Perceptual encoding and the stimulus probability effect.

PERCEPTUAL ENCODING

AND THE

STIMULUS PROBABILITY EFFECT

A Thesis Presented

By

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Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

September 1982

Psychology

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For Chris and Randy, and Cindy, who know their contributions.

ACKNOWLEDGEMENTS

I thank the members of my committee, Dan Anderson and Jerry Myers, for their time, patience, and helpful suggestions. Special thanks go to the Chairperson of the committee, Arnie Well, for his unflagging support and encouragement, and for making his office a place where I could feel welcome.

ABSTRACT

Perceptual Encoding and the Stimulus Probability Effect

(September, 1982)

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Three experiments were conducted to investigate the effect of stimulus probability on perceptual encoding. In Experiment 1, the role of an abstract code as a mediator of the effect was tested. Subjects viewed and responded to stimuli in conditions which either encouraged or discouraged the use of abstract codes. Contrary to prediction, the effect of probability tended to be greater at a low level of stimulus contrast when the use of abstract codes was discouraged, and unaffected by contrast when their use was encouraged. Subjects' responses to a questionnaire indicated that the use of abstract codes was determined to some extent by individual strategies. It was proposed that it is unnecessary to appeal to an abstract code that differs from a name code as a mediator of the probability effect at encoding. In Experiments 2 and 3, the degree to which the probability effect at encoding may be explained by sequential expectancy effects was examined. The probability effect was greater at low contrast in Experiment 2, and the results of Experiment 3 indicated a similar trend. The magnitude of the contrast effect did not vary as a function of the preceding stimulus

sequence in either experiment. Previous results have shown that the size of the contrast effect does not depend on whether or not the ensuing stimulus is preceded by a valid cue. These findings were interpreted as suggesting that the probability effect at encoding is the result of a relatively static mechanism in which expectancies do not shift over trials.

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CHAPTER I

INTRODUCTION

The assertion that the acquisition of information may be guided by preexisting knowledge and other nonstimulus factors is a common one. It is the basis for the top-down/bottom-up distinction, and has been invoked in models of information processing that run the gamut from perception to word recognition to comprehension (e.g., Becker and Killion, 1977; Kintsch and van Dijk, 1978; Meyer, Schvaneveldt, and Ruddy, 1975; Minsky, 1975; Morton, 1969). The present study is an attempt to explicate the mechanism by which nonstimulus factors influence perceptual encoding. Perceptual encoding is defined here as the set of processes including and temporally preceding the identification of a stimulus.

For ease of reference, nonstimulus factors that potentially influence the perceptual encoding process will be termed "cognitive" variables. The use of this label is not meant to imply anything about the degree to which these factors may be under the subject's conscious control. This remains an empirical question. Some examples of cognitive variables are psychological factors such as expectancy and incentive (or motivation), and experimentally induced factors such as adjustment to task instructions, stimulus repetition, and in particular, stimulus probability. It will ultimately be desirable to assess the effects of each of these variables in turn with respect to a model of encoding mechanisms. Initially, though, I have selected stimulus probability as the cognitive variable of interest, with the goal of establishing a general model of the functioning of cognitive factors based on the results obtained via this variable.

The Stimulus Probability Effect and Its Loci

Stimulus probability is defined as the relative frequency with which a given stimulus is presented during a task. Two common ways of manipulating probability have been to vary the number of equally probable stimuli and to vary the presentation probabilities of each stimulus. Hyman (1953) used both of these manipulations in demonstrating that reaction time (RT) is a linear function of the amount of information per stimulus presentation. He found that RT increased with decreasing stimulus probability.

Although in typical manipulations of stimulus probability the effect builds up over trials, effects due to instructions stating stimulus probabilities have also been observed. For example, Bartz (1971) varied the number of equiprobable stimuli and informed subjects of the size of the stimulus set beforehand. When RTs on the first trial were analyzed, results showed the same relationship of RT to amount of information as Hyman found. This suggests that the prior expectancy of the subject, as well as experience in the task, may contribute to the probability effect. This possibility will only be mentioned here, but is worth noting with respect to the potential involvement of conscious control in the mechanism underlying the probability effect.

A good deal of past research has been concerned with establishing the locus of the probability effect. As a result, there have been two major classes of explanation regarding the effect. One of these maintains that more probable stimuli are identified faster; the other states that probability has its effect at the stage of response retrieval. One paradigm that has been used extensively in attempting to decide the issue is that of LaBerge and Tweedy (1964). Three or more stimuli are assigned to two responses in order to compare RTs to stimuli that differ in presentation probability but require the same response, and to compare RTs to stimuli that share the same presentation probability, but require responses associated with different probabilities. It is assumed that RT differences of the first type implicate a perceptual locus of the probability effect, while differences of the second type suggest an effect at the response decision stage. Results of studies using this paradigm have been mixed, with some studies suggesting that more probable stimuli are identified faster, others that response processes are primarily affected, and still others which suggest that the probability effect is composed of both perceptual and response components (e.g., Dillon, 1966; Hawkins, Thomas, and Drury, 1970; LaBerge, Legrand, and Hobbie, 1969).

In addition to the obvious difficulty of interpretation in the face of these conflicting results, it should be noted that the logic which implicates a perceptual locus for the probability effect based on RT differences to unequally probable stimuli with the same response is not necessarily valid. Theios and his co-workers (Theios, 1975; Theios, Smith, Haviland, Traupman, and Moy, 1973) proposed a mechanism based on the retrieval of appropriate stimulus-response (S-R) mappings which seems equally plausible, but would localize probability effects of this nature at a response selection stage of processing. The mechanism is assumed to be comprised of a dynamic memory stack of stimulus representations paired with their responses. The stack is searched in a serial manner until a match with the presented stimulus is found, and ordering in the stack is based on frequency and recency of S-R occurrences.

A second approach that has been utilized in determining the locus of the stimulus probability effect relies on the additive factors methodology of Sternberg (1969). The notion is that if the magnitude of the probability effect varies depending on the level of a variable known to affect only a given stage of processing, then it may be concluded that probability has at least some of its effect on that stage. Two caveats must be heeded concerning this approach: (1) The finding that probability interacts with a factor known to affect one stage of processing does not preclude the possibility that probability may also affect another stage, and (2) care must be taken in interpreting additivity, as illustrated by Taylor (1976). To use one of his examples, a stage labelled "stimulus encoding" may in fact be composed of several substages. It is possible that two factors may affect two different substages, thus failing to interact. The typical conclusion would be that at least one of the factors does not influence encoding. A more reasonable conclusion might be that the encoding "stage" actually involves two stages.

Miller and Pachella (1973) conducted a study which illustrates the use of the additive factors methodology in localizing the probability effect. They manipulated stimulus probability and stimulus quality in a naming task and a memory scanning task requiring a button-press response.

Stimulus quality was manipulated by varying the contrast, or intensity, of visually presented digits. They found that the magnitude of the probability effect increased with decreasing stimulus quality in both tasks. Based on the assumption that stimulus quality affects encoding but not response processing, their conclusion was that stimulus probability has an effect at the encoding stage. (I will discuss this assumption later on.) This interaction of stimulus contrast and probability has been reported a number of times in the literature (e.g., Miller, 1979; Miller and Pachella, 1976; Stanovich and Pachella, 1977).

The additive factors method has also been used to yield results that suggest a response locus of the probability effect. Hawkins, MacKay, Holley, Friedin, and Cohen (1973) manipulated S-R compatibility along with stimulus and response probability in the LaBerge and Tweedy (1964) paradigm. Compatibility was manipulated by asking subjects to verbally respond to visually presented letters with their correct names in the high-compatible condition, and with names of different predesignated letters in the low-compatible condition. Two stimuli were mapped to one response in the task by using as stimuli both upper- and lower-case versions of letters of the same name. It was assumed that S-R compatibility is a variable which affects response processes, but not encoding. Hawkins and his co-workers found that the size of the response probability effect (the difference in RTs to equiprobable stimuli associated with responses of unequal probabilities) increased with decreasing S-R compatibility, indicating that both factors operate on the same (response) stage. In addition, they found that the probability effect resulting from the comparison of RTs to the unequally probable stimuli sharing the same response was also affected by varying S-R compatibility. That is, the "stimulus" probability effect was larger in the low-compatible condition. This result was interpreted as implying that probability does not have any effect on encoding.

The preceding conclusion may be invalid for at least two reasons. First, Hawkins and his associates have implicitly assumed that the "stimulus" probability manipulation may affect either an encoding or a response stage, but not both. In other words, they have ignored the possibility that probability may affect both stages. In order to make a more legitimate claim, they might have also varied contrast in order to provide the opportunity of observing an interaction that would implicate an encoding locus. Second, it was assumed that mechanisms underlying the probability effect are the same regardless of the nature of stimuli or task. This may be a faulty assumption. Using a memory scanning task, Miller and Pachella (1976) found that stimulus probability interacted with contrast when the stimuli were digits, but not when the stimulus set consisted of nonsense figures. They concluded that probability affects the process of naming the stimulus, since names are readily available to the subject for digits, but not nonsense figures. Miller and Pachella also observed a sizeable probability effect for the nonsense figures, which suggests that a response locus for the effect exists along with the encoding locus suggested by the contrast by probability interaction.

In the study by Hawkins and his colleagues, letter stimuli were responded to with their appropriate names in the high-compatible condition, but with names of other letters in the low-compatible condition.

Whereas subjects in the former condition could easily utilize a name in executing their responses, this would be much more difficult for subjects in the latter condition. In fact, the readily available name of the stimulus should actually interfere with the correct response in this condition. In light of the Miller and Pachella (1976) results, it seems likely that processing in the two conditions was fundamentally different. If this were the case, a more accurate interpretation of the results of the study by Hawkins and his co-workers would be that the mechanism underlying the probability effect at the response stage is also affected by S-R compatibility, while the mechanism at the encoding stage is not. Their observation of the compatibility by probability interaction then follows directly.

If this interpretation is correct, there should be a probability main effect for those stimuli in the high-compatible condition that shared the same response, but appeared with unequal frequencies. This main effect was not observed. However, Miller and Pachella (1973) did observe a significant main effect of probability with an absolute mean difference of roughly the same magnitude (15-20 milliseconds) as was present in the study of Hawkins and his colleagues. The latter employed relatively few trials with their subjects (240 versus 800 in Miller and Pachella, 1973). If, indeed, the probability effect is one which builds over trials, it may be that subjects did not undergo enough trials for the effect to sufficiently build up. In support of this interpretation, the advantage of high- versus low-probability stimuli in the Hawkins et al. study increases over blocks. Finally, there is some evidence of a speed-accuracy trade-off, with low-probability items showing a larger error rate. This could have reduced the probability effect in the RT data.

On the basis of the results reviewed up to this point, it seems reasonable to think that stimulus probability may have its effect at both encoding and response stages of processing. Most of the studies that I have mentioned have been primarily concerned with establishing the locus of the effect, and to a lesser extent (if at all) with specifying the mechanism involved. As previously mentioned, the description of the mechanism underlying the probability effect, particularly with regard to encoding, is the primary objective of this project. Accordingly, several studies will now be reviewed which represent attempts to describe this mechanism, or to at least predict when probability will affect encoding, and when it will not.

Assumption Localizing the Effect of Contrast at Encoding

Before considering the research related to the effects of stimulus probability on encoding, I will discuss the assumption which localizes the effect of contrast manipulation at the encoding stage of processing. This assumption is critical in all of the studies that have employed the additive factors methodology in establishing an encoding locus of the probability effect. For this reason, it is important that there exists some evidence in support of this claim.

The assumption that contrast affects encoding is consistent with findings from the literature on visual masking. For example, Schiller (1965) found that a light flash effectively masks a form if presented monocularly, but not when presented dichoptically. In the first case, target and mask presumably travel via the same peripheral pathway, permitting the mask to have its effect at an early level of processing. The convergence of the two is more central in the dichoptic condition, however. A light flash may be thought of as reducing the contrast of the stimulus, and peripheral processing may be considered to occur earlier than central processing. Furthermore, Turvey (1973) and Schiller found that a pattern mask is effective in dichoptic presentation, thus ruling out the possibility that stimuli presented in this manner are simply immune to masking.

Pachella and Fisher (1969) found that asmyptotic performance in a discrimination task was unaffected by luminance level, but was lowered by increasing stimulus similarity. This supports the claim that the effect of contrast is on the rate of information accrual, rather than on the product of the identification process.

Finally, Hardzinski and Pachella (1980) used a memory scanning task with alphabetic stimuli, and asked subjects to respond on the basis of either a physical or name match. Subjects were presented with memory sets of various sizes, which were comprised of upper- and lowercase versions of a letter in the name match condition, letters of the same case in a control condition, and single versions of letters of either case in the physical match condition. Stimulus contrast was also manipulated. Only the scanning rate in the physical match condition was affected by contrast, and this result could not be replicated in a second experiment. Hardzinski and Pachella interpreted these results as indicating that an abstract internal representation is obtained from which the effects of the contrast manipulation have been removed. It is this representation that is used for comparison in the memory scanning stage. The effect of stimulus contrast can thus be presumed to have a locus before the memory scanning stage (hence before a response stage), namely, at an encoding stage. The aforementioned results of studies in which stimulus contrast was manipulated suggest that the assumption localizing the effect at encoding is a reasonable one.

The Probability Effect and Its Potential Causes

This section is divided into two subsections. The rationale for this division may be understood if the effect of probability is analyzed in terms of a state in the subject which somehow arises due to the probability manipulation, and the causes of this state. However it arises, once there, the state manifests itself in some way in the processing of a stimulus. The studies and models discussed in the first subsection address the manner in which this (the probability effect) occurs. In contrast, the studies reviewed in the second subsection concern themselves with how the subject comes to be in a certain state at a given point in time. In other words, how does the manipulation of probability produce varying states in the subject such that their effects on processing may be observed?

Mechanisms of the probability effect. As already mentioned, Miller and Pachella (1976) observed additivity between probability and contrast when nonsense stimuli were used, but not for digits. The conclusion was that probability has some of its effect upon a stimulus identification stage. In an attempt to corroborate this conclusion, Pachella and Miller (1976) manipulated stimulus probability and contrast in a letter matching task (Posner and Mitchell, 1967). Under name identity instructions, Pachella and Miller observed a probability effect on name match and different trials, but not on physical match trials. They reasoned that on physical match trials, a relatively fast response could be made on the basis of physical identity alone, and this response would not have to involve a naming process. If the stimuli are not physically identical, however, a naming process would presumably be involved. The finding of a probability effect for only those trials that required the naming of the stimulus suggests that probability has an effect on stimulus identification. In further support of this conclusion, Pachella and Miller failed to observe a probability effect for any trial type (physical match, name match but different case, or different) when responses were made on the basis of physical identity.

A troublesome aspect of the Pachella and Miller study is the failure to observe a contrast by probability interaction for the trials in which stimulus identification should have been involved. They suggested that the effect of degradation may have been removed by the early physical comparison process as a result of testing for physical identity. However, this suggestion leads to the prediction of an additive relationship between contrast and trial type. While this interaction was not significant at a conventional level, there was a strong indication that the effect might have been present. Under the name identity criterion, the effect of contrast was 72, 40, and 49 milliseconds for physical match, name match, and different trials, respectively. The results of this study are thus more equivocal than might be desired.

Miller (1979) conducted a number of experiments in an attempt to describe the underlying mechanisms of the probability effect at the encoding stage of processing. He used additive factors logic and manipulated stimulus quality, pairing two stimuli of different probabilities with one response, and two equiprobable stimuli (each visually similar to one member of the first pair) with another. An RT difference between two stimuli of the first type is referred to as a direct probability effect, and a difference between stimuli of the second type is an indirect probability effect. An example will explain the reasoning behind the use of these terms.

In one experiment, Miller used the letter pairs I-K and T-R. Notice that a member of each pair has a good deal of featural overlap with a member of the other pair. The assignment of stimuli was counterbalanced, but for some subjects I and K were assigned to one response and appeared with probabilities of .46 and .04, respectively. T and R were assigned to the other response and appeared with probability of .25. Each response was thus equally likely. If probability was to have the effect of sensitizing specific feature detectors such that more probable features are more readily identified, one might expect a direct probability effect when comparing RTs to I and K, and an indirect effect when comparing RTs to T and R. If such effects are present, then they should be affected by contrast, assuming feature detection takes place during encoding. Miller found a direct probability effect which was greater at a lower level of contrast, but failed to observe an indirect probability effect. He interpreted these results as evidence that probability does not affect featural processing, and hypothesized that probability either affects a detector which is sensitive to the entire visual form of the stimulus or the naming process (cf. Miller and Pachella, 1976; Pachella and Miller, 1976).

In order to distinguish between these two alternatives, Miller ran an experiment using the same task, but with different stimuli. The stimulus set consisted of two versions of each of the uppercase letters A and Y. One version of each letter was paired with a single response, and the rest of the procedure was identical to the previous experiment. If probability affects sensitivity to the entire physical form, then one should observe a direct probability effect which interacts with contrast, and no indirect probability effect. Since it is not possible to perform this task solely on the basis of the name of the stimulus (since each name is associated with both responses), the stimulus identification (or naming) explanation predicts that there should be no contrast by probability interaction in the direct condition.

Miller observed a direct probability effect, but there was no contrast by probability interaction in the direct condition. He did not find an indirect probability effect. These results favor the stimulus identification explanation. Although it was logically possible for subjects to make their responses on the basis of the stimulus name coupled with some sort of physical information, it appears that subjects did not do this. In fact, Miller reported that there was a reverse probability effect for the error rates in the indirect condition, suggesting that the overlearned stimulus name became available in spite of subjects' strategies and actually served to interfere in the task. That is, the name of the more probable stimulus in the direct condition became associated with that response, so that when the other stimulus of the same name was presented, subjects had to combat a tendency to respond incorrectly.

Miller was also interested in whether it is necessarily the activation of a name code *per se* that is affected by probability when the contrast by probability interaction is observed, or if some more general abstract code might also be affected. A description of the stimuli that he used to address this question should clarify the notion of an abstract code. Miller used a set of four stimuli that may be thought of as consisting of the orthogonal combination of binary values on two dimensions. Each stimulus was comprised of a shape (an X or a diamond) and a bar position (a horizontal bar which was either above or below the shape). The task and the assignment of stimuli to responses were the same as in the other experiments. To give an example, the X-with-underbar and diamond-with-overbar might be paired with one response and be the direct probability stimuli, while the X-with-overbar and the diamond-with-underbar would be paired with the other response.

As in the previous experiment, subjects cannot respond solely on the basis of the shape name, since it is paired with both responses; nor does it seem likely that subjects would invent their own names for each stimulus, since this did not occur in other experiments using nonsense stimuli (Miller and Pachella, 1976), or in Miller's Experiment 3. Miller argued that in contrast to those experiments, however, the stimuli may easily be uniquely identified on the basis of their values on two salient dimensions, corresponding to the notion of an abstract code.

Miller (Experiment 4) observed both direct and indirect probability effects with these stimuli, but only the former was sensitive to contrast. This result is consistent with the possibility that subjects utilized abstract codes in encoding the stimuli, and that the activation of these codes was affected by probability. As Miller pointed out, the finding that indirect probability did not interact with contrast suggests a different mechanism may be involved than the one underlying the direct probability effect.

To further test the notion that probability has an effect on the activation of an abstract code, Miller (Experiment 6) asked his subjects to perform a task that was identical to that of Experiment 4, but in which the stimuli could not be identified on the basis of their dimensional values. Although Miller referred to the stimuli of Experiment 4 as consisting of two binary features, it may be less ambiguous to adopt some working definitions that have been proposed by Garner (1978). He suggested that an attribute is any variable property of a set of stimuli, a feature is an attribute of a stimulus that either does not exist or exists at only a single level within a stimulus set, and a dimension is an attribute that exists at some positive level within each member of a stimulus set. Thus, the stimulus set of Experiment 4 possessed the dimensions of shape and bar position. In contrast, the four stimuli used in Experiment 6 were comprised of a shape dimension (an X or a box) and one of four features (under- or overbar for the X, vertical or horizontal bar inside the box). The S-R mapping was such that a response could not be made solely on the basis of the stimulus shape. Since dimensional values presumably were represented as abstract codes in Experiment 4, and since this representation was not possible for the combination of task and stimuli in Experiment 6, Miller predicted that probability would not have an effect on encoding in the latter experiment. The results indicated a direct probability effect, no indirect effect, and no interaction with contrast, thus upholding Miller's prediction. He interpreted these results to mean that stimulus probability may affect not only the activation of a name code, but also any abstract, meaningful code. The implication is that somehow dimensions are meaningful or abstract, and features are not.

Logogen model. Miller (1979) explained his results using a version of Morton's (1969) logogen model. According to this conception, the encoding of the visual features of the stimulus activates a particular logogen that may correspond to either a name code or an abstract code, in the sense described earlier. The effect of probability at the encoding level is to adjust the threshold at which a logogen is activated. Specifically, logogens corresponding to highly probable stimuli are assumed to have lower thresholds than those corresponding to less probable stimuli. Thus, the amount of evidence necessary to activate logogens of more probable stimili is less, meaning that those logogens may be activated faster. If one makes the additional assumption that the effect of contrast is on the rate of accumulation of visual features (cf. Pachella and Fisher, 1969), this leads to the interaction between the effects of probability and contrast at the encoding level.

The understanding of this mechanism is relatively straightforward for logogens corresponding to the name of a stimulus, but is less so for logogens corresponding to abstract codes, as would be the case in Miller's Experiment 4. In clarifying the process under these circumstances, Miller claimed that there need not be a one-to-one correspondence between stimuli and logogens. In his Experiment 4, for example, a logogen would exist for each value on the two dimensions. A given stimulus would activate two logogens in this case, and a response would be made on the basis of the particular combination of activated logogens. The direct probability by contrast interaction is thus in accordance with the model. What does not seem to be in accordance, however, is the additivity of contrast and probability in the indirect condition. As Miller pointed out, each stimulus in the indirect condition had a more probable and a less probable dimensional value, so it might be expected that the facilitating effects would cancel. This did not happen, however, and Miller proposed that the indirect effect was due to the greater salience of the shape dimension over the bar position dimension. Since the same mechanism is responsible for the indirect probability effect under this interpretation, one would expect to observe an interaction of the effect with contrast, as in the direct probability condition. The failure to observe such an interaction is problematic for this interpretation.

Finally, Miller suggested that in situations in which the probability effect is unaffected by the level of contrast, the subject does not (or perhaps cannot) utilize abstract codes. One possible reason for this is that abstract codes are useful only when a memorized response rule is necessary in order to perform the task. When this is not the case, subjects may in effect bypass the stimulus identification stage by setting up direct visual-to-motor linkages, according to Miller. It may also be the case that subjects are unable to use an abstract code because one simply does not exist, as in some tasks using nonsense stimuli (e.g., Miller, 1979, Experiments 3 and 6; Miller and Pachella, 1976). Although it was possible to construct arbitrary stimulus names for these stimuli, it may have been that the association between stimulus and name was too weak to allow this to be a viable strategy in those tasks.

If the effect of probability at encoding is to lower the activating threshold of a logogen corresponding to a name or abstract code, it follows that the effect should transfer from a direct probability condition using uppercase letters (for example) to an indirect condition using lowercase letters with the same names. Also, the indirect probability effect should interact with contrast. Miller and Hardzinski (1981) tested these predictions, and found no evidence of transfer across case. They also replicated Miller's (1979) finding of no transfer to visually similar letters, providing further evidence against the sensitizing of feature detectors as a mechanism for the probability effect. They concluded that probability affects the rate of transmission of evidence about specific features to a specific logogen, labelling this phenomenon "route-specific activation." Miller and Hardzinski mention case-specific sublogogens for a given letter as possible sites for probability-induced activation. These sublogogens would then transmit evidence to letter-name logogens. However, it is not clear how this explanation would account for effects with non-alphanumeric stimuli (cf. Miller, 1979, Experiment 4).

Verification model. An alternative mechanism of the probability effect is provided by the verification model proposed by Becker (1976, 1980; Becker and Killion, 1977). Although this model was originally intended as an account of word recognition, Becker has suggested that it may be broadened to include general expectancy effects. According to the model, stimulus information is first stored in sensory memory, from which sensory features are extracted via feature analysis. These sensory features serve to activate what I will call stimulus detectors (corresponding to Becker's word detectors) by accumulating in a manner similar to that in the logogen model. Up to this point, there is essentially no difference between the verification model and the logogen model. The first difference between the two lies in the significance of an activated stimulus detector; namely, the activation of a stimulus detector does not correspond to stimulus recognition. This is because it is assumed that the output of feature analysis is limited to the identification of primitive featural components such as arcs and line segments. The output lacks information concerning the relations between these primitive components. The purpose of feature analysis, then, is to specify a set of stimulus detectors (hereafter referred to as the sensory feature-defined set) that are consistent with the primitive featural characteristics of the stimulus.

Once this set has been identified, a process known as verification commences, and it is through this process that the stimulus is actually identified. The "stimuli" corresponding to the stimulus detectors are serially selected, and are used together with additional information stored with the stimulus detector to construct a representation of the stimulus. The additional information concerns the relationships among the primitive features that have been identified. This information is presumably abstracted from previous experience. The constructed representation is compared with the information in sensory memory, and if a good match is obtained, the stimulus is identified. If a match is not obtained, another "stimulus" is selected and a representation is constructed and compared with the sensory information, the process continuing in this manner until the stimulus is identified. Becker has suggested that the order in which "words" are selected from the sensory feature-defined set in a word recognition task is determined by word frequency. A generalization of this view would be that the order of "stimulus" selection is determined by relative frequency, or probability.

This is only one way that probability may have an effect according to the verification model. A second possibility arises via the factor of expectancy. In this case, an expectation of a particular stimulus by the subject is enough to activate one or more stimulus detectors. The verification process can thus begin without waiting for feature analysis to take place. If it is assumed that more probable stimuli are correctly expected more often than less probable stimuli, this mechanism can produce a probability effect.

The mechanism responsible for the probability by contrast interaction in the verification model is quite different from that in the logogen model. It is assumed that contrast has its effect on the feature analysis process and also on the rate at which information is stored in sensory memory. The verification process is assumed to be unaffected by contrast manipulation. A highly probable stimulus would tend to be correctly expected more often and feature analysis thus bypassed, while processing of less probable stimuli would more often than not include feature analysis. This is because an incorrect expectation would necessitate the selection of further "stimuli" from the sensory feature-defined set. The effect of contrast will thus tend to have two loci (sensory memory and feature analysis) for less probable stimuli, and only one (sensory memory) for highly probable stimuli. The verification model is therefore able to account for probability and contrast main effects, and the probability by contrast interaction. Furthermore, this account differs from that of the logogen model, which uses a combination of varied logogen thresholds and varied rates of accumulation of evidence to explain these effects. While neither model is satisfactory in its ability to predict the presence or absence of a probability by contrast interaction, the verification model perhaps is less so. Whereas the logogen models assumes that a logogen does not exist for stimuli which are not characterized by abstract codes, the verification model lacks a specific construct such as a logogen, assuming that expectancies are not or cannot be generated at a perceptual level when stimuli are not identified on the basis of abstract codes. The importance of the abstract code as a mediator of the probability effect on encoding is the focus of Experiment 1 of the present student.

Causes of the probability effect. It is possible to conceive of the probability effect as an indirect result of one or several (more) basic factors (e.g., Keele, 1973; Posner, 1978). One candidate for such a factor is expectancy, the conscious anticipation of a particular stimulus. RTs to predicted (expected) events are less than to nonpredicted events (e.g., Bernstein and Reese, 1967), and subjects tend to correctly expect frequent events more than infrequent events (e.g., Myers, 1976). Thus, the probability effect may be a result of the fact that the probability of a correct expectation given a more probable stimulus will be greater than the probability of a correct expectation given a less probable stimulus. A second factor that may underlie the probability effect is stimulus repetition. Responses to repeated stimuli tend to be faster than to nonrepeated stimuli (e.g., Bertelson, 1963). The probability effect may merely be a reflection of the fact that stimuli are repeated more often than infrequent stimuli.

A number of investigators have examined the extent to which expectancy, repetition, and probability effects may be identified with one another. The procedure in these studies has been to look for the presence of one effect with the other factor(s) held constant. If the effect is detected, it may be concluded that the factors ought not to be identified with one another. Keele (1969) failed to observe a repetition effect for trials preceded by an incorrect prediction. Geller and Pitz (1970) obtained a similar result, but observed a residual repetition effect when two or more successive repetitions occurred. Bernstein and Reese (1965) manipulated probability via the number of alternative stimuli presented and observed a probability effect for incorrectly predicted stimuli. Similarly, Hinrichs and Crafts (1971) obtained a probability effect for incorrectly guessed stimuli by directly manipulating stimulus presentation probability.

On the basis of these results, it may be concluded that the probability effect does not result solely from expectancy. In addition, expectancy might underlie the repetition effect, implying that probability is also distinct from repetition. The discrepancy between Keele's results and those of Geller and Pitz weakens the latter conclusion, though, and suggests that more than the immediately preceding stimulus should be considered when examining sequential effects.

A number of studies have examined the nature of higher order sequential effects. Remington (1969) manipulated probability and observed a probability effect with sequence held constant. He also noted significant fifth-order sequential effects. (The preceding n-1 stimuli are taken into account in an nth-order analysis.) Using the waveform of the cortical event-related potential as the dependent measure, Squires, Wickens, Squires, and Donchin (1976) reported similar results. Schvaneveldt and Chase (1969) examined fourth-order sequential effects and found that subjects' expectancies obtained via verbal predictions did not correspond well with sequential effects on reaction time, a result consistent with that of Geller and Pitz (1970). This suggests that expectancy might be characterized using two components; one would involve the subject's conscious expectancy (or prediction) made on the basis of hypotheses conforming to probabilistic intuitions, and the other could be a lower level, perhaps unconscious, expectancy produced by the preceding stimulus sequence. Together with the findings regarding probability, the results of the above studies suggest that there are at least three distinct factors operating in choice reaction time tasks: conscious expectancy, sequential expectancy, and stimulus probability.

The previous conclusion follows only if the assumption is made that a subject is in either state E_i or $\bar{E}_i$ (expects or does not) with respect to a particular stimulus. This assumption is not necessarily valid. For example, a model that assumes a subject to be somewhere on an expectancy continuum seems equally plausible. Thus, the finding of a probability effect for unpredicted stimuli (for example) does not necessarily imply that probability is unexplainable in terms of expectancy. The predicted stimulus may merely have been the most expected out of some set of expected stimuli. More probable stimuli could tend to fall higher on the expectancy continuum than less probable ones, so expectancy would then be able to account for the probability effect.

Furthermore, all of the studies previously mentioned in this section have a serious shortcoming in light of the present discussion. None has shown that a unique probability mechanism must exist at an <u>encoding</u> level. It is possible that the factors are independent at a response level of processing, but conscious expectancy (for example) underlies the probability effect at the perceptual level. Such a state of affairs would implicate a dynamic (rather than static) mechanism as responsible for the probability effect at a perceptual level. This possibility was tested by Miller and Anbar (1981). They attempted to separate the effects of probability and conscious expectancy, but unlike previous investigators, they also manipulated contrast, permitting conclusions regarding perceptual encoding. Expectancies were induced by providing subjects with a pretrial cue. Miller and Anbar observed the usual interaction of probability with contrast, but noted no tendency for expectancy to interact with contrast. This null result occurred in one experiment in which probability was also manipulated, and in a second which varied only expectancy and contrast. This suggests that probability is a factor distinct from conscious expectancy at the encoding level, since probability is known to affect encoding, but conscious expectancy did not do so. The conclusion is thus that a relatively static probability mechanism influences encoding. However, conscious expectancy is not the only factor that might underlie a dynamic mechanism. It is also possible that the factor of sequential expectancy, mentioned earlier, could function according to such a mechanism; expectancies would arise on the basis of the preceding stimulus sequence. Experiments 2 and 3 examine the extent to which the effect of probability at encoding may be explained by sequential expectancy.

CHAPTER II

EXPERIMENTS

Experiment 1

Miller (1979) concluded that stimulus probability influences encoding only when the stimuli can be characterized by abstract codes such as a name or dimensional value. Although this conclusion is consistent with results of previous experiments, the evidence is not conclusive, since stimuli in these experiments differed in ways other than the degree to which they could be characterized by abstract codes. The purpose of Experiment 1 was to provide a strong test of the role of the abstract code as a mediator of the probability effect at encoding by presenting the same stimuli in conditions which either encouraged or discouraged the use of abstract codes.

In his third experiment, Miller (1979) used letter stimuli and found that the effects of contrast and probability were additive. Usually, the use of alphanumeric stimuli has yielded a probability by contrast interaction. However, in this experiment, two versions of the same uppercase letter were assigned to different responses so that the stimulus names could not easily be used in making responses and were in fact likely to interfere if they were used. In the studies in which the contrast by probability interaction has been observed (e.g., Miller, 1979, Experiment 1; Miller and Pachella, 1973, 1976; Stanovich and Pachella, 1977), it was possible, and in fact a good strategy, to utilize the stimulus name in performing the task. On the basis of this difference, Miller implicated the name code (and ultimately the abstract code) as a key factor in the mechanism responsible for the probability effect at encoding.

It may be argued, however, that some more subtle difference in the stimuli, and not the availability of an abstract code, was actually responsible for the disparate results. The present experiment was an attempt to rule out this possibility. The same four stimuli were presented in two conditions. One condition was designed to encourage the use of abstract codes, while the other was designed to discourage their use. According to the abstract code explanation, the probability by contrast interaction should be observed in the former condition, and be absent in the latter.

Method.

Subjects. Forty-nine students at the University of Massachusetts received course credit for their participation in an experimental session lasting about 40 minutes. No subject exceeded a pre-experimental criterion of 8% errors at either level of contrast. The data of one subject were replaced because she lost a contact lens during the experiment.

Apparatus and stimuli. A Hewlett-Packard 2114B computer controlled the presentation of stimuli and recorded responses and response latencies. Stimuli were presented on an HP1300A X-Y display oscilloscope in a dimly lit room. Responses were made by pressing one of two keys located on a response panel in front of the subject. Subjects viewed the stimuli from a distance of about 100 cm. Stimuli were approximately 1 cm wide and 1.2 cm high. Contrast between a stimulus and its background was reduced by placing a 1.5 log unit neutral density filter in front of the oscilloscope.

The stimulus set consisted of four figures, each constructed so as to be identifiable by two names. In the letter condition, subjects were told that the stimuli were two uppercase versions of the letters A and O. In the object condition, stimuli were labelled as a table and a tepee (corresponding to the As), and a circle and a square (corresponding to the Os). In the letter condition, two stimuli were associated with each name, while in the object condition, there was only one stimulus per name. The use of a simple name code was thus discouraged in the letter condition, and encouraged in the object condition. Subjects in the latter condition were told that the experiment was concerned with how people identify letters written in different styles of type. Subjects in the object condition were told that the concern was with how people identify simple drawings of objects. When questioned after the experiment, eight subjects in the letter condition reported that they treated the stimuli as something other than letters. All others reported treating the stimuli as instructed. Using the letter names for reference, one letter from each pair was associated with a single response. The pairing was the same for all subjects. One pair comprised the direct probability condition, the other pair, the indirect probability condition. Direct probability stimuli appeared 40 or 10 times in a block of 100 trials, while each indirect probability stimulus appeared 25 times. Subjects were told that the stimuli would not necessarily appear an equal number of times. The assignment of stimulus pairs to direct and indirect conditions was counterbalanced across subjects, as was the assignment of stimuli to presentation probabilities within the direct probability condition.

Procedure. An experimental session consisted of six blocks of 100 trials each. The first two blocks were considered practice, and the level of stimulus contrast alternated from block to block. Stimuli were presented in random fashion by the computer, subject to the constraint that each stimulus appeared with the appropriate frequency during a trial block. One half of the subjects were assigned to the letter condition, and the remaining subjects were assigned to the object condition. The order of contrast level and type assignment of preferred hand to probability condition (direct versus indirect) were counterbalanced across subjects.

Subjects were allowed approximately five minutes to dark adapt before the first practice block. There was a one to two minute rest period between blocks. A trial consisted of the presentation of a warning signal (two crosses above and below the location of the ensuing stimulus) for 250 msec, with the stimulus appearing 250 msec after its offset. The stimulus remained on the screen until a response was made. One second elapsed before the next warning signal, during which time the screen remained blank or the word "error" was presented, depending on the response. Subjects were instructed to respond as quickly and accurately as possible. RTs to error trials were recorded but not analyzed, nor were RTs of two seconds or longer.

Results and discussion. For each of the last four trial blocks, two sets of mean RTs and proportion of correct responses (PC) were computed; one set for the direct probability condition, and one for the indirect condition. Analyses of variance were performed on the RTs and PC of each set. The analyses involved three within-subject variables (two levels each of probability, contrast, and practice), and four between-subject variables. The latter consisted of label condition (letter versus object), order of contrast alternation (beginning with high versus low), mapping condition (which of the two pairs of stimuli were presented in the probability condition of interest), and hand used to respond (preferred or not). The practice variable was constructed by assigning Blocks 3 and 4 to one level, and 5 and 6 to the other.

Direct probability condition. Results of the direct probability condition are summarized in Table 1. RTs were shorter for more probable stimuli ($F(1,32) = 98.72$, $p < .001$, $MS_e = 5,507$), and for stimuli at the high level of contrast ($F(1,32) = 204.22$, $p < .001$, $MS_e = 7,964$). Subjects responded about 25 msec faster in Blocks 5 and 6 than in 3 and 4 ($F(1,32) = 25.38$, $p < .001$, $MS_e = 2,350$). The predicted label condition by contrast by probability interaction did not approach significance ($p > .10$), and the trend in the data was in fact opposite to that anticipated. The probability effect was 16 msec greater at low contrast than at high contrast in the letter condition ($F(1,16) = 3.32$, $.05 < p < .10$, $MS_e = 960$), and virtually the same at both contrast levels in the object condition ($F < 1$). There was no suggestion that any of these effects was due to a speed-accuracy trade-off. More probable stimuli were responded to more accurately ($F(1,32) = 25.81$, $p < .001$, $MS_e = .004$),

TABLE 1

Mean reaction times (in msec) and proportion of correct responses (in parentheses) for the direct probability condition of Experiment 1.

	LETTER CONDITION			OBJECT CONDITION	
	Probability			Probability	
	.1	.4		.1	.4
Low contrast	760 (.956)	681 (.983)	Low contrast	734 (.948)	658 (.984)
High contrast	624 (.954)	561 (.981)	High contrast	604 (.948)	522 (.989)

and this effect was unchanged by label condition ($\underline{F} < 1$). There was no effect of contrast, nor evidence of a probability by contrast interaction, in the overall analysis or in separate analyses performed on the PC data of each label condition ($\underline{F} < 1$ in all instances).

These results are inconclusive with respect to the role of an abstract code as a mediator of the probability effect at encoding. On the basis of Miller's (1979) observation of an additive relationship between contrast and probability when more than one stimulus was assigned to a name, a similar relationship between the two factors was predicted in the letter condition of the present experiment. If an abstract code is important, then a probability by contrast interaction should have been observed in the object condition. The finding of a marginal interaction in the letter condition suggests that subjects in this condition may have invented their own names for some of the stimuli, a strategy to which some subjects admitted. However, the absence of the interaction in the object condition is problematic for this interpretation. Perhaps it is critical to the abstract code explanation that these codes be extremely well learned. This would be the case for alphanumeric stimuli, as in the letter condition, but possibly not for names of the object stimuli. Subjects in the letter condition might have used the letter names for stimuli in the direct probability condition, and used invented names for indirect probability stimuli. Since only some portion of the subjects should have retained the letter names for the direct probability stimuli, the finding of a relatively small, marginally significant interaction is thus in keeping with this view. This interpretation is obviously speculative, and is offered merely as some attempt to account for the present results.

The RT analysis also revealed a number of theoretically uninteresting interactions, which will be reported with no interpretation. The effect of probability was greater when subjects responded with their preferred hand ($F(1,32) = 5.15$, $p < .05$, $MS_e = 5{,}507$). The probability effect was relatively larger in opposing mapping conditions across label conditions ($F(1,32) = 7.13$, $p < .05$, $MS_e = 5{,}507$). Similarly, the practice effect was differentially affected by the order of contrast alternation across mapping conditions ($F(1,32) = 7{,}65$, $p < .01$, $MS_e = 2{,}350$). Finally, the contrast by probability interaction was observed primarily in Blocks 3 and 4 when the high contrast condition was presented first, but not in Blocks 5 and 6 when low contrast came first ($F(1,32) = 5.45$, $p < .05$, $MS_e = 2{,}511$).

Indirect probability condition. Miller (1979) observed what he termed a reverse error rate effect for indirect stimuli in an experiment much like the present letter condition. He suggested that the name of the most probable (.40) stimulus became associated more strongly with the response to direct probability stimuli, while the name of the least probable (.10) stimulus was associated with the hand used in the indirect probability condition. The more probable name would then interfere with the execution of a correct response in the indirect condition, whereas the less probable name would tend to activate a correct response in this condition. This should only happen when the same name is used to respond to stimuli requiring different responses. On the basis of Miller's finding, a reverse probability effect was expected in the PC data, RT data, or both, but only in the letter condition.

Analyses of the RT data for each label condition revealed virtually no effect in the object condition, and a slight trend in the direction opposite to that expected in the letter condition ($F < 1$ in both cases). Results from the PC data were parallel, the effect failing to approach significance in either label condition (both ps > .25). These results are consistent with the interpretation given for the observation of the probability by contrast interaction for letter stimuli in the direct probability condition. The failure to observe even a trend toward a reverse probability effect for letters in the indirect condition suggests that subjects might have used more names than those provided to perform the task.

Experiment 2

Miller and Anbar (1981) demonstrated that expectancy as generated by a pretrial cue did not interact with contrast. Since the probability by contrast interaction has been observed in a number of studies, they reasoned that the effect of probability at encoding is not explainable in terms of expectancy. However, this conclusion may not generalize to expectancies induced in other ways. One alternative cause of expectancies is the stimulus sequence leading up to a particular trial. As previously discussed, sequential expectancy might underlie the probability effect at encoding because more probable stimuli tend to be repeated more often. If so, it should be possible to show that the magnitude of sequential effects increases as contrast decreases. By reasoning similar to that of Miller and Anbar, if sequential effects are not influenced by contrast, it may be concluded that sequential effects do not underlie the probability effect at encoding. This conclusion would be warranted more strongly if an additive relationship between sequence and contrast was demonstrated concurrently with a probability by contrast interaction. Without a concurrent demonstration of effects, the logic of the experiment may require sequential expectancy to account for a nonexistent effect of probability at encoding. Consequently, probability was manipulated along with contrast in the present experiment, and sequential effects were examined.

Method.

Subjects. Twenty-six students at the University of Massachusetts received course credit for their participation in an experimental session lasting about 40 minutes. The data of two subjects were replaced because they exceeded the 8% error criterion at a single level of contrast.

Procedure. The procedure was the same as that of Experiment 1, with several exceptions. The stimuli were the uppercase letters G, N, S, and K. They were about .7 cm wide and 1.2 cm high. One pair of stimuli was assigned to each response, and the pairs were always G-N and S-K. The pairs were constructed such that one globally curved and one globally angular letter were members of each pair. The stimuli were described to subjects as four letters.

Probability was manipulated over a range of values to examine the continuous nature of the effect. The members of one pair appeared with frequencies of 10 or 40 in a block of 100 trials, and members of the other pair appeared 20 or 30 times. The eight possible assignments of stimuli to probabilities are shown in Table 2. Finally, the absolute level of stimulus contrast was decreased in order to increase the size of the contrast effect.

Results and discussion. Analyses related to the probability effect will be considered first, followed by analyses of sequential effects. Only data from the last four trial blocks were analyzed.

Probability analyses. An analysis of variance was performed on the mean RTs. The analysis involved one between-subjects variable, the order of contrast alternation (two levels), and three within-subjects variables. The latter consisted of contrast and practice (each two levels), and probability (four levels). Results are summarized in Table 3. RTs increased with decreasing probability ($F(3,66) = 22.25$, $p < .001$, $MS_e = 4,695$). The effect of contrast was larger than in Experiment 1 (236 versus 120 msec), and highly significant ($F(1,22) = 139.25$, $p < .001$, $MS_e = 38,515$). Subjects responded about 26 msec faster in Blocks 5 and 6 than in 3 and 4 ($F(1,22) = 7.15$, $p < .05$, $MS_e = 8,890$). As expected, the magnitude of the probability effect tended to be greater at low contrast ($F(3,66) = 4.66$, $p < .01$, $MS_e = 2,731$). No other effects approached significance. There was no suggestion that any of the above effects was due to a speed-accuracy trade-off. More probable stimuli were responded to more accurately ($F(3,66) = 24.07$, $p < .001$, $MS_e = .0014$), and the contrast effect approached significance ($F(1,22) = 3.81$, $.05 < p < .10$, $MS_e = .0020$). The contrast by probability interaction did not approach significance ($p > .10$).

TABLE 2

Assignments of stimuli to probabilities for Experiment 2 (response pairs were always G-N and S-K).

Condition	Probability .1	.2	.3	.4
1	N	K	S	G
2	G	K	S	N
3	N	S	K	G
4	G	S	K	N
5	K	N	G	S
6	S	N	G	K
7	K	G	N	S
8	S	G	N	K

TABLE 3

Mean reaction times (in msec) and proportion of correct responses (in parentheses) for Experiment 2.

	Probability			
	.10	.20	.30	.40
Low contrast	801 (.902)	760 (.960)	716 (.969)	708 (.972)
High contrast	538 (.935)	516 (.968)	506 (.972)	480 (.980)

Both the logogen and the verification models predict that the effect of probability on reaction time should be greater at low contrast. Although there was a significant interaction between probability and contrast level which reflected a general tendency for contrast effects to be larger for lower levels of probability, there was a reversal between probability levels .4 and .3 (see Table 3). The results of a trend analysis, however, indicated that only the linear components of the probability effect differed significantly at the two levels of contrast ($F(1,22) = 10.38$, $p < .01$, $MS_e = 2,299$). Furthermore, analyses of the data at each contrast level indicated that for both levels, only the linear component of the probability effect was significant (at low contrast, $F(1,22) = 55.62$, $p < .001$, $MS_e = 4,528$; at high contrast, $F(1,22) = 36.19$, $p < .001$, $MS_e = 2,220$). It may therefore be concluded that probability had its predicted effect at encoding.

Sequential analyses. In the previous section, it was established that probability affected encoding in the present experiment. Given the presence of this effect, it is reasonable to ask if sequential expectancy is the underlying mechanism for it. If so, then a sequence by contrast interaction should be present in the data. By examining sequential effects at a constant probability level, the effect of probability may be prevented from contributing to a potential sequence by contrast interaction. Accordingly, sequential effects were examined only for trials in the .4 probability condition. Several investigators (e.g., Remington, 1969; Schvaneveldt and Chase, 1969) have observed significant fourth-order sequential effects. The preceding three stimuli were therefore taken into account in the present analyses.

There were not enough observations at each sequence level to permit analyses at probability levels of $p < .4$.

A two (order of contrast alternation) by two (contrast level) by eight (sequence) analysis of variance was performed on the RT data. The results are summarized in Table 4. The 228 msec effect of contrast was significant ($F(1,22) = 108.37$, $p < .001$, $MS_e = 46{,}184$), as was the effect of preceding sequence ($F(7,154) = 21.35$, $p < .001$, $MS_e = 4{,}055$). Consistent with past observations of sequential effects (e.g., Schvaneveldt and Chase, 1969), it is apparent in Table 4 that RT decreases with increasing run length, and tends to increase with lag (the number of intervening trials between stimulus presentations). The sequence by contrast interaction was not significant ($F(7,154) = 1.65$, $p > .10$, $MS_e = 2{,}872$). The failure to observe this interaction provides no evidence suggesting that the probability effect at encoding is explainable in terms of sequential expectancy, since probability interacted with contrast in the same experiment, thereby demonstrating a probability effect at encoding in the absence of sequential effects there. However, this conclusion should be accepted with caution. Ninety-five percent confidence intervals were obtained for the contrast effect for each sequence. They revealed that differences of 20 to 40 msec in the size of the effect across sequences (the magnitude typically observed in probability by contrast interactions) could have gone undetected. For example, the 95% confidence interval for the contrast effect in the BBB condition extended from 271 to 173 msec. In the AAA condition, the interval extended from 255 to 141 msec. Stimuli in the latter condition should be expected more strongly, so it is possible

TABLE 4

Mean RTs (in msec), contrast effects, and 95% confidence intervals (in parentheses) as a function of the three preceding stimuli for the .4 probability condition of Experiment 2.*

	$S_{n-3}\ S_{n-2}\ S_{n-1}$							
	Nonrepetitions				Repetitions			
	BBB	ABB	BAB	AAB	BBA	ABA	BAA	AAA
Low contrast	734	733	716	739	672	682	674	601
High contrast	512	500	486	492	458	463	412	403
Contrast effect	222(±49)	233(±53)	230(±52)	247(±50)	214(±40)	219(±42)	262(±81)	198(±57)

*Note that B means "not A."

that the effect of contrast may have been greater for unexpected stimuli. Furthermore, there appears to be a slight tendency for the contrast effect to be greater for sequences that would produce incorrect expectancies. While sequential expectancy does not appear to be a likely candidate for the mechanism underlying the effect of probability at encoding, this possibility cannot be completely ruled out due to the ambiguity of the observed null result.

Experiment 3

In order to achieve a more conclusive result regarding the relationship of sequential expectancy and probability at encoding, Experiment 2 was replicated, with several minor changes. The most significant of these was that only two levels of probability were used (.05 and .45), to allow a greater number of observations to be made for the sequential analysis. The rationale and predictions were identical to those of Experiment 2. In addition, the repeated finding of additivity between the effects of sequence and contrast would strengthen the conclusion that sequential expectancies are not responsible for the probability effect at encoding.

Method.

Subjects. Thirty-three students at the University of Massachusetts received course credit for their participation in an experimental session lasting about 40 minutes. The data of one subject were replaced because the 8% criterion at a single level of contrast was exceeded.

Procedure. The procedure was the same as that of Experiment 2, with several exceptions. There were two levels of stimulus probability, .05 and .45. One member of each letter pair (G-N and S-K) was assigned to each level. This provided 180 observations per subject in the sequential analysis, as opposed to 80 in Experiment 2. The assignments of stimuli to probabilities are shown in Table 5. An initial practice block was added; subjects always viewed stimuli in this block at the high contrast level so that they would be familiar with them when seen for the first time at low contrast. Lastly, the absolute level of contrast was raised a small amount relative to Experiment 2 in order to make stimuli in the dim condition slightly easier to see.

Results and discussion. Analyses related to the probability effect will be considered first, followed by analyses of sequential effects. Only data from the last four trial blocks were analyzed.

Probability analyses. An analysis of variance was performed on the mean RTs. The analysis involved two between-subjects variables, the order of contrast alternation (two levels), and stimulus-to-probability mapping condition (four levels). The four within-subjects variables (each two levels) were: hand used to respond, practice, contrast, and probability. Results are summarized in Table 6. Subjects responded about 19 msec faster with their preferred hands ($F(1,24) = 8.91$, $p < .01$, $MS_e = 5,089$), and were about 21 msec faster in Blocks 6 and 7 than in 4 and 5 ($F(1,24) = 10.48$, $p < .01$, $MS_e = 5,502$). The contrast effect was about 156 msec ($F(1,24) = 82.56$, $p < .001$, $MS_e = 37,636$), and more probable stimuli were responded to faster than less probable stimuli ($F(1,24) = 126.51$, $p < .001$, $MS_e = 29,808$). The probability effect

TABLE 5

Assignments of stimuli to probabilities for Experiment 3 (response pairs were always G-N and S-K).

	Condition			
	1	2	3	4
High probability (.45)	G,S	G,K	N,S	N,K
Low probability (.05)	N,K	N,S	G,K	G,S

TABLE 6

Mean RTs (in msec) and proportion of correct responses (in parentheses) for Experiment 3.

	Probability	
	.05	.45
Low contrast	781 (.927)	598 (.981)
High contrast	614 (.433)	453 (.983)

(172 msec) was considerably larger than in Experiments 1 and 2 (in which it was about 75 msec), reflecting the more extreme probability values used in the present experiment. The probability effect was 22 msec greater at low contrast than at high contrast and this interaction approached significance ($F(1,24) = 3.80$, $.05 < p < .10$, $MS_e = 4,169$). An analysis of the PC data collapsing over practice revealed that probability was the only variable to have an effect ($F(1,24) = 27.24$, $p < .001$, $MS_e = .0065$). Thus, none of the RT effects were due to a speed-accuracy trade-off. The finding that the probability by contrast interaction was only marginally significant was interpreted as most likely being an instance of Type II error. The interaction has been observed numerous times in experiments using alphanumeric stimuli (as cited in the introduction), was observed in Experiment 2, and was very close to significance in the present experiment ($p = .06$). It therefore seems safe to conclude that the difference in magnitude of the probability effect across contrast conditions is real.

Two unpredicted interactions were present in the RT analysis which could not be interpreted or meaningfully described in a concise manner. One was the mapping condition by order of contrast alternation by practice by contrast interaction ($F(3,24) = 3.35$, $p < .05$, $MS_e = 3,226$), and the other was the mapping by order by contrast by probability interaction ($F(3,24) = 3.08$, $p < .05$, $MS_e = 4,169$). Since each cell of these interactions contained data from only four subjects, these effects may have been produced by a few atypical subjects whose impact on the cell means could have been fairly substantial.

Sequential analyses. The data of eight subjects were not available for the sequential analysis due to experimenter error. Consequently, the RT data of the 24 remaining subjects were analyzed with regard to probability effects. This was necessary in order to ascertain whether there was a significant probability effect at encoding demonstrated by these subjects for sequential expectancy to explain. The between-subjects variables of mapping condition and order of contrast alternation were not included in the analysis. Results are summarized in Table 7. There were main effects of contrast ($F(1,23) = 44.95$, $p < .001$, $MS_e = 47{,}925$) and probability ($F(1,23) = 77.15$, $p < .001$, $MS_e = 38{,}687$), but their interaction was not significant ($F(1,23) = 1.93$, $p > .10$, $MS_e = 5{,}591$). The size of the interaction is virtually identical to that obtained using the data of all 32 subjects, so this subset was probably not qualitatively different.

A two (practice) by two (contrast) by eight (sequence) analysis of variance was performed on the RT data. Results are summrized in Table 8. The effects of practice ($F(1,23) = 8.42$, $p < .01$, $MS_e = 8{,}497$), contrast ($F(1,23) = 57.86$, $p < .001$, $MS_e = 64, 751$), and sequence ($F(7,161) = 20.00$, $p < .001$, $MS_e = 4{,}667$) were all significant. As in Experiment 2, it appears that RT decreases as run length increases, and tends to increase with lag. Sequential effects did not vary with contrast ($F(7,161) = 1.24$, $p > .10$, $MS_e = 1{,}963$). Ninety-five percent confidence intervals were calculated for the contrast effect for each sequence. While narrower than those in Experiment 2, they still indicated that contrast effects could be larger for sequences that usually produce incorrect expectancies. The virtual absence of any such trend does not support this possibility, however.

TABLE 7

Mean RTs (in msec) of the 24 subjects whose data were used in the sequential analysis of Experiment 3.

	Probability	
	.05	.45
Low contrast	784	597
High contrast	624	458

TABLE 8

Mean RTs (in msec), contrast effects, and 95% confidence intervals (in parentheses) as a function of the three preceding stimuli for the .45 stimulus condition of Experiment 3 (N = 24).

	$S_{n-3}\ S_{n-2}\ S_{n-1}$							
	Nonrepetitions				Repetitions			
	BBB	ABB	BAB	AAB	BBA	ABA	BAA	AAA
Low contrast	609	625	615	604	600	611	545	533
High contrast	475	474	467	475	462	456	415	400
Contrast effect	134(±36)	151(±38)	148(±39)	129(±34)	138(±40)	155(±55)	130(±42)	133(±48)

*Note that B means "not A."

As in Experiment 2, the evidence is consistent with the lack of a sequential expectancy effect at encoding, but is weak. Of particular note in this regard was the failure to observe a significant probability by contrast interaction. As stated earlier, there may not have been a probability effect at encoding for sequential expectancies to explain. Together with the null result of Experiment 2, though, the total absence of any indication of sequential effects at encoding in the present experiment suggests that the probability effect at encoding does not arise from sequential expectancies. An alternative to this conclusion and an experiment that could strengthen (or weaken) it will be discussed in the next section.

CHAPTER III

GENERAL DISCUSSION

The present experiments were conducted in order to further develop a description of the mechanism by which stimulus probability affects perceptual encoding. The first experiment was an attempt to provide strong evidence for the role of an abstract code as a mediator in the probability mechanism. Its results were inconclusive. The second and third experiments suggested that the probability effect at encoding could not be explained in terms of sequential expectancies.

As mentioned, Experiment 1 was designed to test the importance of the notion of an abstract code as a mediator of the probability effect at encoding. The observed pattern of results, together with the possibility that subjects did not follow instructions in the letter condition, make it difficult to assess the importance of such a code in the probability mechanism. However, whether the abstract code involved must differ from a name code is open to question. The only suggestion of a probability effect at encoding was in the letter condition, in which the stimulus names would have been very well learned. There was no evidence of an effect at encoding in the object condition, in which names would not have been as strongly associated to the stimuli. Furthermore, with the exception of Miller's (1979) Experiment 4, a probability effect at encoding has never been demonstrated using anything but alphanumeric stimuli. The small amount of evidence supporting the importance of abstract codes, combined with the difficulty in precisely defining them (see Miller's Experiments 4 and 6, 1979), suggests that it is unwise to abandon the notion of a simple name code as a mediator. In addition, the absence of a probability effect at encoding in the object condition of Experiment 1 suggests that a mediating code must be well learned to be effective, a status that arbitrary abstract codes (such as stimulus dimensions) are not likely to have.

Experiments 2 and 3 were designed to test the notion that the probability effect at encoding was a result of sequential expectancy effects. The probability effect may be a reflection of the fact that more probable stimuli are repeated and hence expected more often. The results of the present experiments did not support this explanation. Although not as unequivocally as might be desired, a probability effect at encoding was demonstrated in the absence of sequential expectancy effects there. In similar experiments, Miller and Anbar (1981) demonstrated the probability effect at encoding in the absence of a more general expectancy effect there. (Expectancy was induced through the use of a pretrial cue.) It may now be useful to return to the models presented in the introduction in order to understand the implications of these findings.

Mechanisms and Causes of the Probability Effect

The logogen model accounted for the probability effect at encoding by assuming that the activation thresholds of logogens corresponding to probable stimuli are lowered. The probability by contrast interaction follows if it is assumed that the effect of contrast manipulation is on the rate of evidence accrual. The verification model assumes that contrast affects the processing mechanism in two places (sensory memory and feature analysis) for unexpected stimuli, but only sensory memory is affected when stimuli are correctly expected. If one assumes that more probable stimuli are correctly expected more often, the probability by contrast interaction follows directly.

It should be noted that these are models of the probability effect at a certain locus, and as such, do not address the issue of how the effect is generated. One manner in which the latter issue may be addressed is to look for expectancy effects at encoding to determine their ability to account for the probability effect there. This was the method used in Experiments 2 and 3 and by Miller and Anbar (1981). The conclusion that general or sequential expectancies underlie the probability effect implies that the mechanism ought to be fairly dynamic. The conclusion that the probability effect is not a result of one of these factors implies a more static mechanism. There is nothing inherent in either the logogen or verification model that requires a conclusion about the degree to which the mechanism is static or dynamic. For example, one could assume that logogen thresholds were adjusted on a trial to trial basis, or that the expectancy set of the verification model remained fixed over trials. The logogen model would then be dynamic, and the verification model, static. The manner of adjustment could be assigned in just the opposite way, however, so it should be clear that these models do not address this issue. Rather, they are accounts of what might be occurring at encoding to produce a probability by contrast interaction.

The results of Experiments 2 and 3, together with those of Miller and Anbar (1981) suggest that the mechanism which is responsible for the probability effect is a static one. A possible candidate for this mechanism is a process in which subjects monitor the relative frequencies of stimuli over some period of trials (see Hasher and Zacks, 1979), and then set their expectancies accordingly, adjusting them little, if at all, once they are set. This conclusion is consistent with both the logogen and verification models, as described above.

The previous conclusion should be accepted with caution. An examination of confidence intervals suggested the possibility that the size of the contrast effect in Experiments 2 and 3 might have varied with sequential expectancy, but the experiments lacked sufficient power to detect the interaction. Confidence intervals obtained by Miller and Anbar (1981) revealed that this alternative conclusion was also viable for their study. Under any circumstances, it is unwise to accept a conclusion based on so few observations of a null result. Furthermore, Miller and Anbar's conclusion that expectancy does not underlie the probability effect may be challenged on other grounds. They conducted two experiments in which they failed to observe an expectancy by contrast interaction. In the first, probability was also manipulated, and the probability by contrast interaction was observed in the PC data, but not the RT data. In the second experiment, probability was not manipulated at all. In both experiments, the RT data were examined for the presence of the expectancy by contrast interaction. The failure to demonstrate a probability by contrast interaction for the RT data leaves their experiments open to the same criticism that was applied to Experiment 2 of the present study; namely, that it is a questionable practice to require expectancy effects to explain a probability effect at encoding that may not be present in the data under consideration.

Another potential criticism of Miller and Anbar's study is that their cuing procedure may have yielded an expectancy effect that is qualitatively different from that which occurs in a typical choice reaction time task. This is because their pretrial cues were the stimuli themselves. Subjects may have adopted a strategy of preparing the response to the cued stimulus when the cue was presented, and then performing a physical comparison of target to cue when the stimulus was presented. If there was a match, the prepared response could be executed purely on the basis of the physical comparison; if not, the stimulus would have to be identified before a response could be executed. Pachella and Miller (1976) proposed a similar strategy to account for the absence of a probability effect for physical match trials in a letter matching task. The critical aspect of this strategy is that stimulus identification is not necessary when the cue is valid. However, there is reason to believe that the identification process is heavily involved in the probability effect at encoding. By using a task that permits this process to be bypassed when cues are valid (thereby producing an expectancy effect), Miller and Anbar may have made their conclusions based on a type of expectancy effect that does not involve stimulus identification. The possibility remains, however, that expectancy may influence identification in other tasks (i.e., tasks in which the above strategy is not useful), and in so doing, produce the probability effect at encoding.

The Validity of the Additive Factors Assumptions

The present experiments, and all of the studies that have manipulated contrast in concluding that probability affects encoding, may be subjected to a more fundamental criticism than those discussed to this point. The assumption underlying all of this work is that processing is conducted by a series of discrete stages and that, while contrast may affect the rate of processing within the stage or stages responsible for encoding, the contrast manipulation does not affect the quality of the output of any stage. That is, given enough time, the quality of the output for any stage in the low contrast condition will match the quality for that stage in the high contrast condition. If output is affected, it is possible that the effects of contrast could be passed down the line of processing stages, so to speak, and the conclusion that a manipulation influences an early stage of processing because it interacts with contrast would not follow.

The assumption that contrast affects only the rate of processing gains some support from the observation by Pachella and Fisher (1969) that contrast affected the rate, but not the asymptote, of information accrual in a discrimination task. However, there is reason to question the generalizability of this conclusion to the effect of contrast as it has been manipulated in probability studies. In order to observe contrast effects of the size typical of these studies (125 to 250 msec), the luminance at low contrast must be very low. In the present experiments, the probability by contrast interaction was observed in the data of roughly 60% of the subjects, and a small number of individuals contributed heavily to its overall magnitude. This suggests the possibility that, at least for some subjects, the effect of contrast might have been on the quality of the output of some process. For these subjects, it may have been the case that no matter how long they viewed a stimulus, the quality of what they saw never reached the level obtained at high contrast. Until the effect of contrast as it has been manipulated in probability studies is shown to be on the rate, and not the asymptote, of information accrual, the additive factors interpretation of the probability effect on encoding based on the observed probability by contrast interaction is open to question. Similarly, if one assumes a continuous flow of information rather than a discrete stage process, there exists more than one interpretation of a probability by contrast interaction (McClelland, 1979). Miller (1982) has provided some evidence against this notion, showing that a task similar to those used in probability studies involved fairly discrete stages. Given the importance of this assumption, further evidence is desirable.

Probability as a Manipulation of Expectancy in General

In the introduction, it was suggested that stimulus probability may serve as a model of expectancy effects in general. It is thus reasonable to ask whether other types of expectancies have exerted effects at encoding similar to those of probability. In both a lexical decision and a naming task, Becker and Killion (1977) observed that the effect of semantic priming varied inversely with contrast. Stanovich and West (1979) observed a similar result for the effect of a predictive sentence context in a naming task. The findings that the effects of other types of expectancy have varied with contrast suggests that probability is not an isolated instance of some form of expectancy which is capable of exerting an effect at encoding. The interpretation provided by Stanovich and West for their results is noteworthy in this regard, for it suggests still another interpretation for the probability by contrast interaction. Stanovich and West used the distinction of Posner and Snyder (1975) between a fast, automatic spreading activation process and a slower process by which conscious attention is focussed. Only facilitation results from the first process, while the second results in both facilitation and inhibition effects. They reasoned that only the first process occurred under high contrast conditions in their task, because the interval between context and target was too short to allow the attentional process to act. The effect of low contrast, then, was to slow down the early processing of the stimulus so that the conscious attention mechanism had time to act. Stanovich and West argued that anything that increases the interval between the presentation of context and the target should produce a similar interaction. Thus, contrast is equated with all forms of degradation, and the mere passage of time, under this interpretation. Stanovich and West also manipulated the time between context and target presentation, and obtained results consistent with their interpretation.

If the probability mechanism is a dynamic one, then this interpretation of expectancy by contrast interactions would seem to have testable predictions. For example, if the expectancies involved in a probability task arose on a trial to trial basis, the expectancy on trial n should be different from the expectancy on trial n+1. Given these shifting expectancies and the Stanovich and West interpretation, the duration of the intertrial interval (ITI) should be an important variable. With short ITIs, the conscious attention mechanism should not have time to act. While ITI has never been systematically manipulated in a probability experiment, it has varied across studies, with no discernable effect on the probability by contrast interaction.

On the other hand, if the probability mechanism is fairly static, it is not clear how Stanovich and West's interpretation would apply. That is, it is unclear to what the interval between the arisen expectancy and the onset of a stimulus would correspond, since the expectancy is presumably constant given a static mechanism. This indirectly raises the question of the utility of stimulus probability as a model of expectancy effects in general at encoding. If the probability mechanism is shown to be static, its utility as a model would be questionable, since it seems doubtful that more ecologically valid types of expectancies (such as context effects that might arise during reading) are of such a stable nature. If the probability mechanism is of a fairly dynamic nature, however, it would consequently be much more similar to other, inherently more interesting, types of expectancies. Given the vast literature on dynamic expectancies during choice reaction time tasks, the exact nature of an expectancy at a given point in time could conceivably be evaluated more precisely than would be possible when studying more complex forms of expectancy. Thus, a dynamic probability mechanism could well serve as a basis for developing an explicit model of the effects of expectancy over time on the perceptual encoding process.

Future Directions

The potential utility of the probability mechanism as a model of expectancy effects in general argues for the further investigation of the issues that have been raised by this and other research regarding the nature of the probability effect at encoding. In light of the previous discussion, the foremost question is that of the static versus dynamic nature of the effect. To the extent that the effect is dynamic, it should be possible to demonstrate the effect of some form of dynamic (e.g., sequential) expectancy at encoding. One way of doing this might be to include runs of only a few set lengths in a trial block. These run lengths could be chosen such that they would be likely to induce the largest possible sequential expectancy effect. A null result in this case should be difficult to attribute to a lack of power, since it would accompany the finding of large effects obtained with many observations per subject. Alternatively, probability might be manipulated, with run length controlled such that sequential effects would be minimal. If sequential expectancy underlies the probability effect at encoding, the prediction would be that a probability by contrast interaction should not be observable in this situation. A cuing experiment similar to those of Miller and Anbar (1981) could also demonstrate an expectancy effect at encoding. The key difference would be to use cues that were symbolic, and not identical to the target stimuli. The physical comparison strategy discussed earlier would thus not be possible.

A second issue regarding the probability effect is the role of a name code as a mediator of the effect. Is the appeal to an abstract code that is more general than a name code necessary? Miller's (1979) Experiment 4 could be replicated using other stimuli that are seemingly identifiable using abstract codes. The demand for a code more abstract than a name ought to be firmly established before the notion of a simple name code as mediator is abandoned. The importance of a name code might be firmly established by an experiment similar to the present Experiment 1. Proceeding on the assumption that alphanumeric stimuli must be used to observe the probability effect at encoding, Hebrew letters might be used as stimuli, and subjects would be grouped into readers and non-readers of Hebrew. If the existence of a well learned name code is critical, the probability by contrast interaction should be observed in data of the first group, but not the second.

Another issue concerns the validity of additive factors logic in localizing the probability effect at encoding. An experiment analogous to that of Pachella and Fisher (1969) is needed to show that the effect of contrast as manipulated in probability experiments is on the rate, and not the asymptote, of information accrual. To further support the validity of the additive factors logic in probability experiments, a procedure advocated by Meyer and Irwin (1981) might be employed to evaluate the nature of the flow of information (continuous versus discrete) in the task used to observe the probability by contrast interaction.

Finally, the probability effect may be studied with the specific intent of generalizing the results to other forms of expectancy. For example, the interpretation offered by Stanovich and West (1979) to account for expectancy by contrast interactions is very different from that of Becker (1980; Becker and Killion, 1977). Without going into details, the former predicts that the interaction should only be observed in conjunction with an expectancy induced inhibition effect, while the latter yields the prediction that only facilitation-dominated expectancy effects should interact with contrast. The comparatively uncomplicated nature of the probability manipulation may allow insights regarding expectancy that lead to the resolution of this issue.

In conclusion, the results of the present experiments were not in favor of the notion of the stimulus probability effect as a general model of expectancy effects at encoding, since they suggested a static, rather than a dynamic mechanism. However, a number of reasons for not accepting this conclusion were offered, and it was suggested that the potential utility of the probability mechanism as a model warrants further investigation of issues pertaining to the nature of the stimulus probability effect. This course of action could ultimately result in a fairly precise description of the ongoing effects of expectancy on the perceptual encoding process.

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