has been effectively decreased by these 2 conditions, whether interference conditions were presented separately or in conjunction with each other. Therefore, it can be concluded from those experiments that preventing verbal rehearsal by counting backward and displacing items from the rehearsal buffer by an auditory probe constitute independent processes in the STM system, each contributing a given amount to the total loss of information in the short-term store.

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# A COMPARISON OF FORWARD VERSUS BACKWARD RECOGNITION MASKING[1]

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Recognition of a 20-msec. stimulus under forward- and backward-masking conditions was studied. If either a forward- or backward-masking stimulus occurs within 20–40 msec. of a test-stimulus presentation, the masking stimulus decreases the signal-to-noise ratio of the test stimulus. A forward-masking stimulus does not affect recognition if it occurs outside this 20–40 msec. period. In contrast, a backward-masking stimulus continues to interfere with perception of the test stimulus up to an interval of 140–340 msec. These results indicate that backward masking occurs beyond intervals of 40 msec. because the second stimulus overwrites the information in the perceptual representation of the test-stimulus presentation.

A theoretical account of the auditory recognition process has been described by a recent theory of perceptual processing (Massaro, 1972a, 1972b). The 2 main assumptions of the theory describe the perceptual process in terms of the information in the sensory input and the time the information is available for perceptual processing. The first assumption is that an auditory input produces a preperceptual auditory image (representation) that contains the information in the auditory stimulus. The preperceptual auditory image can be thought of as a temporal or perceptual unit of information. Therefore, the image persists beyond the stimulus presentation and preserves its sequential information. The second assumption is that the recognition process entails a readout of the information in the preperceptual auditory image. This readout takes time and is referred to as the temporal course of perceptual processing. Perceptual processing time exceeds the duration of the sensory input, so that the preperceptual image is critical for the recognition process.

The results of auditory masking are directly relevant to the theory. Auditory masking refers to any observation that information in a test auditory stimulus is reduced by presentation of another masking auditory stimulus. The present article is concerned with temporal masking conditions in which the test and masking stimulus do not coexist in time. Backward masking refers to the paradigm of following the test-stimulus presentation by a masking stimulus. In forward masking, the masking stimulus precedes the test stimulus. The interval between the 2 stimuli is called the interstimulus interval.

Massaro (1970) developed a recognition masking paradigm to study auditory information processing. In this task, *S* is required to identify some quality (e.g., pitch) of the test tone. The test and masking tones are presented at the same loudness, a normal listening intensity. Employing a 20-msec. test tone, Massaro showed that backward masking of test-tone identification occurred out to an interstimulus interval of roughly 250 msec. Although *S* hears the test tone in the recognition masking task, he is not able to identify its pitch without sufficient processing time before presentation of the masking tone.

Massaro (1972a) argued that there should be less forward than backward masking in the recognition masking paradigm. Since both stimuli in the recognition masking task are equal in loudness, forward masking should not occur because the second stimulus essentially terminates processing of the

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first stimulus. In this case, the first stimulus should not interfere with the processing of the second stimulus. In Massaro's 1970 study, no forward masking was found in an experiment used as a control for the demonstration of backward masking. In that study, however, the masking tone lasted 500 msec., and the test stimulus lasted 20 msec. Accordingly, it is still necessary to compare forward and backward masking when the masking stimulus is of the same duration as the test stimulus. In terms of the visual masking methodology (Kahneman, 1968), this would also equate for the stimulus onset asynchrony in the 2 masking conditions. Also, in the present experiment, forward- and backward-masking trials were presented randomly in the same session to control for memory and decision processes in this task. Accordingly, the present study provides a more direct comparison of forward and backward recognition masking.

*Method.* Fifteen undergraduates from the university community were employed for 4 days. The test tones were a sine wave and a sawtooth wave of 1,000 Hz. The 2 tones differ with respect to the higher harmonics of 1,000 Hz., and the sawtooth wave sounds sharp relative to the dull sound of the sine wave. The duration of the test tone was 20 msec. The masking tone was also a 1,000-Hz. tone that lasted 20 msec. Two different masking tones occurred with equal probability. The masking tone was either 10 cycles of a sawtooth wave followed immediately by 10 cycles of a sine wave, or 10 cycles of a sine wave followed by 10 cycles of a sawtooth wave. The test and masking tones were presented at the same intensity, about 76 db. when measured at steady-state presentation.

Each day of the experiment consisted of 2 sessions of 300 trials per session. On the first day of the experiment, *Ss* learned to identify the test tones in an absolute judgment task without the masking tone present. The forward- and backward-masking conditions were presented on Days 2, 3, and 4. In backward masking, the masking tone followed the test tone. In forward masking, the masking tone preceded the test-tone presentation. The silent interval between the 2 tones is referred to as the intertone interval. The intertone interval lasted 0, 20, 40, 80, 140, 220, 340, or 480 msec. All 64 experimental conditions (2 Test Tones × 2 Masking Conditions × 2 Masking Tones × 8 Silent Intertone Intervals) were presented randomly with equal probability.

Each trial was initiated with visual presentation of a cue digit, 1 or 2, signifying whether the test tone would occur first or second. The *Ss* were instructed to identify this test tone as sharp or dull and to ignore the other tone. The cue digit was presented for 250 msec. and occurred 1.25 sec. before the first tone presentation. A 1.5-sec. response period followed the second tone presentation. Feedback was given by presenting the digit 3 or 4 for 500 msec., indicating whether the dull or sharp tone had been presented. The intertrial interval was 1.5 sec.

All experimental events were controlled by a PDP-8L computer. The pure tones were produced

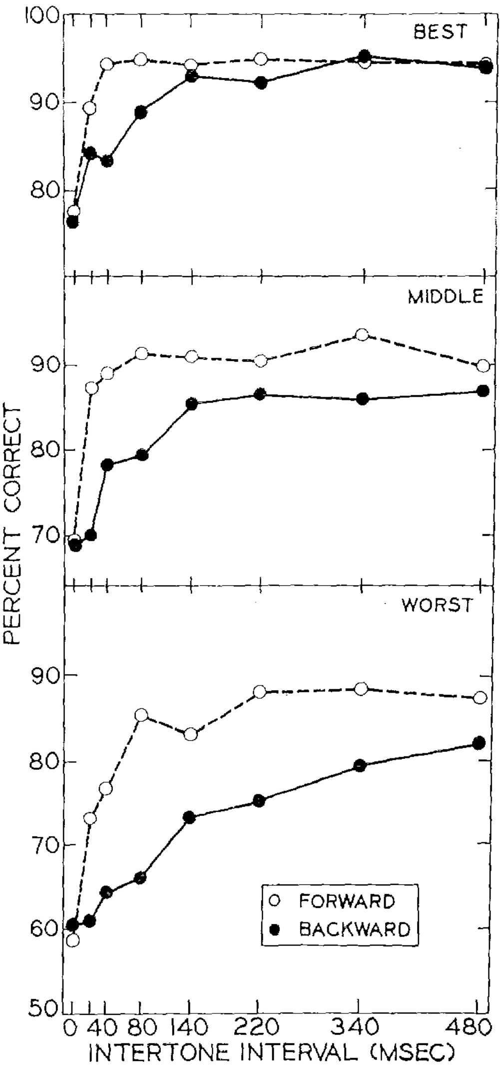


FIG. 1. Percentage of correct identifications as a function of forward and backward masking and the intertone interval. (Top, middle, and bottom panels give performance for the 5 best, middle, and worst *Ss*, respectively.)

by a digitally controlled oscillator (Wavetek Model 155). The tones were presented binaurally over matched headphones (Grason-Stadler TDH-49). The digits were presented over rear-projected readouts (Industrial Electronic Engineers, Series 80). Four *Ss* could be tested simultaneously in separate sound-attenuated rooms. Only the results of Days 3 and 4 were included in the data analysis. The first 5 trials of each day were also eliminated. The data were not analyzed to measure performance as a function of the type of masking tone (sine wave preceding sawtooth vs. the reverse), since a previous study found no effect of the pitch quality of the masking tone (Massaro, 1970). Accordingly, pooling over the 2 test tones gives about 74 observations per $S$ at each experimental condition.

*Results.* The results were partitioned into 3 groups of 5 $S$s each according to overall performance. Pooling over $S$s with similar overall performance should not eliminate performance differences that are related to the level of overall performance. Figure 1 shows the percentage of correct identifications for each of the 3 groups as a function of forward or backward masking and the intertone interval. Overall, performance improved with increases in the silent intertone interval, $F$ (7, 84) = 22, $p < .001$. There was, however, significantly more backward masking than forward masking, $F$ (1, 12) = 45, $p < .001$. The figures also show that the forward- and backward-masking functions differ significantly; the Masking Condition × Intertone Interval interaction was significant, $F$ (7, 84) = 3.54, $p < .005$. Very little forward masking occurred beyond 40 msec. compared to significant backward masking at up to at least 140 msec.

Overall, identification performance reached asymptote at a higher level under forward masking than under backward masking. This result probably reflects another process operating in this task. The forward-masking stimulus could function as a warning signal at the longer intertone intervals. Reaction time performance and signal detection performance are enhanced with introduction of a warning signal and also improve as the warning interval increases up to about 200–500 msec. (Bertelsen, 1967). The warning signal effect should also decrease with increase in asymptotic performance, since there is less room for improvement. For example, if $S$'s performance is already perfect, the warning signal can have no facilitatory effect. Supporting this, the results for the different groups in Figure 1 show that the difference between the forward- and backward-masking asymptotes decreased with increases in overall performance. Accordingly, it appears that the higher asymptote for forward than backward masking is due to the forward-masking stimulus functioning as a warning signal relative to no warning signal in the backward-masking situation.

*Discussion.* Some forward masking was observed at intertone intervals of 0, 20, and 40 msec. In forward masking, processing time is maximal, since the test tone is followed by a silent period. Therefore, any forward masking would be due to the amount of information available in the test stimulus presentation. If the test tone does not overwrite the auditory image of the masking tone completely, the masking tone could increase the background noise and, therefore, decrease the signal-to-noise ratio in the test-tone presentation. Therefore, the image of the forward-masking stimulus must have interfered with the test-tone identification at the 0-, 20-, and 40-msec. silent intervals. Beyond this interval, the test tone must have essentially erased or overwritten the auditory image of the masking tone completely since it did not interfere with perception of the test tone.

The differences observed for forward and backward masking support the different processes assumed to operate in these paradigms. Backward masking beyond 40 msec. occurs because the masking tone essentially overwrites the auditory image of the test tone and, therefore, terminates the perceptual processing of the test-tone presentation. Forward masking occurs because the auditory image of the masking tone decreases the signal-to-noise ratio of the test-tone presentation. Two processes are critical in auditory recognition: stimulus information and processing time. At short intertone intervals, masking occurs because the masking tone decreases the signal-to-noise ratio in the test-tone presentation. At longer intervals, however, the second tone appears to completely overwrite the auditory image of the first tone. Therefore, no forward masking occurs at these intertone intervals. Backward masking occurs until the information in the auditory image of the test tone has decayed or until it has been completely processed.

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