BEHAVIORAL DEFINITION OF MINIMAL REACTION TIME IN MONKEYS¹

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Two monkeys (*Macaca mulatta*) were trained to press a key after onset of a tone and to release it after a 1-sec fixed foreperiod terminated by a light. The effects of imposing temporal contingencies on key release reaction times were determined by reinforcing only those releases whose latencies from the light fell within a "payoff band", two time limits 50 msec apart located at some delay following the light. Over several days this delay was first gradually decreased, shortening the interval between light and payoff band, and then gradually increased again. For each delay, the median reaction time and a measure of variability were obtained from the latency distribution. For both animals, median latency could be decreased to 180 msec with the variability remaining small. Moving the payoff band still closer to the light resulted in further decrease in median latency but an abrupt increase in variability. This is in agreement with a model for simple reaction time derived from human research which suggests that this increased variability results from the inclusion of high-variability foreperiod time estimations in the latency distribution. These results indicate that interpretation of monkey response latencies as "minimal reaction times" requires examination of temporal reinforcement contingencies and variability of latencies.

Interest in the simple reaction time (RT) of animals has centered on the control of this performance by the intensity and quality of the stimulus. Experimenters have desired to use simple RT as an indication of the delays in sensory processing (Miller and Glickstein, 1967) or as a possible substitute measure for stimulus scaling (Stebbins, 1966). However, because many other factors that affect the animal's bias towards fast responding are imperfectly understood and as yet little investigated, care must be exercised in the interpretation of existing RT data as reflecting primarily sensory processing. One such important area that needs clarification is the role of appropriate latency dependent feedback in establishing a consistent bias for speed of response to stimuli of different characteristics.

The trial events of a classical human simple RT experiment include a warning stimulus

(S^w), a foreperiod (fixed or variable), a single reaction stimulus (S^p), and a single response to S^p. For most of the last century, human RT experiments have relied upon extended practice and the admonition to be "fast but accurate", combined with informal reports at the end of a session as to the quality of performance, to produce minimal RTs with low anticipation rates and an assumed consistent bias for fast responding to stimuli of different characteristics. Changes in RT with stimulus changes were then assumed to be completely under stimulus control (Chocholle, 1940).

In addition to verbal instructions, some human RT experiments have investigated the effects of trial-to-trial feedback and reinforcement on fast RTs. Johanson (1922), using variable foreperiods, demonstrated that a fast key release RT of 140 msec to offset a loud noise stimulus could be reduced by 10 msec by simply displaying the RTs trial-by-trial to the subject, and by 20 msec by punishing slow reactions with an electric shock. Variability decreased with mean RT. These effects were seen for different orders of presentation of the three conditions, indicating that continuing feedback was required to produce the reduced RTs. Church and Camp (1965), also using

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variable foreperiods, found that trial-by-trial knowledge of results decreased RT over several daily sessions while RT in the absence of feedback changed little.

Snodgrass, Luce, and Galanter (1967), using a fixed foreperiod of 2 sec, found that a subject could adjust the location of his RT distribution appropriately to a payoff band composed of upper and lower latency limits 20 msec apart, located anywhere between 85 and 205 msec after onset of a moderately loud tonal stimulus. The highest per cent successful RTs was achieved for payoff bands of 105 to 125 or 125 to 145 msec, with mean RTs of between 125 and 140 msec. Slower bands produced longer mean RTs, moderately increased variability, and a gradual decrease in per cent successful responses. Faster bands produced shorter mean RTs, but a sharply increased variability and an abrupt decline in per cent successful responses, presumably because the subjects were attempting to time some of their responses from S^W rather than from S^D . Minimum RT in the Snodgrass *et al.* experiment could, therefore, be defined as that RT achieved with the fastest band that still produced a low variability RT distribution. In conclusion, there is good indication in the human RT literature that feedback and reinforcement, in addition to the usual verbal instructions, are important in establishing minimal latency distributions with small variability.

In animal experimentation, where verbal instructions are not easily used, understanding the role of feedback and reinforcement in producing a consistent bias for speed becomes even more crucial. Animal experiments that reinforce responses to S^D without limits on response latencies produce very long and variable RTs in comparison to the human data. Gates, Romba, and Martin (1963) studied auditory response latencies of rhesus monkeys in a simple RT experiment with no limits imposed on acceptable latencies. The RTs obtained were very variable and showed large differences between days for any one subject, as well as large differences between subjects. The fastest average RT was about 450 msec for a 2000-Hz tone at 23-dB Sensation Level. However, in humans, using only verbal instructions, Chocholle (1940) found low-variability RTs of about 175 msec for a 2000-Hz tone of this intensity. Even for stimuli only a

few decibels above threshold, the human subjects were still capable of RTs shorter than 450 msec. Stebbins and Reynolds (1964) found macaque visual simple RTs of 350 to 450 msec in the absence of limits on reinforced latencies. Again, these latencies were very variable, and there were large differences between the two subjects. It is obvious that minimal or even relatively fast RTs, similar to those achieved in human experiments by instructions alone, cannot be produced in animals without some sort of latency-dependent feedback.

Imposition of limits on acceptable RTs can greatly decrease both an animal's average response latency and variability. Reynolds, Hay, and Pegram (1965) attempted to reduce visual RTs of pre-adolescent chimpanzees by imposing an upper time limit on response latencies that would allow the animal to escape shock. Their experiment was not appropriately designed to elicit low-variability, fast responding for there was no warning stimulus and the response manipulanda were awkward; however, they were able to decrease single-alternative visual RT from 1440 msec to 360 msec, by decreasing the time limit from 5 to 0.5 sec. It is doubtful whether the final RT achieved can be considered in any sense minimal, since day-to-day changes in the limit were rather large and the experiment was terminated on the first day the animal exceeded the limit on 25% of the trials. Stebbins (1966) imposed a 1-sec upper limit on response latencies that would be reinforced by a food pellet. The fastest median RTs to a 95-dB SPL (re 0.0002 dynes/cm²), 1000-Hz tone were 215 msec for one macaque subject and 250 for another. These times are still rather long compared to Chocholle's (1940) estimate of approximately 110 msec for human RT to a sound of this intensity.

Miller, Glickstein, and Stebbins (1966) demonstrated that visual simple RTs of well-trained monkeys could be considerably reduced by a procedure of gradual day-to-day reduction of the upper time limit. One monkey decreased from 350 to 215 msec. Another, whose RT appeared to be increasing day-to-day in the absence of a limit, was decreased from 240 to 165 msec. Variability decreased as well as median RT. If the limit were decreased below 250 msec, the animal's performance became very unstable. It is obvious that imposition of an upper time limit can have

large effects on reducing and stabilizing monkey RTs. However, it is still not clear how to decide whether the RTs achieved are the fastest that could be obtained. More important, it is not clear whether a constant time limit on RT produces the same bias towards speed for stimuli of different intensities or qualities, or whether training for fast responding to one stimulus necessarily generalizes to responses to another stimulus.

The present experiments were based on a model for simple RT proposed by Snodgrass *et al.* (1967). In this model, a response latency distribution can be composed of a mixture of as many as three kinds of responses: time estimations from S^W , fast or minimally delayed reactions to S^D , and delayed reactions or time estimations from S^D (of which fast reactions are the lower limit). The mean or median RT alone cannot indicate which type of responding is predominant, but an examination of the variability of the distribution should be an indication. Extensive work on both man (Chocholle, 1940; Snodgrass *et al.*, 1967) and monkey (Saslow, 1968) indicates that the variability of a response latency or a time estimation distribution remains proportional to the average interval between the stimulus and the response. This means that if the subject, under the pressure of time contingencies, switches from fast RTs of a couple of hundred msec to time estimations of foreperiods of 1 sec or more, there should be an abrupt inflation of response latency variability.

According to this model, a payoff band, defined by lower and upper time limits for reinforced response latencies, could be located so close to S^D that fast or minimally delayed reactions to S^D would have latencies greater than the upper time limit of the band. In this case, the subject would have to estimate foreperiod duration in order to make some successful responses and, therefore, the variability of the latency distribution should be high. For example, Saslow (1968) found for monkeys that the semi-interquartile range remains about 3 to 6% of the median latency as RT is manipulated in the range of 200 to 700 msec by use of different payoff bands. From these data, one would predict that the semi-interquartile range would be 30 to 60 msec for time estimation of a 1000-msec fixed foreperiod, if the subject were responding to S^W rather than S^D because of the pressure of a time contingency. On the

other hand, if the payoff band were located so that fast reactions to S^D could be successful, variability should be very low. For example, a semi-interquartile range covering only 6 to 12 msec has been found for median RTs to light of 200 msec for the monkey (Saslow, 1968).

When the payoff band is narrow compared to the latency distribution that could be produced by estimating the foreperiod, the subject would be expected to continue responding to S^D as long as a sizable number of successes were still possible. If there is a physiologically defined region of minimum RT to S^D , the shift from low to high variability should be rapid when the payoff band is moved below this region and the subject shifts from reacting to S^D to time estimating from S^W . When the payoff band is located above this fast RT region, the variability of the response latencies should again increase, but more gradually, since the subject would now be timing from S^D . For example, a median light response latency of 300 msec would be expected to have a semi-interquartile range of only 9 to 15 msec for the monkey (Saslow, 1968). Given this model, if a series of payoff bands were used that forced the subject to switch from responding to S^D to estimating the foreperiod, one could behaviorally define the minimum RT region as the fastest RT distributions for which the subject still maintained low variability.

The present experiments were performed to test these implications of the time estimation model. A series of gradually descending payoff bands in combination with a fixed foreperiod of 1 sec was used to force the monkey to change from responding to S^D to time estimating the foreperiod. A minimal RT, in accord with the definition given above, was estimated from the median RTs given on the fastest band in either a descending or an ascending series that resulted in consistent low-variability performance. Further tests with variable foreperiods were conducted to confirm that the animal was not including foreperiod estimations in the minimal RT distributions. To test the generality of this model and also to develop a method for rapidly producing minimal RT distributions, a newly trained monkey was used as well as one highly experienced in the RT task. A further implication of the model was then tested with the experienced

animal; namely, if attenuating the stimulus increases the physiological delays in simple RT, the point of rapid increase of variability should shift to a slower band. Accordingly, the more experienced animal participated in another payoff band series with a dimmer light stimulus. Finally, this animal's performance on minimal reaction-time bands appropriate to the two light intensities was compared to begin to develop a technique for testing stimulus differences while maintaining a constant pressure for fast responding.

METHOD

Subjects

Two adolescent male monkeys (*Macaca mulatta*) were maintained at 80 to 90 per cent of their free-feeding body weights (4 to 5 kgm). They were deprived of food for 22 hours before each session and were given supplemental feeding 30 min after the end of a session. The monkeys were kept in home cages and placed in primate restraining chairs only for the 1 to 1.5 hour daily experimental sessions (Barrow, Luschei, Nathan, and Saslow, 1966).

Monkey W had been used for 2 yr in experiments on simple RT and was a subject in an earlier study on the control of time estimation by payoff bands (Saslow, 1968). With variable foreperiods, W could produce low variability RTs of 190 to 200 msec to the same light stimulus used in the present study when an automatically adjusting upper limit was imposed to reinforce differentially fast responding (Saslow, 1968, p. 91). Before the present study, the monkey's "minimum" RT to this light stimulus had been assumed to be about 195 msec.

Monkey S had just completed three months of preliminary training at the beginning of this experiment. With variable foreperiods, Monkey S's median RT to light had been decreased from 260 to 225 msec by decreasing the upper limit day-to-day from 350 to 250 msec. Repeated attempts to reduce RT still further by decreasing the upper limit below 250 msec had resulted in inconsistent responding, increased variability, cessation of working, and a tendency to skip those trials with short foreperiods; effects similar to those noted by Miller *et al.* (1966).

Apparatus, Training, and Trial Events

By a shaping procedure similar to that of Stebbins (1966) and Stebbins and Miller (1964), the subjects were trained in a dimly lit, sound-attenuating booth (Industrial Acoustics Company, model 400A) to await the onset of a clearly audible 1000 Hz tone (S^w), then to press a telegraph key and hold it down through a variable 0.6- to 1.4-sec foreperiod initiated by the press, releasing it after the occurrence of a light flash (S^v). The light flash was 60 msec long and was produced by turning on an NE-40 neon bulb mounted behind a 0.25 in. (1-cm) hole located 6 in. (15 cm) from the monkey's right eye when facing forward. Key release terminated the tone.

Key release following the S^v was reinforced by a 190-mg banana-flavored pellet. The inter-trial interval was 6 sec. Releases during a foreperiod and responses during an intertrial interval started a new intertrial interval. Trials, stimulus events, and reinforcement contingencies were arranged automatically by a system of DigiBit logic located outside the experimental chamber. Tests with both humans and monkeys indicated no detectible switching sounds. Continuous low-level white noise masked extraneous sounds from the room.

The telegraph key was positioned on the right side at waist height. The monkey was restrained by belly and breast plates and by a panel that blocked access to the key with the left hand. The timing of all trial events was recorded on magnetic tape and response latencies for key release to S^v were measured in milliseconds by a Hewlett-Packard electronic counter and printed out by a Hewlett-Packard digital recorder. Latencies were then transferred to IBM punched cards for computer analysis.

When a payoff band was in effect, the key release was reinforced only when its latency from S^v fell between two fixed time limits 50 msec apart. For example, on a 150- to 200-msec band, a key release was reinforced only if its latency was longer than 150 msec (lower limit) and shorter than 200 msec (upper limit). Responses with latencies outside this band terminated the trial without reinforcement. Latencies shorter than the lower limit were signalled by a blink of the houselight; those falling within the band, by feeder noises and

Table 1
Details of Experimental Procedure for Monkey W

<i>Experiment</i>	<i>Starting Band (in msec)</i>	<i>End Band (in msec)</i>	<i>Size of Daily Band Change (in msec)</i>	<i>Number of Days on each Band</i>	<i>Foreperiods</i>
1. Descending Band Series	180-230	145-195	5 msec	1	1 sec fixed, 2 sec fixed or variable
	140-190	75-125	5 msec	1	1 sec fixed
2. Rapid Return to Low-Variability RTs	—	150-200	—	3	1 sec fixed or variable
3. Descending Band Series with Dim S ^D	200-250	190-240	5 msec	1	1 sec fixed or variable
	185-235	135-185	5 msec	1	1 sec fixed
4. Wide Band at End of Descending Series (Dim S ^D)	—	20-185	—	1	1 sec fixed
5. Ascending Band Series with Dim S ^D	150-200	175-225	5 msec	1	1 sec fixed
	180-230	200-250	5 msec	1	1 sec fixed or variable
6. Direct Comparison of Performance on Low-Variability Bands for Bright and Dim S ^D	—	140-190	—	2	1 sec fixed (blocks 1 and 3) and variable (block 2)
	—	(Bright S ^D) or 190-240 (Dim S ^D)	—		

delivery of a pellet; those longer than the upper limit, by a 0.5-sec noise burst. Thus, the animal was given feedback information as to whether each response was too fast, within the band, or too slow.

Procedure for Descending and Ascending Band Series

Since training an animal to a low-variability, fast RT performance or to a time estimation performance is essentially a process of successive approximation, the procedures used are

not exactly the same for the two animals or for the same animal in different parts of the experiment. Summaries of the different experiments performed in sequence are given for Monkey W in Table 1 and Monkey S in Table 2.

Each daily session consisted of 300 to 600 trials, divided in 100-trial blocks, each taking 10 to 15 min to run. Ten free trials, with no limits on RT were given before the first block of each session. Between blocks the monkey was given 3 to 5 min rest with access to water.

Table 2
Details of Procedures for Monkey S

<i>Experiment</i>	<i>Starting Band (in msec)</i>	<i>End Band (in msec)</i>	<i>Size of Daily Band Change (in msec)</i>	<i>Number of Days on each Band</i>	<i>Foreperiods</i>
1. Initial Training	210-260	180-230	5 msec	1 or 2	Variable or 1 sec fixed
	175-225	160-210	5 msec	1 or 2	1 sec fixed
2. Descending Band Series	175-225	105-155	5 msec	1	1 sec fixed
3. Wide Band at End of Descending Series	—	20-155	—	1	1 sec fixed
4. Ascending Band Series	125-175	180-230	5 msec	1	1 sec fixed
5. Reintroduction of Variable Foreperiods	150-200	135-185	5 msec	3	Variable

About 200 to 250 pellets were delivered each day.

The location of the 50-msec wide payoff band was usually shifted only 5 msec between sessions. Preliminary work with Monkey W indicated that a larger shift, especially when the animal was working in the fast RT region with semi-interquartile ranges of 6 to 8 msec, might suddenly reduce reinforcement by as much as 50% and result in gross disruption of performance and failure to continue responding.

In most of the experiments, a 1-sec fixed foreperiod was used to encourage timing from the bar press when fast releases to S^D no longer resulted in reinforcement. In some sessions, when the payoff band was in or above the fast RT region, other foreperiods were used for a block or two within a session to check further that the animal was responding to S^D rather than timing from the bar press. Either variable foreperiods were randomly selected trial to trial from a continuous rectangular distribution of times between 0.6 and 1.4 sec, or fixed foreperiods of other durations were used.

For a descending series, the animal was stabilized on a band well above its estimated fast RT region. Using a fixed foreperiod of 1 sec, the band location was decreased in 5-msec steps until the animal appeared to be timing a large proportion of its responses from the bar press, as indicated by a greatly increased variability. At the end of some of the descending series, the lower limit of the payoff band was dropped to 20 msec for a session to encourage releases timed from the bar press. Occasionally, when a daily session was skipped or when the animal had worked erratically and received very few pellets in a session, a band was repeated for a second daily session before the 5-msec daily decrements were resumed.

After a descending series was completed, the animal was either abruptly returned to a band allowing low-variability responding to S^D or gradually shifted upwards in an ascending series with daily 5-msec increments in band location.

Several different experiments were performed in the investigation of the low-variability, fast RT region (Tables 1 and 2). Monkey W was run on a descending series and Monkey S on both a descending and an ascending series using fixed foreperiods of 1 sec and the unattenuated stimulus light. The fastest

band for which the animal could give a consistent low-variability performance was determined for each of these series and the median RT given on this band was defined as the monkey's minimal latency to S^D . Monkey S was then retrained to work with variable foreperiods on its minimal latency-band. Monkey W was also run on both a descending and an ascending series with the stimulus light attenuated by three log units, and the fastest low-variability band for this dimmer stimulus was ascertained.

Reintroduction of Variable Foreperiods for Monkey S

Because both the descending and ascending series were done with the same fixed foreperiod, it was decided to retrain S to work on variable foreperiods at a low-variability band of 150 to 200 msec. After stabilizing performance with a 1-sec fixed foreperiod on this band, fixed foreperiods of 0.6 and 1.4 sec were alternated with 1-sec foreperiods in 50-trial blocks over the next three sessions. The block size was reduced to 10 trials in the third session and then the animal was placed directly on variable foreperiod. After three days on variable foreperiod, the band was shifted to 145 to 195 and then to 140 to 190 msec, spending three days on each band. Attempts to shift the band further downward disrupted performance, but performance on the 140 to 190 msec band was easily restored.

Descending and Ascending Band Series with a Dim Stimulus Light

After the descending series with the unattenuated stimulus light, Monkey W was given first a descending and then an ascending series with the original stimulus light attenuated by three log units (Wratten neutral density filter, #96). For all sessions with the dim stimulus light, a 25-trial practice block followed the initial 10 free trials before the first experimental block began, in order to allow 5 min of dark adaptation. The day before the filter was first introduced, W had been producing stable fast RTs on a 15- to 200-msec band with either fixed or variable foreperiods. For the first 100-trial block of the first session with the dim light, a wide payoff band, 150 to 400 msec, was used in conjunction with variable foreperiods. From the RT distribution for this block it was estimated that 190 to 240 msec would be an

appropriate band and this band was used on subsequent blocks in the initial session. Descending and ascending band series were then run with the use of the dim stimulus light (Table 1).

Comparison of Performance on Low-Variability Band for Bright and Dim Stimuli

On the last two days of the experiment, following the ascending band series for the dim stimulus, Monkey W's performances with the bright and dim stimuli were directly compared. Each session consisted of six 100-trial blocks, three at each intensity. Before each intensity condition, the animal was given 5 min of dark adaptation followed by 15 free trials and 10 practice trials while adapting for an additional 5 min. Within each intensity condition, a 1-sec fixed foreperiod was used for blocks 1 and 3 and variable foreperiods for block 2. The animal was given five free trials before each block and a 2-min rest at the end. There was a 5-min break at the end of the first three blocks to change the filter and allow the animal access to water. A 140- to 190-msec payoff band was used for the bright stimulus and a 190 to 240 band for the dim stimulus. On the second day, the order of intensities, each with its appropriate band, was reversed.

RESULTS

Data Processing

Medians and semi-interquartile ranges are used as distribution statistics because they are much less affected than parametric statistics by occasional deviant latencies. In contrast to the more usual practice in RT experiments, "anticipations" were included in the response latency distributions when calculating distribution statistics. Since the control system did not count a trial on which an anticipation occurred as a true trial, the actual N for blocks in which anticipations occurred is 100 plus the number of anticipations. When fixed foreperiods were used, the recording system made it possible to retrieve bar-press durations on anticipatory trials and calculate how long before the expected occurrence of S^D the anticipatory release had occurred. Generally, the anticipation rate was low, being 0 to 2% for bands near or above the low-variability, fast-RT region and only 10 to 12% for even the fastest

bands where most of the responses were probably timed from the bar press.

Block medians and semi-interquartile ranges are plotted against payoff band centers in Figures 1, 4, 5, and 6. Block rather than session statistics are given to display the animal's stability over 100-trial blocks for any one band. Histograms of response latency distributions for whole sessions are given in Figures 2, 7, and 8. In these histograms, the proportion of response latencies falling within each 10-msec class is plotted as a function of response latency in order to equalize different sample sizes.

Monkey W, Descending Band Series

In W's first descending series, the initial payoff band of 180 to 230 msec was decreased 105 msec over a period of three weeks by daily 5-msec changes (Table 1). The block medians and semi-interquartile ranges for this series are given in Figures 1A and 1B. From these figures it can be seen that the median response latencies continued to decrease for the entire series, although the increased scatter of the block medians for the fastest bands indicated somewhat less stability of performance for sessions with bands centered below 150 msec. The semi-interquartile ranges, unlike the medians, remained low only down to bands centered at 170 or 165 msec and then increased rapidly for bands centered below 165 msec, having doubled for a band centered at 150 msec and tripled for one centered at 130 msec, a total change in band location and associated median RT of only 40 msec.

The change in performance with the fastest bands appears even more dramatic when latency histograms are examined. Figure 2 displays histograms for four sessions on payoff bands at and below the fast RT region. The rapid flattening and spreading of the latency distribution below the 145- to 195-msec band (band center of 170 msec) is obvious in Figures 2B-2D, as is the development of an elongated tail in the very fast latency region (Figure 2D). A wide distribution with a substantial number of high variability foreperiod time estimations (Figure 2D) would have to be better centered over a 50-msec wide payoff band than a narrow RT distribution (Figure 2A) in order to maximize reinforcement. The sharper cutoff at the upper end of the distribution for the fastest band (Figure 2D) may indicate that some reactions to S^D were still occurring and that

Fig. 1. (A) Block latency medians and (B) semi-interquartile ranges as a function of payoff band center from Monkey W's descending band series. Unfilled dots are for blocks done with fixed foreperiod 1 sec; triangles, fixed foreperiod 2 sec; and filled dots, variable foreperiod. Dashed lines mark the upper and lower band limits. Data for band centers of 215 msec and above come from an earlier study on the same animal (Saslow, 1968).

this distribution was not entirely composed of time estimations. When the "latency" of anticipatory responses was plotted for the 1000 msec preceding S^D , it could be seen that they formed a continuation of the lower tail of the distribution, rather than a separate class of responses (Figure 2E).

In contrast to this great increase in variability for bands below the fast RT region, from Figure 1 it is clear that for payoff bands centered in the 40 msec above the fast RT band centered at 170 msec, the median RT continued to vary directly with payoff band center, but the semi-interquartile range remained low. In fact, when the data on time estimation from S^D gathered in an earlier experiment (Saslow, 1968) for payoff bands centered at 215 msec and above are considered, the semi-interquartile ranges for median RTs of about 285 msec given to a band centered at 300 msec are still only 10 to 14 msec. It is also apparent from Figure 1 that changing the foreperiod structure for these low-variability bands had little effect on RT distribution statistics for an experienced animal, further evidence that the animal was timing these fast responses from S^D .

The data from this descending series corresponded well to the predictions of the model given in the Introduction and indicated that

a band of 145 to 195 msec (band center of 170 msec) or perhaps, 140 to 190 msec was the fastest band for which this animal continued to produce a low-variability RT distribution. In this series, the RT distributions given on these two bands had medians of about 185 msec.

Monkey W, Return to a Low-Variability Band

Since the foreperiod time estimation distributions were so broad with respect to the 50-msec wide payoff band and the maximum per cent reinforcement, as a consequence, was relatively low (30 to 40%), it was predicted that W would readily return to working on a low-variability band where relatively high per cent reinforcement was possible (80 to 90%), although such a large band shift in the opposite direction would have resulted in inconsistent responding. In Figures 3A-C, medians, semi-interquartile ranges and anticipation rates are given for the blocks of three successive sessions on a 150- to 200-msec band introduced immediately after the animal had terminated the descending series with a 75- to 125-msec band. As expected, the animal returned rapidly to working on the low-variability band and by the end of the second day was producing block distributions with median RTs and semi-interquartile ranges similar to

Fig. 2. Whole-session response latency histograms for four payoff bands from Monkey W's descending band series. Location of payoff band center (PBC), medians, semi-interquartile ranges (SIQR), and Ns are given with each histogram. The bar press occurred at -1000 msec; the S^p at 0 msec. (A) 145- to 195-msec band. (B) 135- to 175-msec band. (C) 105- to 155-msec band. (D) 85- to 135-msec band. (E) Expanded display of the anticipations (responses before S^p) in (D).

its performance on this same band about three weeks before. Block-to-block changes from a fixed foreperiod of 1 sec to variable foreperiods did not affect its RT distributions.

Monkey S, Initial Training Series

Although this relatively inexperienced animal had repeatedly shown response disruption while working with variable foreperiods when the upper limit was reduced below 250 msec, Figures 4A and 4B show that S quite readily decreased its RT with decreased payoff band location when a fixed foreperiod of 1 sec was introduced, without greatly increasing its variability. At the beginning of this series its median RT had been about 225 msec with a semi-interquartile range of 12 msec; two weeks later it was about 180 msec with about the same semi-interquartile range.

Monkey S, Descending Band Series

After the initial training series, Monkey S was returned to a band of 175 to 225 msec and then this band was decreased by 70 msec over a two-week period (Table 2). This less-extensive descending series for S showed results similar to those for W. In figures 5A and 5B, median RT decreased with decreasing payoff band location but the semi-interquartile ranges begin to increase for bands centered on 175 to 170 msec. The median RTs for the low-variability bands in this region were about 175 msec with semi-interquartile ranges of about 9 msec. Unlike W, this animal had had no previous experience with time estimation of long intervals and showed a less stable performance at the fastest bands, occasionally giving a block of latencies more appropriate to a slower band located in the fast RT region, with corresponding lower variability but with few of the responses achieving reinforcement. Decreasing the lower band limit to 20 msec on the last day, while holding the upper limit constant at 155 msec, resulted immediately in a decreased median latency with a sharp increase in variability, as can be seen for the data plotted at the 130-msec band center.

Monkey S, Ascending Series

At the conclusion of Monkey S's descending series, the band was abruptly changed to a 125- to 175-msec band and then the band location was increased by 55 msec over approxi-

Fig. 3. Monkey W's direct return from foreperiod estimation to performance on a low-variability band (150 to 200 msec). Data come from successive blocks of the first three sessions on this reinstated band. Unfilled dots are for blocks with fixed foreperiod 1 sec; filled dots, variable foreperiod. (A) Median latency over blocks. The arrow indicates the median latency on this band in the descending series. (B) Semi-interquartile ranges (SIQR) over blocks. The arrow indicates the SIQR on this band in the descending series. (C) Percent anticipations over blocks.

mately two weeks (Table 2). As Figures 5C and 5D show, S returned rapidly to a low-variability performance as the band center was increased, and when a distribution with a median of 175 msec and an SIQR of about 8 msec had been reestablished, it was maintained although the increasing band location permitted slower responding. This may partly reflect the fact that in the low-variability, fast RT region the payoff band is actually relatively wide with respect to the RT distribution, permitting some latitude in locating the distribution without greatly changing per cent reinforcement. Although the performance appears to stabilize at a band center of 175 msec, the animal was able to do relatively well at the next two faster bands with about the same median RT, and it was thought desirable to retrain it on variable foreperiods for bands in this region to confirm that its fast latencies were for responses to S^D .

Monkey S, Reintroduction of Variable Foreperiods

Before being trained on a descending band series, Monkey S had shown inconsistent responding when the upper limit was reduced

Fig. 4. (A) Block latency medians and (B) semi-interquartile ranges (SIQR) from Monkey S's initial training series. Unfilled dots are for blocks done with fixed foreperiod 1 sec; filled dots, variable foreperiod.

to below 250 msec and variable foreperiods were used. At the end of its ascending series, it was retrained to work with variable foreperiods on a 150- to 200-msec band, the location of which was then gradually reduced to 135 to 185 msec. After a week of experience with variable foreperiods, S was giving median RTs of 185 to 190 msec with semi-interquartile ranges of about 7 msec on bands centered at 165 or 170 msec (See Figures 5C and 5D). This is about 10 msec longer than S's performance on the same bands with fixed foreperiods of 1 sec. The experiment was discontinued at

Fig. 5. Block statistics for Monkey S as a function of payoff band center. Payoff band limits are indicated by dashed lines. Unfilled dots are for blocks done with fixed foreperiod 1 sec; filled dots, variable foreperiod. Unfilled triangles indicate fixed foreperiod 1-sec blocks on which the upper limit was maintained while the lower limit was reduced to 20 msec. (A) Medians and (B) semi-interquartile ranges (SIQR) from the descending payoff band series. (C) Medians and (D) SIQRs from the ascending series. The blocks with variable foreperiod were run after the termination of the ascending series.

this point, but it is possible that continued practice with variable foreperiods would have reduced the median RT slightly more to the fastest RT estimate from the fixed foreperiod series. Monkey W, with much more extensive experience with variable foreperiods, was able to maintain the same median RT when switched from fixed to variable foreperiods on its fastest low-variable bands.

Monkey W, Descending and Ascending Series with a Dim ($-3 \log$) S^D

On the first variable foreperiod block of the first session with the dim S^D , W gave a median RT of 230 msec with an semi-interquartile range of 7.5 msec on a wide 150- to 400-msec initial band and maintained this distribution on subsequent variable and fixed

Fig. 6. Block statistics as a function of payoff band center for Monkey W with -3 log attenuation of S^D (dim stimulus). Payoff band limits are indicated by dashed lines. Unfilled dots are for blocks done with fixed foreperiod 1 sec; filled dots, variable foreperiod. Triangles are fixed foreperiod 1-sec blocks on which the lower limit was reduced to 20 msec. (A) Medians and (B) semi-interquartile ranges (SIQR) from the descending band series. (C) Medians and (D) SIQRs from the subsequent ascending series.

foreperiod blocks on a 190- to 240-msec band. This was an increase of about 45 msec from the 185-msec median RT given on the 150- to 200-msec band on the last day with the unattenuated, or bright, stimulus.

The subsequent descending series, shown in Figures 6A and 6B, indicated that the 190- to

240-msec band, centered at 215 msec, resulted in the fastest consistent low-variability performance, with a median RT of about 225 msec, about 40 to 45 longer than the minimum RT estimate for the bright stimulus. A three-day gap before the last two fast bands disrupted the time estimation performance and

W, like S, began to give RT distributions for some blocks that tended back towards the fast RT region, despite the resulting large reduction in per cent reinforcement. As with S, reduction of the lower limit to 20 msec on the last day reversed this trend and the median response latencies were reduced with a corresponding increase in semi-interquartile range.

As with S, the ascending series (Figures 6C and 6D) resulted in a rapid return to the low-variability, fast RT performance somewhat in advance of the increasing band location. This series indicated as optimal for the fast RT performance the same band region as was indicated by the descending series: one centered at 215 msec or, perhaps, at 210 msec. The median fast RT estimate from the ascending series is slightly faster, 215 to 220 msec, than for the descending series, although the optimal band was the same.

If Figure 6 is compared with Figure 1, it can be seen that the semi-interquartile range functions are similar, with the low-variability semi-interquartile ranges being slightly greater for the dim stimulus and with the region of rapid increase in semi-interquartile range occurring at a band centered 40 to 50 msec above that for the bright stimulus. In fact, if Figure 6B is displaced -45 msec and placed over Figure 1B, the two semi-interquartile range functions superimpose.

It is interesting to compare histograms for various sessions conducted with the bright and dim stimuli. Figure 7A is for the bright stimulus with a low-variability band, 150 to 200 msec, which produced a median RT of about 190 msec. The same band with the dim stimulus (Figure 7B) resulted in a latency distribution located in almost the same place with a median of 197 msec but with a semi-interquartile range three times greater. It is probable that to work on this band with the dim stimulus, a considerable number of fore-period time estimations were necessary. To produce the same median RT as in Figure 7A with the dim stimulus (Figure 7C), a slightly faster band was necessary, one corresponding to the minimal RT band for the bright SP. However, now the variability was almost four times as large. Finally, in order to increase the variability of the latency distribution to the bright stimulus to be the same as that obtained with the dim stimulus and a 150- to

Fig. 7. Comparison response latency histograms for Monkey W from sessions with no attenuation of the stimulus light (A & D) and from sessions with SP attenuated -3 log units (B & C). Dashed lines indicate payoff band limits. (A) Bright stimulus, band of 150 to 200 msec. (B) Dim stimulus, same payoff band as for (A). (C) Dim stimulus, band of 145 to 195 msec, which resulted in a distribution with the same median latency as in (A). (D) Bright stimulus, band of 105 to 155 msec, which resulted in a distribution with the same semi-interquartile range as in (B).

Table 3
Comparison of W's latency distributions for payoff bands producing the same medians and SIQRs for two different light intensities (entries in msec).

A. Bright S^D , 150 to 200 msec Band				B. Dim S^D , 150 to 200 msec Band			
Block	N	Median	SIQR	Block	N	Median	SIQR
1*	100	187.4	6.7	1	104	191.9	25.7
2*	100	187.4	6.7	2	119	192.1	26.1
3	100	191.8	7.4	3	103	201.7	27.8
4	100	191.8	7.6	4	104	204.0	21.6
				5	100	198.8	16.9
Total†	400	189.5	7.2	Total†	530	196.9	20.4
C. Dim S^D , 140 to 190 msec Band				D. Bright S^D , 105 to 155 msec Band			
Block	N	Median	SIQR	Block	N	Median	SIQR
1	102	166.0	34.4	1	100	152.6	27.0
2	103	183.2	22.8	2	100	133.0	26.4
3	100	211.5	19.6	3	100	135.0	19.4
				4	100	137.8	18.1
				5	100	148.0	21.0
Total†	306	188.1	26.2	Total†	500	140.6	21.1

*Variable foreperiod; all other blocks were done with fixed foreperiod 1 sec.

†Statistics are from the combined distribution and are not averages of block statistics.

200-msec band, it was necessary to decrease the bright stimulus band to 105 to 155 msec. (Figure 7D). It is interesting that this shift in band location is 45 msec, about the difference found between the estimated minimal RTs to the bright and dim stimuli. The block statistics for the sessions plotted in Figure 7 are given in Table 3.

Monkey W, Comparison of Performance on Low-Variability Bands for Bright and Dim Stimuli

If the minimal RT bands found for the bright and dim stimuli represent approximately equivalent time pressures, the animal should be able to perform at either intensity

in a highly stable manner as long as an appropriate band is used. W was tested within each day on the two intensities with a 140- to 190-msec payoff band for the bright S^D and a 190- to 240-msec band for the dim S^D , in both cases the payoff band estimated to produce the fastest RTs at each intensity. The resulting session histograms are given in Figure 8 and the corresponding block statistics in Table 4. The stability of the data from block to block and between days is impressive. In each case, the animal gave nearly the same latency distribution for a given intensity on the two days, and the difference of about 40 msec between median RTs to the two intensities is replicated on the second day, despite the reversed order

Table 4
Comparison of W's minimal latency band distributions for two different light intensities (entries in msec).

	Bright (0 log) S^D , 140 to 190 msec Band					Dim (-3 log) S^D , 190 to 240 msec Band				
	Block	N	Median	SIQR	% in Band	Block	N	Median	SIQR	% in Band
Day 1										
(overall dif.	1	100	179.8	6.0	96	4	100	217.1	8.6	93
= 40.2 msec)	2*	100	176.0	5.5	93	5*	101	217.1	7.2	89
	3	100	176.6	6.2	96	6	100	219.0	6.8	95
	Total†	300	177.5	6.2	95	Total†	301	217.7	7.3	93
Day 2										
(overall dif.	4	100	174.0	6.4	95	1	100	210.9	7.2	86
= 41.6 msec)	5*	101	175.8	8.8	88	2*	100	217.4	9.2	85
	6	100	172.9	7.6	96	3	100	218.8	7.6	91
	Total†	301	174.1	7.6	93	Total†	300	215.7	9.0	87

*Variable foreperiod; all other blocks were done with fixed foreperiod 1 sec.

†Statistics are from the combined distribution and are not averages of block statistics.

of the intensities. In each case, the performance was similar to that in the fast RT region of the payoff band series for that stimulus intensity. The semi-interquartile ranges for latencies to the dim stimulus are slightly larger than those to the bright stimulus in each case, but the variability remains a constant proportion of the median RT.

DISCUSSION

The data from these experiments are generally in accord with the predictions of the simplified RT model given in the Introduction. It was possible to vary the median response latency through a region in which the animal appeared to shift from responding to S^D to responding to S^W , that is, to time estimating the foreperiod. Although this change in behavior is not apparent from the plots of median latency, it is clearly seen in the semi-interquartile range plots and in the changing appearance of the session latency histograms. The semi-interquartile ranges vary as predicted by the model, remaining low for bands centered above a certain region and then inflating rapidly for median latencies in bands centered below this region as the animal is forced to time estimate the foreperiod. Also in accord with the model, decreasing the intensity of the stimulus shifts the inflection of the semi-interquartile range plot to a slower band and increases the estimated minimal RT. In agreement with this, comparison of performance on a band in the fast RT region for a bright stimulus to performance with the same band limits for a dim stimulus clearly indicates that the latency distribution for the dim stimulus contains a large number of foreperiod estimations, further evidence that the fastest RT possible is different for the two intensities. Finally, the data from blocks done with variable foreperiods confirm the prediction that low-variability latency distributions for bands in or slower than the minimal RT region do not include time estimations from the bar press even when fixed foreperiods are used.

Several factors are important to consider when determining the fast RT region. These factors include band width, foreperiod duration, amount of change in band location, and order of presentation of bands. The 50-msec band width used in the present experiments was somewhat wide for precise control of the

Fig. 8. Response latency histograms for Monkey W from the two days in which bright and dim S^D s were directly compared. The thin-line histograms are for 300 trials with the bright S^D ; the heavy-line histograms, dim S^D . Dashed lines indicate band limits for the two intensities: 140 to 190 msec for the bright S^D ; 190 to 240 msec for the dim S^D . (A) Day 1, bright S^D trials occurred first. (B) Day 2, bright S^D trials occurred last.

location of median latency in or above the fast RT region because the variability of the latency distribution is so low that the animal has some latitude in placing its distribution without greatly changing the number of reinforcements. However, the 50-msec band was almost too narrow for developing and main-

taining a good foreperiod estimation performance, because the possible success rate for this more variable behavior falls so low. If the band were widened to favor foreperiod estimation, it is possible that an animal would switch from responding to S^D to foreperiod estimation at a higher median RT. Band width, of course, interacts with foreperiod duration. Had a foreperiod of greater than 1 sec been used in the present case, time estimation would probably have been so unreinforcing that the animal would have shown response disruption rather than continuing to meet the band. Such disruption obscures the determination of minimal RT from a continuous change in behavior and also has effects on performance that persist over several sessions. Thus, the choice of band width and foreperiod duration have to be so balanced that it is relatively unrewarding for the animal to time estimate the foreperiod when it can still respond to S^D , yet time estimation behavior is sufficiently reinforcing to maintain continuous behavior just below the fast RT region.

The characteristics of the payoff band series used to determine the minimal RT region are also important. As can be seen from Figures 5 and 6, the results of the ascending series, especially the variability plots, look somewhat different than those of the descending series. The apparent minimal RT band is somewhat faster for the ascending series and the semi-interquartile ranges fall more abruptly. The median RT plots give a clue to the animal's behavior, for the animal increased its median response latency somewhat faster than band center was increased in the ascending series. This is emphasized in Figures 6C and 6D, where the animal returned abruptly to its fast RT performance, although this resulted in distributions with medians lying above the upper limit for several of the faster bands. The estimated minimal RT is about the same, however, for both the descending and ascending series, even though the return from foreperiod estimation to responding to S^D occurred at a faster band.

The amount by which the payoff band is shifted as well as the direction of the shift is critical. Large shifts of band position, especially when a limit is crowding a narrow distribution, can result in a sudden large change in reinforcement and consequent response

disruption with the animal failing to meet the band requirements. Fast RT is probably best determined from a gradually descending payoff band series. If a precise estimation of fast RT is desired, repetition of descending and ascending series for a restricted region around the suspected minimal RT should make clear the band or bands at which the animal begins to time estimate at least part of the time, as indicated by increased variability and decreased stability of medians and semi-interquartile ranges between blocs.

The use of variable foreperiods, long considered obligatory to prevent foreperiod estimation, is unnecessary in an RT experiment conducted with narrow payoff bands. The animal appears not to time estimate the foreperiod as long as reacting to the stimulus is still profitable; and when it does begin to use foreperiod estimations, this is reflected in the characteristics of its latency distribution. In fact, variable foreperiods, especially for a relatively untrained animal, can greatly retard and even prevent the development of the fastest RT performance. The response disruption with variable foreperiods and limits below 250 msec referred to by Miller *et al.* (1966), and seen during the training of Monkey S, usually results in the experimenter promptly increasing the limit to prevent development of nuisance behavior patterns, such as making extremely long responses on a large proportion of the trials, which carry over to other sessions and are hard to eliminate. This is not an optimal situation for determining the fastest that an animal can work. It would seem better to control the behavior in such a way that serious disruptions do not occur and to identify the point of interest as some detectable change in a stable response and not as the point at which the animal, for a host of reasons, quits working. The latency distribution can easily be placed anywhere by the use of the payoff band and an appropriate fixed foreperiod; and variable foreperiods, if desired, can easily be reintroduced once the latency distribution has been stabilized in its band, provided this is in or above the fast RT region. Variable foreperiods should not be used as a customary and uninvestigated part of the RT paradigm; rather, experiments are needed to attempt to determine how variable foreperiod complicates the latency distribution.

In addition to investigating a model for RT and developing a technique for training an animal for fast RT performance, these experiments were designed to begin to investigate the significance of feedback control of response latency for use of RT as a measure of the characteristics of sensory systems. It has long been established that RT varies with stimulus intensity (Woodworth and Schlosberg, 1954, p. 19), but the question remains as to how much of this variation, under any given set of circumstances, is due to limits on the processing capabilities of the sensory system or can be considered uniquely characteristic of the sensory system. Examination of the existing data indicates that quite different latency *versus* intensity curves can be produced for the same set of stimulus intensities in the absence of feedback or when different kinds of feedback are employed. The sensory effects cannot be isolated until the bias for speed of response is somehow equated across the different stimulus intensities.

From Stebbins and Miller (1964, p. 311), it can be seen that changing the limit on reinforced latencies from no limit to one of 400 msec greatly changed the shape as well as the ordinate position of an auditory latency *versus* intensity plot. The latencies were decreased overall by imposition of the limit, but those to the weaker stimuli were decreased much more than those to the more intense. Thus, the amount of change in latency between any two stimulus intensities differed both absolutely and relatively under the different limit conditions. The same time limit for all intensities would not seem to be equal pressure for speed if the physiological limit on RT differs with intensity; since the limit would lie much closer to the minimum possible RT for the weak stimuli than for the more intense.

In Figure 9, a similar effect for the visual modality can be seen from an examination, using the same scales, of separately published visual latency *versus* intensity plots for the same monkey before (Stebbins and Miller, 1964, p. 310) and after (Miller and Glickstein, 1967) extensive training was given with upper limits imposed on reinforced response latencies. For the most intense stimulus reported in the Miller and Glickstein study (1967), this monkey had been trained with limits systematically reduced down to 250 msec (Miller *et al.*, 1966). For the weaker stimuli, the mon-

Fig. 9. Comparison of visual latency *versus* intensity data obtained under different experimental conditions. Unfilled dots are medians obtained by Stebbins and Miller (1964) on Monkey F without limits on latency. Filled dots are medians obtained with a 1-sec limit by Miller and Glickstein (1967) on the same monkey after training for fast responding with descending limits (Miller *et al.*, 1966). Horizontal bars are medians for Monkey W on minimal RT bands for two intensities. Each median is bracketed by its twenty-fifth and seventy-fifth percentile points (interquartile range).

key's experience with limits was less extensive and systematic (Miller, personal communication). This training effected a dramatic change in the shape as well as in the ordinate position of the latency *versus* intensity plot for the same stimulus range. Since the testing that produced the later latency *versus* intensity curve was done with a 1-sec limit for all intensities, one would have to assume generalization from the extensive training at the most intense stimulus, if one were to infer a constant bias for speed across all intensities. Obviously, there is ample evidence that the latency *versus* intensity relationship can be qualitatively as well as quantitatively influenced by reinforcement and feedback contingencies and it is not yet certain what set of conditions produces equal bias for speed at all intensities.

Understanding and controlling the factors affecting the animal's bias towards fast responding becomes crucial when RT is con-

sidered as a possible substitute measure for stimulus magnitude scaling. Chocholle (1940) found for experienced human subjects that equal latency contours across auditory frequency exactly coincided with equal loudness contours determined by having the individual subjects match stimuli of different frequencies for equal subjective loudness. The human latency *versus* intensity functions at each frequency from which the equal latency contours were derived were gathered from subjects instructed and trained to go as fast as possible under all conditions. Under these instructions, the latency distributions were compact with standard deviations about 10% of the mean, even for long latency responses to weak stimuli only a few decibels above threshold. Equal subjective intensity matching between two qualitatively different stimuli is so far unfeasible with animals; therefore, Stebbins (1966) attempted to measure indirectly loudness scaling in monkeys by determining equal latency contours. It is important to observe that if some of the latency *versus* intensity curves in Chocholle's experiment had been of different shape, the derived equal latency contours would have also had different shapes and would have no longer coincided with the equal loudness contours. Furthermore, there is no human data indicating that, when the subjects are working under any other instructions than to respond as fast as possible to every stimulus, equal latency and equal loudness contours should coincide. Therefore, since the discussion above indicates that quite different latency *versus* intensity curves for the same stimulus can be produced in the monkey by changes in feedback and training, the validity of Stebbins' attempt would seem to rest on the degree to which conditions in his experiment duplicated the pressures for speed created by verbal instructions and extensive practice in the human experiment.

Stebbins (1966) trained two monkeys on a 1000-Hz, 100-dB (re 0.0002 dynes/cm²) auditory signal with a 1-sec limit on latencies. When the animals were emitting stable response latencies to this stimulus, they were tested for two sessions at each of six frequencies. Within each session the intensity was randomly varied trial to trial among six levels. The resulting latency *versus* intensity curves for the different frequencies show an abrupt inflation of variability for weaker intensities

and in some cases refusal to work consistently at the lowest intensities, although these were well above threshold reported for the same monkey species in Stebbins, Green, and Miller (1966). The fastest latencies achieved for the strongest stimuli were about twice as long as those obtained from Chocholle's human subjects at about the same sensation level. Thus, it is likely that the control over responding to the weak stimuli was poorly established and that the 1-sec limit was not strong time pressure for fast responding to the more intense stimuli. The idea that control for speed was not consistent is also suggested by the fact that the equal latency contours for Stebbins' two monkeys look qualitatively quite different. It is difficult to see how this situation could equate bias for fast responding over the different stimulus intensities and frequencies or how it could be considered a duplication of Chocholle's instructions.

The two sets of equal latency contours for Stebbins' monkey (1966, p. 140) are both very unlike what one might expect from Chocholle's data. The human equal loudness contours, as well as the equal latency contours obtained under Chocholle's conditions, parallel the human audiogram for weak stimuli and progressively flatten as the stimuli become more intense, both loudness and latency changing more slowly with intensity in the mid-frequency range where threshold is low. When audiograms obtained on *M. irus* (Stebbins *et al.*, 1966) are plotted on the same graph as the separately published equal latency contours obtained for the same monkey species (Stebbins, 1966), it can be seen that the longest latency contours for the weak intensities do not parallel the audiogram but bend up very rapidly for frequencies higher than the training frequency of 1000 Hz, although the audiogram indicates that monkey thresholds still remain relatively low at 10 and 20 kHz. Also, the latency contours do not flatten at the higher intensities as much as in the human; in fact, the equal latency contours of one monkey remain approximately the same shape, with a marked depression at 1000 Hz, from weak to strong intensities. This is difficult to explain if these equal latency contours are taken as equal loudness contours, unless the monkey auditory system codes subjective loudness in a very different way from the human. However, considering that the animals received all their

training at 1000 Hz and 100 dB, and were given only 60 trials at each of the other frequency and intensity combinations, it is possible that the unexpected rapid increase of latency at the ends of the frequency range might be interpreted as decreasing generalization of training to stimuli differing from 1000 Hz. Therefore, it is likely that equal latency functions gathered under the conditions of Stebbins' experiment do not correspond to equal loudness contours. It is clear that there are many factors affecting RT in animals and that these must be understood and controlled before it is possible to use response latency to derive scaling functions for animals similar to those that have been obtained from magnitude estimation and cross-frequency matching with humans.

To equate the bias for fast responding for different stimuli, one could always require the animal to go as fast as possible by finding the minimal RT region and the appropriate limits to maintain fast responding under each stimulus condition. In the preliminary experiment on intensity in the present article, this was done at only two intensities (Figure 9). Use of the minimal RT bands appropriate to each intensity established very stable and repeatable distributions, with the animal transferring easily between the two intensity conditions. The technique, as executed here, is time consuming. An experiment designed to establish a set of equal latency contours would be prohibitively long if one were to do a complete payoff band series for each intensity condition, of the extent used to establish the present minimal RT bands for Monkey W. For the design used by Stebbins (1966), for example, this would result in 36 payoff band series, one at each combination of intensity and frequency. However, when W was switched from a minimal RT performance for the bright S^D to one for the dim stimulus, the 50-msec payoff band judged to be appropriate to the latency distribution produced on the first 100 trials with the very broad band was the same as that judged to be the minimal RT band after the subsequent extended descending and ascending series. Also, the initial median RT on this band was only 5 msec longer than that judged to be minimal from the descending series and 15 msec longer than the estimated minimal RT for the ascending series. This 10-msec decrease in minimal RT estimate for

the same band between the descending and ascending series for the dim S^D was reflected in a 10-msec decrease in the minimal RT estimate on the minimal RT band for the bright S^D , so that the difference in minimal RT estimates for the two intensities remained constant at 40 msec. It seems likely that after a minimal RT performance has been established at one intensity, locating it for other intensities will take much less experimental time.

It is anticipated that application of the techniques described here can lead to better understanding and control of the non-sensory influences upon RT performances. Such understanding and control should, in turn, result in more valid and meaningful measurement of sensory influences.

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