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Effects of Carbon Monoxide on Fixed-Consecutive-Number Performance in Rats[1]

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SMITH, M. D., W. H. MERIGAN AND R. W. MCINTIRE. *Effects of carbon monoxide on fixed-consecutive-number performance in rats.* PHARMAC. BIOCHEM. BEHAV. 5(3) 257–262, 1976. – Four rats were trained under a fixed-consecutive-number (FCN) schedule to make sequences of 20 or more consecutive responses on one lever followed by a single response on a second lever. When performance was stable, they were exposed to 200, 400, and 600 parts-per-million (PPM) carbon monoxide (CO) for either 30 or 60 min before and during a 45-min session. Decreases in response rate at CO levels as low as 200 ppm were due to both decreased local response rate and extended pauses. A lowered percentage of reinforcement, due to decreases in response sequence length, was also found at CO levels as low as 200 ppm. This decreased sequence length may reflect effects of CO on response rate, or a disruption of discriminative aspects of FCN schedule performance.

Carbon monoxide Response rate Discrimination schedules of reinforcement

EXPOSURE to carbon monoxide (CO) reduces the response rate of animals trained on schedules of reinforcement. This result has been obtained with several reinforcement schedules, with both food and brain stimulation reinforcement, and in both rats and pigeons [1, 2, 3, 4, 5, 8, 11].

The present study was designed to extend the analysis of CO effects on animal behavior to measures other than response rate. The fixed-consecutive-number (FCN) schedule used in the present study requires that the animal emit more than a specified number of responses on one lever before a single response on a second lever produces reinforcement [9]. This schedule generates rapid sequences of responses on the first lever (runs) whose length is closely related to the required minimum. Thus, it permits an assessment of CO effects on the accuracy of run length, as well as on response rate.

METHOD

Animals

Four 180-day-old naive, male Long-Evans rats were maintained at 80% body weight by postsession feeding, and had free access to water in the home cage.

Apparatus

The experimental chamber was an aluminum box, 24 cm by 21.5 cm by 19 cm high, with a floor of stainless steel rods and a wire mesh ceiling. On one wall of the chamber was a centrally mounted food cup and two retractable levers, one on each side of the food cup. Each lever was 5 cm from the floor and 5 cm from the center of the wall and required 18 g (0.18N) for operation. A yellow house-light was located 3.5 cm directly above each lever. Noyes rat food pellets (45 mg) were used for reinforcement.

The experimental chamber was within a 35 cm by 50 cm by 45 cm high aluminum enclosure. Room air was drawn through this and four other enclosures and exhausted from the building. CO (99.3% purity) was injected through a fine metering valve into the intake stack of the enclosure, and CO concentration within the enclosure was continuously monitored with a Beckman 215 B infrared CO analyzer. The analyzer was calibrated each day using pure nitrogen to set the zero point and a precision mixture of 940 parts per million (ppm) CO in nitrogen to set the gain. Approximately four minutes were required to reach the desired CO concentration within the enclosure or to completely clear the enclosure of CO. The gradient of CO concentration within the enclosure did not exceed 5%.

White noise at 58 dB was always present in the experimental room. All programming, recording, gas delivery and gas monitoring equipment was located in an adjacent room.

Procedure

Training. During training each rat was tested in 2 daily sessions, which were terminated after 120 reinforcements. Initially, all responses on the right lever, lever B, were

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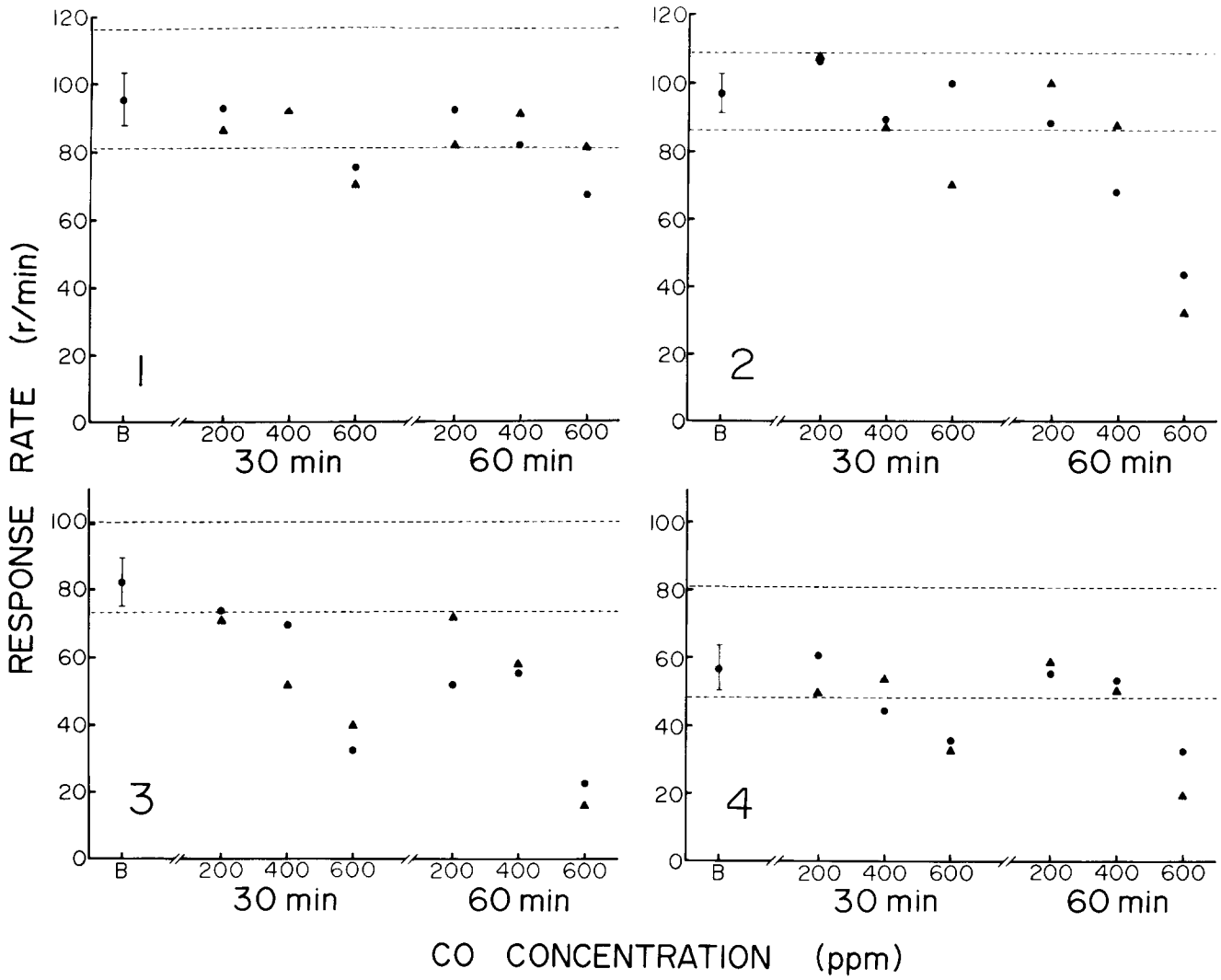

FIG. 1. Response rate on lever A for all animals during exposures to 200, 400, and 600 ppm CO with both 30 and 60 min presessions, and during baseline sessions. The mean ± 1 SD of baseline sessions response rates are shown at B, and the range of baseline sessions is indicated by dashed lines. The first exposure is represented by a circle, and the second exposure by a triangle. The first determination at 400 ppm could not be reported for Rat 1 due to equipment problems.

reinforced. After 100 reinforcements were obtained, the rats were required to precede a response on lever B by one response on the left lever, lever A. The lever A requirement was gradually increased until a minimum of 20 consecutive responses was required before a lever B response was reinforced (FCN 20).

From this point on, sessions were terminated after 45 min and the number of sessions per day was reduced to one, 5 days a week. A brief blackout was introduced before each session, and gradually increased in length to 60 min. During this blackout both levers were retracted and inoperative.

CO probe sessions. When all rats had been exposed to these final conditions for a minimum of 40 daily sessions, a series of CO probe sessions was begun. The duration of CO exposure was either the last 30 min of the blackout and the duration of the session (30-min presession exposure) or the entire 60 min of the blackout and the duration of the session (60-min presession exposure). The sequence of CO probes consisted of two blocks of 6 exposures each. Each block was composed of both 30 and 60 min presession exposures to 200, 400 and 600 ppm. The order of exposure within a block was nonsystematic and different for each rat. CO exposure sessions were always separated by a minimum of five days, including at least 3 non-CO sessions, to allow responding to return to baseline levels.

RESULTS

The response rate on lever A during CO exposure and baseline sessions (all non-CO sessions) is plotted in Fig. 1 for each rat. This figure shows response rates during exposure to 200, 400 and 600 ppm CO, with both 30 and 60 min presessions.

Exposure to CO was considered to have a clear effect on response rate when the response rate under CO was outside of the baseline range of values. All rats showed decreases in response rate under 600 ppm. Exposure to 400 ppm produced decreased response rates in one session for Rats 2 and 4, and in all 4 sessions for Rat 3. Only Rat 3 showed

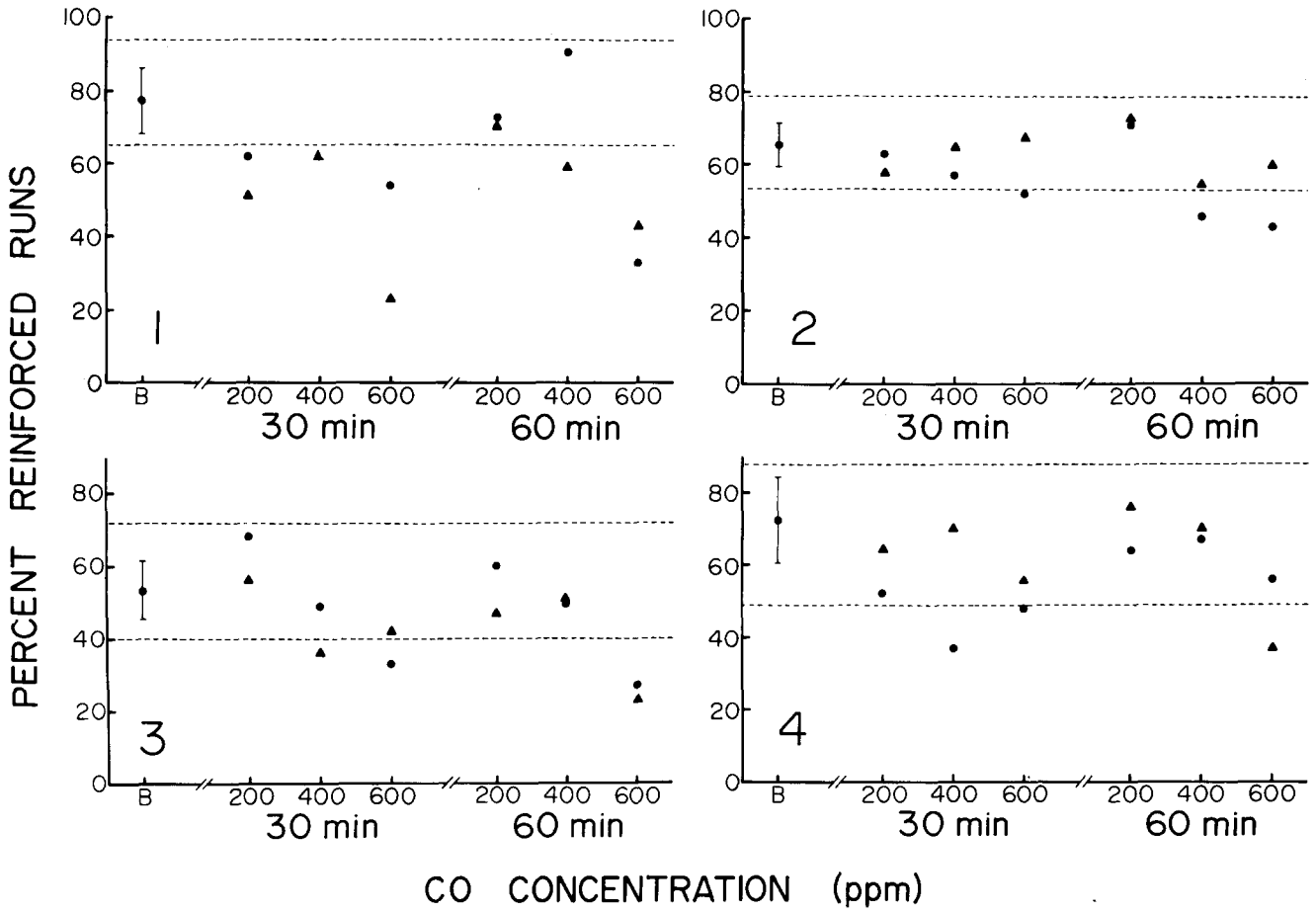

FIG. 2. The percentage of reinforced runs (20 or more consecutive lever A responses followed by lever B response) for all animals during exposures to 200, 400 and 600 ppm CO, with both 30 and 60 min presessions, and during baseline sessions. The mean ± 1 SD for baseline sessions are shown at B, and the range of baseline sessions is indicated by dashed lines. The first exposure is represented by a circle, and the second exposure by a triangle. The first determination at 400 ppm could not be reported for Rat 1 due to equipment problems.

response rate decreases when exposed to 200 ppm CO. The extent of the response rate decrements appeared to be somewhat greater after 60- than after 30-min presession exposure for Rats 2, 3, and 4.

Figure 2 shows the percentage of reinforced runs (20 or more consecutive responses on lever A before a lever B response) for all animals for baseline and CO sessions. Exposure to 600 ppm CO produced decreases out of the baseline range in all sessions for Rat 1, in 3 of 4 sessions for Rat 3, and in 2 of 4 sessions for Rats 2 and 4. Under 400 ppm, Rat 1 showed a decrease in reinforced runs in 2 of 3 sessions, and Rats 2, 3, and 4 in only 1 of 4 sessions. Exposure to 200 ppm produced decreases only in 2 of 4 sessions for Rat 2. There appeared to be no consistent difference in this measure between the effects of 30- and 60-min presession exposure.

Run length is the number of consecutive lever A responses that preceeded a lever B response. Figure 3 shows the relative frequency distribution of run lengths for all animals during the second exposure with a 60-min presession exposure to each CO level (solid line) and for the 2 sessions preceeding each CO exposure (dotted lines). Relative frequency was calculated by dividing the number of runs in each category by the total number of runs. Run lengths to the right of the vertical lines were followed by reinforcement. In baseline sessions, the mode of the distribution of run lengths on lever A was consistently at or above the minimum required for reinforcement. At 600 ppm CO, the modal run lengths of Rats 1, 3 and 4 shifted from values equal to or greater than the minimum required for reinforcement, to values less than the minimum requirement. Such modal shifts to the left occurred in 10 of 16 exposures to 600 ppm. In 3 of the 16 cases at 600 ppm, the distributions shifted to the left, although modal run length was not changed (non-modal shift). At 400 ppm, modal run lengths shifted to values less than the minimum required for reinforcement in 6 of 16 cases. Non-modal shifts to the left occurred at 400 ppm in 4 of 16 cases (e.g. Fig. 3, Rat 1). In 1 case out of 16, there was a modal shift to the left at 200 ppm, and 3 non-modal shifts to the left. Only 2 cases of modal shifts to the right, and a single case of a non-modal shift to the right were seen, all at 200 ppm.

A more detailed picture of responding under this schedule can be seen in the cumulative response records of Fig. 4. Records of Rats 2 and 3 were chosen to illustrate baseline performance and various degrees of disruption under CO which were representative of findings with all rats. In baseline sessions, responding on lever A occurred at

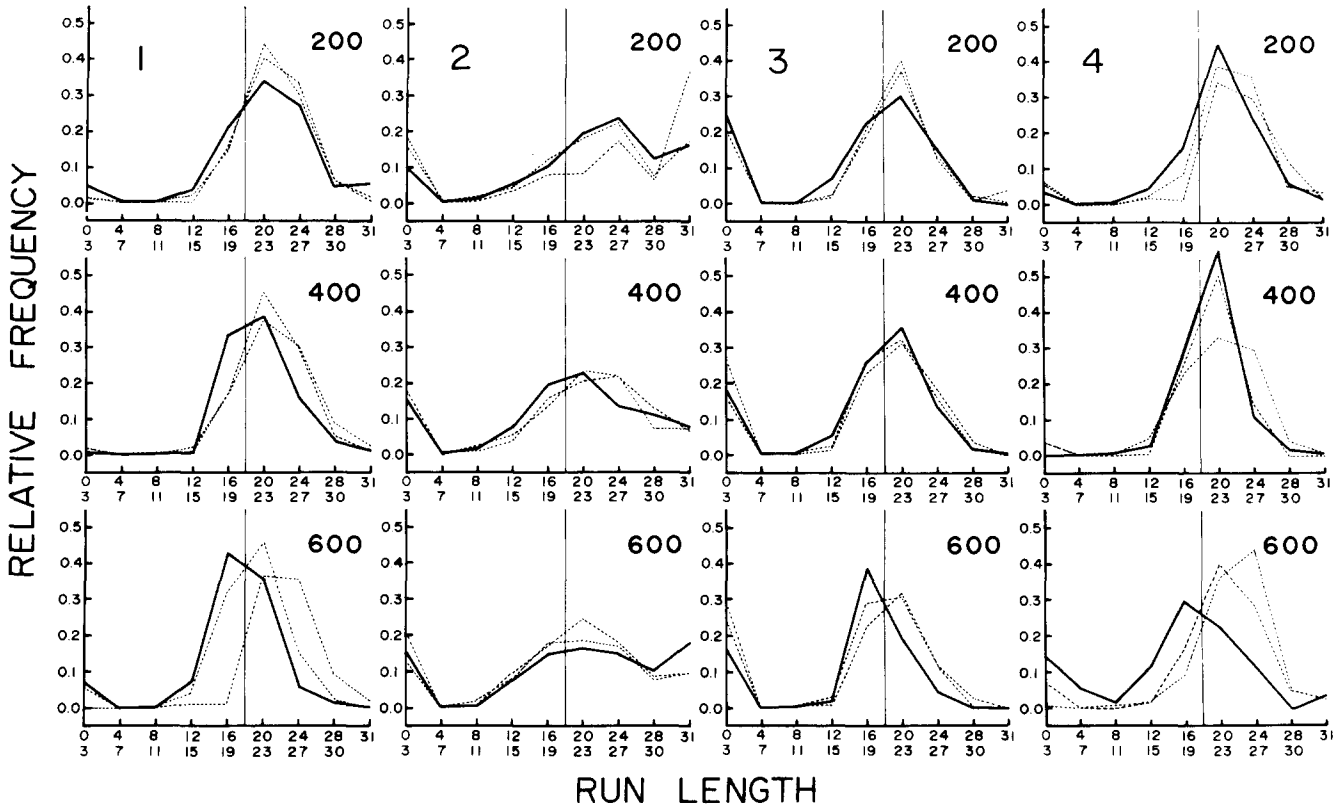

FIG. 3. Relative frequencies of run lengths for all animals during the second exposure to 200, 400 and 600 ppm CO with 60 min presessions (solid lines), and during the two sessions preceeding each CO exposure (dotted lines). Run length was recorded in categories of 3 responses, all runs of more than 30 consecutive responses were recorded in the last category. These categories are represented on the abcissa (e.g. the first category is 0 to 3, the second is 4 to 7, etc.). Relative frequency was calculated by dividing the number of run lengths in each category by the total number of run lengths. Run lengths to the right of the vertical lines were followed by reinforcement.

a high steady rate, and reinforcement density was high throughout the session. Two changes in this pattern of responding were seen consistently during exposure to 400 and 600 ppm CO. The local rate of response (response rate during a run) was decreased in Rats 1, 2, and 4 at 400 ppm and in all rats at 600 ppm. The record of Rat 2 at 400 ppm in Fig. 4 illustrates such a decrease in rate.

The second change seen in the cumulative response records was the appearance of extended pauses or a complete cessation of responding. Such pauses were the major contributors to the reduced response rate under CO seen in Fig. 1, and they were found in all CO exposure sessions in which responding was below the baseline range. In Figure 4, multiple pauses can be seen in the record of Rat 2 at 600 ppm, and a cessation of responding in the record of Rat 3 at 600 ppm. These pauses appeared earlier in sessions with higher CO levels than in sessions with lower CO levels. For Rats 2, 3 and 4, such extended pauses typically followed a period of low or zero rate of reinforcement. Rat 1 continued to respond throughout most CO sessions despite short run lengths and lowered reinforcement density.

DISCUSSION

Carbon monoxide exposure resulted in decreased response rate and a disrupted pattern of responding at values as low as 200 ppm. In 3 rats the CO effects were primarily on response rate, and in the fourth rat primarily on run length. Rats 2 and 3 showed slightly greater decrements in response rate with 60-min than with 30-min presession exposure to CO.

The finding of reduced response rate under CO exposure is similar to results from many previous studies of CO effects on operant behavior [1, 2, 3, 4, 5, 8, 11]. Two types of behavioral changes contributed to this reduction in response rate. The local rate of response was slightly decreased in most CO sessions and the extent of the decrease was related to the concentration of CO. Despite this decreased local rate, run lengths early in the session remained appropriate to the requirement, and reinforcement density remained high. In the latter part of CO sessions short run lengths led to a decrease in reinforcement density, and three of four rats showed extended pauses.

The present findings of reduced local response rate and extended pauses can only be compared to previous studies which reported detailed characteristics of responding under CO. Merigan and McIntire [11] used a progressive ratio schedule which generates high rates of responding similar to those seen on the lever A in the present study. They found decreases in local response rate and extended pauses caused early termination of the session at CO levels as low as 330 ppm. Behavioral effects of CO have also been studied with a differential reinforcement of low rate (DRL) schedule which generates very low rates of responding [2]. Under this schedule, local response rate was unaffected, and the

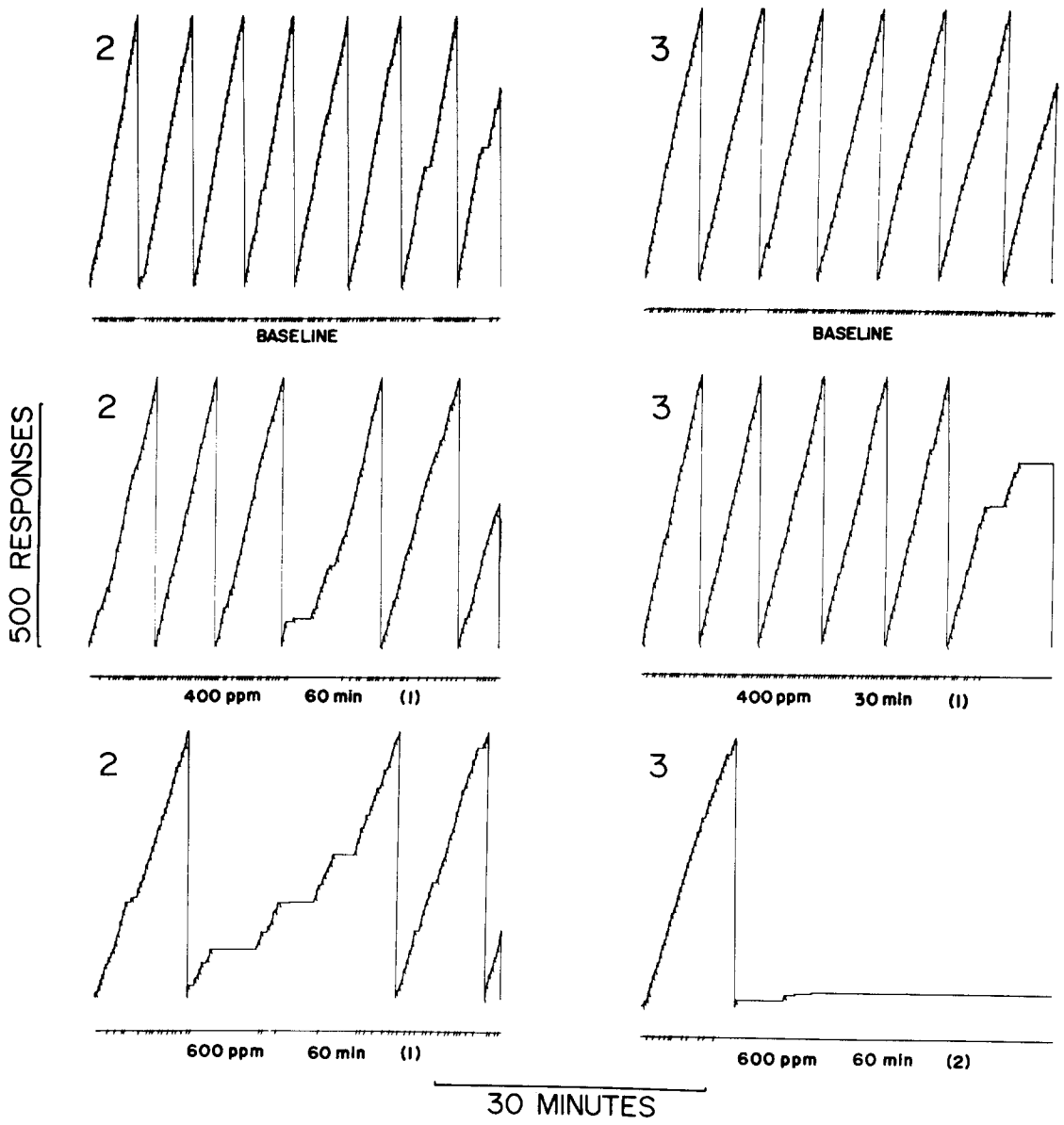

FIG. 4. Representative cumulative response records for Rats 2 and 3 during a baseline session, and during exposures to 400 and 600 ppm CO. Both pens moved to the right with time. The top pen moved upward with each lever A response, and was deflected down with each response on lever B. The base pen was deflected downward with each reinforcement.

major finding was the appearance of extended pauses during CO exposure.

Presession exposure of 60 min was somewhat more effective than a 30 min presession in reducing response rate in the present study. However, run length was not differentially affected by the different periods of exposure. Relative carboxyhemoglobin (COHb) levels for the two lengths of presession can be estimated from measurements of the rate of COHb uptake by Long-Evans rats [11]. With 30 min pre-exposure, the COHb level was approximately 65% of equilibrium at the beginning of the session and over 90% at the end. After 60 min pre-exposure, levels ranged from about 90% of equilibrium at session onset to close to 100% at session end. Thus, mean COHb level was greater after 60-min presession exposure, but the rate of change of COHb was greater after 30-min presession exposure. The greater effect of the longer presession on response rate is consistent with the common assumption that behavioral disruption is related to COHb level and not to the rate of change of COHb level.

The extended pauses seen in the cumulative records of Rats 2, 3, and 4, during CO sessions typically followed a period of short run lengths on lever A and reduced density of reinforcement. The regularity of this pattern suggests that the extended pauses may have been secondary to the reduced reinforcement rate. This also suggests that the relative insensitivity to CO of the reinforced run length measure (see Fig. 2) is due to the rapidity with which pauses follow unreinforced runs. The performance of Rat 1 supports the notion that pausing reduces the impact of CO

on the percentage or reinforced runs. This rat was apparently more resistant to nonreinforcement since it showed no long pauses despite frequent short unreinforced run lengths. Inspection of Figs. 1 and 2 reveals that the response rate of this rat was insensitive to CO while percent reinforced runs were strongly reduced.

Under the FCN schedule, lever B responding is differentially reinforced (differentiated) along the dimension of number of responses on lever A. It has been argued that the differentiation of a response along any dimension necessarily involves a discrimination of a stimulus correlated with that dimension [12]. Under the FCN schedule either number of responses, or time spent responding on lever A could provide such a stimulus. Rilling [13] and LeFever [7] have offered evidence that the organism discriminates number of responses when responding on this schedule and not the passage of time. Thus, FCN schedule performance may be seen as a discrimination of stimuli arising from the organism's own behavior [6], and the present finding of reduced run lengths under CO exposure as a disruption of that discrimination.

On the other hand, the shorter run lengths under CO might be due to direct effects of CO on response rate on one or both levers. A rate increase on lever B would by definition decrease run duration (time to complete a run on lever A) Which might in turn result in a decrease in run length. Previous studies have shown that run duration on FCN schedules is decreased both by drugs [10] and by increases in deprivation [9]. However, run length was found in both of the above studies to be independent of changes in run duration, suggesting that run length changes in FCN schedules are not related in a simple way to response rates on the second lever.

Of course, if run duration remained constant in the present study, decreases in run length might be due simply to the decreased response rate on lever A under CO. A careful inspection of cumulative response records revealed many instances of changes in local response rate with no change in reinforcement density, as well as changes in reinforcement density with no changes in local response rate (see Fig. 4, Rat 2, 400 ppm). Thus, it is unlikely that run length changes were due solely to changes in lever A response rate.

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