Stimulus information vs processing time in auditory pattern recognition*

DOMINIC W. MASSARO†
University of Wisconsin, Madison, Wisconsin 53706

Previous studies have shown that pitch perception improves with increases in tone duration. An increase in tone duration increases the information available in the stimulus presentation. Other recent experiments have shown that sufficient perceptual processing time is also necessary for accurate pitch perception. The present study determines the relative contribution of stimulus information and processing time in an absolute pitch indentification task. The results indicate that processing time is more critical than stimulus information. The results are described accurately by a model that describes the perceptual process in terms of the information in the stimulus and the time the information is available for perceptual processing.

An auditory perception of pitch quality of tonal stimuli requires some minimal stimulus duration (Creel, Boomsliter, & Powers, 1970; Doughty & Garner, 1947; Stevens & Davis, 1938). Tones lasting a few milliseconds are heard as clicks, while, with longer durations, they take on a tonal quality. The improvement of pitch perception with tone duration is also supported by the observation that the accuracy of pitch discrimination improves with increases in the duration of tonal stimuli (Anderson, 1914; Békésy, 1960; Turnbull, 1944). For example, Békésy found that the just noticeable frequency difference for an 800-Hz sine wave tone at 40 dB above threshold increased as its duration decreased below 250 msec. Os could detect a 3-Hz change with a tone duration of 250 msec, but required a 7-Hz change if the tone was shortened to 20 msec.

Intensity can also be an important variable affecting pitch discrimination. Turnbull (1944) showed that a decrease in tone intensity from 60 to 20 dB increased the difference limen for pitch. Reducing tonal intensity had a larger effect when the comparison tone lasted 35 msec than when it lasted 100 msec. Differences in intensity may also account for differences in the minimal duration for optimal frequency discrimination reported by Békésy and by Turnbull for similar tones. Comparing Békésy's

and Turnbull's results, it appears that a decrease from 60 to 40 dB in tone intensity doubles the minimal duration necessary for optimal frequency discrimination.

These results indicate that increasing the duration of a repetitive wave pattern enhances the perception of the pitch quality of that pattern. Creel et al (1970) have shown that patients with an impaired blood supply to the brain stem have poorer tonal recognition than do normals. These patients require 200 to 400 msec of a 1,000-Hz tone to perceive it as a tone rather than a noise. In contrast, a normal listener needs a minimum of about 10 msec of a tone burst for a tonal sensation (Stevens & Davis, 1938). Patients with certain impairments, then, require more information than do normals to perceive tonal quality.

Recent studies have shown that perceptual processing time is also important for accurate pitch perception (Massaro, 1970c, 1971). Perceptual processing time refers to the presentation time of the signal which includes both the duration of the signal and the silent interval afterward (Massaro, 1970b). In Massaro's (1970c, 1971) studies, processing time was manipulated by varying the duration of the silent interval after a test tone presentation of 20 msec. Os identified the pitch of a high or low test tone followed by a masking tone after a variable silent intertone interval. The test and masking tones were presented at 81 dB. Os identified the high test tone as high and the low test tone as low. Although the Os heard the test tone on every trial, the masking tone interfered with pitch perception. Identification of the test tone improved with increases in the silent intertone interval up to about 250 msec. Increases in perceptual

processing time also improves pitch identification performance.

The results indicate two processes responsible for accurate perception of pitch. First, the improvement in pitch discrimination with increases in tone duration and intensity can be attributed to an increase in the information in the stimulus (cf. Doughty & Garner, 1947). The distribution of energy in a tone spreads across a range or bandwidth of frequencies centered at the tone frequency. Since the bandwidth of energy is inversely proportional to the duration of the tone, increasing tone duration increases the stimulus information available. Second, the improvement in pitch identification with increases in the retroactive silent interval is assumed to be due to an increase in perceptual processing time which is necessary for accurate perception (Massaro, 1970b, 1972). The present study aims to determine the relative contribution of stimulus information and processing time in an absolute pitch identification task.[1]

In Massaro's (1970c, 1971) studies, identification improved with increases in the silent interval up to 250 msec. The results indicate that optimal perceptual processing of a 20-msec tone requires at least ¼ sec. It is possible that tones longer than 20 msec do not require 250 msec for accurate pitch identification. Kahneman (1968), reviewing the visual masking literature, concluded that stimuli longer than 100 msec were not vulnerable to masking stimuli. Contrasting this, identification might be a continuous process that lasts longer than some arbitrary duration of the stimulus (Massaro, 1970b, 1972). Therefore, it is of interest whether a masking tone can terminate perceptual processing of tones lasting longer than the 20-msec tones used by Massaro (1970c, 1971). Some evidence for this is found in a study of short-term recognition memory for pitch (Massaro, 1970a). In a delayed comparison task, an interference tone presented immediately after a 200-msec test tone decreased its memory strength relative to delaying the interference tone. The parameter estimates of a simple storage-forgetting model of performance indicated that delaying the interference tone enhanced the storage or perception of the test tone. Since this result required a theoretical measure of the perceptual component in a memory task, a more direct study of a test tone's vulnerability to masking as a function of its duration is needed.

The present study also determines whether perceptual processing during the silent intertone interval is as efficient as processing a continuous
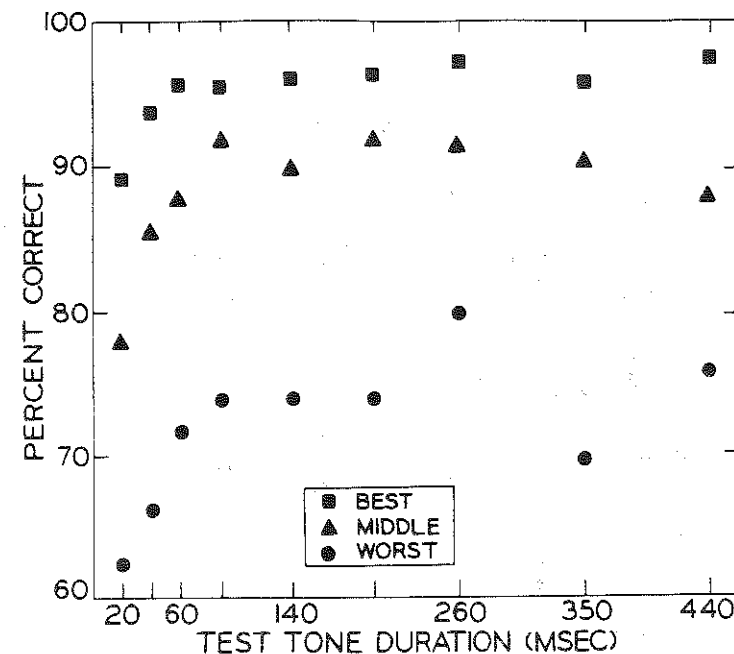
tone. As noted above, increasing a tone's duration increases its pitch discriminability because an increase in duration increases the information available (up to some point) in the tone presentation. However, in addition to the gain in information, will perceptual processing of a continuous tone differ from perceptual processing during the silent interval after a short tone presentation? For example, Turnbull (1944) found that increases in duration of a 1,024-Hz comparison tone beyond 100 msec did not improve pitch identification. His results have at least two possible explanations. First, assuming that the tone was not completely processed within 100 msec, the results indicate that Os were able to process the information made available by the tone presentation during the silent interval after its presentation. Second, it may be that the tone was processed within 100 msec and no further processing was required during the silent interval. The present study tests these two alternatives by first determining the amount of information gained with increasing duration of the tone. A direct comparison can then be made between perceptual processing during the silent interval after the tone and perceptual processing during the continuous tone presentation.

The comparison between the efficiency of tone presentation time and perceptual processing time is analogous to a study of visual letter

Fig. 1. Percent correct identification responses for the three groups on Day 1 as a function of the duration of the test tone.

recognition by Haber and Nathanson (1969). These investigators measured the number of letters an O could report in a display of sequentially presented letters. Duration of each letter and processing time (measured by the onset of one letter to the onset of the next letter) were covaried independently. The results indicated that processing time predicted the number of letters correctly reported, independent of the duration of letter presentation.

In the present study, the contributions of tone duration and processing time are compared to determine which predicts pitch identification best. In Experiment 1, pitch identification of a test tone presented for 20 msec is compared to identification of the test tone presented at eight other longer durations, with perceptual processing time held constant. In Experiment 2, four durations of the test tone are covaried independently of eight silent processing intervals.

EXPERIMENT 1
Method

Forty-five undergraduates fulfilling a course requirement at the University of Wisconsin were employed in the present study. The absolute judgment task required the O to identify a sawtooth wave of 800 Hz as "sharp" and a sine wave of 800 Hz as "dull." In the masking conditions, the test tone was followed by a square wave of 800 Hz after a variable silent interval. These test and masking tones differ

only with respect to the higher harmonics of 800 Hz. A pure tone consisting of sawtooth waves sounds sharp relative to the dull sound of a pure tone consisting of sine waves. The square wave, which sounds like buzz, lasted 240 msec and is referred to as the masking tone. The onsets and offsets of the tones were essentially instantaneous.

If the silent intertone interval is to represent processing time accurately, the test and masking tones must be roughly equal in loudness. All tones in the present study were presented at 50 mV peak-to-peak intensity (about 76 dB SPL). To determine whether these tones were equal in loudness, latencies of simple detection responses were recorded from two practiced Os in a reaction time experiment. McGill (1961) has shown that simple reaction times provide a good index of stimulus loudness. Average reaction times to the saw, sine, and square waves were 151, 161, and 154 msec, respectively. These latencies indicate that the tones in the present study were roughly equal in loudness, and therefore the intertone interval provides a reliable measure of perceptual processing time.

On the first day of the experiment, Os identified the pitch quality of the test tone. The duration of the test tone was 20, 40, 60, 90, 140, 200, 260, 350, or 440 msec. The test tone lasting 20 msec was presented as often as the other durations combined. All nine experimental conditions were completely random within a given session. Two sessions of 300 trials each were given, and Os did not respond to the first five trials of each session. Therefore, the 20-msec test tone was presented about 295 times and the other eight durations about 37 times each.

On the second day, the masking tone was introduced. In the silent processing condition, the test tone was presented for 20 msec, followed by a silent interval of 30, 50, 80, 130, 190, 250, 340, or 430 msec, followed by the masking tone. In the continuous processing condition, the test tone was presented for 40, 60, 90, 140, 200, 260, 350, or 440 msec, followed by a silent interval of 10 msec, followed by the masking tone. All 32 experimental conditions (2 test tones by 2 processing conditions by 8 processing intervals) were completely random in a given session and were programmed to occur equally often. Therefore, on every trial on Day 2, Os heard a test tone of variable duration, followed by a variable silent interval, followed by the masking tone. They identified the test tone as "sharp" or "dull" and were then informed of the correct answer for that trial. As on Day 1, two sessions of 300 trials each were given

and Os did not respond to the first five trials of each session. Therefore, each O contributed about 37 observations to each processing condition by processing interval condition.

All experimental events were controlled by a PDP-8L computer. Four Os could be tested simultaneously in separate sound-attenuated rooms. The pure tones were produced by a digitally controlled Wavetek Model 155 oscillator. The tones were presented binaurally over matched Grason-Stadler Model TDH-49 headphones mounted in 001 headsets. Each O recorded his "sharp" or "dull" decision by pressing one of two pushbuttons labeled "sharp" and "dull," respectively. Following a 1.5-sec response period, feedback was presented by illuminating a small light for 500 msec above the correct response button. The intertrial interval was 2 sec.

The performance of Os differs widely in this task. Os were divided into three groups of 15 Os each according to their overall discrimination performance on Day 1. The three groups are designated worst, middle, and best, respectively. This should help reduce the problems with averaging results of Os with major differences in overall performance.

Results

The identification of the test tone on the first day improved with increases in the duration of the test tone. Fig. 1 shows percent correct identifications for each group as a function of the duration of the test tone. For all groups, identification performance improved with increases in test tone duration up to about 40 or 60 msec. Beyond 40 or 60 msec, increasing the duration of the test tone had no consistent effect on identification performance.

Figure 2 presents the observed percent correct identifications on Day 2 for each group as a function of the silent or continuous processing condition and the processing time available. Averaging across groups, correct pitch identification increased 17% in both the silent and continuous tone conditions, with increases in the processing time available. Figure 2 shows that overall performance averaged across groups was 3% better in the continuous tone condition than in the silent condition. These two results indicate that increasing processing time was about six times more effective in improving identification performance than increasing the duration of the test tone.

An analysis of variance performed on the percent correct identification with groups, Os, processing condition,

ad processing time supports these conclusions. Identification performance was better in the continuous tone condition than in the silent interval condition [F(1,42) = 6.89, p < .025]. Performance also showed a large improvement with increases in the processing time available [F(7,294) = 45.44, p < .001]. These two independent variables had additive effects on identification performance; their interaction was not significant [F(7,294) < 1].

Figure 2 also provides a graphic analysis of how processing condition and processing time affected each of the three groups. The continuous vs silent processing condition had roughly the same effect in each group. In contrast, the improvement in performance with increases in processing time increased with increases in overall group performance [F(14,294) = 4.99, p < .001]. Increasing processing time from 50 to 450 msec improved performance by 6%, 21%, and 26% for the worst, middle, and best groups, respectively. This result indicates that the processing time variable also provides a good index of individual differences.

The results indicate that processing

time is more important for accurate tone identification than stimulus duration. Performance is very near chance if the O has only 50 msec of processing time available. However, a 20-msec tone can be identified about 70% of the time if the O has 270 msec to process the information in the test tone presentation. Furthermore, the improvement in test tone identification with increases in processing time occurs at roughly the same rate during the continuous and silent processing conditions.

EXPERIMENT 2
Method

Sixteen undergraduates fulfilling a course requirement participated in this experiment for 4 days with two sessions of 300 trials each per day. Os were practiced with the test tones without the masking tone on Day 1. On Days 2, 3, and 4, four durations of the test tone were covaried with eight silent intertone intervals. The test tone lasted 20, 40, 60, or 80 msec. The silent intertone interval lasted 20, 40, 70, 120, 180, 240, 330, or 420 msec. The masking tone always lasted 80 msec. All 64 experimental conditions (2 test tones by 4 test tone durations by 8 intertone intervals)

Fig. 2. Percent correct identification responses for the three groups on Day 2 as a function of the processing condition (continuous or silent) and the processing time available.
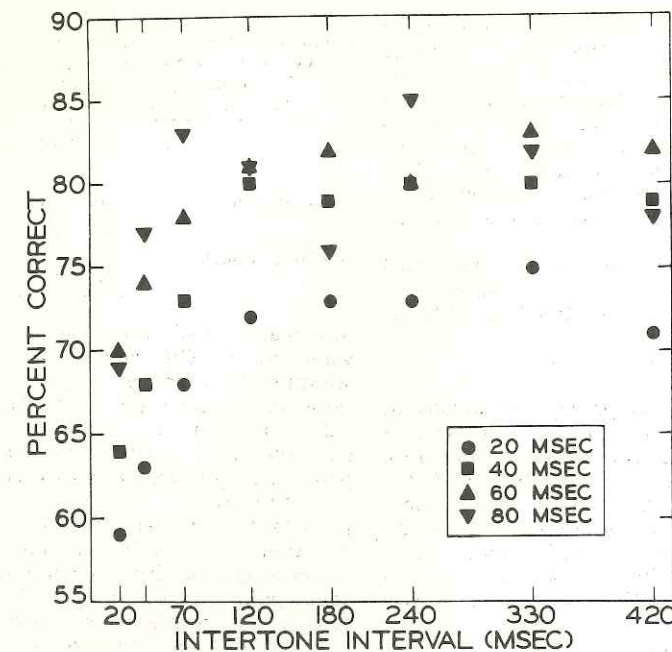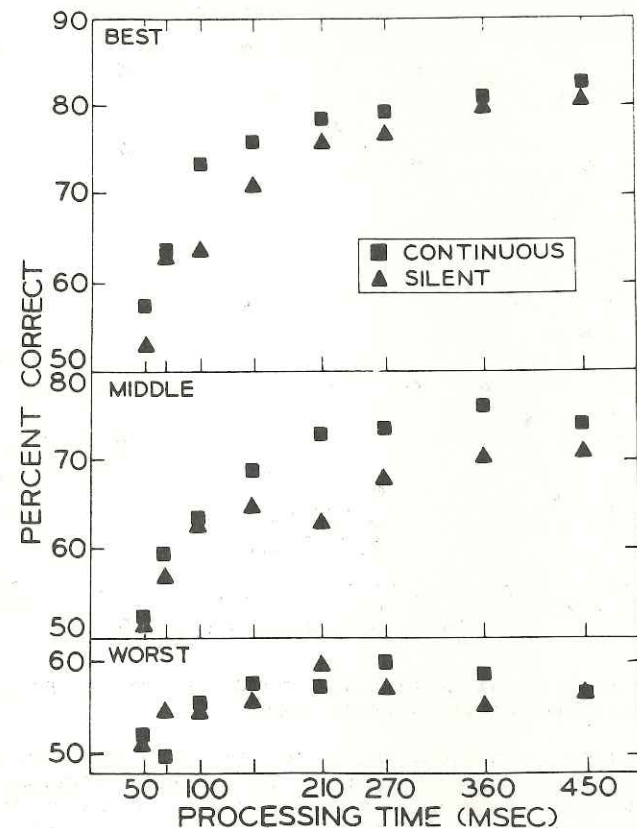

Fig. 3. Percent correct identification responses as a function of test tone duration and the silent processing time available.

were completely random in a given session and occurred about equally often. All other procedural variables were the same as in Experiment 1. Only the results of the last 2 days of the study were used in the data analysis. Therefore, each O contributed about 37 observations at each test tone duration by intertone interval condition.

Results

Figure 3 presents the average percent correct identifications for the 16 Os on Days 3 and 4 as a function of the test tone duration and the silent intertone processing interval. The graph shows significant contributions of both test tone duration and silent processing time. Identification performance improved with increases in the test tone duration [F(3,45) = 9.75, p < .001]. Averaged over the silent interval, correct identifications occurred 64%, 75%, 79%, and 79% of the time for the 20-, 40-, 60-, and 80-msec test tones, respectively. Identification also showed an overall 12% improvement with increases in silent perceptual processing time [F(7,105) = 20.17, p < .001]. Figure 3 shows that test tone duration and silent processing time had additive effects on identification performance [F(21,315) = 1.47, p > .10].

DISCUSSION

The present results provide a test of a perceptual model of stimulus identification (Massaro, 1971b, 1972). The two 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 of the theory is that an auditory input produces a preperceptual auditory image that contains the information in the auditory stimulus. The preperceptual auditory image can be thought of as a temporal 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 increases the strength of the item and is referred to as the temporal course of perceptual processing.

Massaro (1970b, 1972) has presented evidence that supports the two main assumptions of the theory. Perceptual processing outlasts the sensory input so that the preperceptual auditory image is necessary for accurate identification. The preperceptual image is similar to the auditory image present during the stimulus presentation. In the present study, the masking tone appears to terminate perceptual processing of the test tone because it interferes with the auditory
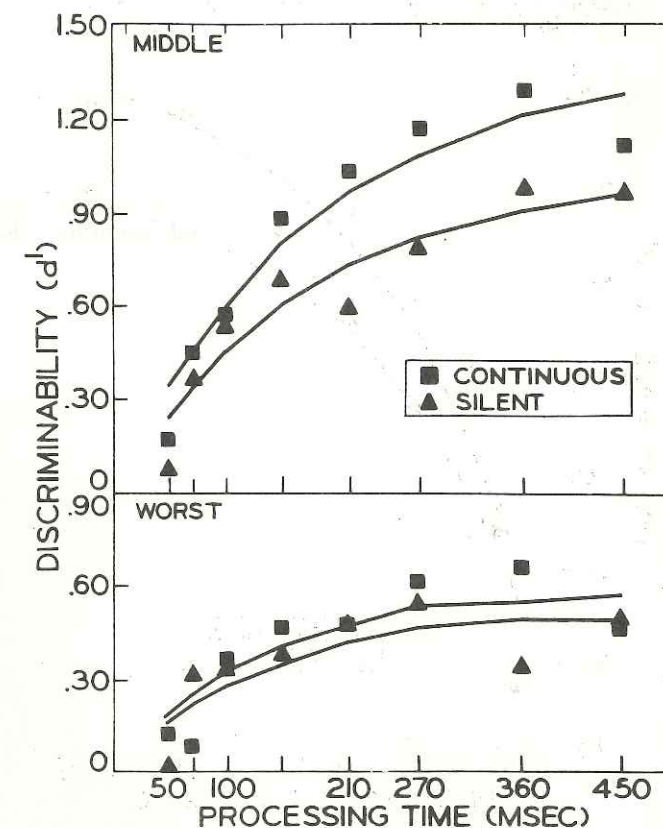

Fig. 4. Predicted and observed discriminability (d') values for the worst and middle groups as a function of the processing condition (continuous or silent) and the processing time available.

image (Massaro, 1971). It is possible that the masking tone does not interfere with the auditory image, but simply prevents perceptual processing. In this case, a short tone would not be an effective masking tone, since Os could continue to process the auditory image of the test tone after the short masking tone terminated. However, the results indicate that decreasing the duration of the masking tone from 500 to 20 msec does not decrease masking or interference (Massaro, (1971[2]). Therefore, the onset of the masking tone seems to interfere with perceptual processing of the test tone by decreasing the signal-to-noise ratio of the auditory image.

Kahn and Massaro[3] have shown that the interference effect of the masking tone is not due to a simple switch in the O's attention. It is possible that the masking tone distracts the O's attention and therefore prevents perceptual processing of the auditory image. In this case, the processing of a nonauditory stimulus should also interfere with pitch identification. Light and tone masking stimuli were employed in the pitch identification task. Os were also required to identify the duration (long or short) of the masking stimulus to direct their attention to the light masking stimulus. The results indicated that the masking light did not interfere with pitch identification. These results support the hypothesis that the masking tone interferes with pitch identification because it decreases the information available in the auditory image.

In the formal theory, the perceptual strength of an item follows an exponential growth function of time:

$$s(t) = \alpha(1 - e^{-\theta t}) \qquad (1)$$

where s(t) is the perceptual strength of the item after a presentation time of t sec. Presentation time includes both the duration of the item and the retroactive silent interval. Equation 1 indicates that the strength of a single item approaches a finite asymptote α at rate θ. This implies that percent correct identifications increase with increases in s(t).

Each item is assumed to have a certain amount of stimulus information. An item with more information would be expected to have a larger value of α. A noisy or unclear item would have less stimulus

Table 1

Parameter Estimates for Equation 1 of the Perceptual Processing Model Describing the Temporal Course of Test Tone Identification in Experiment 1

	Group		
Parameter	Worst	Middle	Best
α (Silent)	.52	1.06	1.90
α (Continuous)	.60	1.41	2.30
θ	7.81	5.65	5.09

information and, therefore, a smaller value of α. The rate at which the stimulus information is processed is reflected in the value of θ. Thus, the values of α and θ provide indexes of stimulus information and rate of perceptual processing, respectively. In the framework of the perceptual processing model, increasing the duration of the test stimulus should increase its stimulus information up to some point but should not affect the rate of processing this information. Accordingly, in the present study, increases in the duration of the test tone should affect α, the index of stimulus information, but not θ, the rate of perceptual processing.

According to the model, identification is determined by the perceptual strength of the item. In the present task, it is assumed that the O chooses a criterion value along a sharp-dull dimension and responds "sharp" if and only if the item's strength exceeds the criterion. Therefore, observed s(t) values correspond to the d' values of signal detection theory (Massaro, 1970b). The perceptual processing model was applied to the data from each of the three groups in Experiment 1. Observed d' values were computed by first pooling the response frequencies over the Os in each group. Then response probabilities were computed at each experimental condition. The probability of responding "sharp" given the sawtooth wave, P(sharp | saw wave), was arbitrarily designated as a hit, and the probability of responding "sharp" given a sine wave, P(sharp | sine wave), was designated a false alarm. The observed d' values were determined by using the tables given by Elliot (1964). The predicted d' values were obtained by estimating the parameter values of Eq. 1 using a reiterative search routine that minimized the square deviations between the predicted and observed d' values.

In Experiment 1, the processing interval was either silent or continuous with the test tone. Increasing the duration of the test tone should increase its stimulus information up to some point. The main effect of the silent vs continuous processing
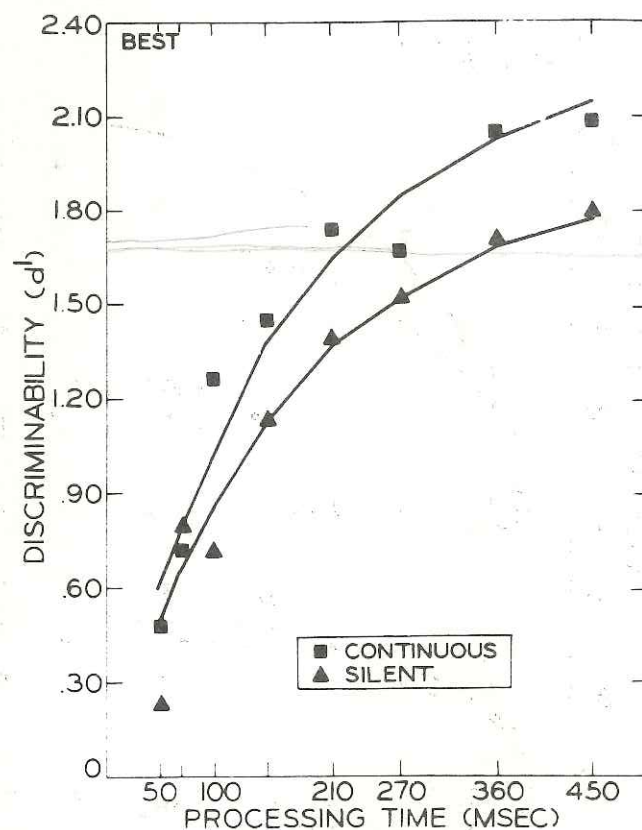

Fig. 5. Predicted and observed discriminability (d') values for the best group as a function of the processing condition (continuous or silent) and the processing time available.
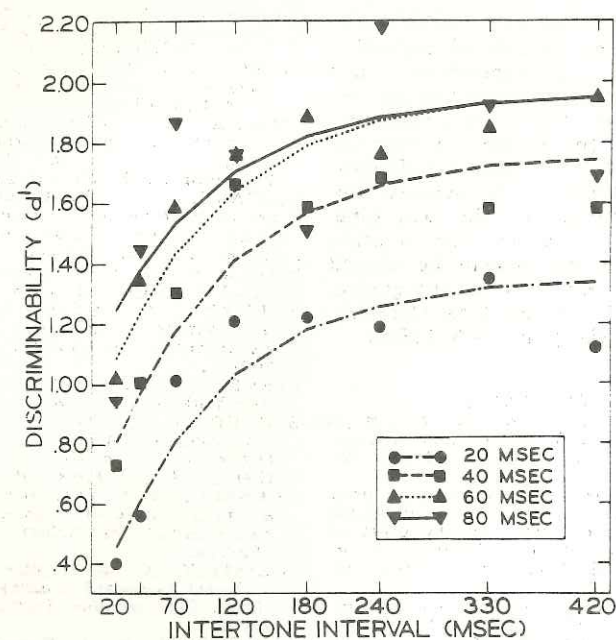

Fig. 6. Predicted and observed discriminability (d') values as a function of test tone duration and the silent processing time available.

condition indicated that the tones in the continuous processing condition had more stimulus information than the 20-msec tone. It is reasonable to assume that the amount of stimulus information in the 20-msec test tone was constant at all silent processing intervals. Therefore, the nonsignificant interaction of processing condition with processing time indicated that stimulus information was also relatively constant within the continuous tone condition. Accordingly, a different value of α, the index of discriminability, is necessary for the silent and continuous processing conditions. Furthermore, the rate of perceptual processing, θ, should be equal in the silent and continuous conditions. Given eight processing intervals at both the continuous and silent processing conditions, 16 data points are predicted using three parameter estimates.

The observed and predicted discriminability (d') values for the three groups are presented in Figs. 4 and 5. The parameter estimates are presented in Table 1. The estimated value of α is larger for the continuous condition than for the silent condition for all groups. This result indicates that with processing time held constant, the continuous tone provides slightly more information for identification than a 20-msec test tone. The good description of the results supports the assumption that the onset of the masking tone terminates perceptual processing of the test tone. The results are also described accurately, with the restriction that the rate of perceptual processing is the same for both the silent and continuous tone conditions. This indicates that the efficiency of processing information in an auditory image of a tone does not differ from processing information in the continuous tone itself. The auditory afterimage, then, does not seem to differ qualitatively from the auditory image during the test tone presentation.

In Experiment 2, stimulus information was increased by increasing the duration of the test tone. Processing time was increased by increasing both test tone duration and silent intertone interval. The perceptual processing model accounts for increases in the information in the stimulus with increases in α. The rate of perceptual processing should be constant under all information conditions. Furthermore, since overall performance did not differ with test tones of 60 and 80 msec, only one value of α was estimated for these two conditions. Therefore, three values of α and one value of θ were estimated for the 32 experimental conditions. The observed and predicted d' values were computed as in Experiment 1.

Figure 6 presents the observed and predicted d' values with the parameter estimates presented in Table 2. The estimated values of α increase with test tone duration. The model gives a reasonable description of the results, with the restriction that the rate of perceptual processing is constant and independent of the duration of the test stimulus. Therefore, the results of Experiment 2 also support the assumed distinctions between stimulus information and perceptual processing time.

The present results are relevant to studies of perceived duration of short auditory stimuli. If the auditory afterimage is continuous with the auditory image present during the tone presentation, Os may mistake the afterimage for the actual tone presentation. Supporting this, the results of Efron (1971a, b, c) and Gol'dburt (1961) indicate that Os overestimate the duration of short tones. In Efron's studies, Os estimate the duration of tones shorter than 130 msec to be about 130 msec. This result indicates that the auditory afterimage of a short tone does not seem to be discontinuous with the image present during the test stimulus presentation. Gol'dburt (1961) has shown that a second tone presented immediately after a brief tone shortens its perceived duration. In agreement with the present results, Gol'dburt's results indicate that a second tone can erase the auditory image from an earlier tone presentation.

The results of memory studies varying the rate of presentation of a list of verbal items also indicate that presentation time can influence the perceptual strength of the items (Massaro, 1970b; Norman, 1966; Wickelgren, 1970). These investigators have shown that decreasing the presentation time of an item decreases the perception (as measured by the storage component of a memory model) of the item. What is striking about these results is that the presentation times were between 100 and 1,000 msec. The enhancement of memory with increases in presentation time is usually attributed to rehearsal. However, results have indicated that fast presentation rates also disrupt the perception of the test items (Aaronson, 1967). Unfortunately, it will be difficult to isolate the contributions of perception and rehearsal processes in these memory studies.

The present results disagree with the assumption of a psychological moment postulated by Stroud (1955) and reiterated by Kahneman (1968).

Table 2

Parameter Estimates for Equation 1 of the Perceptual Processing Model Describing the Temporal Course of Test Tone Identification in Experiment 2

Parameter	Estimate
α (20 msec)	1.36
α (40 msec)	1.76
α (60, 80 msec)	1.96
θ	9.99

According to the theory of psychological moment, the perceptual experience occurs within a psychological moment of time. After the moment, a second input should not disrupt the perceptual experience of the first input. For example, Kahneman concludes that a stimulus presented for 100 msec or more will not be masked by a stimulus of equal intensity. In contrast, the present results indicate that perception of an event is not determined by some arbitrary stimulus duration but rather is a continuous analysis of the information available to the O.

In most visual recognition masking studies, masking has not been found to exceed 100 msec. However, in these studies (Erikson, Becker, & Hoffman, 1970; Weisstein & Haber, 1965), two letters are usually employed as the stimulus alternatives. Given only two overlearned stimulus alternatives, it seems reasonable that recognition can take place within 100 msec. Decreasing the distinctiveness of the alternatives or increasing the number of alternatives, however, should increase the time necessary for perception. In this case, backward masking should occur at intervals exceeding 100 msec.

The absolute judgment task has certain similarities with delayed comparison studies of pitch memory (Massaro, 1970a, b; Wickelgren, 1966, 1969). The important difference is that the operation of the masking tone in the absolute judgment task differs from the operation of the interference tone in the delayed comparison task. A second tone can affect both perception and memory of an earlier tone. A second tone interferes with perceptual processing of a first tone and also interferes with the memory trace of the synthesized percept over time. Only the first operation is important in the identification task, whereas both operations are important in the delayed comparison task. Since the onset of the masking tone interferes with perceptual processing of the test tone, the identification or readout of the test tone must occur before presentation of the masking tone. Accordingly, the duration of the masking tone has no effect on absolute identification performance (Massaro, 1971[2]).

In the delayed comparison task, the O acquires a memory trace for later test. As in the absolute identification task, the onset of the interference tone ends perceptual processing of the test tone. However, the O must remember the test tone (no matter how weak the trace) for later test. The interference tone now functions to decrease the memory strength of the test tone. Accordingly, increasing the duration of the interference tone in the delayed comparison task decreases recognition memory for the test tone (Massaro, 1970a, b; Wickelgren, 1966, 1969).

REFERENCES

AARONSON, D. Temporal factors in perception and short-term memory. Psychological Bulletin, 1967, 67, 130-144.

ANDERSON, D. A. The duration of tones, the time interval, the direction of sound, darkness and quiet, and the order of stimuli in pitch discrimination. Psychological Monographs, 1914, 16, 150-156.

BEKESY, G. von. Experiments in hearing. New York: McGraw-Hill, 1960.

CREEL, W., BOOMSLITER, P. C., & POWERS, S. R. Sensations of tones as perceptual forms. Psychological Review, 1970, 77, 534-545.

DOUGHTY, J. M., & GARNER, W. R. Pitch characteristics of short tones: I. Two kinds of pitch threshold. Journal of Experimental Psychology, 1947, 37, 351-365.

EFRON, R. Effect of stimulus duration on perceptual onset and offset latencies. Perception & Psychophysics, 1970a, 8, 231-234.

EFRON, R. The minimum duration of a perception. Neuropsychologia, 1970b, 8, 57-63.

EFRON, R. The relationship between the duration of a stimulus and the duration of a perception. Neuropsychologia, 1970c, 8, 37-55.

ELLIOT, P. B. Tables of d'. In J. A. Swets (Ed.), Signal detection and recognition by human observers. New York: Wiley, 1964.

ERIKSON, C. W., BECKER, B. B., & HOFFMAN, J. E. Safari to masking land: A hunt for the elusive U. Perception & Psychophysics, 1970, 8, 245-250.

GOL'DBURT, S. N. Investigation of the stability of auditory processes in micro-intervals of time (new findings on back masking). Biofizika, 1961, 6, 717-724. English translation: Biophysics, 1969, 6, 809-817.

HABER, R. N., & NATHANSON, L. S. Processing of sequentially presented letters. Perception & Psychophysics, 1969, 5, 359-361.

KAHNEMAN, D. Method, findings and theory in the studies of visual masking. Psychological Bulletin, 1968, 70, 404-425.

MASSARO, D. W. Consolidation and interference in the perceptual memory system. Perception & Psychophysics, 1970a, 7, 153-156.

MASSARO, D. W. Perceptual processes and forgetting in memory tasks. Psychological Review, 1970b, 77, 557-567.

MASSARO, D. W. Preperceptual auditory images. Journal of Experimental Psychology, 1970c, 85, 411-417.

MASSARO, D. W. Effect of masking tone duration on preperceptual auditory images. Journal of Experimental Psychology, 1971, 87, 146-148.

MASSARO, D. W. Preperceptual images, processing time, and perceptual units in auditory perception. Psychological Review, 1972, 79, 124-145.

McGILL, W. J. Loudness and reaction time. Acta Psychologica, 1961, 19, 193-199.

NORMAN, D. A. Acquisition and retention in short-term memory. Journal of Experimental Psychology, 1966, 72, 369-381.

STEVENS, S. S., & DAVIS, H. Hearing. New York: Wiley, 1938.

STROUD, J. M. The fine structure of psychological time. In H. Quastler (Ed.), Information theory in psychology. Glencoe, Ill: Free Press, 1955.

TURNBULL, W. W. Pitch discrimination as a function of tonal duration. Journal of Experimental Psychology, 1944, 34, 302-316.

WEISSTEIN, N., & HABER, R. N. A U-shaped backward masking function in vision. Psychonomic Science, 1965, 2, 75-76.

WICKELGREN, W. A. Consolidation and retroactive interference in short-term recognition memory for pitch. Journal of Experimental Psychology, 1966, 72, 250-259.

WICKELGREN, W. A. Associative strength theory of recognition memory for pitch. Journal of Mathematical Psychology, 1969, 6, 13-61.

WICKELGREN, W. A. Time, interference, and rate of presentation in short-term recognition memory for items. Journal of Mathematical Psychology, 1970, 7, 219-235.