Behavior Research Methods, Instruments, & Computers
1993, 25 (1), 2-8

METHODS & DESIGNS

A fast procedure for studying conditional accuracy functions

CLAUDE BONNET and BIRGITTA DRESP
Laboratoire de Psychologie Expérimentale
Université Paris V, EPHE, EHESS, CNRS, Paris, France

This paper describes a procedure for obtaining conditional accuracy functions (CAFs) from naive observers and a restricted number of trials. The method permits the experimenter to counter the subjects' tendency to favor accuracy in tasks in which stimulus discrimination is easy. Each time a block of 12 trials contains less than three errors, observers are instructed, by means of a speed-up signal, to respond faster. The subject is continuously informed about her/his effective reaction time. The data show that the desired speed-accuracy tradeoff was obtained within each of the 7 observers. The mean percent error was around 25%.

Our aim in this paper is to introduce a fast experimental procedure for obtaining data for estimating conditional accuracy functions (CAFs; Ollman, 1977) with naive subjects and a restricted number of trials. CAFs relate the duration of reaction time (RT) to the accuracy of performance within a given set of experimental conditions (see Luce, 1986, for a review). They reveal important information about response strategies in choice reaction time tasks. Furthermore, relations between speed and accuracy appear to be of crucial importance for continuous-processing models (see, e.g., Link & Heath, 1975; McClelland, 1979; Ratcliff, 1988) and discrete-processing models (see, e.g., Miller, 1982; Sternberg, 1969). The principles of speed- accuracy tradeoff methodology have recently been reviewed by Meyer, Irwin, Osman, and Kounios (1988), although these authors did not distinguish between CAFs obtained within particular experimental conditions and speed-accuracy tradeoff functions obtained when experimental conditions are varied (see Luce, 1986). Both types of functions, however, can reveal the same patterns, but only under exceptional conditions (Luce, 1986; Ollman, 1977; Schouten & Bekker, 1967).

How to obtain CAFs is illustrated in Lappin and Disch (1972): all RTs have to be listed in length order from the shortest to the longest. The whole distribution is then divided into blocks of a constant number of trials. Mean RT as well as an accuracy index are calculated for each block.

In experiments in which stimulus discriminability is above threshold and untrained observers can easily be used for data collection, the usual instruction to respond as fast as possible without making errors turns out to be unsatisfactory. The large majority of naive subjects favor accuracy, paying more or less attention to the speed instruction. This type of response strategy usually leads to high interindividual variability within the RT distributions. Furthermore, a valid analysis of the relation between speed and accuracy is not possible under such conditions. Several authors have proposed procedures that allow the experimenter to control the subjects' speed-accuracy performance. The basic idea is to provoke a certain type of speed-accuracy tradeoff by means of adequate manipulation of the observers' response strategies.

To make sure that subjects effectively take into account an instruction (concerning speed or concerning accuracy), either short reaction times or low error rates can be rewarded (Fitts, 1966; Link & Tindall, 1971; Swensson & Edwards, 1971). In procedures of this type, feedback informing the observer about her/his performance is given. The basic idea here is to modify performance through trial-by-trial intructions (Hinrichs & Krainz, 1970). Another option is to require a precise level of accuracy. Lappin and Disch (1972) asked highly trained subjects to respond as fast as was necessary to make approximately 25% errors on the average. Other methods introduce a deadline for the response (Link, 1971; Ollman & Billington, 1972; Pachella & Pew, 1968). In some of these deadline procedures, a peremptory response signal is given at various delays after the offset of the stimulus (Reed, 1976; Schouten & Bekker, 1967). Link (1971) demonstrates the effect of trial-to-trial changes in the application of RT deadlines in an experiment that complements the earlier work by Ollman (1966) and Yellott (1967, 1971).

Hinrichs and Krainz's (1970) and Link's (1971) studies are the only examples in which performance has been manipulated on a trial-by-trial basis. Moreover, all these procedures require a certain level of training before the desired result can be observed.

Acknowledgements are due to Ketty Vergé-Dépré for running the experiment and to Noelle Bonora for programming assistance. We owe special thanks to Jeff Miller for having encouraged us to write this paper and for his most helpful comments on an earlier draft. The conclusion is essentially based on Miller's suggestions. The referees' helpful comments on the submitted manuscript were greatly appreciated. Correspondence should be addressed to C. Bonnet, Laboratoire de Psychologie Expérimentale, Université Paris V, EPHE, EHESS, Associé au CNRS, 28 rue Serpente, 75006 Paris, France.

The aim of the present study was to elaborate a new procedure that makes it possible to control speed–accuracy tradeoffs in experiments with naive subjects. We demonstrate that estimates of individual CAFs are possible with an extremely limited number of trials and absolutely untrained observers. Actually, none of the hitherto reported procedures presents both these advantages.

Basic Principles

To obtain a CAF, a certain percentage of errors must be produced. The mean rate of errors chosen a priori for our procedure is 25%. An increase in error rates with increases in time pressure being widely demonstrated, our idea was to maintain the latter *continuously* in order to obtain the desired rate of error. The procedure that we have elaborated was inspired by various adaptive psychophysical procedures (e.g., Bonnet, 1986), such as the staircase technique (Levitt, 1971) and the PEST technique (Taylor & Creelman, 1967).

The procedure runs as follows. The subject is told that a speed-up signal will be given during the experiment each time her/his reaction times are too long. The task is to respond fast enough to avoid hearing the sound without making too many errors. After each trial, the duration of her/his reaction time is communicated verbally to the subject.

Actually, the speed-up signal turned out not to be contingent on subjects' RTs but on their error rates. For empirical reasons, which will be presented in the discussion, we decided to calculate error rates on blocks of 12 trials. Whenever a block contained less than three errors, the speed-up signal was given.

The experiment is based on two empirical arguments: Introducing increased time pressure is known to reduce accuracy. However, with naive observers, this effect disappears when no feedback informing them about their performance is given. This phenomenon has already been observed in previous, unpublished experiments.

METHOD

Procedure

A two-choice reaction time procedure was used in this experiment. Subjects had to discriminate the orientation of a square-wave grating shown through a three-channel tachistocope (Pharmaceutical Prototype).

The grating, oriented either at +45° or at −45°, was flashed through a circular aperture of 3.5° diameter, cut out of a white background (180 cd/m^2). The intensity of the dark bars of the grating was 3.5 cd/m^2 (96% of contrast). The observers responded by means of two response keys. The left key had to be pressed when the grating was tilted clockwise (+45°) and the right key when it was tilted counterclockwise (−45°).

A warning signal (440 Hz) preceeded the gratings with a constant delay of 600 msec (150 msec for the sound and a 450-msec time interval). The onset duration of the gratings was 32 msec. The next signal was given 3 sec after a response. All trials with RTs shorter than 100 msec or longer than 1,000 msec were repeated immediately, to guarantee a constant number of trials for data analysis. The experiment started with a training period consisting of 50 trials on which the subject was requested to respond as fast as possible without making too many errors. No speed-up signal was delivered during this period. The experimental procedure itself included 200 trials, with a short break in the middle of the session. The speed-up signal ("bip-bip") was given each time the subject made less than three errors during the preceeding 12 trials. The observers were told that this was a signal indicating that they did not respond fast enough.

The experiment was under computer control, but RTs were communicated verbally after each response. Seven undergraduate students participated as part of their course requirements.

RESULTS

The average of the median RTs was 305.3 msec (*SD* = 42.4). The mean error rate was 29.7% (*SD* = 4.3). Mean RT was 321 msec for correct responses and 269 msec for errors.

CAFs were established with group data and with individual data (Lappin & Disch, 1972). The 200 experimental trials were ordered by duration and divided into blocks. For each block, two statistics were computed: mean RT and an accuracy index. Several accuracy indices were examined (d', $-\ln(\eta)$, H'_C, and A'; see Swets, 1986a, 1986b). As described before by Lappin and Disch (1972), these different indices reflected the same tendency, and we decided to use A' for our results in order to minimize the effects of response bias that strongly affect any percent correct index (see, e.g., Swets, 1986a, 1986b).[1] On large samples, A' varies between .50 (chance level) and 1 (no errors).

The second step in the analysis consists of dividing the whole set of trials into a certain number of blocks.[2] Three analyses were made here: one with 4 blocks (n = 50), another with 5 blocks (n = 40), and a last one with 8 blocks (n = 25).

Speed and accuracy indices were computed individually and then averaged. The mean results for the three types of analysis are shown in Figure 1.

The three analyses reveal the predicted speed–accuracy tradeoff with some particularities concerning the low-accuracy–fast-response range. Below 260 msec, subjects

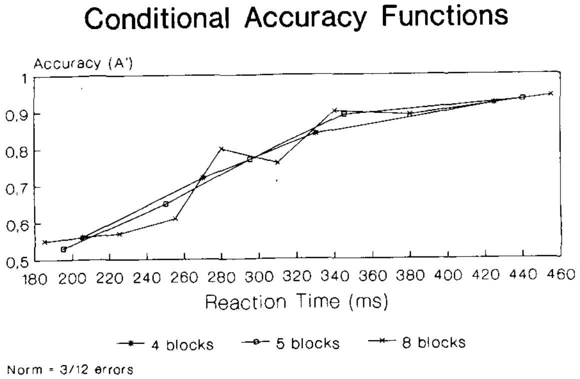

Figure 1. Conditional accuracy function for different samples of varying size (mean data for 7 subjects). For each observer, reaction times (RTs) were listed in length order and divided into blocks of 25 (8 blocks), 40 (5 blocks), or 50 trials (4 blocks). *A′* was calculated for each block. An increase of mean RT with increases in mean accuracy is observed in the three samples.

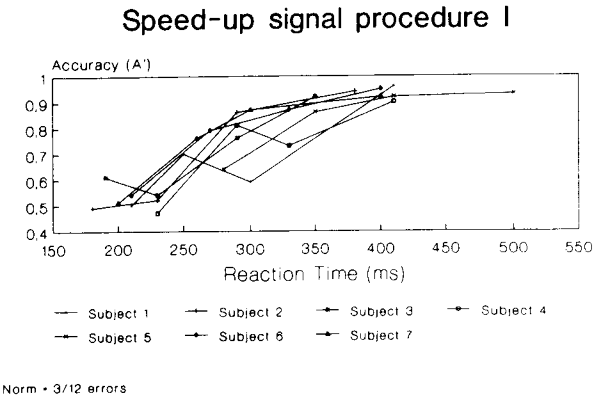

Figure 2. Individual conditional accuracy functions showing interindividual data consistency. For each subject, a rather regular increase in accuracy is observed with increases in reaction time.

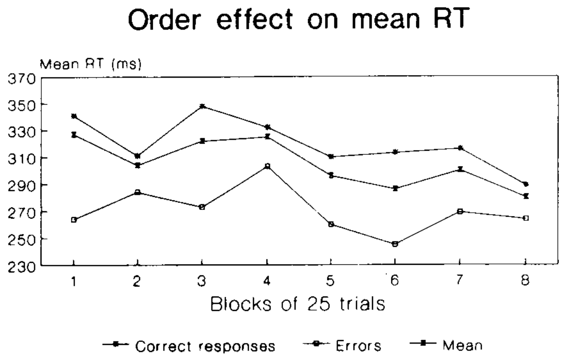

Figure 3. Rank order effect on mean reaction time (RT). The 200 experimental trials (in order of appearance) were divided into 8 blocks of 25 trials. The figure shows decreasing mean RTs with increases in rank of the trials.

respond at the chance level (*A′* between .52 and .55). However, in that range, with regard to the small sample size ($n = 25$), accuracy is interindividually rather variable. For that reason, it is convenient to present individual data for the largest sample size. They are shown in Figure 2 (see also Table A1 in the Appendix).

For each subject, accuracy increases as RT increases. Two aspects of the results deserve attention. On the average, no ceiling effect is observed: the mean error rate for the last block of RTs is 11%, which corresponds to a mean *A′* of .93. The results reported here show progressively increasing RTs going along with increasing accuracy. The interindividual consistency of the data is remarkable.

It is worthwhile to make sure that the data are not contaminated by a response bias such as a preference for one of the two responses. A simple way of doing this is to look at the ratio of the number of responses for each category (*a* and *b*). On the average, this ratio equals 1.02 (see Table A2 in the Appendix for more details). Block by block analysis does not reveal any response bias, on the average. Nevertheless, in some particular blocks, an apparent response bias may appear because of the small sample size.

Results were also examined as a function of the order of trials. As may be expected with untrained observers (see, e.g., Bonnet, 1989), RTs decline when the rank of the trials increases. Figure 3 shows the phenomenon with RTs for correct responses and errors. The practice effect is stronger for correct responses. However, the mean accuracy and standard deviation of the subjects decline as the rank of the trials increases (see Figures 4 and 5).

In fact, this observation is a direct consequence of the procedure used in this experiment. On the average, each subject received speed-up signals on 21% of the trials. The probability of receiving the speed-up signal diminishes as the rank of trials increases. Only 25% of these signals were given in the second half of the experiment. The observers end up respecting the time constraint and adjust to a faster speed level, which goes along with a progressive loss of accuracy. This argument finds support in the fact that the average standard deviation of RTs also diminishes as the rank of trials increases. Most of the subjects seem to adjust rapidly to the time pressure by adopting a relatively stable speed criterion.

With an adaptive procedure like that used here, sequential analysis of the data can clarify the effect of feedback on performance. We calculated the mean RTs and per-

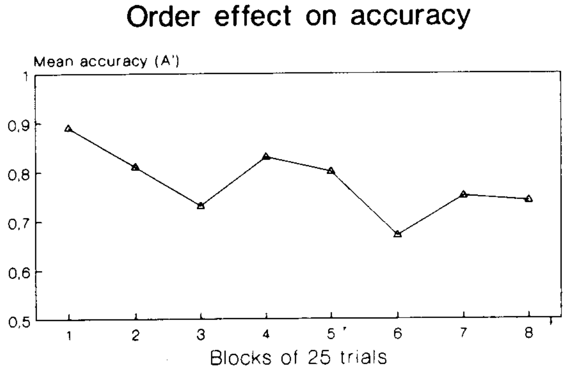

Figure 4. Order effect on accuracy. *A′* declines with increases in rank of the trials.

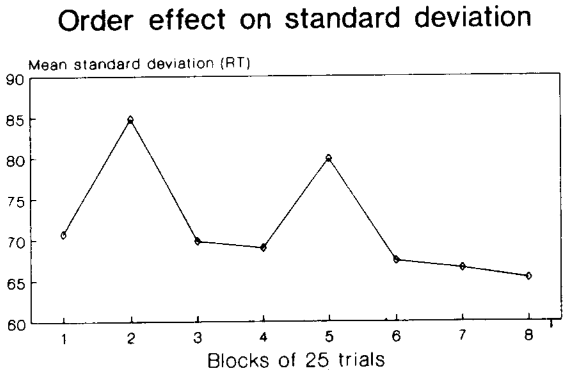

Figure 5. Order effect on standard deviations of reaction times. The decrease in standard deviations with increases in rank of trials is attributed to a progressive adaptation of the subjects' responses to the constraints of the task.

Table 1
Mean Reaction Time (RT, in Milliseconds) and Mean Number of Responses on Trial n, Depending on the Events of Trial $n-1$

	Trial n Response Versus Trial $n-1$ Response							
	Same Response				Different Response			
	Correct		Error		Correct		Error	
Trial $n-1$	No.	RT	No.	RT	No.	RT	No.	RT
No Feedback								
Correct	37.4	317.8	9.6	281.2	35.4	329.2	21.5	255.6
Error	20.4	329.6	7.2	273.4	18.8	332.8	7.6	249.6
Feedback								
Correct	9.8	291.2	5.0	266.8	12.8	302.0	7.6	269.6
Error	2.0	286.7	1.5	221.5	2.2	324.0	1.3	296.3
Total responses	69.6		23.3		69.2		38.0	
Mean RT		306.3		260.7		322.0		267.7

Note—The numbers of responses and the reaction times are averages of individual means. Total responses = 200.

centages of responses on trials following a speed-up signal and compared them to results on trials that were not preceded by the speed-up signal. Table 1 shows these data averaged over subjects.

A speed-up signal preceded 20.9% of the trials. Generally, the responses given at trials following such feedback (hereafter called *feedback trials*) are slightly faster (282.3 vs. 296.1 msec) than those not preceded by feedback (no-feedback trials). This decrease in RT affects correct responses (300.9 vs. 327.3 msec), not errors (263.5 vs. 264.9 msec). The mean difference between correct RTs ($\mathrm{RT_{CR}}$) and error RTs ($\mathrm{RT_{ER}}$) is larger for no-feedback trials than for feedback trials (62.4 vs. 37.4 msec).

When an error has been made at trial $n-1$ (R_{n-1} = ER), the $\mathrm{RT_{ER}}$ at trial n does not appear to be affected. On the contrary, the $\mathrm{RT_{CR}}$ is likely to be larger than in the case of a correct response on trial $n-1$ (R_{n-1} = CR). The mean difference ($\mathrm{RT_{CR}} - \mathrm{RT_{ER}}$) following an error is 69.7 msec for a no-feedback trial and 46.4 msec for a feedback trial. In comparison, these differences are, respectively, 55.1 and 28.4 msec when a correct response has been given at trial $n-1$.

When the stimulus changes from trial $n-1$ to trial n, the percentage of errors increases in comparison with the case when stimuli at trial $n-1$ and at trial n are the same. This result suggests that the subject tends to change his/her response after an error. The effect of stimulus changes is larger at no-feedback trials ($\mathrm{RT_{CR}} - \mathrm{RT_{ER}}$ = 78.4 msec).

Errors on no-feedback trials occur more frequently when the stimulus changes from trial $n-1$ to trial n, especially when the response on trial $n-1$ is correct. Furthermore, in this case, $\mathrm{RT_{ER}}$ is shorter than $\mathrm{RT_{CR}}$ (255.6 vs. 329.2 msec).

The main effect of feedback is that it reduces mean RT, particularly for correct responses. It furthermore reduces the difference between the percentage of correct RTs and the percentage of error RTs. Further analyses are, unfortunately, not possible given the small sample size for some of the cells in Table 1.

DISCUSSION

The present procedure seems to constitute an economical means of obtaining conditional accuracy data. Despite the small number of trials (200), a CAF could be estimated for each of our 7 subjects. Two factors seem to explain the efficiency of the procedure used in this experiment: The first is the continously maintained time pressure that is taken into account by the subjects and to which they adjust their responses. A second seems to be the verbal information about RTs that is communicated to the observers.

In a previous experiment, speed-up signals were given on the basis of a 25% error rate calculated on the cumulated number of all past trials. No verbal information concerning RTs was given to the subjects. Individual data of this experiment are shown in Figure 6. The mean error rate was 11.1% (*SD* = 8.8), and the mean median RT was 360 msec (*SD* = 54.2).

As is usually the case during the first trials, subjects favored accuracy over speed. As a consequence, in this experiment, in which the error rate is calculated on the cumulated number of past trials, at a given moment most of the subjects heard the speed-up signal at every trial. This creates such a hopeless situation for the observers that they end up ignoring the signal completely. As can be seen in Figure 6, only 2 subjects tried to adjust to the continous time pressure; the 5 others showed a ceiling effect with nearly perfect accuracy.

In another experiment, the procedure was essentially the same as the one reported here. A speed-up signal was delivered when the 12 preceeding trials contained less than 3 errors. However, the time pressure was increased by a response norm of 200 msec, which had been communicated to the observers. After each trial, they were informed verbally about their RTs. The results are shown in Figure 7. The mean value of median RTs was 264 msec (*SD* = 36.8); the mean error rate was 36.4% (*SD* = 11.8). Reasonable CAFs were obtained with 6 observers.

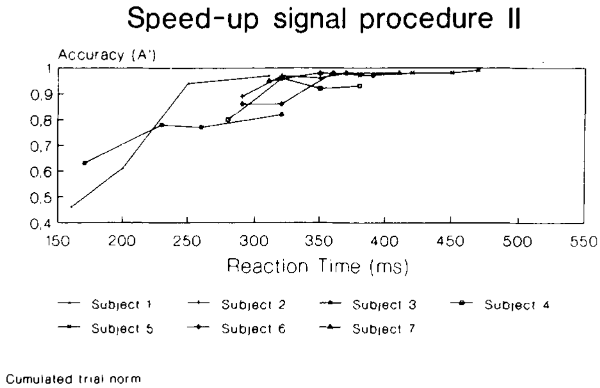

Figure 6. Individual conditional accuracy functions obtained in a preliminary experiment. The error rate was calculated on a cumulated number of past trials. Five of the 7 observers obviously did not take into account the speed-up signal and favored accuracy rather than speed.

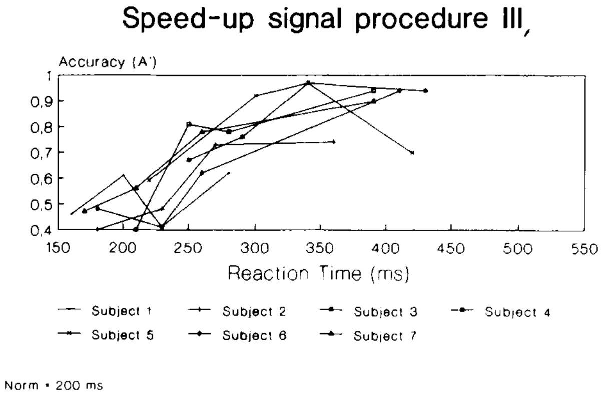

Figure 7. Individual conditional accuracy functions obtained in another preliminary study. An explicit norm for reaction time (200 msec) was communicated to the subjects. The results show a high interindividual variability concerning accuracy.

Comparison of Figures 7 and 2 shows that fast-guess tendencies are more distinct when an exacting RT norm is given. Most of the subjects almost never received the speed-up signal. Furthermore, interindividual variability turned out to have been higher in this preliminary experiment.

Under accuracy conditions, the discrimination task used in the experiments reported here was very easy to perform. Without time pressure, it can be done with 100% success, and a fast-guess model is likely to apply to the present data. In other words, the speed-up signal would have no effect on the sensory processing; it would merely induce the subjects to increase the probability of fast guesses. To summarize, four arguments favor the fast-guess interpretation. First, the mean RT on error trials was less than the mean RT on correct trials. Second, the mean RT on error trials showed almost no effect of practice, whereas the mean RT on correct trials decreased with practice. Third, on trials following a speed-up signal, the mean RT was faster on correct trials but it was unchanged on error trials. Finally, on trials following an error, the mean RT increased on correct trials but was unchanged on error trials.

Now the question is whether the speed-up signal brings about a change of state, which is consistent with the fast-guess assumption, or whether it leads to a response bias. Some of the sequential effects reported above tend to back up the response bias interpretation (e.g., Bonnet, 1990; Luce, 1986) because they mainly occur on no-feedback trials. In fact, our results do not allow us to settle this question, for two reasons. First, the effect of feedback does not work on a trial-by-trial basis. We have seen that feedback was less frequent in the second half of the experiment. Since the number of trials is limited and the subjects are untrained at the beginning, changes in the results should occur during the experimental session until an asymptotic response level is reached. Second, our data being non-asymptotic, a discussion of the two theoretical alternatives mentioned above becomes irrelevant.

CONCLUSION

Our goal for this method was limited to introducing a new experimental procedure for the study of CAF (or CAF-like) functions that does not require any training of observers or an important number of experimental sessions (which is usually the case with classic procedures). Our main empirical argument is that, generally, in RT experiments with untrained observers, high interindividual variability occurs, making data analysis difficult or impossible. We think that such undesirable variability is essentially a consequence of inappropriate control of the time pressure. The present procedure provides an economical and efficient solution to this problem.

The procedure can be used to generate speed-accuracy tradeoff functions as well. Between blocks, subjects could be told that the RT norm had increased or decreased, and that they should, as a consequence, respond faster or less fast. Then the experimenter would merely change the accuracy criterion and present the speed-up signal as a function of a higher or lower rate of errors.

Another advantage of our method is that it allows the experimenter to control error rates while the observers pay attention to their response times. In the deadline procedure, the experimenter manipulates RT in such a way that problems arise if different subjects need different times to perform at a given error rate. Then, deadlines have to be set individually for each subject to obtain the desired proportion of errors. In the procedure presented by Lappin and Disch (1972), the observers are instructed to generate a certain proportion of errors. Although this may work with highly trained subjects, it seems to be inappropriate for naive observers, since one does not want them to make errors deliberately. These problems do not arise with the procedure introduced here, where the experimenter controls error rates and the subject controls speed.

Finally, the proposed method is useful primarily for comparing RTs with accuracy held constant, or for comparing accuracies with RT held constant. In no case is it a substitute for response signal methods (Reed, 1973), which bring the duration of the processing phase of the task under experimental control. Our method may shorten any or all phases of processing during the task and not just the response phase.

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NOTE

1. The A' index, which is the surface under the receiver-operating curve, characteristic was obtained in the following way:

$$A' = 1 - \frac{p(a|B)/p(a|A) + p(b|A)/p(b|B)}{4},$$

where a and b refer to the responses, and A and B, to the stimuli.

2. Taking into account the aim of the experiment and the consistency of the trend observed whether we divided the RT data into 4, 5, or 8 blocks, we decided not to smooth the data by, for instance, a moving window technique.

APPENDIX

Table A1
Number of Correct Responses and Mean Reaction Times (RT, in Milliseconds), With Standard Deviations (*SD*) Corresponding to Figure 2

Subject	Block	No. Correct	A'	RT	
				M	*SD*
1	1	25	.50	211	30
1	2	31	.70	252	19
1	3	28	.59	307	21
1	4	46	.96	406	52
2	1	25	.49	176	29
2	2	27	.52	235	16
2	3	38	.86	291	20
2	4	45	.94	376	66
3	1	28	.61	185	21
3	2	28	.54	232	14
3	3	34	.76	286	13
3	4	43	.92	350	29
4	1	24	.47	231	24
4	2	34	.81	288	12
4	3	32	.73	337	17
4	4	42	.90	411	33
5	1	29	.64	282	30
5	2	39	.86	350	15

Table A1 (continued)

Subject	Block	No. Correct	*A*′	RT *M*	RT *SD*
5	3	43	.92	407	19
5	4	44	.93	498	57
6	1	25	.54	212	20
6	2	31	.79	252	10
6	3	41	.87	304	19
6	4	46	.95	405	46
7	1	26	.51	198	22
7	2	34	.76	259	13
7	3	41	.87	303	15
7	4	43	.92	400	40

Note—Maximum responses in each block = 50.

Table A2
Number of Correct Responses (RT, in Milliseconds) and Errors, With Corresponding Reaction Times, *A*′, and Mean Reaction Times

	Correct Responses				Errors					
	a/*A*		*b*/*B*		*b*/*A*		*a*/*B*			
Subject	No.	RT	No.	RT	No.	RT	No.	RT	*A*′	*M*
1	67	310	63	342	33	272	37	268	.73	298
2	72	297	63	278	28	223	37	230	.76	257
3	58	291	75	263	42	221	25	249	.75	256
4	70	322	62	328	30	305	38	282	.74	309
5	71	404	84	383	29	347	16	348	.85	370
6	78	305	65	313	22	249	35	253	.80	280
7	71	320	73	332	29	258	27	252	.80	290

Note—*a* and *b*, responses; *A* and *B*, stimuli.

(Manuscript received December 12, 1990;
revision accepted for publication August 18, 1992.)