present results the reversal of those found by earlier researchers? A strategy or speed accuracy trade-off do not appear to be a problem in this study. Errors were relatively low (3.2%) and accuracy measures followed the same pattern of costs and benefits as RT. If the subjects in this experiment were using a strategy of matching the prime against the target letters before they made their responses, DIFFERENT response would have been faster and more accurate when none of the letters matched (A/BC) than when the prime matched one of the letters (A/AB) which was not the case. A possible answer for the differences in results may be that in the present experiment 70% of all the trials that began with a letter prime had a matching letter in the target (e.g., A/AA or A/AB)[2]. Therefore, in order to maintain a reasonable level of accuracy the subjects would have to process both of the target letters on at least 70% of the trials which may have deterred them from using the strategy of matching the prime against the target letters as an aid to responding. It would be interesting to see in another experiment if the prime did match the first letter of the target during 0.7 of the DIFFERENT trials if the results would be the same as Posner and Snyder's.

Probed letter-matching

2 In Posner and Snyder's (1975) experiment it appears that the prime did not match one of the target letters on 0.8 of the DIFFERENT trials.

In Block 3 introducing the tone (probe) with letter-matching resulted in the elimination of costs in letter-matching but left the benefits to primed targets intact and constant over ISI. An explanation for this result can be found if it is assumed that the construction of expectations require the limited capacity of attention (e.g., LaBerge, 1973; Posner, 1978). Expectations presumably require the directing of attention to an appropriate area of memory in anticipation of a particular signal. When the probe appeared, attention may have been redirected to the probe signal which would eliminate expectations and hence costs to an unexpected target (McLean & Shulman, 1978). The distraction caused by the probe would in effect preclude any costs and the enhanced benefits brought by conscious expectations. However, because pathway activation is said to be automatic, unintentional benefits would still persist and should not vary as a matter of encoding time (i.e., ISI) and the result would be a flat function as was evidenced from the present data. One problem with this explanation, however, is that in a similar study a secondary task did not disrupt primed expectations and costs developed in spite of the probe (McLean & Shulman, 1978).

An alternative explanation is that the subjects, with practice or experience, may have decided to choose to not use any of the predictive information contained in the prime. Subjects reported that they became aware that a large percentage of the letter primes were also identical to the first letter of the targets that did not match (e.g., A/AB) and that if they used the prime to prepare for a matching target they would "make too many errors". In other words, subjects may have learned by the time that they were in the probed condition in the third block that the prime matched one of the letters in the target (A/AB) as frequently as it matched both letters (A/AA) and therefore, chose to ignore the prime. If subjects tried not to attend to the prime, according to the automaticity hypothesis, performance should still be benefited unintentionally whenever the prime and the target share a similar pathway. Of course the way to test this explanation would be to run an experiment without the probe where the subjects are given vast amounts of letter-matching trials to see if costs do in fact disappear.

Probes

Combining letter-matching with the two-choice auditory probe task resulted in the processing of the probe being delayed by a mean of 369 ms with no difference in errors compared to when it was performed alone in Block 1. In addition, the benefits for probe latencies were mirrored by the benefits seen in the letter-matching results. Decreased RTs to the primed targets (benefits) were matched by decreases in processing the probe signal. When a target matched the prime, (A/AA) letter-matching latencies benefited by 37 ms and probe responses during these benefit trial were benefited concurrently by a 28 ms reduction in RT. This evidence suggests that the processing of the second signal is delayed until the the first signal is finished. This type of delay or additivity is exactly what the single-channel hypothesis would predict. According to this model, decreases to RT1 (letter-matching) will decrease RTs to the second task RT2 (probe) by a similar amount because when two signals compete for the limited capacity of the single-channel central processor each must be handled in sequence (Welford, 1980).

Since the probe was used to measure the processing demands of the primary letter-matching task, subjects were asked to concentrate on letter-matching rather than to alternate attention between the two tasks or group their responses. To test for this, letter-matching performance in the dual-task condition was compared to performance without the probe. Performance on the letter-matching task in the dual-task situation was equal statistically in overall RTs and errors to the scores for the letter-matching task in the baseline situation without the probe in Block 2 and in Block 3. When these scores differ, due to grouping or switching attention, results are hard to interpret since probe performance cannot be considered a pure measure of processing during normal primary task performance (Kerr, 1973). Therefore, it can be concluded that results from probing were not compromised by problems of grouping and switching attention which seem to plague many dual-task studies (Brebner, 1977).

EXPERIMENT 2

The first experiment demonstrated that the benefits of priming were not removed by a simultaneous attention demanding task. This implied that in the dual-task condition, the effects of priming were mediated by automatic rather than attentional processes. According to definitions of automaticity, automatic processes do not require the the limited capacity of attention and thus may proceed with other operations that demand attention. Therefore, if priming occurs automatically then it should be possible to prime two tasks simultaneously with no loss in effect compared to when each task is primed individually. The next experiment was designed to see if in fact two concurrent tasks could be primed simultaneously.

For the second experiment the primary task was once again primed letter-matching, however; the two-choice tone identification probe task was also primed. Each of the tasks were performed separately and then concurrently. Letter-matching was the same as the first experiment except the prime was positioned either above or below the center of the screen. The position of the prime was also used to prime the identity of the tone. It was predicted, based on the single-channel hypothesis, that if each dimension of the prime (its spatial position and physical form) is utilized separately, priming each task individually, then the effects of priming in the dual-task condition should be additive. In other words, if the RT to the primary task was benefited then the concurrent secondary task should be facilitated by the same amount regardless of how the position of the prime affects probe performance. In contrast to serial processing, if concurrent tasks are primed in parallel then the effects of priming should occur independently of the other task and thus the amount of priming should be the same whether the task is performed alone or with another task. Priming that appears to be parallel would suggest that the information contained in the prime is processed automatically independently of processes that require the limited capacity of attention.

In addition to priming the second task, two other changes were introduced in the second experiment. In the second block of trials the tone was presented concurrently with the letter-matching targets although subjects were not required to respond to the probe. According to Posner's theory of priming, when conscious attention is directed to a memorial representation of a target in anticipation of an upcoming target benefits will be increased along with the appearance of costs. Anything that causes attention to be withdrawn from a primed target will eliminate the effects of conscious attention without affecting automatic processes. Therefore, if the sounding of the tone in the first experiment caused attention to be redirected then costs should be eliminated even when the subject is not required to respond to the tone. The second block in this next experiment was deigned to test this explanation as a reason for the removal of costs. To help ensure that the subjects were attending to the prime, neutral and informative letter-matching trials within each block were grouped into sub-blocks. Some of the subjects in the first experiment complained that the total probability of a prime matching a target in a block of trials was too low for them to be bothered to use the prime to help predict the following target. Separating the trials within a block, rather than presenting the trials randomly, meant that subjects responded to neutral and informative letter-matching trials as a group which doubled the overall probability in a sub-block that the prime actually matched the target. This would hopefully induce the subjects to attend to the prime.

EXPERIMENT 2

Method

Subjects

Sixteen undergraduates were selected from the psychology department subject pool at the University of Calgary. All participants were right handed and had normal or corrected-to-normal vision. Eight females and 8 males with an age range of 18 to 29 years participated. Each person served individually for two 90 min sessions performed on consecutive days. They received nine dollars for each session.

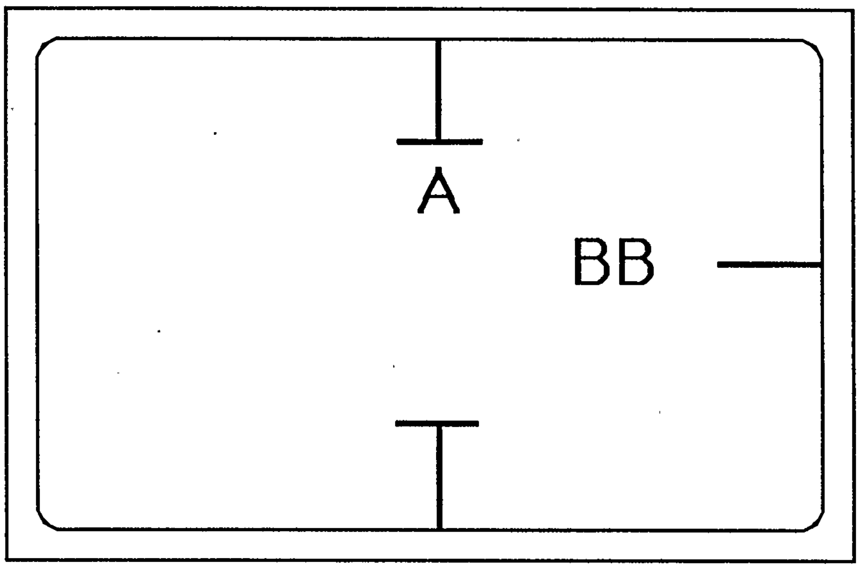
Apparatus and Stimuli

The stimuli and the apparatus were exactly the same as those used in Experiment 1, except for the spatial position of the prime. The prime was displayed either above or below a horizontal midline affixed to the right of the screen. The upper and lower position of the prime was accentuated with four black lines that made up two **T**s on the oscilloscope. One **T** was in an upright position centered at the bottom of the screen and the other **T** was inverted positioned directly above the top **T**. The prime either appeared directly below the top **T** or directly above the bottom **T**. The distance between the nearest edge of the prime and the center of the screen subtended approximately 0.2°. A diagram of the location of these lines, the prime and the target can be seen in Figure 5.

Procedure

This experiment was identical to the first except for three

Figure 5. A diagram of the screen on the oscilloscope used in second experiment with prime 'A' and target BB



changes. First, the display position of the prime was presented, with equal probability, either above or below the center of the screen. When a prime was positioned above center, 70% of the time a high frequency tone sounded and when the prime was positioned below center 70% of the time a low frequency tone sounded. Therefore, there was a 30% probability that the location of the prime was not compatible with the "high "or "low" tone discrimination required for the probe response. This 70-30 probability allowed the calculation of "costs-plus-benefits " only, but not costs and benefits individually as no neutral position prime was provided for comparison. Subtracting latencies from the 70% cued probe trials from the 30% miscued trials measured the costs-plus-benefits for probe RTs. This 70-30 probability was independent of the 70-30 probability of the prime matching the target letters. The second change was that the tone appeared randomly and concurrently with 80%, of the letter-matching trials in the second block; however, subjects did not respond to the probe but only to the letter targets. The third change was that trials were grouped according to whether the prime was neutral or informative. In Block 1, the 300 letter-matching trials were separated into 150 neutral and 150 informative trials creating two sub-blocks. In Block 2, the 600 trials were divided into sub-blocks of 300 neutral and 300 informative, in Block 3 there was a sub-block of 400 neutral and 400 informative trials. Prime validity was still 70-30, but because the probability of a prime matching both of the target letters was conditional (i.e.,given that the target is SAME there is a 70 % probability that if a letter prime appear it will match the target), separating the trials into informative (A/BB) and neutral (+/AA) trials doubled the percentage of the total trials where the prime matched the target in the sub-block of trials compared to when the neutral and informative trials were intermixed randomly in the first experiment. That is, during SAME trials in the informative sub-block 70% of the time the prime matched the target compared to 35% of the total in the first experiment.

Subjects were informed that attending to the prime would allow them to reasonably predict the target. A sample of 50 trials from each sub-block served as practice with a total of 2000 trials to be completed by each subject. Subjects were allowed a short rest after every 200 trials.

The order in which subjects performed each block of trials was the same as the first experiment; Block 1, Block 2 and Block 3. In Block 1, the probe task base-line conditions, subjects performed the two-choice tone discrimination task without responding to the letter-matching targets. In Block 2, the letter-matching control condition, subjects responded only to the letter targets and not to the probe. In Block 3, the dual-task condition, subjects responded to both probes and letter-targets. The orders of sub-blocks, neutral and informative, were balanced however. Within these three blocks, each subject received the two sub-blocks in different order, one subject receiving each of the eight possible combinations of sub-blocks within this order of task performance. Sixteen subjects were used to replicate this order of sub-blocks twice in an effort to provide the desired statistical power.

In addition to the instructions in Experiment 1, subjects were informed that the position of the prime would be compatible with the pitch of the tone 70% of the time. It was emphasized that the position of the prime reasonably predicted the tone independently of how the physical form of the letter prime cued the identity of the letter-target.

Results

The calculation of the results was based on the logarithmic transformation of the correct mean RTs for individual subjects. Reaction times for letter-matching and the probe were measured under each of the 15 (3 prime X 5 ISI) letter-matching conditions. SAME and DIFFERENT letter-matching responses, probe responses and the mean percentage of errors were analyzed separately for each block of trials. Probe responses were analyzed for costs plus benefits and letter-matching for costs and benefits.

SAME Responses

Probe baseline: Block 1.

In Block 1, both letter targets and tones were presented, although subjects responded only to the probe. The mean RTs were analyzed using a 16 (subject) X 5 (ISI) X 3 (prime) X 2 (predicted) ANOVA resulting in a main effect for predictability only, F (1,15) = 10.78, $p < .01$. The means in Table 8 are probe RTs from Block 1, for predicted and unpredicted probes as a function of ISI. The results in Table 8 represent data that were averaged across the three types of letter-matching primes (i.e., valid, invalid and neutral) for SAME letter-matching trials. Probes that were cued correctly by the position of the prime (70% predicted) were processed 27 ms [0.02108] faster than than the mean RTs to the probes that were cued incorrectly (30% predicted). However, costs-plus-benefits did not vary significantly as a function of ISI.

Table 8

Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Probes Predicted and Unpredicted From Block 1 SAME Trials (Responded only to Probes)

ISI

	0	50	100	250	450	$\bar{X}$
Predicted	2.69539 [509] (0.0)	2.68745 [500] (2.4)	2.68025 [494] (0.6)	2.67472 [492] (0.9)	2.68137 [496] (0.9)	2.68384 [498] (1.0)
Un Predicted	2.72348 [548] (3.4)	2.69561 [510] (2.8)	2.70130 [521] (2.1)	2.68829 [510] (2.8)	2.71589 [537] (1.4)	2.70491 [525] (2.5)
Costs + Benfits	0.02809 [39] (3.4)	0.00816 [10] (0.4)	0.02105 [27] (1.5)	0.02105 [18] (1.9)	0.03452 [41] (0.5)	0.02108* [27] (1.1)

* $p < .05$

Letter-matching baseline Block 2.

The results of a 16 (subject) X 3 (prime) X 5 (ISI) ANOVA of the SAME responses can be seen in Table 9. The prime and ISI variables provided significant main effects; F (2,30) = 18.18, p < .01 and F (4,60) = 12.91, p < .01. The interaction of these two variables was also significant, F (8,120) = 3.01, p < .01. Figure 6 illustrates the results of this interaction as separate patterns of costs and benefits in mean RTs for SAME responses. Significant costs begin at the second interval (ISI 50), drop slightly at the next ISI and then are absent statistically at the following 250 ISI. Evidence of costs appeared again at the last ISI. Benefits, however, begin later than costs, ISI 100. Benefits rise sharply at the next ISI and decline at the 450 ms ISI creating a pattern of benefits appearing as an inverted "V" function. This time course of costs and benefits is similar to the results of the first experiment except for absence of costs at the 250 ms ISI. As in the first experiment, however, costs did begin to accrue earlier than benefits. A Newman-Keuls test substantiated these costs and benefits at these specified ISIs, q (2,120) = .00204, p < .05.

Probed Letter-matching: Block 3.

Letter-matching latencies:

A 16 (subject) X 5 (ISI) X 3 (prime) X 2 (predicted) ANOVA for SAME RTs substantiated only a prime main effect, F (2, 30) = 10.56 p < .01 and a ISI main effect, F (4,60) = 14.10, p < .01. The interaction of these factors upon letter-matching RTs was not

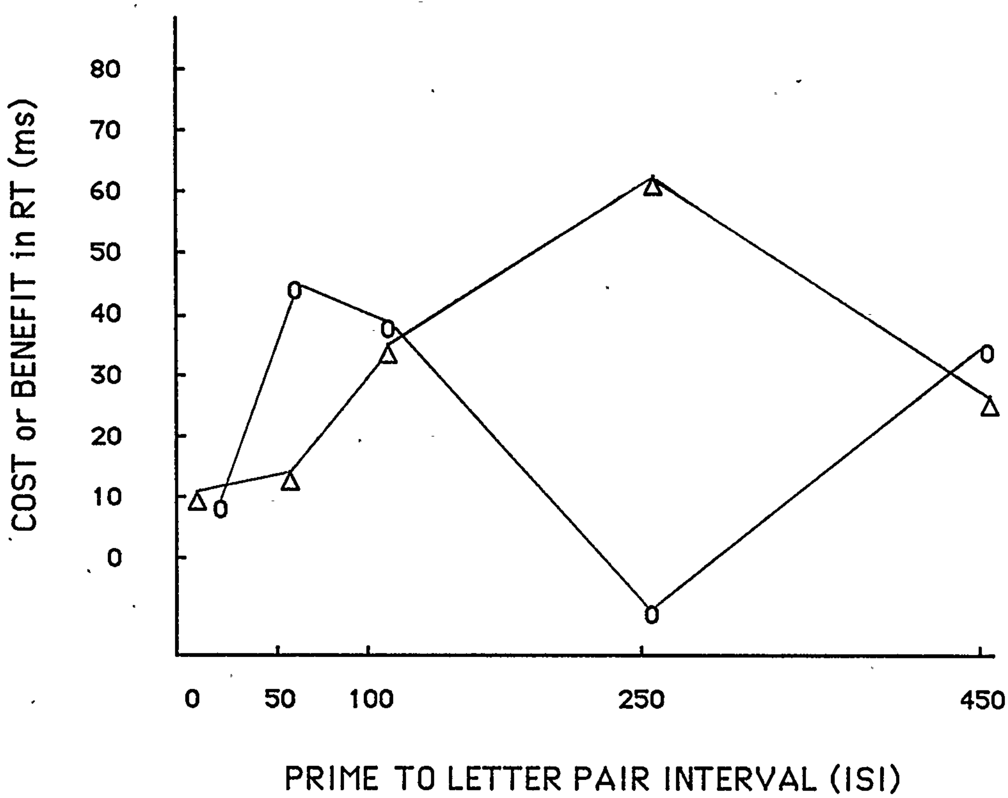
Table 9

Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Letter-Matching From Block 2 SAME Responses

(ISI)	A AA valid	+ AA neutral	A BB invalid	Benefit	Cost
0	2.69687 [508] (4.5)	2.70625 [516] (3.5)	2.70812 [523] (7.1)	0.00938 [8] (1.0)	0.00187 [7] (3.6)
50	2.68375 [493] (1.8)	2.69812 [506] (3.3)	2.73062 [551] (3.6)	0.01437 [13] (1.5)	0.03250* [45] (0.3)
100	2.65937 [467] (2.7)	2.69375 [501] (5.0)	2.71812 [537] (6.2)	0.03438* [34] (2.3)	0.02437* [36] (1.2)
250	2.64063 [445] (3.0)	2.69437 [505] (4.0)	2.69188 [497] (7.6)	0.05374* [60] (1.0)	-0.00249 [-8] (3.6)
450	2.64437 [452] (3.1)	2.67188 [477] (3.7)	2.69875 [511] (3.8)	0.02751* [25] (0.6)	0.02687* [34] (0.1)
$\bar{X}$	2.66500 [473] (3.0)	2.69287 [501] (3.9)	2.70950 [524] (6.0)	0.02787* [28] (0.9)	0.01663* [23] (2.1)

* $p < .05$

Figure 6. The time course of costs and benefits as a function of the time between the prime and a matching letter pair in the second experiment from Block 2.



Δ = Benefit trials (e.g., A/AA)

o = Cost trials (e.g., A/BB)

significant. The costs and benefits in mean RT due to the different types of primes are shown in Table 10. The 27 ms [0.02265] of overall benefit from primed letter-matching was significant, q (2,30) = 0.01553, $p < .05$ (Newman-Keuls) but the 14 ms [0.01167] of cost was not.

Probe latencies:

Probe RTs that were obtained during concurrent SAME letter-matching trials were subjected to a 16 (subject) X 5 (ISI) X 3 (prime) X 2 (predicted) ANOVA. There was only an ISI main effect, F (4, 60) = 4.41, $p < .01$ and a predictability main effect, F (1,15) = 9.36, $p < .01$. Predicted tones were, on the average, 26 ms [0.01215] faster than the RTs obtained from incorrectly predicted tones (see Table 11) and yet there is no statistical evidence to suggest that the type of letter-matching prime had an effect upon the concurrent probe task. In this dual-task condition probed letter-matching responses benefited from priming by 27 ms [0.02265]. However, there is no statistical evidence to support the idea that concurrent probe responses were decreased consecutively by any significant amount, unlike the first experiment where primed letter-matching was benefited by 37 ms [0.03276] and these benefits were added to concurrent probe RTs.

<u>Error data for all Blocks.</u>

No statistical evidence was found for costs and benefits in mean error rate for letter-matching in Block 2 or 3 during SAME response. There was also no evidence of costs plus benefits in

Table 10

Correct Log RTs, Mean RTs [ ] and % Errors ( ) for Probed Letter-Matching From Block 3 SAME Responses (Both Targets and Probes Responded to)

(ISI)	A AA valid	+ AA neutral	A BB invalid	Benefit	Cost
0	2.73387 [557] (6.0)	2.74672 [575] (4.1)	2.74750 [577] (5.5)	0.01285 [18] (-1.9)	0.00078 [2] (1.4)
50	2.71812 [540] (4.4)	2.72995 [556] (5.3)	2.73293 [565] (6.9)	0.01183 [16] (0.9)	0.00298 [9] (1.6)
100	2.69045 [503] (5.2)	2.71538 [536] (6.4)	2.73031 [558] (6.9)	0.02493 [33] (1.2)	0.01493 [22] (0.5)
250	2.67125 [489] (5.5)	2.70877 [530] (5.2)	2.73269 [554] (11.2)	0.03752 [41] (-0.3)	0.02392 [24] (6.0)
450	2.67232 [489] (6.4)	2.69846 [516] (3.8)	2.71422 [530] (5.3)	0.02614 [27] (-2.6)	0.01576 [14] (1.5)
$\bar{X}$	2.69720 [516] (5.5)	2.71986 [543] (5.0)	2.73153 [557] (7.2)	0.02265* [27] (-.5)	0.01167 [14] (2.2)

* $p < .05$

Table 11

Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Probes Predicted and Unpredicted in Block 3 SAME Trials (Both Targets and Probes Responded to)

	ISI 0	50	100	250	450	$\bar{X}$
Predicted	2.89109 [802] (0.9)	2.89798 [813] (0.8)	2.88585 [787] (0.9)	2.87538 [773] (2.1)	2.87112 [763] (1.6)	2.88428 [788] (1.3)
Un Predicted	2.89552 [808] (2.5)	2.91758 [861] (1.6)	2.89735 [822] (0.4)	2.88916 [798] (1.6)	2.88255 [782] (1.6)	2.89643 [814] (1.5)
Costs + Benfits	0.00443 [6] (1.6)	0.01960 [48] (0.8)	0.01150 [35] (-0.5)	0.01378 [25] (-0.5)	0.01143 [19] (0)	0.01215* [26] (0.2)

* $p < .05$

accuracy to probe responses in Block 1 or 3. Overall, the percentage of errors were positively correlated with mean RTs, thus negating any evidence of a speed accuracy trade-off.

Comparing Baselines: Block 1 , 2 and 3

Table 12 displays the results of letter-matching RTs for SAME response in Block 3 for trials when the probe was omitted (i.e., 20% of all trials). A significant interaction of ISI and prime was evidenced, F (8,120) = 2.52, $p < .05$, along with a prime main effect, F (2,30) = 4.00, $p < .01$ and ISI main effect, F (4 60) = 19.29, $p < .01$. The interaction of these two factors created a peculiar pattern of costs and benefits - there were 35 ms [0.02165] of costs at the first interval (ISI 0) and 33 ms [0.02430] at the 250 ms ISI (33 ms) [0.02430] only. Benefits in contrast were only significant at the last two intervals, 250 and 450 ISI; q (2,120) = 0.01980, $p < .05$ (Newman-Keuls). Cost data points, at each of the five ISIs, are representative of 38 trials and benefit trials 90 in total within this condition in Block 3, a very small sample considering a total of 154 and 358 were performed by all subjects during probed letter-matching in this block. The relatively small number of data points in this situation may be responsible for the inconsistent results.

Comparing the observed RTs in letter-matching where the probe was omitted in Block 3 with probed letter-matching RTs shows no statistical differences between the two conditions in mean RTs or errors. The letter-matching RTs from Block 2 (single-task condition), however, appeared to be smaller as a

Table 12

Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Letter-Matching From Block 3 SAME Responses Without the Probe

(ISI)	A AA valid	+ AA neutral	A BB invalid	Benefit	Cost
0	2.74030 [567] (7.3)	2.73826 [558] (4.7)	2.75991 [593] (3.1)	-0.00204 [-9] (-2.6)	0.02165* [35] (-1.6)
50	2.71558 [535] (3.1)	2.72582 [542] (2.3)	2.75991 [550] (6.3)	0.01024 [7] (-1.1)	-0.0021 [8] (4.0)
100	2.69062 [506] (3.1)	2.70776 [520] (3.9)	2.71527 [539] (3.1)	0.01714 [14] (0.6)	0.00751 [19] (-0.8)
250	2.67006 [487] (11.2)	2.70810 [523] (3.9)	2.73240 [556] (0.0)	0.03804* [36] (-7.3)	0.02430* [33] (-3.9)
450	2.67695 [498] (10.0)	2.69991 [513] (3.1)	2.70784 [524] (6.2)	0.02296* [15] (-6.9)	0.00793 [11] (3.1)
$\overline{X}$	2.69870 [519] (7.0)	2.71597 [531] (3.6)	2.73507 [552] (3.7)	0.01727 [12] (-3.4)	0.01910 [21] (0.1)

* $p < .05$

whole (500 vs 538 ms) [2.6856 vs 2.71368] than letter-matching latencies from Block 3 (dual-task condition) but there is no statistical evidence that probing delayed letter-matching performance. Probes therefore appear to have little effect on overall primary letter-matching performance.

Compared to Block 1, probe performance was delayed by a mean time of 288 ms [0.19776] when it was the secondary task in Block 3 but the error rates were almost the same, 1.4 and 1.5 percent respectively. Moreover, the 26 ms [0.01215] of costs plus benefits to the probes in Block 3 is comparable to the 27 ms [0.02108] difference between predicted and unpredicted tones when the probe was performed alone in Block 1.

These comparisons help rule out an explanation that any differences between single- and dual-task conditions are simply the result of response strategies such as subjects using a strategy of grouping letter-matching responses with probe responses to emit a simultaneous response rather than consecutive responses which tend to delay primary performance (Welford, 1980). Furthermore, the lack of difference in error rates between the tasks performed alone and the dual-task situation suggests that the results are not contaminated by differences in accuracy.

<u>DIFFERENT Responses</u>

Costs-plus-benefits in probe performance for Block 1 are shown in Table 13. Costs and benefits in RTs and accuracy for targets and probes, under each of the 15 letter-matching condition, for Block 2 and 3 can be seen in Tables 14, 15 and 16.

Block 1.

Analysis of probe RTs revealed that the main effects of predictability and ISI were significant but the interaction was not; F (1, 15) = 19.73 $p < .01$ and F (4,60) = 14.10, $p < .01$. Probe RTs were 28 ms [0.02126] faster when they were predicted relative to unpredicted tones. Costs plus benefits did not change significantly as a function of ISI.

Letter-Matching for Block 2 and 3:

Only the main effect for ISI was significant for the DIFFERENT RTs from Block 2 and 3; Block 2 letter-matching RTs, F (4, 60) = 17.75, $p < .01$ and Block 3 letter-matching RTs, F (4,60) = 3.14, $p < .05$. These results show that RTs decreased as ISI increases regardless of the type of prime used.

Probe latencies:

Analysis of the probe RTs in Block 3 did not produce any significant effects.

Error data

There were no significant costs-plus-benefits in accuracy in Block 1. In Block 2 there were significant differences in errors depending on the type of prime that preceded the target, F (2,30) = 122.01, $p < .01$. These differences resulted in a 18 % cost to trials where the prime did not match the first letter of the target (A/BT) relative to the neutral trials (+/BT), q (2,30) = 2.62, $p < .01$ (Newman-Keuls). There was also a 13.8% cost in mean error rate to letter-matching responses in Block 3 when the letter prime did not match either of the letters in the target, q (2,30) = 5.00, p <.01. When the probe in Block 3 was cued with a compatibly positioned prime during letter-matching, the mean probe response error rate was 0.3 % and when the position of the prime was not compatible with the frequency of the tone there was a 3.1%. error rate. This 2.8 % difference between the predicted and unpredicted probe (i.e., costs-plus-benefits) was significant, F (1,15) = 6.93, p < .05. The costs-plus-benefits in mean RTs to probe performance was not significant however. Significant costs-plus-benefits in accuracy would suggest that unpredicted probe responses are the same in RT only at the expense of a higher error rate during concurrent DIFFERENT letter-matching trials.

Table 13

Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Probes Predicted and Unpredicted From Block 1 DIFFERENT Trials (Responded to Probes Only)

ISI

	0	50	100	250	450	$\bar{X}$
Predicted	2.74137 [514] (0.0)	2.71138 [507] (0.3)	2.67647 [492] (0.0)	2.69010 [496] (0.3)	2.71533 [492] (0.3)	2.70693 [500] (0.2)
Un Predicted	2.69796 [571] (2.8)	2.69001 [538] (2.1)	2.67960 [497] (1.4)	2.67894 [502] (3.4)	2.68184 [534] (1.4)	2.68567 [528] (2.2)
Costs + Benfits	0.04341 [57] (2.8)	0.02137 [31] (1.8)	-0.00313 [5] (1.4)	0.01116 [6] (3.1)	0.03349 [42] (1.1)	0.02126* [28] (2.0)

* $p < .05$

Table 14

Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Letter-Matching From Block 2 DIFFERENT Trials

(ISI)	A AB valid	+ AB neutral	A CB invalid	Benefit	Cost
0	2.75590 [580] (6.8)	2.74548 [569] (3.7)	2.74275 [563] (20.3)	-0.01042 [-11] (-3.1)	-0.00273 [-3] (16.6)
50	2.73103 [548] (4.8)	2.72350 [537] (6.5)	2.73985 [557] (19.4)	-0.00753 [-11] (1.7)	0.016335 [20] (12.9)
100	2.72440 [539] (7.2)	2.72671 [548] (2.3)	2.71998 [542] (28.4)	0.00231 [9] (-4.9)	-0.00673 [-6] (26.1)
250	2.70414 [516] (4.2)	2.69316 [505] (4.4)	2.69131 [505] (18.0)	-0.01098 [-11] (0.2)	-0.00185 [0] (13.6)
450	2.71002 [523] (4.1)	2.70566 [522] (2.1)	2.69994 [513] (23.1)	-0.00436 [-1] (-2.0)	-0.00572 [-9] (21.0)
$\overline{X}$	2.72510 [541] (5.4)	2.71890 [536] (3.8)	2.718766 [536] (21.8)	-0.00620 [-5] (-1.6)	-0.00013 [0] * (18.0)

* $p < .05$

Table 15

Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Letter-Matching From Block 3 DIFFERENT Trials

(ISI)	A AB valid	+ AB neutral	A CB invalid	Benefit	Cost
0	2.76469 [604] (8.8)	2.75212 [582] (8.5)	2.74288 [586] (24.6)	-0.01257 [-22] (-0.3)	-0.00924 [4] (16.1)
50	2.74218 [575] (8.6)	2.75787 [583] (6.0)	2.75536 [611] (17.3)	0.01569 [8] (-2.6)	-0.00251 [28] (11.3)
100	2.74523 [575] (9.9)	2.74000 [568] (7.7)	2.77715 [617] (21.2)	-0.00523 [-7] (-2.2)	0.03715 [49] (13.5)
250	2.73586 [560] (10.2)	2.73715 [551] (7.7)	2.71703 [550] (24.6)	0.00129 [-9] (-2.5)	-0.02012 [-1] (16.9)
450	2.74723 [578] (9.0)	2.72746 [547] (7.1)	2.70945 [546] (18.3)	-0.01977 [-31] (-1.9)	-0.01801 [-1] (11.2)
$\bar{X}$	2.74704 [578] (9.3)	2.74292 [566] (7.4)	2.74037 [582] (21.2)	-0.00412 [12] (-1.9)	-0.00255 [16] (13.8)*

* $p < .05$

Table 16
Correct Log RTs, Mean RTs [ ] and % Errors ( ) For Probes From Block 3 DIFFERENT Trials

(ISI)	A AB valid	+ AB neutral	A CB invalid	Benefit	Cost
0	2.91683 [852] (2.0)	2.93531 [886] (1.4)	2.91881 [862] (3.0)	0.01848 [34] (-0.6)	-0.01650 [-24] (1.6)
50	2.91114 [834] (1.6)	2.91578 [852] (1.8)	2.89190 [834] (0.8)	0.00464 [18] (0.2)	-0.02388 [-18] (-1.0)
100	2.90490 [829] (1.9)	2.91719 [864] (0.5)	2.93337 [872] (0.0)	0.01249 [17] (-1.4)	0.01618 [26] (-0.5)
250	2.89403 [820] (3.0)	2.91812 [843] (2.2)	2.89670 [827] (0.7)	0.02409 [23] (-0.8)	-0.02142 [-16] (-1.5)
450	2.91967 [860] (2.6)	2.90455 [831] (0.8)	2.89944 [825] (1.7)	-0.01512 [-29] (-1.8)	-0.00511 [-6] (0.9)
$\overline{X}$	2.90927 [839] (2.2)	2.91819 [852] (1.3)	2.90804 [844] (1.2)	0.00892 [13] (-0.9)	-0.01015 [-8] (-0.1)

* $\underline{p} < .05$

Discussion

The general findings of the second experiment replicated the letter-matching results of the first experiment and revealed that during probed letter-matching, two tasks could be primed independently.

Probe base-line

The first block of 300 trials provided a baseline measure for probe RTs. Letter-matching targets were displayed in the same way as the letter-matching trials that followed in Block 2 and 3. When subjects responded only to the tone, it was demonstrated that response times were 27 ms faster when the tone was cued correctly (predictive) relative to responses to the tones that were cued incorrectly (unpredictive). There was no control or neutrally positioned prime for a metric for tone RTs and therefore costs and benefits could not be calculated separately. Because a neutral prime was not available during the performance of the probe, it is impossible in this situation to tell if these 27 ms of costs-plus-benefits , calculated from when the position of the prime was compatible with the tone response and when it was not, were the result of automatically primed benefits or attentional costs or a combination of both.

Letter-matching

In the second block of trials, participants performed letter-matching under conditions similar to Experiment 1. The differences in procedure from the first experiment were: the grouping of informative and neutral trials into two sub-blocks, the introduction of the tone, and the positioning of the prime. Grouping the trials within each block was used to help ensure that the subjects would attend to the prime in anticipation of specific targets. The tone was introduced to test the hypothesis that if a person expects a certain event or signal to occur then selective attention is directed to a memorial representation in anticipation of that event or signal (McLean & Shulman, 1978; LaBerge, 1973; Posner, 1978). Therefore, if attention were to be distracted by the tone the costs and benefits from the commitment of selective attention should be eliminated. Despite these changes in procedure, the letter-matching results from Block 2 are much the same as the results in the first experiment. Costs first appeared at the second interval (ISI 50) and continued throughout the prime to array interval except for the 250 ms ISI. Costs at the 250 ISI were absent (-8 ms). Significant benefits, in contrast, started at the 100 ms ISI, took a sharp rise at the fourth interval and then receded at the last interval to form what looks like an inverted "V" function (see Figure 6). This time course of costs and benefits is similar to the findings of the first experiment, the only difference being the absence of costs at the 250 ms interval. There is no ready explanation as to why costs disappeared at this particular interval.

Posner and Snyder (1975) propose that when subjects are presented with an informative prime, one that indicates which target is most likely to occur, they will direct their attention to the location in memory representing the anticipated target. Because attention has a limited capacity, the RT to an unexpected target will be delayed as attention is switched from the area in memory to which it was directed to a new representation. However, the processing of the prime will not affect the processing of the unexpected target until subjects have enough time to encode the information contained in the prime. According to Posner and Snyder this takes approximately 300 ms to accomplish. By contrast, if the prime is presented too briefly (i.e., short SOAs) for attention to be directed by the prime, the prime will still activate its respective pathway, speeding the processing of any subsequent target that happens to share that pathway. As long as the prime is processed in this fashion, that is automatically along parallel pathways, no inhibitory effects of presenting a prime will occur.

From this account of priming two possible explanations of the present results follow. First, processing tones which did not require an overt response did not distract or require attention since costs in RT, the product of selective attention, were not removed. Subjects in this second block did not have to respond to the tone and it is plausible that the tone was encoded automatically. Posner (1978) maintains that attentional capacity is reserved for operations such as making overt responses, not for encoding. Therefore, reacting to an unexpected target reduces the capacity needed for a second response, but if the processing of the tone did not use attentional capacity then it would have no effect on costs. Second, the reason for the present time course of costs and benefits must be that attention can be directed by the prime earlier than hypothesized (at ISI of 50 ms) creating costs in RT to unexpected targets and yet no benefits to expected targets at this early interval. In addition there was no evidence from this time course of costs and benefits of automatic priming as costs appeared earlier than benefits. This is of course, a reversal to what is predicted: facilitating effects should begin to accrue almost immediately upon presentation of the .prime, benefits that will be increased at longer intervals as attention is directed correctly as announced by the prime coupled with the onset of costs when an unexpected target appears.

An alternative explanation of the effects of priming is that there may be two types of costs in processing targets that mismatch the prime. There may be costs whenever signals share different pathways as well as costs associated with strategic processes that represent subjects' expectations about the relations between the prime and the target. This idea will be extended in the General Discussion.

Different responses

Compared to the neutral prime (+/AB), there were no significant differences in mean RT from Block 2 or 3 when the prime matched the first letter of the target (A/AB) or when it did not match either of the target letters (A/BC), however, there was an 18% difference in Block 2 and 13.8% difference in Block 3 in the mean number of errors when all three letters were different. Although there were no delays in mean RTs when the prime did not match either of the target letters there were significant costs in accuracy. These results are accountable by Posner and Snyder's attentional theory of priming. When the prime matches neither letter (A/BC), costs in RT or accuracy would be expected because the subject is induced to attend to the prime which interferes with the attending to the target. In the condition where the prime matches one of the target letters (A/AB) there is some facilitation of encoding which may enhance the processing time for these targets.

In Posner and Snyder's (1975) study, data from the DIFFERENT trials followed an opposite pattern. When all three letters were different (A/BC), RTs were faster and more accurate and when the prime matched one of the target letters RTs were slower and less accurate. These results would imply that subjects were using a strategy of matching the prime with the first letter of the target to determine their response. Their data from their SAME response also showed that there was a response strategy. When all three letters matched (A/AA) responses were facilitated (benefited) but when the prime did not match the first letter (A/BB) subjects were inclined to respond DIFFERENT creating the delays and increased errors in RT (costs) found in this condition. Their results indicate clearly that a matching strategy explanation is also needed to give a complete account to their data.

The discrepancy in results between these experiments, for the DIFFERENT responses, may begin to explain why the time course of costs and benefits of primed letter-matching for the SAME response were a reversal to those of Posner and Snyder's. In this experiment there is no evidence to suggest that subjects were incorporating the prime in their response selection, not at least in the same way as they were in the original study. If subjects were using different strategies or no strategy at all, as it appears they were from the DIFFERENT data, then the subjects may have been allocating their attention in a different way. Strategic and attentional accounts of priming are not necessarily antithetical but instead may help explain the different ways in which attention can be directed as a result of various strategies, something that researchers have yet to look at.

Probed Letter-Matching

When the 400 SAME letter pairs were probed in Block 3, costs were statistically absent but benefits remained. When the prime matched the targets there was a mean of 27 ms benefit in RT performance. This facilitation did not vary as a function of ISI. The costs in letter-matching that were initially observed in the second block were absent. The analysis of the letter-matching trials where the probe was omitted (10% of the SAME trials) showed that costs were still maintained when the prime did not match the target. Thus it would seem that responding to a second simultaneous probe signal prevents the development of costs.

This loss of costs in the highly demanding dual-task situation is reconcilable within any capacity models of attention if it is assumed that reacting to the probe draws upon the attentional resources needed to prepare for a particular target. This depletion of attention would effectively preclude the chance for costs to arise. In the second block simply presenting the probe without having the subjects respond to it may have not required enough capacity to prevent expectations. Because costs were removed by the performance of the concurrent probe task, it must be assumed that the costs were indeed the product of attention and that the benefits of stimulus repetition were automatic as the benefits of priming seemed to be unaffected by the concurrent attention demanding task.

Presenting the tone, without the subjects responding to it, did not interfere with costs in letter-matching in the second block but responding to the tone in the third block did. The reason that costs were not removed or attenuated in Block 2 may be that both signals, the letter target and the tone, were encoded automatically and that interference only appeared when two decisions had to be made concurrently. Having the subjects respond to the tone in the third block requires that subjects consciously identify the tone before selecting the correct response. If this decision required attention it would interfere with the primary task possibly removing the costs in letter-matching. Therefore, it is not the encoding of simultaneous stimuli that creates interference rather it is that two decisions cannot be made simultaneously.

Placing the source of interference at the response selection stage rather than encoding is based on the results and speculations of several other divided attention experiments that suggest that concurrent stimuli are encoded automatically in parallel (Broadbent,1956, 1982; Duncan, 1980; Ostray, Moray & Marks, 1976). In these studies it was found that subjects could process two sources of information with no signs of interference as long as only one signal had to be detected or responded to. Interference appeared only when the simultaneous signals had to be identified independently with a separate response to each. The authors conclude that the selection of two responses cannot proceed simultaneously, however, during the selection of the first response the second signal is encoded while the single-channel is occupied with the decision of the first response. Thus, the location of the limited capacity single-channel is most likely at the decision stage and not the encoding stage.

One objection to this above conclusion is that many of the earlier dual-task studies revealed that responses are delayed as a result of presenting a second signal to which no overt response is made (e.g., Davis, 1959; Kay & Weiss; 1961; Koster & Becker, 1967; Nickerson, 1965). It is also possible that in the later studies, the second signal was either ignored completely or its processing was delayed until the single-channel was free. A more serious problem with these divided attention studies, and any other study that presents subjects with two sources of information that require a single response, is that there is no objective way to measure at what level the second source of information was processed, if at all.

Experiment 2 overcomes some of these problems by providing a new technique that tests the ability to encode different sources of information simultaneously in a situation where attention has to be divided between separate stimulus-response processes rather than different signals where only one signal requires a response. Each of the two sources of information used in this experiment were represented by different dimensions of a visual prime. Each dimension of the prime , its position and physical form, was used to prime the letter-matching and the probe task singly and concurrently. It was predicted that if each dimension required processing capacity, both competing for the limited capacity of the single-channel, each dimension of the prime would be encoded serially. If this happens, according to the single-channel hypothesis, when each task is performed together, benefits in RT to primed letter targets should benefit the RT to the probe (RT2) by the same amount. In other words, if the RT to the primary task (RT1) is reduced by 50 ms the RT to the secondary probe task will be decreased consecutively by 50 ms. The second hypothesis was, if each dimension is encoded in parallel automatically, each task will be primed simultaneously and independently. The effects of priming will therefore not be additive but will be the same for each task as when each is primed alone or concurrently.

Dual-Priming

The results of dual-priming seem to favour the second hypothesis. In the third block, subjects performed letter-matching concurrently with the auditory probe task. The spatial location of the prime was compatible with the tone discrimination 70% of the time, independently of the prime matching or mismatching the letter targets. There were 26 ms of costs-plus-benefits due to the positioning of the prime. However, these costs-plus-benefits did not depend on the 26 ms of benefit that appeared in RT to primed letter targets. In other words, when the probe occurred simultaneously with letter targets that were preceded with matching primes, probe performance was not consecutively decreased by 26 ms. This result is not what is predicted by the single-channel hypothesis which states that any decrease in processing of the first signal should decrease the processing time of the second signal by the same amount. Therefore, it would appear that the identity of the prime affected letter-matching independently of the effect that the position of the prime produced in response latencies to the tones.

The single-channel hypothesis is based on the many findings of serial processing of concurrent signals, an example of which occurred in the first experiment. In the first experiment, when letter-matching was benefited by 37 ms, concurrent probe RTs were decreased by 28 ms. The decrease in RT to the second signal thus depended directly on the processing time of the first signal. This type of serial processing seems to be the rule with few if any exceptions (Welford, 1980).

The results of the second experiment, however, revealed that dual priming allows a certain degree of parallel processing, which would not be predicted by a strict serial model of attention. The RT to the probe (RT2) was still significantly delayed (by a mean of 288 ms) compared to when it was performed alone which indicates that complete parallel processing was not possible. However, there is evidence that attention was divided between different stimulus dimensions, which resulted in the priming of two concurrent tasks with no loss in effect compared to when each was performed alone. When letter-matching was performed without the probe in Block 2 the overall mean benefits of priming were 28 ms. When the probe was performed alone in Block 1 the mean costs-plus-benefits were 27 ms. Combining the two tasks in the third block resulted in 27 ms of mean benefit to primed letter targets and 26 ms of costs-plus-benefits to primed probe RTs. Because the magnitude of priming did not vary across conditions, it must be assumed that the different dimensions of the prime were encoded automatically in parallel affecting each task independently and simultaneously. In contrast, if processing of each dimension of the prime requires capacity, encoding one dimension at a time, the effect that the prime had on the primary letter-matching task should be additive according to the single-channel hypothesis. Moreover, if prime utilization required the limited capacity of attention then during dual-priming any effect of priming should be reduced severely or even impossible in the dual-task situation.

The notion that two primes (those being the two different dimensions of the prime) can be encoded in parallel automatically is further supported by the finding that in the dual-task capacity demanding situation the effects of the prime were not removed or attenuated. Benefits of priming letter targets appeared to be unaffected by the presence of the probe and the effect of priming the probe, as manipulated by the positioning of the prime, was unaffected by the attentional demands of the letter-matching task. Thus, according to Posner and Snyder's two process model of priming, these effects can be considered the result of automatic activation rather than conscious attention.

In conclusion, the results of this second experiment do not support the contention that strict serial processing is the rule. Benefits in letter-matching and costs-plus-benefits in probe responses were shown to accumulate simultaneously and independently for two distinct tasks. The magnitude of the priming did not covary between tasks, a possible demonstration of parallel processing. In addition, prime utilization does not appear to be limited by the capacity of attention as each of the two tasks were primed as effectively whether performed alone or concurrently.

General Discussion

The present studies were designed to address three questions. First, does the primed letter-matching paradigm support reliably a temporal distinction between automatic and attentional processes? Second, does a secondary or probe task affect the automatic and attentional operations that mediate priming? Third, can two concurrent tasks be primed simultaneously? To answer these questions a variant of Posner and Snyder's (1975) letter-matching task was combined with a two-choice tone identification task. The following is a summary of the results of two experiments in the light of these questions.

The results of the first experiment demonstrated that, in a condition where subjects performed letter-matching without the probe, costs appeared earlier than benefits. When a letter prime was unrelated to matching target letters, the effect of attentional inhibition (i.e., costs) appeared at an ISI of 50 ms and remained throughout the longer three ISIs. When primes were identical to the targets, facilitation (i.e., benefits) in letter-matching latencies did not appear until the 100 ms ISI. The results of a second condition showed that costs were absent when the subjects responded to both the letter targets and the probe. Probing the letter-matching task, however, did not affect the benefits of priming. During probed letter-matching, when primes matched the target letters, RTs were benefited by 37 ms. Probe RTs that accompanied these benefit trials were concurrently decreased by 28 ms compared to the RTs from probes performed concurrently with letter targets beginning with a neutral prime. The results from the dual-task condition suggest that each input was processed serially in accordance with the single-channel model of attention.

The second experiment, however, provided some evidence of parallel processing. Here the spatial position of the prime helped cue the identity of the tone. The magnitude and the time course of costs and benefits from the data, where letter-matching was performed alone, were similar to those in the first experiment. The only difference was the absence of costs at the 250 ms ISI in the second experiment. Probing letter-matching in the second condition once again removed costs and yet left benefits intact. Probe performance did not, however, depend on the 27 ms of benefit from primed letter-matching as it did in the first experiment. Analyses showed that when the position of the prime was compatible with the identity of the tone, probe RTs were 27 ms faster than when it was incompatible. The effect produced by the position of the prime appeared to be independent of any benefit produced by the identity of the prime, contrary to the prediction of the single-channel hypothesis. Moreover, there was no difference in the effect of priming when each task was performed alone or concurrently implying that two primes can be encoded automatically in parallel, affecting concurrent tasks simultaneously and independently.

Letter-matching

The combined letter-matching results in the two experiments, from the conditions where letter-matching was performed without the probe, provided a pattern of costs and benefits that were a reversal to the predictions of Posner and Snyder's two process theory of priming. According to Posner and Snyder, the presentation of a prime automatically activates a set of codes that facilitates the processing of a signal that shares that pathway. The effect of automatic facilitation is said to appear quickly and unintentionally. Signals can activate their respective pathways in parallel with the automatic activation of unrelated signals having no inhibitory consequences. The effects of automatic processing are hypothesized to be quite different from what happens when the subject begins to direct attention toward the prime. The mechanisms of attention operate more slowly and deliberately. Attention has a limited processing capacity and therefore can only process simultaneous signals serially. Once attention is committed to a particular pathway, other unrelated pathways are inhibited from attaining consciousness. The amount of attention directed toward the prime is manipulated by varying the probability that the prime matches both of the target letters. In order to map the onset of automatic and attentional effects the ISI between the prime and target was varied also. According to the two process model of priming, ... "when subjects commit little processing capacity to the prime they will benefit from automatic pathway activation but would have no costs or inhibition" (Posner, 1978 p 100). However, when they have enough time and incentive to attend selectively to the prime, performance will benefit from both automatic activation and directed attention accompanied with costs when the prime is unrelated to the target. When there is not enough time to attend to the prime, RTs should be benefited due to automatic facilitation with no costs to performance..

Posner and Snyder (1975) based their model on the observation of facilitating and inhibitory effects when a high proportion of primes (80%) matched the target letters, whereas only facilitatory effects were observed when a low proportion of primes (20%) matched the target. The results of benefits only, when the subjects paid little attention to the uninformative prime, are said to be the result of unintentional automatic processes. The costs and benefits observed when the subjects committed attention to the informative prime are said to be the product of both automatic and attentional effects. The presence of costs indicated the use of attention. The appearance of costs were, however, relatively late to appear (300 ms ISI) whereas benefits seemed to appear almost immediately after the presentation of the prime (50 ms ISI). This asymmetry of costs and benefits led the authors to concluded that benefits occur earlier than costs because of automatic facilitation and that costs are the sole product of the misdirection of selective attention.

The present findings, however, revealed that when subjects are given an informative prime (matching the target 70% of the time) costs in letter-matching can occur earlier than benefits. This finding suggests that attention can be directed to the prime earlier (ISI 100) than predicted. Moreover, there was no evidence in this condition of the predicted early benefits of automatic facilitation. Therefore, the present data, from letter-matching performance without the probe in the second blocks, do not provide evidence of benefits without costs and, as such, there was no indication of automatic processes that are predicted to appear before the onset of costs.

Related research, using uninformative primes, has also been unable to find evidence of benefits without costs. In a unpublished study, Snyder and Posner (cited in Posner, 1978) used the same type of letter-matching experiment as the original with the exception that subjects matched target letters based on their phonetic identity (Aa) rather than physical identity (AA). The data revealed that, when the uninformative prime (the prime matched the target on 20 % of the SAME trials) was the same name as the target (A/aA), there was evidence of benefits in RTs and error rate. However, there were also costs when the prime was phonetically unrelated to the target (b/aA). When an uninformative prime is used, subjects should pay little attention to the prime and therefore only benefits should be expected which would be considered the results of automatic facilitation. But since there were no benefits without costs there is no way to be sure if the benefits of priming were automatic or attentional.

Flower, et al. (1984) applied Posner and Snyder's cost-benefit analysis to a primed digit task. Subjects in this experiment named targets that were single digits. Prior to the presentation of the digit a pair of flanking noise digits appeared. There were five different SOAs between the flanking digits (primes) and the target. The noise digits and the target were identical 25 % of the time, creating a condition similar to Posner and Snyder's (1975) uninformative priming. The results showed that when the primes were not identical with the target, costs appeared at the 100 ms SOA and then gradually decreased over time. There was no evidence of facilitation when the flanking digits and the targets were identical. These data are interpreted as being at odds with Posner and Snyder's model that purports automatic priming as totally inhibitionless pathway activation.

Studies using semantic priming also do not always report the predicted outcomes (e.g., Becker, 1980; Schreuder, Flores d' Arcais & Glazenberg, 1984). One recent study examined priming effects in two experiments using a naming and a lexical decision task (McLeod & Walley, in press). The results of both experiments showed significant interference in the low attention condition and at the 200 ms SOA. In the naming latency experiment benefits in voice RTs did not appear until the 400 ms SOA. These two experiments appear to confirm that significant inhibition can take place during semantic priming even when there is no incentive to attend to the prime and in a condition where there was supposedly not enough time to attend to the prime.

In another recent paper a highly predictable target word followed semantically related primes at two different SOAs (Smith, Briand, Klein & Den Heyer, 1987). Analysis revealed benefits at short SOAs (200 ms) but no costs, as would be predicted by Posner and Snyder's model. However, there was no indication of inhibition at the longer SOA (1000 ms). According to the priming model, when attention is directed to an informative prime word recognition of related words should benefit and recognition of unrelated words should suffer, which was not the case in their experiment (Smith, et al., 1987) .

In contrast, other studies using semantic priming report findings consistent with those of Posner and Snyder's (1975). The results of semantic priming, however, have been criticized as being the product of strategic factors rather than automatic facilitation (e.g., Becker, 1980). The basic criticism is that the variation in the magnitude and time course of cost and benefit, thought to be attributable to automatic and attentional processes, may also be explained on the basis of semantic strategies. For example, the subject is presented with a prime (e.g., NURSE) which may lead them to expect a similar word to follow (e.g., DOCTOR). When the "expected" appears performance will be facilitated and when the "unexpected" appears performance will be inhibited. Strategic factors and levels of accuracy have confounded Posner and Snyder's data and possibly those of Neely's as well. Therefore, given the inconsistent findings from different studies of priming along with the possibility of confounds of accuracy and strategic factors it is hard to discern if the benefits observed in any priming experiment are the result of automatic facilitation or the product of conscious strategies.

The results from masking studies seem to contradict a strategy explanation. Masking a prime below recognition should prevent the subject from being aware of the recurrent relationship between the prime and the target thus preventing any expectations of what the target would be. Any evidence of priming should therefore, be the result of automatic processes. One problem with masking studies is that the subject is focusing attention directly at the location of the prime. Even if the subject did not perceive the prime, it does not necessarily mean that attention was not involved. Attention and perception are not necessarily the same; one may be the product of the other. Despite the problem with terms like "attention" and " perception," critics of masking have reported that the subject may be more aware of the prime than the experimenters thought (Merikle, 1982).

More problematic to the two-process model of priming is that the results of masking are not always what they were predicted to be. The prediction is that benefits appear quickly and unintentionally and there should be no costs in performance because the prime is processed automatically. An example of contradictory results is found in two studies that failed to find a priming effect at short SOAs but then found them at longer SOAs (Balota, 1983; Fowler, et al., 1981). Worse for the model was the report of costs at long SOAs (Balota, 1983). In another experiment priming was evident at short intervals during masked priming but no effects of priming were found when the prime could be identified (Balota, 1983). Therefore, not only is masking a controversial procedure but masking also does not provide conclusive evidence that the benefits of priming are mediated by automatic processes which are thought to be independent of attention.

From these lexical-decision and masking studies it can be seen that the results of priming are, at best, inconsistent. Part of these inconsistencies are most likely due to the different experimental procedures used to study priming and therefore make the comparisons between experiments difficult. Another reason for inconsistent results may arise from the different uses of the term "attention". Some researchers use the words attention and expectancy as if they are synonymous (e.g., LaBerge, 1973; Posner, 1978). In a priming experiment, when the subject is presented with an informative prime, (a high proportion of which match the target) the prime supposedly conveys to the subject which target to expect on a certain trial. The subject may then adopt a strategy to use the prime to help predict the upcoming target or response. However, when a person is presented with an uninformative prime (only a small proportion of which match the target) there would be no reason for the subject to adopt a strategy and, according to theory, there would be no costs but only benefits during uninformative priming. This does not mean necessarily that the subject does not attend to the uninformative prime or that he or she did not have enough time to perceive it. Consider Posner and Snyder's first experiment. The uninformative prime was presented at the center of the screen for half a second making it difficult for the subject not to see the prime or not have enough time to attend to the prime. In spite of the subjects being able to attend to the prime there were no costs in this condition . Therefore, the conclusion should have been that costs are the result of subjects generating expectations or response strategies. Costs occur only when subjects are given a reason for adopting a strategy and when there is enough time to construct them. This is not the same as saying that the subject was attending to the prime. Costs therefore do not necessarily mean that priming required attention; they may also represent a situation where a subject used a particular strategy inappropriately.

The point to be made is that attention may be involved in both the perception of the prime and in using the prime to anticipate consciously that the next target will be from the same category. Each of these operations may have inhibitory effects. This idea comes from the combination of two different ideas of the function of attention. Posner (1978) assumes that information is processed automatically along parallel pathways, facilitating signals that share a common pathway, uninhibited by the limits of the central mechanism of attention. The main function of attention is to inhibit inappropriate response tendencies, not the accrual of information. An alternative view sees attention as serving a specific function to perception (Walley & Wieden, 1973). These authors assume that when a signal activates a pathway, neighboring pathways must be inhibited to ensure that two or more representations are not perceived simultaneously. Attention is thought to operate much like the lateral inhibition effects that occur in the visual system. Therefore, Posner (1978) identifies attention with consciously guided intentions and strategies whereas Walley and Wieden assume that attention and perception are synonymous.

An alternative approach is to assume that there may be both facilitatory and inhibitory effects to pathway activation regardless of any strategic processes. It is possible that when a prime is presented initially it will automatically activate a pathway spreading excitation to related pathways but as it is processed further, being packaged for conscious awareness, at a certain point related excited pathways would have to be inhibited so as to allow for that particular signal to be indentified precisely. When the subject begins to perceive the prime this inhibitory process may attenuate temporarily any facilitating effect in the processing of related targets. If the prime were to be masked or presented too quickly to be perceived, there would be no inhibitory results. Once the prime had attained consciousness, its excitation exceeding the neighboring pathways, this excitation will again begin to automatically excite related representations. When the subject is attending fully to the prime related targets will be facilitated but because of the limited capacity of attention attending to the prime will interfere with targets that do not match the prime. The facilitatory and the inhibitory effects that occur because of pathway activation will be enhanced by consciously guided strategies which would take an appreciable amount of time to develop. There would, therefore, be costs associated with perceptual interference and costs due to consciously guided strategies each of which is a product of attention.

Some studies of priming have, in fact, found evidence of inhibitory effects in the processing of primes that do not match the target in conditions where consciously guided attention should not be involved (e.g., Flowers & Wilcox, 1982; Taylor, 1977). These studies used uninformative primes and still found evidence of inhibition where there should only be automatic facilitation, according to Posner and Snyder's model. Varying ISI revealed that costs appeared at early ISIs that decreased over time with benefits that decreased more slowly. A closer look at the results from Posner and Snyder's second experiment, where the prime was an informative cue, reveals that there may be costs due to perceptual interference that take place early in the encoding of the prime. In their results, in the condition that mapped the time course of cost and benefit, it can be seen that at the 50 ms ISI there were approximately 18 ms of cost, not statistically significant, but perhaps theoretically significant. Costs then disappeared at the next interval and then reappeared at the 300 ms ISI, the time when attention was supposedly committed. The "early" costs, (ISI 50) may have been the result of perceptual interference between the prime and the target and the "later" costs (ISI 300), the product of the misdirected expectation. In contrast, significant benefits began at the 50 ms ISI, reached their peak at the 150 ms ISI, and remained constant at the 300 and 500 ms ISI. Benefits therefore, appeared at the same time as the "insignificant" 18 ms of costs. Benefits were also at the highest point at the 150 ms ISI, before the onset of attention, when they should have, according the model, peaked at the 300 ms ISI. Therefore, their data may also be interpreted as providing support for the idea that there are two types of cost, cost due to perceptual inhibition and cost from consciously controlled strategies. Costs from perceptual interference appear early (possibly earlier than benefits) but costs from strategies take an appreciable amount of time to construct. Benefits from perceptual facilitation or stimulus repetition and strategic factors may follow a different time course than costs from inhibition, depending on the parameters and possible strategies involved in each task.

One reason for the different time course of costs and benefits in the present experiments may be that subjects, in these experiments, did not adopt consciously the strategy of matching the prime letter to the target letters, as they perhaps did in Posner and Snyder's study. However, the parameters of these experiments allowed subjects enough time, at certain intervals, and incentive to attend to the prime. According to the alternative ideas of priming, costs began before benefits because of the perceptual interference between the unrelated prime and the target. It was at this interval (ISI 100) that the prime had activated the pathway fully, inhibiting related pathways. Because subjects were led to attend to the prime, costs would be maintained at the longer intervals as the prime interfered with attending to the target. Benefits from stimulus priming began later (ISI 100) because at the 50 ms ISI the prime had just begun to reach conscious awareness, a process that requires some inhibition of related targets, which possibly reduced the amount of automatic facilitation that may have occurred earlier, before subjects could perceive the prime. Increased facilitation then appeared later, (ISI 100) resulting in significant benefits in the processing of related targets at longer intervals when the subjects were fully conscious of the prime. This time course of costs and benefits would indicate that costs, and much of the benefits, occurred when the subject began to perceive the prime (attend to it in Walley and Wieden's terms). However, just because subjects could attend to the prime it does not mean necessarily that the benefits in processing targets that matched the prime were not automatic. It appears, from the present data, that letter-matching performance was benefited in a condition where subjects did not use intentionally any consciously guided strategies. In the dual-task situation benefits were unhampered during probing and thus, according to the proposed definitions of automaticity, these effects should be considered automatic.

Probed letter-matching.

In the second condition, of these two experiments, subjects were presented with simultaneous stimuli each requiring a separate response. Subjects were asked to respond to the letter targets (S1) first and the tones (S2) second rather than try to respond to each simultaneously. The general results of this procedure were that costs in letter-matching were removed and RTs to the probes (RT2) were delayed significantly compared to when the probe was performed alone.

The removal of costs, which are thought to be the product of attention, is understandable, if it is assumed that the probe drew from the resources needed to "attend" to the prime. With respect to the idea of two kinds of costs, perceptual and strategic, the explanation of why there were no costs would be that during probed letter-matching the probe uses the resources necessary to inhibit the target. It has been theorized that attention inhibits irrelevant information. This inhibition causes interference when unrelated signals compete for the single-channel because of the limited capacity of attention. Therefore, whether or not it is assumed that costs are the product of using strategies inappropriately or perceptual interference, both require attention which would be affected by a second task that demands attention. When the probe appeared, the attentional resources that were required to process the tone depleted the resources necessary to inhibit the prime and hence there were no costs in letter-matching. Benefits, however, should be unaffected by the probe because there is no inhibition involved in the processing of related signals. Since benefits remained constant during probing, it can be concluded that they occurred unintentionally and were unaffected by a task using the limited resources of the single-channel. Therefore, although letter-matching alone did not reveal when automatic processes occurred, probing did provide evidence of automatic priming.

The delay in the probe RT, past its baseline measure, is a typical dual-task result. The delay in the second (concurrent) task indicates how much attention the first task required. Several models have been advanced to explain the reason for this delay. These models can be divided into structural and capacity models. Structural models are based on the premise that the slowing of RT2 is due to delays imposed by the central mechanism of attention. In each of the structural models it is assumed, as each stimulus is transformed into a response, that stimuli must pass through a series of stages concerned with encoding, choice of response and initiation of a motor response. Certain stages of processing can only be performed one at a time. These models differ however, as to which stage of processing requires the central processor or single-channel. Capacity models, in contrast, propose that all stages of processing draw upon a common limited pool of attention (e.g., Kahneman, 1973), or that there are specific attentional resources that can only be allocated to different cognitive operations (e.g., Wickens, 1980).

Structural Models

The first structural model states that the encoding of two signals cannot be performed simultaneously. The perceptual encoding of a signal is said to require attention and thus each signal must be processed serially (Broadbent, 1980; Treisman, 1969; Welford, 1952). The information in the second signal (S2) has to be held until the single-channel is finished processing the first signal (S1). The RT to the second signal (RT2) is postponed until the end of the RT to the first signal (RT1). Support for this theory has come from the early studies of the psychological refractory period (PRP) that have shown that the RT to the second of two concurrent signals was delayed well above its baseline measure (see Smith, 1967 for a review). The single-channel hypothesis predicts that the second RT will equal RT1 plus RT2 (baseline). Moreover, any factor that delays or facilitates RT1 should delay or facilitate RT2 by the same amount (Welford, 1952). The problem with strict serial processing, later pointed out by Welford, is that the time for which the single-channel is occupied with the information from S1 is equal to the whole of RT1, not taking into account the time in which the encoding mechanism may have been dealing with the information from S2 in parallel with the processing of S1 (Welford, 1980). In other words, according to the single-channel model, perception requires attention and therefore each signal must be processed in sequence which contradicts the evidence that suggests that unattended information often is encoded automatically.

As an alternative to complete serial processing, the second structural model locates the source of RT2 slowing after the encoding stage. At the decision stage, between the encoding and initiation of a response, the central processor can only handle one task at a time. Encoding is performed without attention, automatically; but two decisions cannot be made simultaneously. Direct evidence from dual-task studies for this model is weak. However, studies like Duncan's (1980) would suggest that when two decisions have to be made, performance is significantly reduced. Welford (1980), in his later writing, also states that the perception can occur in parallel, but decisions about two different signals have to be performed one at a time.

The third structural model tries to establish that decisions about simultaneous stimuli can made automatically (Keele, 1973; Keele & Neill,1978). The source of RT2 slowing is that two responses cannot be initiated simultaneously. All processing prior to the execution of a response is completed in parallel, automatically. Keele uses Karlin and Kestenbaum's (1968) study, (the details of which will be discussed later), as evidence that decisions can be performed concurrently and it is the interference caused by the first response that delays the second RT.

Capacity Models

Capacity models do not rely on the idea that the central mechanism is responsible for certain stages of processing. Rather, it is assumed that all processing requires the limited capacity of attention. Parallel processing is possible as long as the demands of concurrent signals do not exceed the demands of the available capacity (Kahneman, 1973) or if the two tasks are sufficiently different from one another, drawing on different types of resources (Wickens, 1980). Deficits in divided attention therefore, appear if one or both tasks are difficult or require some degree of effort. Capacity models that propose that there are multiple pools of attention hold that two tasks can be time shared as long as they do not compete for the same type of resource (Navon & Gopher, 1979). Evidence for this model has been taken from McLeod (1977) where there were delays to S1 caused by increases in the difficulty of S2 and observations that attention appeared to be divided between two tasks when the first task was an auditory task and the second was visual (Allport, Antonis & Reynolds, 1972).

The problem with the capacity model is that any dual-task result is possible because interference between competing signals does not depend on any particular stage of processing. Interference depends instead upon the total demands made by each task. Since interference is nonspecific there is no way of predicting or locating the source of interference thereby making testing of this model difficult.

Of the three structural models, the only one that provides concise predictions is the first. For the single-channel hypothesis the source of interference begins early, at the encoding stage. According to this model, the central mechanism of attention functions as a single-channel of limited capacity that postpones the encoding of the second signal until the response to the first signal is complete. As a rule it has been found that the delays in response to the second signal depend directly upon the response time to the first signal. Research, past and present, has therefore tried to find conditions which either eliminate dual task interference completely or allow operations associated with the second task to be processed in parallel with the first task.

In the dual-task situation of the present two experiments, subjects were presented with a visual and auditory signal simultaneously which required a manual and vocal response. Different sensory modalities and response systems were used to avoid sensory and motor interference. Interference could then be considered the result of attentional limitations. Performance of the second or probe task was always delayed indicating that letter-matching did require the capacity of the single-channel.

Analysis of the first experiment showed that delays to the probe depended upon the response time to the letter pairs. Benefits in letter-matching were passed on to probe latencies. When probed letter targets were decreased by 38 ms, tone RTs were decreased concurrently by 28 ms. This serial processing is exactly what the single-channel hypothesis predicts.

For the second experiment probe RTs did not, however, depend directly on the response time to the simultaneous letter target. In this experiment the spatial position of the prime was also used to cue the upcoming tone. Priming benefited letter-matching by 27 ms. These benefits had no effect, however, on the 27 ms of cost-plus-benefit created by priming the tone. According to the single-channel hypothesis, when letter-matching responses were decreased by 27 ms, RTs to the probe should have been sequentially decreased by 27 ms regardless of the position of the prime. It would appear from the results of the second experiment, according to the structural models of attention, that during dual-priming the encoding of the tone was occurring automatically in parallel during the processing of the letter pair, consistent with the second or third structural model of attention.

In a related study (Karlin & Kestenbaum,1968) increasing the difficulty of the second task may have also created a condition in which a certain degree of parallel processing may occur. Karlin and Kestenbaum presented subjects with one of two possible digits followed by an auditory signal. The second signal consisted of a single tone in one case and two tones in the other. At the longest ISI (890 ms) the RT to the auditory signal when there was only one tone was 199 ms and 280 ms when there were two tones. The difference of 81 ms between the simple and choice RT task presumably represents the amount of time to select a response. At the shortest ISI (90 ms) the difference between these two task. was 27 ms. The single-channel hypothesis would predict that, if only one signal is processed at a time, the difference should be a constant 81 ms through-out all ISIs. On the basis of these findings Keele (1973) has argued that the encoding stage is not the bottleneck in information processing but that the source of limitations is at the subsequent stage of response initiation. He concluded that, while the first signal was being processed, the second signal was also making contact with memory. Furthermore, since there was no difference between choice and simple RTs at the short ISI, the decision about the tone must have been occurring concurrently with the first task and thus the stage of interference is at the initiation of a response.

The Karlin and Kestenbaum (1968) study, however, has been criticized for not providing adequate baselines for S1 and S2. The authors themselves state that the results could be attributed to a grouping strategy because it appeared that the subjects delayed the first response to determine what the second response would be. Becker (1976), in a similar study, failed to obtain the same results. In this study, a control measure was given for the simple and choice tone latencies. These tones later probed a lexical decision task. It was thought that when the word did not require a decision (during early encoding) the decision for the tone could be carried out. During these early stages, the difference between RT2 simple and RT2 choice should be equal as in the Karlin and Kestenbaum study; however, this was not the case. Becker concluded that either the encoding of the word or the decision about the tone or both required attention.

An important factor in the amount of interference in a dual-task situation is the compatibility between the stimuli and the responses. According to Greenwald and Shulman (1973), if two stimuli have ideomotor compatible responses, then decisions about the two stimuli can be made concurrently because they bypass the single-channel completely. The two ideomotor or S-R compatible tasks required subjects to respond to a visual arrow by moving a switch in the direction indicated by the signal and repeating one of the two spoken letters "A" or "B". Varying the interval between the two signals (ISI) revealed that RT2 did not decrease as ISI increased. According to the single-channel equation, RT2 should decrease and ISI increases. This finding led the researchers to hypothesize that, if two signals have ideomotor compatibility, then at least one of the decisions about the stimuli can be made automatically without interfering with the decision about the other signal.

Part of the reason for the Greenwald and Shulman (1973) result may be that the subjects tried to hold back their response to S1 until S2 appeared, that is, they tried to 'group' their responses which, in effect, lengthened the RT to S1 and left the RT to the second signal (S2) the same throughout the ISI. When their study was replicated, controlling for the grouping confound, the usual PRP or single-channel effect was found (Brebner, 1977). Stimulus-response or ideomotor compatibility may reduce the amount of interference in overlapping tasks but it does not seem to eliminate it.

Another hypothesis is that if combined tasks involve different response and sensory modalities there will be no interference and hence complete parallel processing is possible. In other words if two tasks do not compete for the same resources they can be performed together as well as they can alone. Allport, Antonis & Reynolds' (1972) paper supposedly challenges single-channel theory based on this idea. They showed, in the second of two experiments that, playing piano from a written score could be combined with an auditory shadowing task with no interference to either task. They stated that there was no (significant) increase in errors from a well practiced errorless shadowing baseline. Piano playing was also judged no worse under the combined performance. The authors claim that tasks that are very dissimilar, supposedly using distinct or independent channels, are exceptions to PRP.

Despite the many methodological problems with this experiment, it is interesting to note that either these two task can be combined or that, on closer examination, given the nature of the situation, there was still some interference. The reason that the two tasks were performed together, as well as alone, cannot be because one task was visual and manual and that the other is auditory and vocal, as the authors believe. Early dual-task studies showed that the PRP remained when the signals where visual and auditory and the responses were manual and vocal (e.g., Davis, 1957; Smith, 1969). The reason for the apparent parallel processing could be that subjects alternated playing the piano from the score with shadowing. From the context of a piece of music and spoken prose, upcoming information is highly predictable and as such would allow ample preview. It is possible that during the gaps in shadowing or reading music subjects were able to switch from one task to the other giving the appearance of parallel processing. Part of the results could also be attributed to the S-R compatibility that existed in the shadowing task that would lessen the amount of interference. This study has often been cited as an example of complete divided attention but, considering that their measures of stimulus input and responses were so poor, it is hard to draw any sound conclusions.

From the evidence of the above mentioned studies it would seem that people cannot divide attention completely between two competing sources of information when each source requires a separate response as is predicted by the single-channel hypothesis. However, when factors such as ideomotor compatibility, different modalities and increased alternatives or difficulty are introduced there appears to be less of a decrement due to divided attention than would be predicted by the single-channel hypothesis. Therefore, when these factors are introduced the amount of interference between simultaneous tasks seems to be reduced allowing some degree of parallel processing to occur. Whether or not any degree of parallel processing results from two or more processes dividing the limited capacity of the single-channel, or that some stages of processing do not use the central processor and are performed automatically are still an unanswered questions.

Conclusions

The two experiments have shown that costs and benefits coexist simultaneously unless a secondary probe is used to investigate the resources required to utilize or construct a strategy. These findings suggest that the benefits of priming are not attentional and occur automatically. The inhibition associated with costs, however, may be the product of either using strategies inappropriately or perceptual interference, or a combination of both, possibilities that remain to be tested. The second experiment relied on a relatively new technique, dual-priming. From this it appears that attention can be divided between separate stimulus dimensions, encoding each in parallel priming two task with no loss in performance. In this condition cue utilization did not seem to be limited by attentional resources. Rather, both cues were processed automatically thus providing evidence at odds with a strict serial processing theory of attention. This dual-priming method would be useful in measuring the limit in the number of primes that can be processed simultaneously and the level of information that can be extracted in parallel when higher level primes are used.

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