Title
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Abstract. Human processing systems face a continual challenge of extracting only the most important information from the environment, resulting in awareness of some but not all of the available information. The current study investigates the psychophysical determinants of awareness. It examines the hypothesis that relative energy level of a stimulus is the critical factor in determining what comes to consciousness. In Experiments 1 and 3 two conceptually incompatible stimuli (one lexical, one pictorial) are presented successively in the same position of a tachistoscope for only 1 msec each, with a zero interstimulus interval. Observers report seeing one or the other, or nothing at all, at a more-or-less chance level when the stimulus durations are equal. As soon as one stimulus is given as little as one-quarter to one-half a millisecond more duration than the other, the longer stimulus is reported on 68% to 84% of the test trials. In Experiment 2 an advantage for word perception at these low energy levels was investigated and measured. The results of these experiments indicate that extremely small differences in duration (about .25 or .50 msec) were sufficient to bring one concept to the consciousness of the observer at the expense of the other. Small stimulus intensity differences were investigated in Experiment 4, yielding similar results. The results can be accounted for by contemporary parallel-distributed-processing, connectionist network models of perception and cognition which use a winner-take-all decision rule.

Experiment 1: The Complete Time Course of the Evolution of a Percept

Humans, as information processors, are faced with the challenge of continually gleaning information from the world. As the environment offers an infinite amount of information, the task of the processing system is to sufficiently and efficiently extract only what is most important. In this regard, we experience awareness of any particular stimulus only at the expense of other, competing stimuli. An obvious question to arise is "What are the determinants of awareness?" What is it that causes some information to rise to consciousness, while other information does not? The purpose of this paper is to investigate this issue. The experimental paradigm used is to present two conflicting stimuli within the same unit of psychological time, and manipulate the variable or variables which determine the resolution of the conflict. In short, we wish to discover the variables which are critical in determining the evolution of a percept from sensory stimulation to conscious cognition.

Connectionist Network Models with a Winner-Take-all Decision Rule. Parallel-distributed-processing, connectionist models provide a framework of conceptualizing visual processing in which information is represented within a network of interactive nodes. When two conceptually incompatible stimuli are presented in the same small unit of psychological time, it is likely that the two concepts may not reach consciousness simultaneously since consciousness requires the participation of the entire system. If multiple concepts are presented to an observer at a single point in time, the outcome may be likened to a massively parallel race through the lower-order levels to a limited capacity, high order, cognition or consciousness. What is proposed here is that when two conceptually incompatible stimuli are presented in the same perceptual moment, both stimuli will activate their low-level representations within the system. As these representations in turn activate higher levels, the processing capacity of the system becomes more and more limited. At some point there is a bottleneck in which only one concept may be represented. The "challenge" to the competing concepts is to get through the lower levels quickly in order to arrive first at the point of the bottleneck, and thus capture control of attention or consciousness. In this "race for awareness" what factor is critical? The hypothesis under consideration is that it is the energy of the stimuli which will determine the victor. And to the victor, goes the spoils - conscious awareness. As Bloch's law describes energy as intensity times duration, whichever stimulus is presented for a slightly longer time, or at a slightly higher intensity should have a higher probability of capturing the awareness of an observer.

Method. The stimuli were the concepts UP, DOWN, LEFT, and RIGHT. Each trial consisted of presenting both a word and arrows pointing in one of the three directions not represented by the word. Experimental conditions manipulated the target position (first or second), target type (picture, word), and target duration. The "target" was the stimulus whose duration was manipulated on any particular test sequence, and the "standard" was the stimulus which was held at a constant duration of one millisecond. Target duration was then raised in increments of .25 ms for each successive test presentation, while duration of the standard stimulus remained constant at 1 ms. Each trial sequence continued until the observer correctly reported the target three times in a row. On the first trial of each sequence the two stimulus concepts were presented for only .25 and 1 ms, respectively. The interstimulus interval for all trials was zero. The observer's task was merely to identify what was presented. If the observer reported not knowing, he was forced to guess. On successive test trials, the target duration was then raised in increments of .25 ms until the observer correctly identified the concept on three successive presentations.

Results. The results of this experiment may be seen in Figure 1. When the target is presented at .25 ms, and the standard is presented for 1 ms, observers never report the target. As the target duration is increased to .50, .75 and then to 1 ms, recognition of the target increases to proportions of .035, .138, and .392. When the target duration is 1.25 ms (only .25 ms longer than the duration of the standard), it can be seen that target recognition increases dramatically to a mean proportion of .677. When the target duration is 1.5 ms, half a millisecond longer than the standard, the probability of reporting the target is .84. Probability of reporting the target continues to increase steadily as duration increases, until it asymptotes at 1.0, perfect recognition, at a 2 ms difference. What we have here is a complete psychometric recognition function which goes from 0 to 1.00 in a stimulus difference domain covering only 2 ms, -1 to +1 ms. This is close to a step function.

Experiment 2: Measuring the Unconditional Word Advantage

This experiment explores the advantage of recognition for words over recognition for less familiar pictorial stimuli. The experimental paradigm of Experiment 1 was used, **mutatis mutandis**. By presenting words and arrows at an equal duration on the first trial of each sequence, it was hoped to get an unconditional measure of recognition differences based on stimulus surface structure. Recognition would be relatively unaffected by any immediately preceding perceptual events or sequences of responses.

Method. Six observers were used. All aspects of Experiment 2 were identical to Experiment 1 except the manipulation of target duration. On the first trial in every test sequence in Experiment 2 both stimulus concepts were presented for 1 ms each. On successive trials, target duration was raised in increments of .5 ms. The standard remained at 1 ms throughout the entire test sequence.

Results. At a zero difference in stimulus duration between target and standard, observers report the target stimulus at a proportion of .28. The fact that this value is so low indicates that with equal durations, each stimulus is masking the other somewhat. When there is as little as a one-half a millisecond difference in the stimulus durations, observers report the stimulus with the greater duration at a proportion of .69. The proportion of reporting the longer duration stimulus rises as the target duration increases until it asymptotes at 1.0 between a 2.5 and 3 ms difference in stimulus durations. Figure 2 shows the effect of target modality. It can be seen that word identification has an advantage over analogical pattern recognition. At the zero difference condition, observers correctly reported the word target at a proportion of .44. This may be compared to a .13 proportion of correctly reporting the pictorial stimuli at the same equal exposure duration condition. This value is at the chance level of one correct guess out of eight possibilities. Thus, the word stimuli completely masked the pictorial stimuli when the two exposure durations were equal. The difference in recognizability of these two stimuli diminishes as target duration increases. The psychometric functions for both conditions reach an asymptote of near 100% target recognition at similar duration differences between target and standard, approximately 2 ms. Target position (order) had no effect.

Discussion. The results of these two experiments strongly suggest that the energy value of a stimulus plays a crucial role in the evolution of a visual percept. In these experiments we manipulated stimulus energy by varying exposure duration. It has been shown that an exposure duration difference of as little as .25 or .50 ms between two contiguous, successively presented stimuli is enough for the slightly longer stimulus to capture the observer's attention or awareness. Moreover, this effect has been demonstrated to hold true regardless of whether the longer stimulus is presented first or second, or whether it is a picture or a word.

Experiment 3: Psychophysical Method of Constant Stimuli

In Experiments 1 and 2 the psychophysical method of ascending limits was used. On any given test sequence, the target and standard stimuli remained in the tachistoscope for as many trials as needed until the observer consistently reported the target on three consecutive trials. It could be argued that observers may have been aggregating featural and semantic information from one trial to the next. This argument could be made in spite of the fact that on the early trials of a test sequence the observers were unaware of the target and unable to report it. If so, they could have been building up a mental prototype of what the target was before they recognized it. If this was the case, then the recognition threshold values (the points at which the observers switched from seeing and reporting the standard to seeing and reporting the target) may be lower than the "true" objective threshold values. In Experiment 3, in order to make sure the observer could not aggregate information from one test trial to the enxt, we switched from an ascending method of limits procedure to the method of constant stimuli in which the test stimulus pairs were chosen at random on each trial. Here, information on successive test trials are independent, and any stimulus information, conscious or unconscious, the observer may have picked up on one test trial could not possibly be of systematic help on the next test trial.

Method. Four observers were used. All aspects of Experiment 3 were identical to Experiment 1 except that the psychophysical method of constant stimuli was used. The standard was presented for 1 ms, but the exposure duration of the target was variable, ranging from .5 ms to 2 ms, in steps of .25 ms. The interstimulus interval between the target and the standard was zero msec. Randomly, from test trial to test trial, the target could be presented first or the standard could be presented first. Also, randomly from trial to trial, the target could be a word or a pictorial analog. For any given test series of 48 trials, the target exposure duration was choosen at random, and then each of the 12 pairs of test stimuli were randomly (without replacement) tested at that target duration in both stimulus orders and stimulus modalities.

Results. The results of Experiment 3 using random presentation of stimulus pairs were almost exactly the same as the results of Experiment 1 using the ascending method of limits.

Experiment 4: Effect of Differential Intensity Contrast on Recognizability

In our discussion of the results we have talked about relative stimulus energy being the deciding factor in determining what the observer cognitively sees. However, in our first three experiments we have only varied exposure duration differences, knowing Block's Law of "Energy is equal to intensity times duration in an interval up to 100 msec." In Experiment 4 we reduce the standard stimulus intensity in half, but increase its duration to 2 ms, yielding a standard of the same subjective brightness as in the first three experiments. Then we vary the intensity of the 2 ms duration target from three small brightness units below the standard to three small brightness units above the standard. At each intensity difference we use the method of constant stimuli.

Method. Five observers were used in this study. Experiment 4 was similar to Experiment 3 except for constant exposure durations and the manipulation of stimulus intensity. The duration of both the standard and target were fixed at 2 ms each. The intensity of the standard was set at the midrange value of our tachistoscope, 8.4 cd/m^2 for all test trials. In Experiment 4 the target was presented at an intensity value of 4.2, 5.6, 8.4, 13.1, or 20.5 cd/m^2.

Results. The results of this experiment may be seen in Figure 3. When the target was presented at 4.2 cd/m^2, and the standard was presented for 8.4 cd/m^2, the observers never reported the target. As the target intensity is increased to 5.6 and then to 8.4 cd/m^2, recognition of the target increases to proportions of .167 and .555. Thus, observers are at a chance level in reporting the target when the duration and intensity of the target and standard are exactly equal. When the target intensity is 13.1 cd/m^2 (only one brightness unit above the intensity level of the standard), target recognition increases dramatically to a mean proportion of .883. When the target intensity is increased to 20.5 cd/m^2, only two units brighter than the standard, the probability of reporting the target is almost perfect, .977. Again, what we have here is a complete psychometric recognition function which goes essentially from 0 to 1.00 in an intensity difference domain starting at 4.2 cd/m^2 and going to 20.4 cd/m^2 in only four equal brightness steps.

Discussion. By investigating processing in the 1 to 2 ms stimulus onset asynchrony range we have done away with encumbering phenomena such as central pattern masking which cloud the issue at hand. We believe we have investigated the psychophysical determinants of consciousness in a most fundamental sense. As a result of the present investigations, the claim can be made that at the most basic level it is stimulus **energy** which is the critical determining factor in perception. The longer, brighter, stronger, larger, and lower spatial frequency environmental events are those that tend to capture the awareness of an observer. These higher energy stimuli (both forwardly and backwardly) mask their temporally equivalent but weaker cohort stimuli. If there are multiple stimuli available in the same small perceptual moment, then an energy advantage of even the slightest degree may be enough to allow the evolution of any particular percept at the expense of the others in the same small psychological time frame. A theoretical microstructure can be given by any number of contemporary connectionist network models of human information processing. Low-level featural information extracted from the input stimulus is assumed to activate subsequent internal representations, which are of increasingly higher and higher orders. In this manner, featural information provided by a stimulus evolves into a state of a high-level conceptualization as it flows through the neural net, being augmented in some areas and meeting resistence or inhibition in others. As awareness of a concept is represented as a pattern of activation in the system at the highest level, enlisting the participation of the system as a whole, no two conceptually incompatible concepts may be fully activated simultaneously within one small psychological moment in time. The interpretation given to the present results is that the featural information from both our test stimuli is extracted from the persisting, doubly exposed visual icon. As information is sent on for higher-order analysis, processing resources become more limited. At some point there is a bottleneck (perhaps just before the point of consciousness) which allows an awareness of only one of the two presented concepts. Within this interpretation, the first stimulus to reach the bottleneck is the stimulus of which the observer becomes consciously aware. Therefore, the situation may be thought of as a struggle between the two stimuli to get to the point of the bottleneck first, and thereby capture attention and conscious awareness. What is the critical factor in determining the outcome of this sensory struggle? The present experiments have provided evidence that it is the **energy** contrast level of a stimulus, relative to the competition which can provide the "winning edge". What is remarkable is the tremendous influence very small energy differences seem to have. Small intensity differences and duration differences of less than a thousandth of a second can sway the outcome of this perceptual competition in either direction. In summary, give me a half a millisecond, and I will change your mind.

Figure 1. Target detection, Exp. 1.

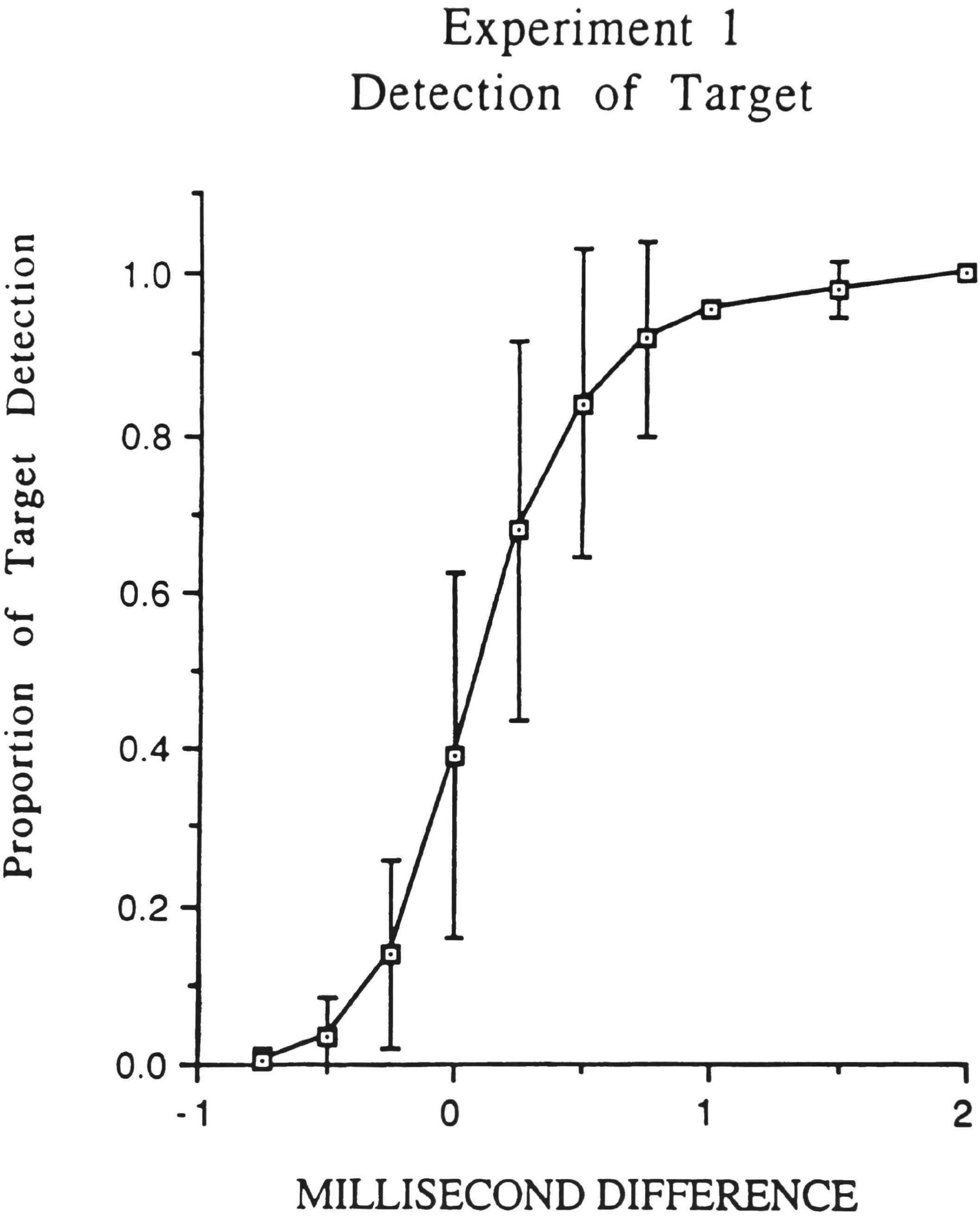

Figure 2. Lexical vs. Analogical recognition, Exp. 2.

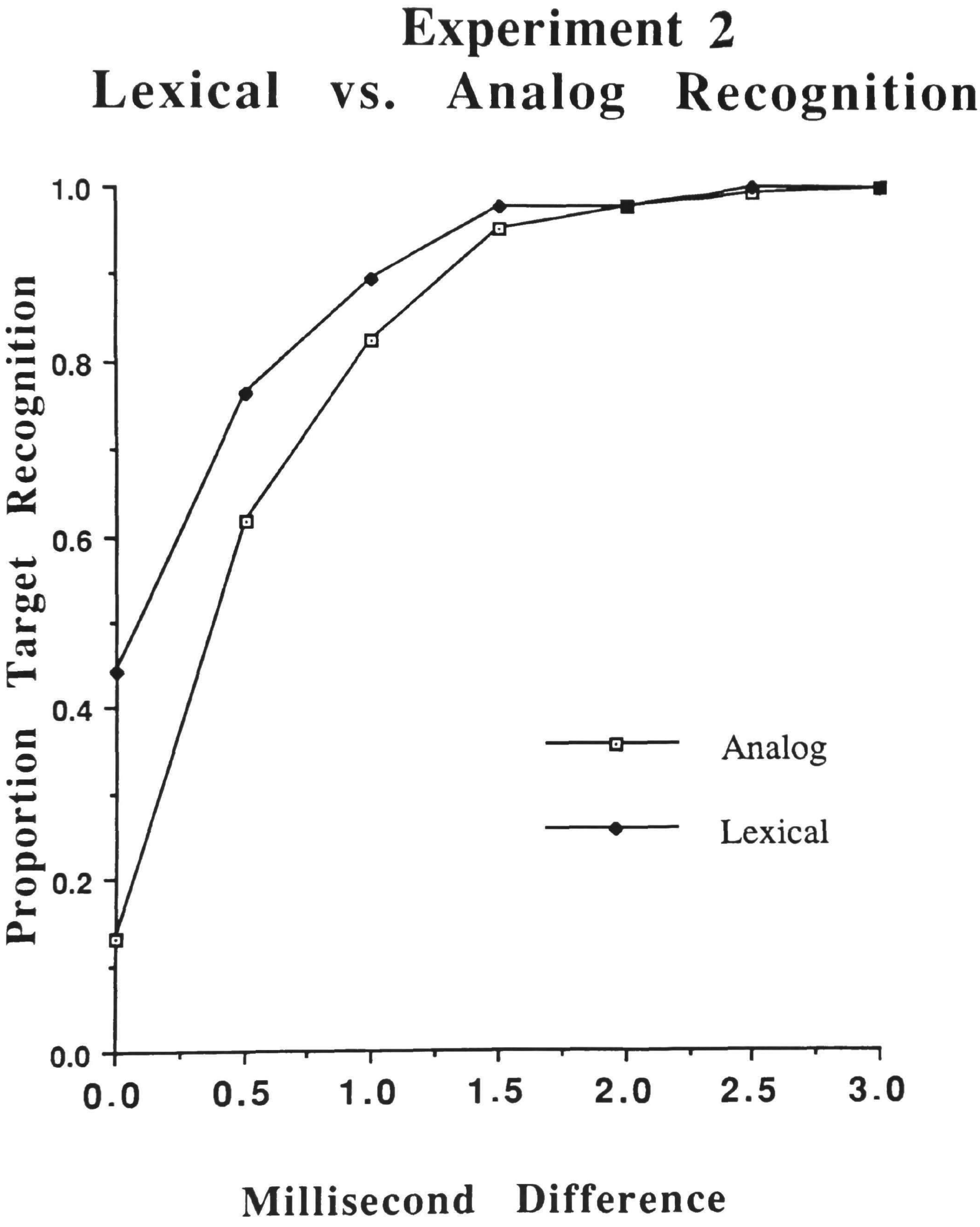

Figure 3. Target recognition, Exp. 4.