Notes and Comment

Backward masking in judgments of duration

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In a series of systematic studies, Massaro and his colleagues (Massaro, 1970, 1975; Massaro, Cohen, & Idson, 1976) have demonstrated that the judgment about the pitch, timbre, or lateralization of an auditory stimulus can be influenced by following the stimulus to be identified (the test stimulus) by a second auditory stimulus (the mask). Correct recognition improves as the interval between the offset of the test stimulus and the onset of the mask is increased to about 250 msec. The data from these recognition masking studies form the foundation for Massaro's (1975) theory for auditory recognition.

Massaro (1972b) suggested that the recognition masking paradigm might also prove to be useful in understanding the manner in which temporal information is processed, and recently he has used this paradigm to investigate the perceived duration of brief auditory events (Massaro & Idson, 1976). On each trial, one of two auditory test stimuli which differed in duration was followed, after a variable silent interval, by a second auditory stimulus, the mask. The subject's task was to identify the task stimulus as short or long. The durations of the test stimuli and the masks were brief—less than 110 msec. The data clearly indicate that performance was influenced by the duration of the test stimulus, the duration of the silent intertone interval, and the duration of the mask. For the purpose of the present note, the important finding was that duration discrimination improved as the interval between the offset of the test stimulus and the onset of the mask was increased to about 165 msec.

Cantor and Thomas (1976) have reported a duration masking study using visual stimuli. The duration of the test stimulus was either 20 or 50 msec, the duration of the mask was 500 msec, and the test stimulus-offset/mask-onset interval varied from

0 to 110 msec. There were two pairs of test stimuli: two circles which differed in area and two abstract dot forms. They found that the perceived duration of the form stimuli increased with increases in the mask delay, for mask delays less than 70 msec.

The model proposed by Massaro and Idson (1976) to account for their data is based on Massaro's (1975) theory for auditory recognition. An auditory stimulus is stored in a preperceptual memory which has a capacity limit of a single sound. Information in preperceptual store is read out continuously for approximately 250 msec. If a second auditory stimulus (the mask) is presented before processing of the first stimulus (the test) is completed, the onset of the mask will erase the representation of the test stimulus and therefore terminate processing. The improved performance found in backward recognition masking tasks with increases in the intertone interval represents the extraction of greater amounts of information about the test tone given longer processing times prior to the onset of the mask.

In the case of duration, Massaro and Idson (1976) suggest that the perceived duration of the test tone as well as its discriminability increases with intertone interval. If sufficient time is allowed for complete processing of the test tone, the perceived duration, while being directly related to the temporal extent of the tone, will be overestimated. If less than complete processing time is available, the test tone is perceived as shorter than its asymptotic value. Perceived duration depends both upon test stimulus duration and intertone interval. In terms of their model, discrimination between two test durations is simply equal to the difference between their perceived durations. A masking tone decreases the test tone's perceived duration and its discriminability from other test tones.

Massaro and Idson (1976) found that performance in a duration masking task reached an asymptote at an intertone interval of about 165 msec. This implies that the perceived duration of the test tone was at its asymptotic value when the intertone interval was 165 msec. Therefore, for a 90-msec test tone (the longest used by Massaro & Idson), perceived duration and discriminability were asymptotic for a processing time of approximately 255 msec, where processing time refers to test stimulus duration plus intertone interval.

Massaro and Idson (1976) argue that processing time is a critical variable affecting performance in a recognition masking task. If this is the case, their results suggest that the introduction of a mask should not influence duration discrimination performance for test stimulus durations around 250 msec.

This research was supported by National Research of Canada Grant A8260 to L.G.A. Requests for reprints should be sent to Lorraine G. Allan, Psychology Department, McMaster University, Hamilton, Ontario, Canada.

In contrast to the Massaro and Idson (1976) erasure explanation of duration masking, Cantor and Thomas (1976) consider duration masking within an integration framework. Processing time, and therefore perceived duration, is a function of the test stimulus duration, the test-offset/mask-onset delay, and the time the test stimulus (and the mask) is processed after the mask onset. Cantor and Thomas (1976) do not consider the masking function for longer duration stimuli.

One purpose of the present note is to report an experiment conducted to compare the masking function for brief test durations (50 and 60 msec) with that for longer test durations (250 and 270 msec). The second purpose is to comment briefly on a number of models for temporal judgments.

Nine paid subjects were used. The stimuli were pure tones with a 2-msec rise-decay time. They were produced by a Wavetek function generator and were presented binaurally over earphones. The subject responded by means of two pushbuttons on the arm of his chair. Small indicator bulbs were used to signal the beginning of a trial, and to provide trial-by-trial feedback. The experiment was controlled on-line by a PDP-8E computer.

Each trial began with a 500-msec visual warning signal, followed 2 sec later by either an S_0 or an S_1 auditory test stimulus. Both test tones were of equal intensity (68 dB), and the same frequency (800 Hz), and differed only in duration, d_0 or d_1 msec, for $d_1 > d_0$. On each trial, the test tone was followed, after a variable silent interval (t), by a 500-msec, 68 dB, 800-Hz masking tone. The subject was then given 2.5 sec to indicate his judgment about the duration of the test tone, short (R_0) or long (R_1). He was required to withhold his response until after the offset of the second tone. At the end of the response period, visual feedback was provided for 500 msec. The next trial began 1.5 sec after the termination of the feedback.

For five subjects (P.S., B.T.M., T.F., K.M., and A.M.), d_0 was 250 msec, d_1 was 270 msec, and there were seven values of the intertone interval (25, 50, 75, 100, 200, 300, and 500 msec). For three of these subjects (P.S., B.T.M., and T.F.), a "no-mask" condition was also included. When this condition was in effect, the test tone was not followed by a second auditory stimulus. In order to control for delay of response, 25 msec after the termination of the test tone an indicator bulb was illuminated for 500 msec. The subject was required to withhold his response until the termination of the light.

For five subjects (K.M., P.K., B.T.F., L.M., and R.B.), d_0 was 50 msec and d_1 was 60 msec. The same seven intertone intervals were used. (K.M. also participated in the $d_0 = 250$ -msec condition.)

During each session, there were three blocks of

100 trials. During each block, S_0 and S_1 were presented equally often. The intertone interval (t) was constant during a session and varied between sessions. The seven values of t were presented in a random sequence, with the restriction that each value had occurred an equal number of times before any value was repeated. Each subject received at least one practice session at each intertone interval. The data to be presented represent performance after these practice sessions and are based on either two or three sessions at each intertone interval.

The probability of a correct response conditionalized upon stimulus, $P(R_1 | S_1)$ and $P(R_0 | S_0)$, is presented in Table 1 for each subject under each experimental condition. In Figure 1, the probability of a correct response, $P(C)$, averaged over subjects is plotted as a function of t for each value of d_0 . For $d_0 = 50$ msec, performance improves with increases in intertone interval, while for $d_0 = 250$, performance is basically invariant.

Data under the no-mask condition are available for three subjects (P.S., B.T.M., T.F.) for $d_0 = 250$ msec. $P(C)$ averaged over these three subjects is shown in Figure 2 for each value of t and for the no-mask condition ($t = 25$). Performance under

Figure 1. $P(C)$ as a function of t for each value of d_0 .

Figure 2. $P(C)$ as a function of t for three subjects in the $d_0 = 250$ -msec group. Performance under the no-mask condition for $t = 25$ msec is also shown.

Table 1
 $P(R_1|S_1)$ and $P(R_0|S_0)$ for Each Subject Under Each Experimental Condition

Subject	t	$P(R_1 S_1)$	$P(R_0 S_0)$	t	$P(R_1 S_1)$	$P(R_0 S_0)$
$d_0 = 250$						
B.T.M.	25	.657	.580	200	.712	.554
T.F.		.729	.554		.724	.472
A.M.		.940	.867		.920	.783
P.S.		.739	.739		.796	.697
K.M.		.900	.865		.820	.862
Average		.793	.721		.794	.674
B.T.M.	50	.706	.597	300	.708	.570
T.F.		.677	.565		.742	.544
A.M.		.943	.877		.913	.843
P.S.		.765	.742		.702	.633
K.M.		.900	.876		.827	.842
Average		.798	.731		.778	.686
B.T.M.	75	.722	.536	500	.758	.586
T.F.		.782	.537		.740	.650
A.M.		.936	.867		.917	.725
P.S.		.796	.706		.693	.627
K.M.		.863	.836		.737	.866
Average		.820	.696		.769	.691
B.T.M.	100	.679	.546	No Mask	.752	.607
T.F.		.640	.654		.705	.701
A.M.		.937	.883			
P.S.		.716	.729		.699	.697
K.M.		.843	.842			
Average		.763	.731			
$d_0 = 50$						
L.M.	25	.814	.857	200	.960	.782
R.B.		.787	.878		.978	.931
K.M.		.780	.856		.884	.909
B.T.F.		.589	.522		.743	.769
P.K.		.729	.452		.920	.534
Average		.740	.713		.897	.785
L.M.	50	.887	.861	300	.926	.926
R.B.		.918	.953		.944	.922
K.M.		.884	.891		.904	.967
B.T.F.		.753	.690		.797	.843
P.K.		.698	.574		.940	.559
Average		.828	.794		.902	.843
L.M.	75	.893	.788	500	.909	.899
R.B.		.916	.911		.958	.947
K.M.		.920	.946		.870	.930
B.T.F.		.667	.607		.759	.732
P.K.		.672	.403		.886	.522
Average		.814	.731		.876	.806
L.M.	100	.874	.774			
R.B.		.924	.922			
K.M.		.937	.924			
B.T.F.		.699	.589			
P.K.		.720	.457			
Average		.831	.733			

the no-mask condition does not differ from the performance observed when the test tone is followed by a second auditory stimulus.

It is conceivable that when $d_0 = 250$ msec, the 500-msec auditory stimulus provides a referent or standard, as well as acting as a mask. It could be argued that increasing the delay between the test stimulus and the standard results in a decrement in performance which is compensated for by the incre-

ment in performance resulting from increasing the delay between the test stimulus and the mask. Since backward masking of an auditory test stimulus by a visual mask has never been demonstrated (Massaro and Kahn, 1973), the 500-msec light in the no-mask condition would act as a standard but not a mask and performance should be considerably better in the no-mask condition than in the $t = 25$ msec mask condition. This is clearly not the case.

The data from the present experiment are consistent with the claim of Massaro and Idson (1976) that processing time is a critical variable affecting performance in a duration discrimination task. However, Massaro and Idson (Note 1) have recently obtained data which are at odds with the data from the present experiment. They used vowels with durations of 180 and 240 msec and found that performance improved until processing time was approximately 400 msec. Massaro and Idson explain their most recent results in the following way. In recognition of pitch, the information relevant to the discrimination is available virtually from the onset of the test stimulus, as tones differ immediately in frequency. However, this is not the case for duration, since no useful information about the identity of the test tone is available until the span of the short test tone has been exceeded. Therefore, the masking function will extend over longer processing times with increasing stimulus duration.

This explanation raises a question about the model discussed by Massaro and Idson (1976). Two of the parameters, θ_S and θ_L , represent the rate of growth of the perceived duration of the short and long test tones, respectively. Massaro and Idson have consistently found that for any pair of test stimuli the estimate of θ_S differs considerably from the estimate of θ_L . Since the short and long test tones are identical for a major portion of their extent, the rate of growth of perceived duration has to be identical over this span, and $\theta_S = \theta_L$.

The estimates obtained for these growth parameters are troublesome in other ways as well. For example, for 60- and 80-msec vowels, $\theta_S > \theta_L$, while for 180- and 240-msec vowels, $\theta_S < \theta_L$. Also, for the short pair of vowels, both θ_S and θ_L were considerably larger than for the long pair of vowels, again indicating that rate of growth depends on stimulus duration (Massaro and Idson, Note 1).

In the version of the model used to account for pitch recognition, Massaro (1972a) explicitly stated that "increasing the duration of the test stimulus . . . should not affect the rate of processing" (p. 54) and that the rate of processing during the stimulus was the same as that during the intertone interval. Furthermore, in that paper, Massaro found that one value of θ could account for data obtained for stimulus durations which varied from 20 to 440 msec.

A few years ago, when Allan and Kristofferson (1974) reviewed the literature concerned with judgments about brief temporal intervals, only three quantitative models had been formulated. Two of these, the onset-offset model (Allan, Kristofferson, and Wiens, 1971) and the quantal counting model (Allan, Kristofferson, & Wiens, Note 2) stemmed from their laboratories. The third, the Poisson counting model, was developed by Creelman (1962).

Since that time, a number of quite diverse models have appeared in the literature (for example, Eisler, 1975; Getty, 1975; Gibbon, in press; Kristofferson, 1977; Massaro & Idson, 1976; Thomas & Brown, 1974). Except for Massaro and Idson (1976), none of these models explicitly consider duration masking. We discussed the Massaro and Idson (1976) model earlier and noted a logical inconsistency.

Kristofferson (1977) has distinguished between two hypotheses concerning the manner in which duration judgments are made. According to the *interval-measure* hypothesis, a measure is taken of the duration stimulus over its temporal extent, and the decision as to whether the stimulus is relatively long or short is based on this measure. According to the *real-time criterion* hypothesis, the judgment is determined by the outcome of a race between an internally timed interval and the presented stimulus. According to this hypothesis, duration discrimination is a matter of temporal order discrimination (Kristofferson & Allan, 1973).

Kristofferson (1977) has developed a real-time criterion model for duration discrimination, and has presented data which clearly indicate that in some experimental situations subjects do *not* take an interval measure of the duration to be judged. In essence, this model states that onset of a stimulus triggers an internally timed interval, *I*. If *I* terminates before the stimulus, the subject responds long; if the stimulus terminates before *I*, the subject responds short. Thus long responses are time-locked to stimulus onset, and short responses to stimulus offset. There is only one source of variability, the timing of the internal interval, *I*.

In terms of this model, it is plausible that the effect of the mask would be to increase the variability in *I*. The source(s) of this variability has not yet been isolated. Duration masking may prove to be useful in understanding the generation of the internal interval.

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(Received for publication February 14, 1977.)