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Effect of Signal Duration on Detection for Gated and for Continuous Noise

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ABSTRACT

A series of two-alternative, forced-choice experiments showed that for short durations, the detection of a tonal signal in noise when the two are gated synchronously is superior to the detection of the signal in a background of continuous noise. The experiments also showed that for gated signal and noise, there is a steady improvement in detection as the duration is shortened, provided that highly-practiced observers are employed in the task. Naive observers exhibit a similar trend but their performance drops at the short durations (5 and 10 msec) where the listening task becomes very difficult.

INTRODUCTION

The role of duration in signal detection is of vital importance to the theory of signal detectability (TSD). For the case where the phase of the signal is unknown, Peterson, Birdsall, and Fox (1954) have shown that optimal detection should occur at a duration that is the reciprocal of the bandwidth of the filter involved. Since in the detection of signals by human observers, the filter of concern is the critical band of the ear, the theory predicts that subjects should show a pronounced peak of detection at durations that are the reciprocal of the critical bandwidth. Such a finding has not been observed in experiments with human listeners. Green, Birdsall, and Tanner (1957) found almost uniform detection over a considerable range of durations when the energy of the signal was kept constant. When the detection index, d', for their four observers was averaged, the highest value occurred at a duration of 50 msec, with only slightly inferior detection at durations of 20 msec and 100 msec. The suggested bandwidths, ranging from 10 Hz to 50 Hz, are much narrower than the usual estimates. The sharp peak predicted by TSD did not occur. Green *et al* concluded, "A rational theory is still badly needed which will explain why these or similar relationships exist."

The predictions of TSD are based on taking similar samples of noise (*N*), and of signal plus noise (*SN*). This sampling procedure was probably not satisfied by the subjects in the experiment by Green *et al*, since they were furnished a *continuous* noise, and only the signal was gated. A four-alternative, forced-choice procedure was employed, with the *onset* of the signal indicated by a flash of light. The subjects were, therefore, not furnished information about how long to sample the noise. Even if the subjects had been given a visual signal to indicate the onset and termination of the sampling interval, it is doubtful whether they could have used the information to obtain the similar samples of N and SN required by TSD assumptions. The present experiment was undertaken, using noise that was gated in the same way as the signal, in order more nearly to fulfill the requirements of TSD.

EXPERIMENT I

Experiment I was conducted[1] to study the detection of gated signals of various durations when the noise was gated synchronously. It employed a two-alternative, forced-choice procedure, with no feedback supplied to the subject. The noise (100 Hz to 3000 Hz in width) had a spectral level of about 50 dB re 0.0002 microbars. The energy of a 500 Hz signal was kept constant at an E/N_0 of 8. The durations used were 10, 20, 50, 100, 200, and 500 msec, with a 0.5 msec rise-fall time. Three naive observers served for an hour twice a day, with the sittings separated by at least two hours. The first 600 trials for each duration were discarded, and the data points based upon 1800 additional trials. The observers were told the value of the *a priori* probability of a signal (0.50). Data were collected first at 100 msec, then at 200 and 500, at 100 again, and then at 50, 20, and 10.

Results

The results of Experiment I are presented in Fig. 1. Observer RDB showed his best detection at a duration of 20 msec, JAB at 50 msec, and DFH at 100. Detection at the two shortest durations was generally superior to detection at the two longest. If we infer widths of the critical band from the durations at which best detection occurred, we obtain 50 Hz for RDB, 20 Hz for JAB, and 10 Hz for DFH, generally much narrower than the usual estimates. The average detection indices for the three subjects tended to be similar for durations from 20 msec to 100 msec as in the experiment by Green *et al*.

EXPERIMENT II

Experiment II was undertaken to compare detection for gated *N* and *SN* with detection for continuous noise and gated signal. It was motivated in part by an observation by Jeffress and Gaston (1966) (see Jeffress, 1967), that an electrical model, which closely approximated the findings of Green *et al* with continuous noise and gated signal, showed detection for gated *N* and *SN* that was superior at short durations. It was superior not only to detection for continuous *N* and *S*, but also to detection for gated *N* and *SN* at longer durations. For a constant energy signal, the model's detection improved consistently as the duration was shortened to 5 msec.

Experiment II used essentially the same procedure as Experiment I, except that the data points were based on 1,200 observations instead of 1,800. As in Experiment I, the onset and termination of an interval was indicated by a lamp adjacent to the response button for that interval. A new group of three naive observers was employed.

Results

The results of Experiment II are shown in Figs. 2, 3, and 4. Again each observer showed his best performance at a different duration from the others. Figure 4 shows the superiority of gated *N* and *SN* over gated

S and continuous N, as predicted by the electrical model. It does not show, however, the predicted superiority of detection with gated N and SN for short durations over detection for longer. There was a decided drop at 10 msec.

EXPERIMENT III

Whitmore (1967) suggested, on the basis of considerable experience as a listener in experiments involving short-duration stimuli, that the task of the observer in deciding which of the two brief intervals contains the signal is a very difficult one, and that practiced observers might give different responses to the very short stimuli than naive observers. Accordingly Experiment III was undertaken. Three observers who had been working with short-duration stimuli for some time were given practice on the present experiment, along with practice with other short stimuli in a study being conducted by Whitmore (see Whitmore, 1968). The sessions continued over a period of about four months, at the end of which time the observers had reached plateau in the present experiment. Only then were the data employed in the final summary collected.

Seven different signal levels (in random sequence) were used in 2AFC experiment, although data for only one signal level ($E/N_o = 10$) are reported here. To avoid the sharp transients resulting from abrupt gating of the noise, which may have been a disturbing factor in Experiments I and II, the gated N and SN was passed through a Krohnhite filter having a passband of about 400 Hz (centered at the signal frequency, 500 Hz). Three hundred or more observations were obtained for each data point. The results are presented in Fig. 5.

It will be seen that for all three observers, there is a consistent improvement in detection as the duration is decreased. The same trend was shown in the data for the other signal levels employed. To determine whether the difference between gated and continuous noise shown in Fig. 4 continued to hold for experienced observers, data were gathered at 10 msec and at 5 for JW. He showed an even greater difference between detection for gated N and SN and for continuous noise than the naive observers had shown.

DISCUSSION

As Jeffress (1968) pointed out, the results of Experiment III are to be expected not only on the basis of the electrical model, but from the very nature of the filtering process. If we accept the idea that in detecting a tonal signal in noise, the auditory system serves in some fashion (no matter how) as a fairly narrow bandpass filter, we are forced to predict that when we employ gated N and SN and keep the signal energy constant, we will eventually reach a duration where detection will improve with further reduction of the duration. When it is less than the reciprocal of the filter's bandwidth, both signal energy and noise energy will be lost due to frequency spreading-- $\Delta f \cong 1/\Delta t$. Now, if, as we shorten the duration, we increase the signal power, but do not increase the noise (thus keeping E/N_0 constant) we are certain to reach a point where the loss of noise power due to frequency spreading is sufficient to allow the signal (of increased power) to be detected more easily.

A similar conclusion follows from the energy-detector model of Green and McGill (Green and McGill, 1968, and McGill, 1968). Their mathematical model predicts that as duration is decreased, there will be a corresponding decrease in the number of degrees of freedom of the underlying non-central, chi-square distribution function, with a consequent improvement in detection for any constant value of E/N_o. (See Jeffress, 1968 for a more detailed discussion of this point.)

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FOOTNOTES

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[1]Experiments I and II were conducted by Tucker (1967). The results of Experiment I were presented by Tucker, Evans, and Jeffress (1966) at the 72nd meeting of the Acoustical Society of America. Experiment III was conducted by Williams for purposes of the present article.

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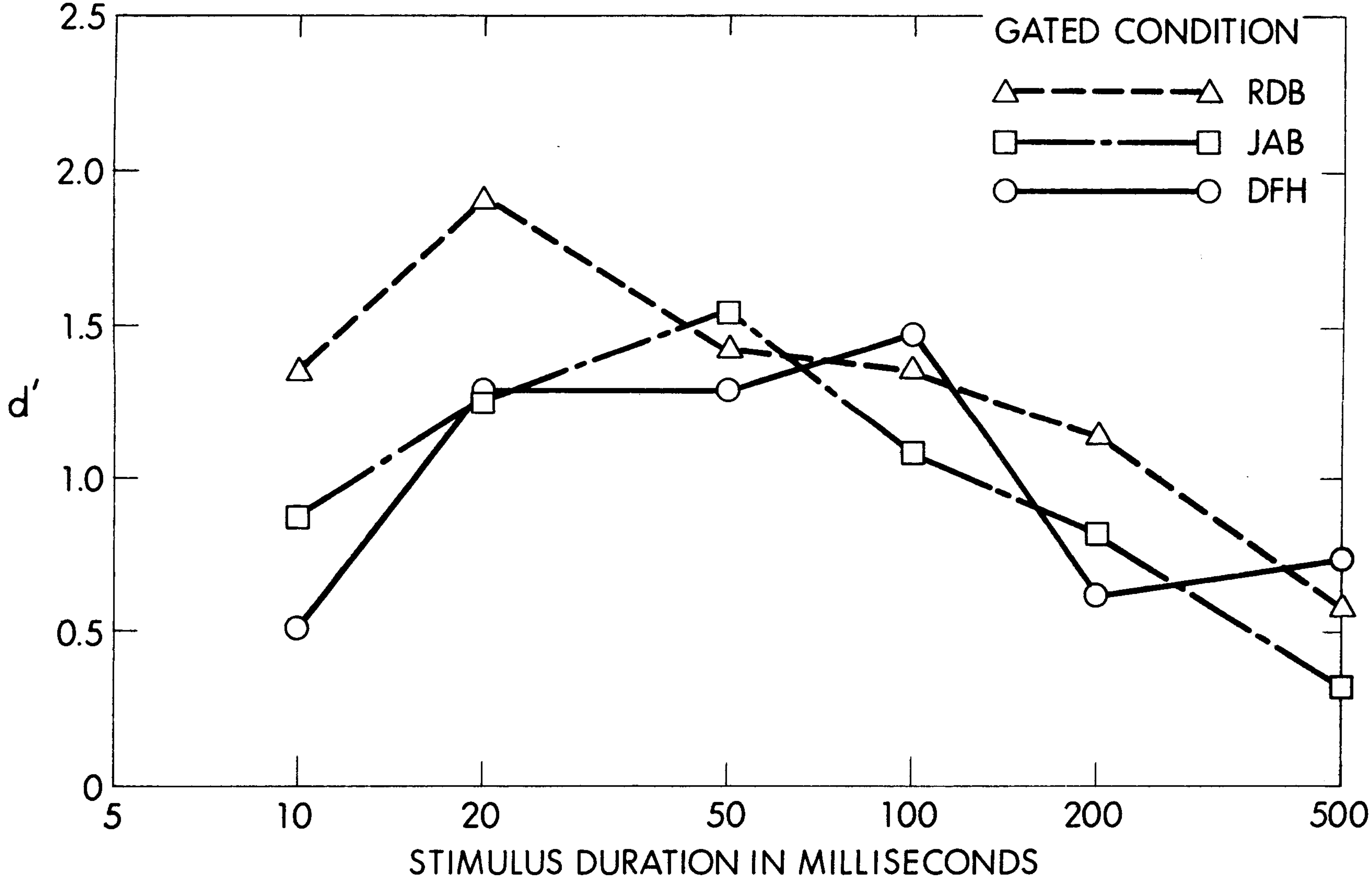

FIGURE 1

DETECTION FOR THE THREE OBSERVERS OF EXPERIMENT I

DRL - UT
DWG AS-66-423-S
AT - EJW
5 - 13 - 66

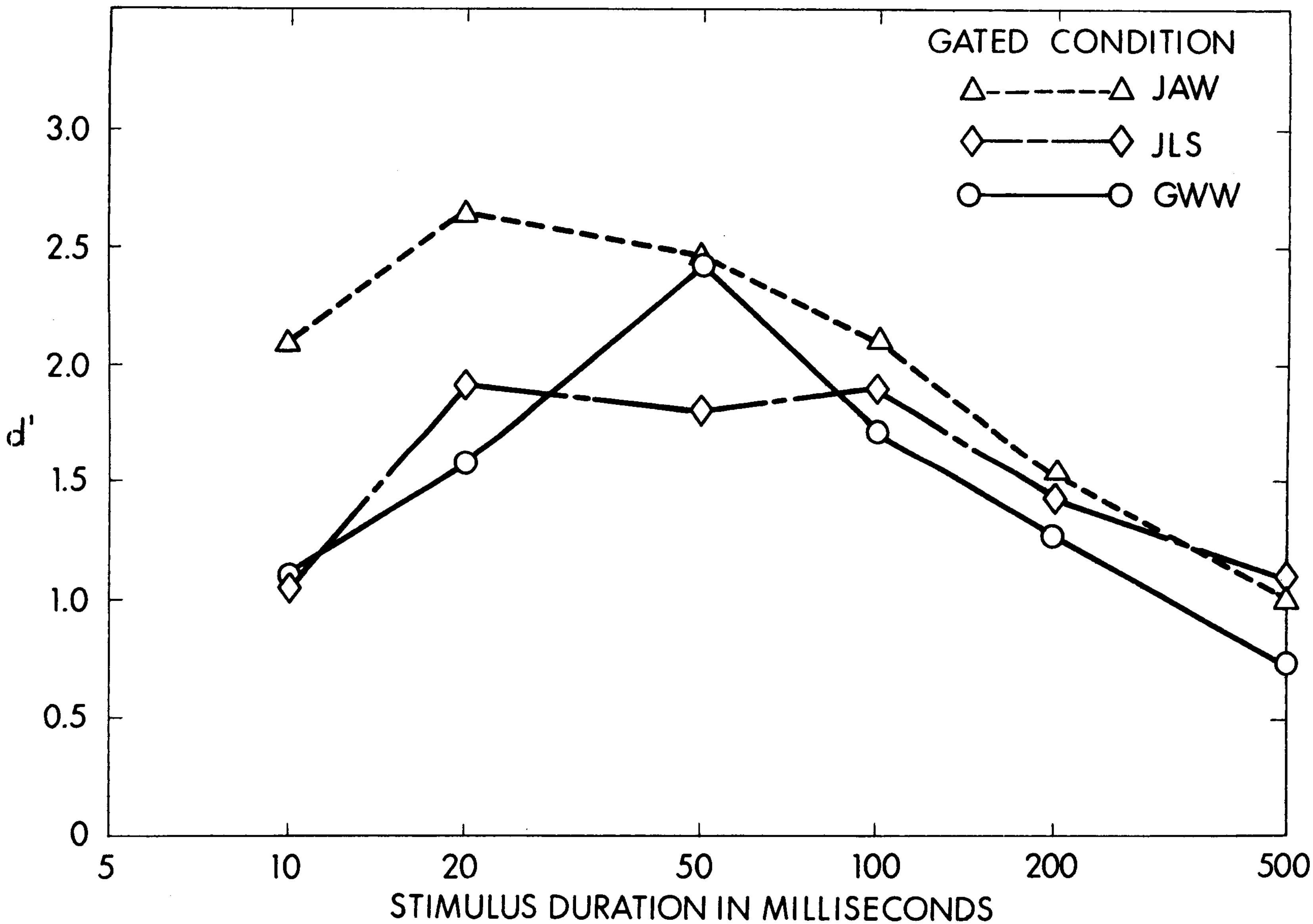

FIGURE 2

DETECTION FOR THE THREE OBSERVERS OF EXPERIMENT II,
FOR GATED NOISE AND SIGNAL

DRL - UT
DWG AS - 66-1034-S
AT - ORS
10 - 19 - 66

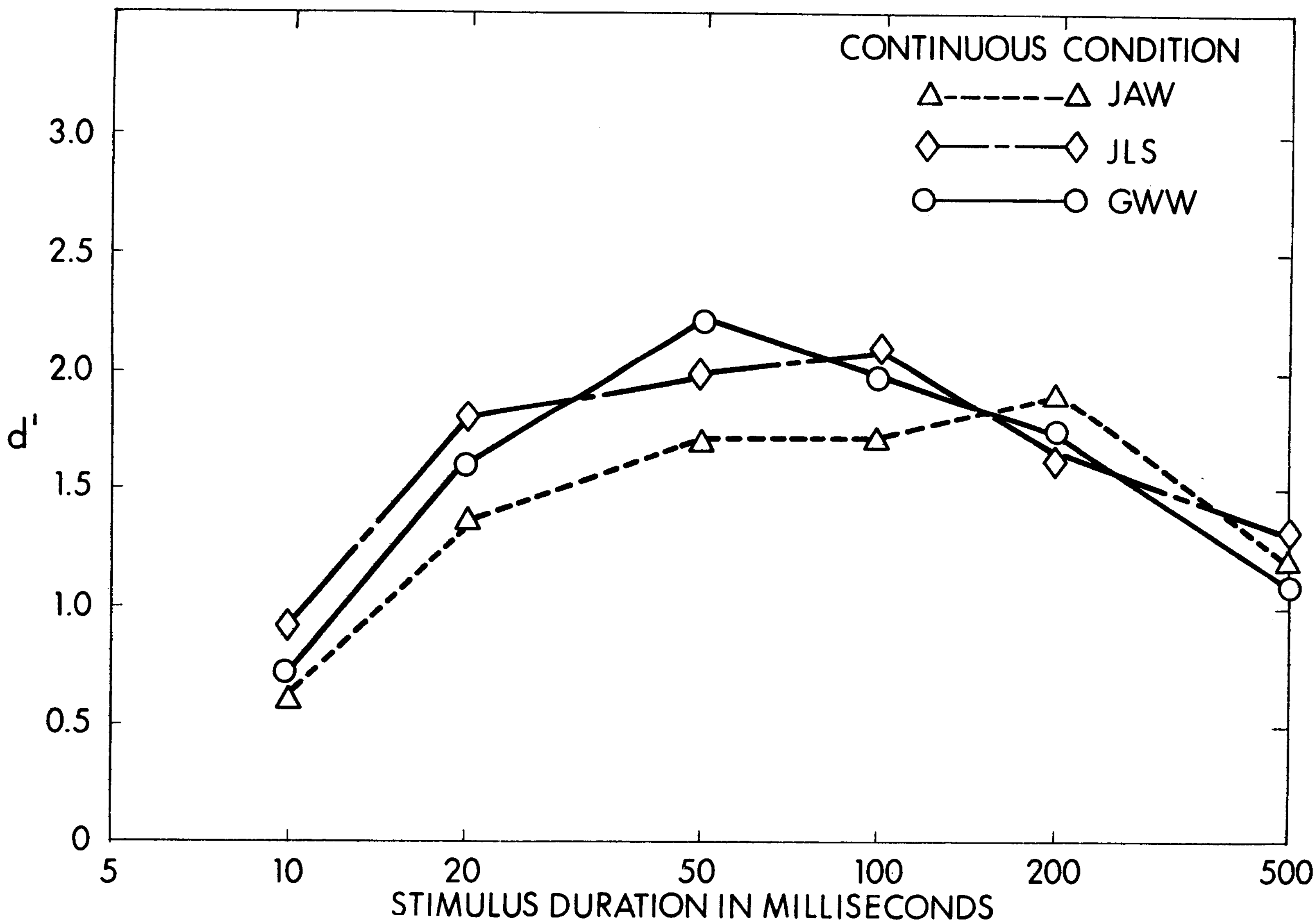

FIGURE 3

DETECTION FOR THE THREE OBSERVERS OF EXPERIMENT II,
FOR CONTINUOUS NOISE AND GATED SIGNAL

DRL - UT
DWG AS-66-1035-S
AT - ORS
10 - 19 - 66

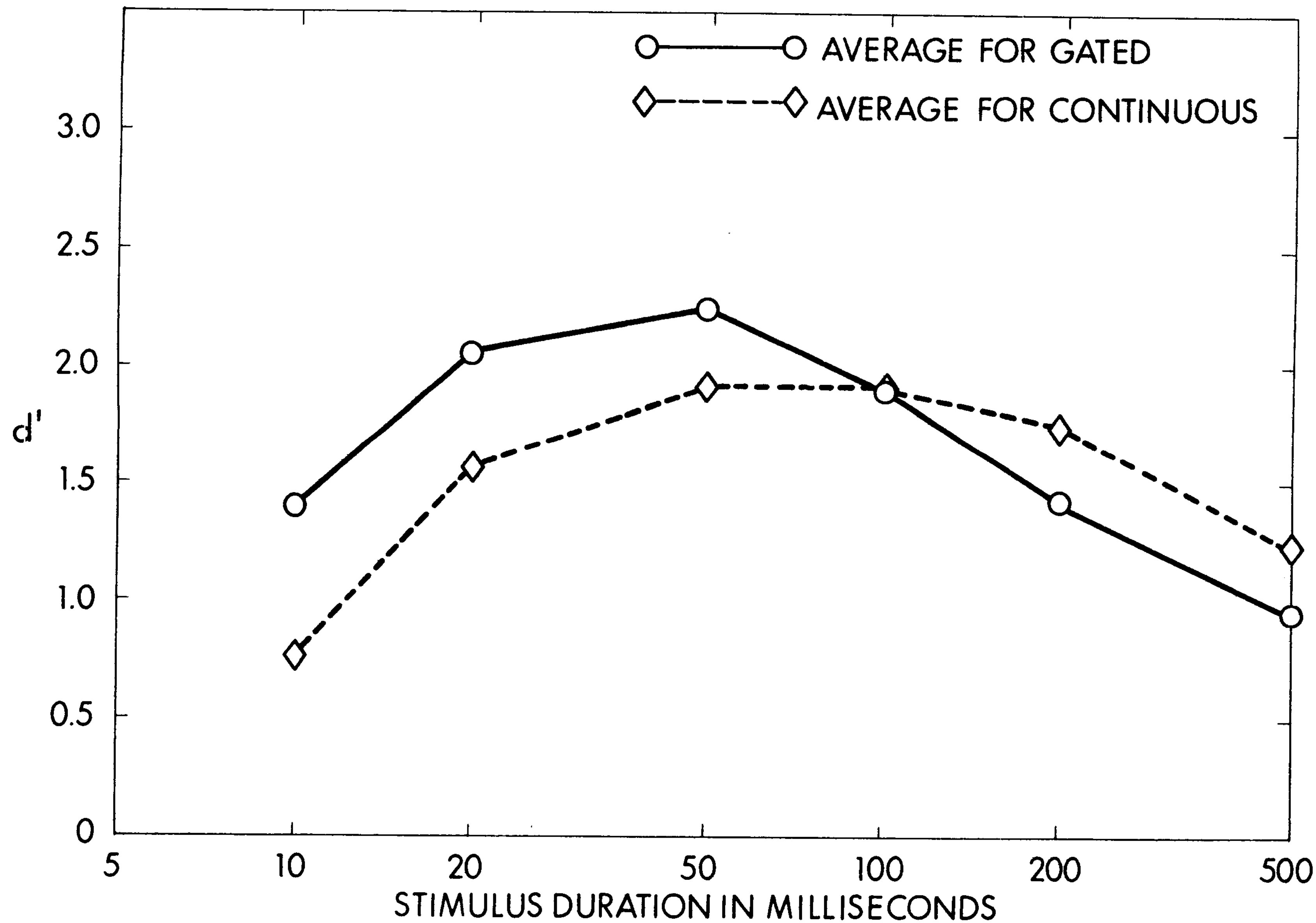

FIGURE 4

DETECTION FOR THE THREE OBSERVERS OF EXPERIMENT II (AVERAGES)
Solid line represents data for gated noise and signal. Dashed line represents data for continuous noise and gated signal

DRL - UT
DWG AS - 66-1036-S
AT - ORS
10 - 20 - 66

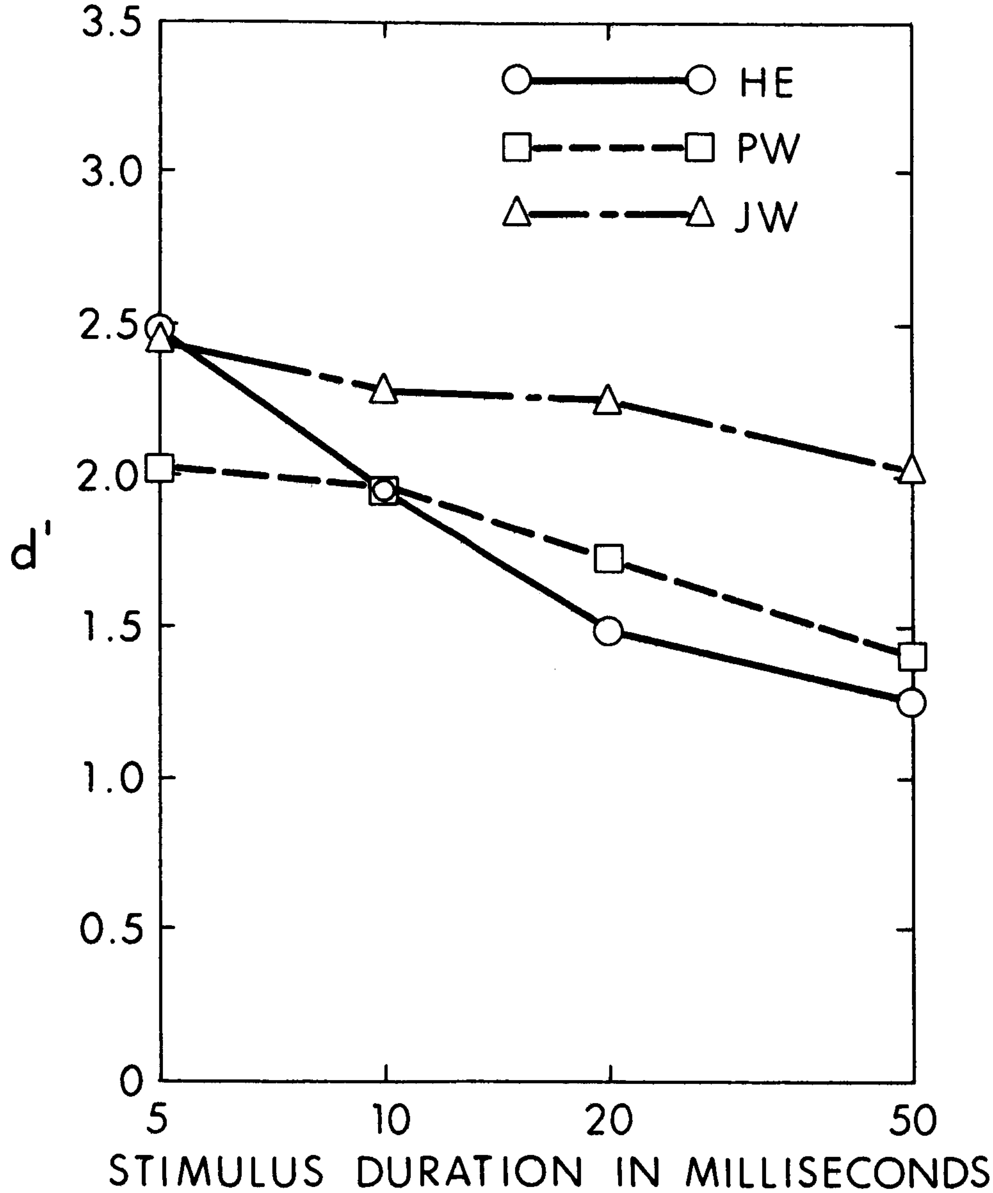

FIGURE 5

DETECTION FOR THE THREE OBSERVERS OF EXPERIMENT III

DRL - UT
AS-68-497
LAJ - DR
4 - 19 - 68

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