Chapter IV. Information Transfer Rate

The goal of the experiments on information transfer rate was to assess the dynamic information transmission capabilities with the TACTUATOR. The IT rate is defined as the product of information transfer per presentation (in *bits/item*) and presentation rate (in *items/sec*).

IV-1 Background

It takes a very long time to train a subject to receive continuous streams of encoded information. The first step in training is to learn to recognize the individual signals that make up the continuous presentation stream. This process, as we have shown earlier, takes relatively little time provided that the stimulus and response sets are well designed. The next step is to become highly proficient in processing the basic signals so that recognition time is minimized. This prepares the subject for the next stage of organizing basic signals into meaningful "chunks" that can be stored in short-term memory and retrieved later on. According to Miller (1956), the span of immediate memory, or the number of chunks people can recall correctly, is about seven items in length. However, there is no absolute limit on the information each chunk can contain. Therefore, the goal is to maximize the chunk sizes in *bits/chunk*. This process can take many years. Also, there is evidence that reaching a temporary plateau in performance does not necessarily imply completion of the training process. For instance, Bryan and Harter (1899) showed that students of Morse code reached several plateaus with regard to their ability to receive the code. The plateaus in the reception curves were interpreted as evidence that a student of telegraphy first learned to receive individual letters, then developed the skills to receive common words as the basic units, and eventually, after many years of full-time practice on the job, learned to receive short phrases. Our subjects were not trained extensively on chunking for two reasons. First, our signals are nonsense

materials and not particularly well suited for chunking. The advantage of having nonsense materials is that it is relatively easy to control stimulus uncertainty. Once meaningful materials are used for testing, the redundancy inherent in the codes needs to be assessed. Second, even if we had used meaningful materials, it is not clear that sufficient training could be given in a period commensurate with this thesis.

In view of these problems, our strategy in assessing information transfer rate was to measure identification performance in the context of other signals using an identification paradigm with both forward and backward masking.

A general understanding of the conditions under which optimal IT rate occurs is useful for selecting the values of stimulus uncertainty and presentation rate. According to Garner (1962), given sets of stimuli with a range of stimulus uncertainties, maximum IT rate occurs when stimulus uncertainty is at its maximum. Therefore, the three stimulus sets developed earlier should be used in their entirety. According to Klemmer & Muller (1953), the optimal presentation rate is two to three *items/sec* independent of the stimulus uncertainty in the items. To find the optimal presentation rate for our setup, the presentation rate was varied over a large range. Finally, since our subjects were already trained on the 500-*msec*, 250-*msec* and 125-*msec* stimulus sets, we were also able to examine the dependence of performance level on signal duration.

IV-2 Experimental Paradigm: Identification with Masking

The identification paradigm used in this portion of our research incorporates both forward and backward masking as it would occur in a continuous presentation stream (Fig. IV-1). On each trial, the subject was asked to identify the target X, sandwiched between two interfering maskers A and B. The duration of the target and maskers was kept the same (T_1). The duration of the two gaps was also kept the same (T_0). The time between signal onsets, T_{onset}, was simply (T_0+T_1) and the presentation rate, λ, was $1/T_{onset}$. Note, that, our notion of possible masking effects is meant to be general, including opportunities for peripheral and central masking effects.

Table IV-1 shows the three stimulus sets used in these experiments. Three finger locations were used: the thumb alone, the index finger alone, or the middle finger alone. We decided not to

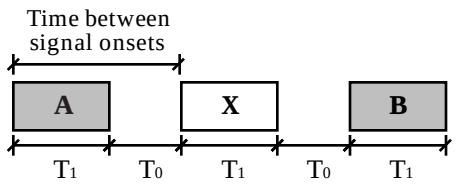

Figure IV-1. Diagram for identification paradigm with both forward and backward masking.

TABLE IV-1. The three stimulus sets.

Stimulus Set	No. of Waveforms	T_1 (*msec*)	No. of Alternatives (*k*)	IS_k (*bits*)
#1	30 (Table III-1)	500	30×3	6.5
#2	30 (Table III-1)	250	30×3	6.5
#3	19 (Table III-1)	125	19×3	5.9

apply waveforms to all three digits because the F_M and F_H components tended to spread in time and space.[1] T_1 was either 500 *msec*, 250 *msec*, or 125 *msec*. T_0 was 500, 400, 300, 200, 100, or 20 *msec*.[2] Each combination of T_0 and T_1 was tested. The presentation rate, λ, ranged 1-1.9 *items/sec* for T_1 = 500 *msec*, 1.3-3.7 *items/sec* for T_1 = 250 *msec*, and 1.6-6.9 *items/sec* for T_1 = 125 *msec*.

Data were collected with the same three subjects (S_1, S_2, and S_3) used in our static tests for all 18 conditions ($3\ T_1 \times 6\ T_0$). Each subject was first tested with T_1 = 500 *msec* and descending values of T_0, then with T_1 = 250 *msec*, and then T_1 = 125 *msec*. This ensured that the subjects had maximum training on easier tasks before they were tested with the more difficult ones. With each stimulus set, the subject was required to repeat the one-interval AI paradigm (without the maskers A and B) conducted earlier for static IT measurements in order to get familiar with the signals again. The subject was then tested with the identification paradigm with masking. On each trial, A, X, and B were each randomly selected from the same stimulus set. No additional timing cues were available to mark the three intervals. Subjects had to wait until all three signals were presented

1. For example, if masker A contained a 300 *Hz* signal component applied to all three digits, subjects tended to judge the 300 *Hz* to be present in the target X. The "spreading" of F_M and F_H components was less of a problem during static IT measurements, because the inter-stimulus duration was much longer than T_0.
2. According to Gescheider (1966, 1967), gap detection threshold is on the order of 10 *msec* with relatively strong signals (e.g., 35 dB SL). A nonzero minimum value of 20 *msec* for T_0 ensured that there was enough "gap" between the three intervals.

before entering the response for X. If the response did not have the right syntax (i.e., an icon for the finger location followed by an icon for the waveform), the trial was counted as an error and was not repeated later on. Trial-by-trial correct-answer feedback was not provided.[1] Three runs of 100 trials each were performed with each T_1 and T_0 combination.[2] The percent-correct score on X was shown to the subject at the end of each run.

IV-3 Results

For each T_1 and T_0 combination, the three percent-correct scores were averaged. Results are presented in terms of T_{onset}, with T_1 as a parameter (Fig. IV-2). The individual points on each curve correspond to the six T_0 values (i.e., T_{onset} - T_1) used with that particular T_1. For all subjects, percent-correct scores are dependent on T_{onset}, but not on T_1 alone. In other words, there seems to be a trade-off between T_1 and T_0. The data curves show a knee in the region $325 \leq T_{onset} \leq 450$ *msec*, corresponding to a presentation rate of roughly 2.2 to 3 *items/sec*. Overall, the results for S_1 and S_2 are quite similar, (except for the data points at T_1 = 125 *msec* and T_0 = 500 *msec*). The data curves for S_3 reach a slightly lower plateau at a slightly larger T_{onset} value.

To estimate the IT rate potentially available with streams of these signals, we will assume that the same percent-correct scores hold for the identification of each (consecutive) signal. The lower-bound $IS_k \times (1-2\bar{e})$ is used to estimate IT, where IS_k is given in Table IV-1 and $\bar{e}$ is the observed average error rate. The results, shown in Fig. IV-3, indicate an optimal presentation rate of roughly 3 *items/sec* for S_1 and S_2, and roughly 2.2 *items/sec* for S_3. Note that when the percent-correct score was below 50% and therefore $(1-2\bar{e}) < 0$, the estimated IT rate was set to 0. For S_1, a maximum IT rate of 13 *bits/sec* occurred at T_1 = 250 *msec* and T_0 = 100 *msec*. For S_2, a maximum IT rate of 12.1 *bits/sec* occurred at T_1 = 125 *msec* and T_0 = 200 *msec*. For S_3, a maximum IT rate of 10.2 *bits/sec* occurred at T_1 = 250 *msec* and T_0 = 200 *msec*. The maximum IT rates averaged over all

1. Feedback was not provided for two reasons. First, all subjects were well trained with all signals in all three stimulus sets by now. Second, requiring the subjects to attend to correct-answer feedback tended to break the “rhythm” of the run whenever an error was indicated.
2. There was one exception. The percent-correct scores of the first three runs for S_2 at T_1 = 125 *msec* and T_0 = 500 *msec* were 18%, 77% and 76%. Given the inconsistency of these three scores, one more run was conducted.

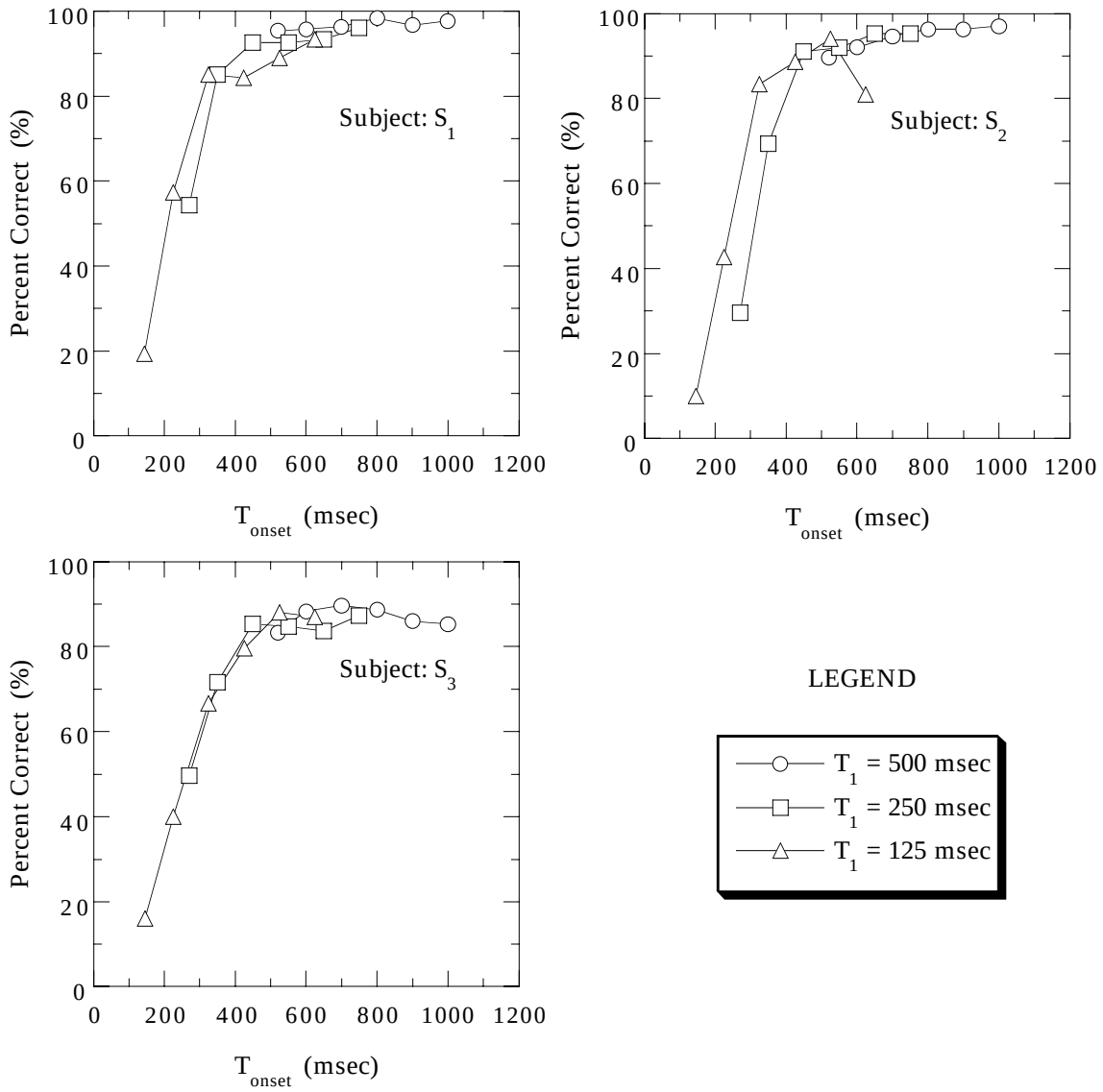

Figure IV-2. Percent-correct scores for identification of X as a function of T_{onset} for all subjects.

subjects was about **12 *bits/sec***. The validity of this estimate is largely dependent upon the assumption that with sufficient training, these subjects would eventually learn to "chunk" individual presentations into longer "messages" so that continuous streams of information can be received at a similar rate. Although we believe this assumption to be a reasonable one, it

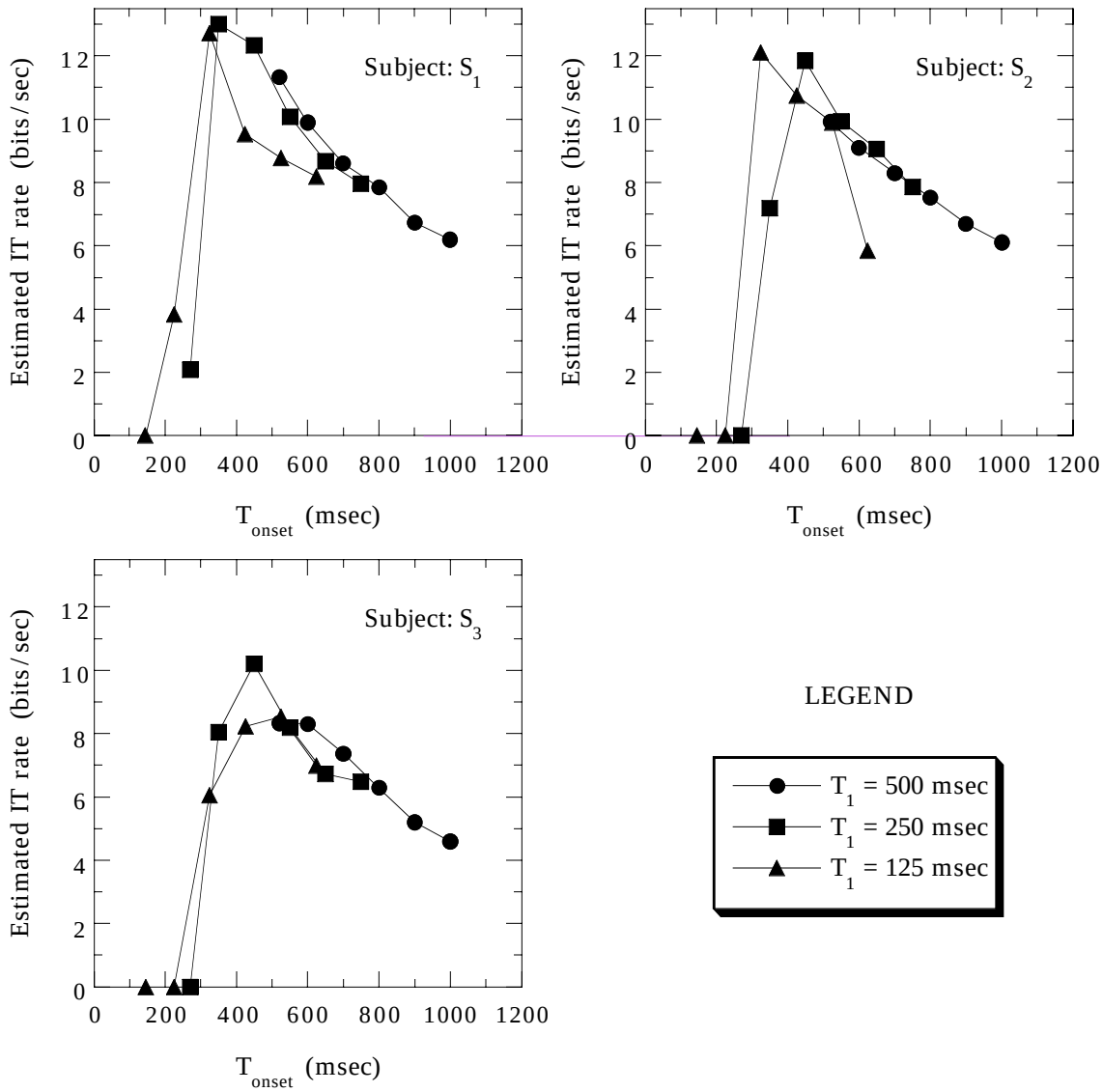

Figure IV-3. Estimated IT rates as a function of T_{onset} for all subjects.

obviously needs to be tested empirically. Because such a test would consume a very long training period, we were not able to include it in this thesis work.