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WARMUP IN AVOIDANCE AS A FUNCTION OF TIME SINCE PRIOR TRAINING[1]

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On avoidance procedures, rats and pigeons typically show warmup effects, characterized by improving performance within sessions and loss of the improvement ("warmup decrement") between sessions. Between-session losses were examined by varying the time between periods of avoidance training. In one experiment, rats lived fulltime in conditioning chambers while intermission intervals were varied. In a second experiment, the animals lived in home cages between sessions; timeout intervals were introduced at midsession, producing recurrence of warmup in the second half-session. In both experiments, the warmup decrements increased substantially as the timeout or intersession intervals were increased from zero to 30 minutes. With intervals of 60 or 120 minutes, the decrements approached or exceeded those obtained with intervals of a day or more. When avoidance was interposed between appetitive sessions, the appetitive responding was disrupted, but this seemed unrelated to the warmup or to the proficiency of avoidance. The warmup in avoidance shares characteristics with transient punishment effects, with the Kamin effect, and with habituation phenomena, but it is premature to assume that they reflect common processes.

Key words: warmup, avoidance, suppression, punishment, Kamin effect, lever press, chain pull, rats

When rats are exposed to avoidance training procedures, a "warmup" effect is frequently observed. Day after day, a rat takes more shocks early in the session than it did late in its preceding session, or than it will take later in its current session. Reports of experiments on avoidance often tacitly acknowledge this by discarding data from early parts of experimental sessions (*e.g.*, Clark and Hull, 1966; Neffinger and Gibbon, 1975). Some investigators have discussed the warmup explicitly, as when Weissman (1962) reported that more than 90% of a large sample of rats showed this effect, and when Sidman (1960) and Hoffman (1966) identified it as a prominent feature of performance on avoidance procedures. It has been reported most often in experiments using lever-press responses, but it also occurs with a wheel-turn response (Nakamura and Anderson (1962); Reynierse, Zerbolio, and Denny (1964). Powell and his colleagues have found the warmup to be a feature that distinguishes avoidance in different species, contrasting albino and hooded rats with wood rats, cotton rats, gerbils, and black rats (Powell, 1971, 1972, 1976; Powell and Mantor, 1970; Powell and Peck, 1969). The phenomenon is not limited to rodents, however. Warmup effects have been reported in avoidance experiments with pigeons, using either a key-peck (Foree and LoLordo, 1974; Ferrari, Todorov, and Graeff, 1973) or a treadle-press response (Foree and LoLordo, 1970; Klein and Rilling, 1972, 1974).

For rats and pigeons, warmup effects may occur irrespective of whether warning stimuli are included in the avoidance procedure (Foree and LoLordo, 1970; Hoffman, 1966), although these stimuli have occasionally been seen to affect the degree of warmup, either decreasing it (Ulrich, Holz, and Azrin, 1964) or increasing it (Powell, 1972).

There have been several explicit but largely unsuccessful attempts to eliminate warmup. Increased shock intensities either had no appreciable effects (Powell, 1970), or affected mainly the late-session performances, rather than early-session warmup (Hoffman, Fleshler,

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and Chorny, 1961; Leander, 1973). Supplementary positive reinforcement, contingent on the avoidance response, reduced the warmup but did not eliminate it (Hineline, 1966). David (1973) administered d-amphetamine just before avoidance sessions, and found warmup effects to be still evident, although overall performances were improved. On the other hand, Hoffman *et al.* (1961) succeeded in eliminating the warmup in signalled avoidance by delivering a series of unavoidable shocks, in the absence of the response lever and warning stimulus, just before the daily avoidance session. By comparison, mere presession confinement in the avoidance chambers did not affect warmup.

The rationale for the present experiments stems from the fact that while the warmup is usually identified and described as a within-session change, it is also a change between sessions. With daily sessions a rat's performance during the initial minutes of a session is inferior to the same rat's performance hours earlier, during the final minutes of the preceding session. Spear (1973) labelled this change, from the end of one session to the beginning of the next, the "warmup decrement". These considerations suggest that if one conditioning session immediately followed another, little or no decrement would occur at the start of the second session. If the interval between sessions were systematically increased, the warmup decrement should systematically reappear. The time course of the decrement's reappearance was the main focus of the present experiments. In addition, appetitive behavior was examined before, after, and between avoidance sessions to obtain additional information about between-session changes, for it had previously been observed that avoidance sessions can affect responding in adjacent sessions of appetitive conditioning (Hineline, 1966).

EXPERIMENT I

The rats in this experiment were housed round-the-clock in conditioning chambers to eliminate possible effects of handling and of unspecified cues provided by work routines in the animal colony. Sessions of appetitively reinforced responding occurred before and after each avoidance session, to see whether the appetitive performances would bear some relation to the performance in avoidance. The possibility that these appetitive sessions themselves might affect the recurrence of the warmup was dealt with in a later systematic replication of the intersession functions (Experiment II).

METHOD

Subjects

Four Long-Evans male rats, designated 2-2, 2-3, 2-4, and 10-4, served. They were obtained from Rockland Farms, and were approximately 90 days old at the beginning of experimentation. They were housed in the conditioning chambers, with water continuously available, and were maintained at 80% of their free-feeding weights. Weighing and supplementary feeding with Purina Lab Chow were accomplished daily, several hours after the day's conditioning sessions. The chambers were scoured weekly during the weighing and feeding routine; the grids and manipulanda were checked daily.

Apparatus

The conditioning chamber measured 20.3 cm wide by 23.5 cm long by 19 cm high. The end walls were made of aluminum, the side walls and ceiling were transparent plastic. The floor grids were parallel to the metal walls and measured 4 mm in diameter; they were spaced 1.4 cm apart, center-to-center. A water bottle was mounted with its drinking tube protruding through the left plastic wall, midway between the end walls. The response lever (Lehigh Valley Electronics No. 1352), mounted to the right of center on a metal end wall, was 2.7 cm wide and 0.9 cm thick. The lever was insulated from the wall and protruded 2 cm into the chamber; its top surface was 5 cm above the grid floor, and its force requirement was 0.15 N. A solenoid-operated dipper, centered at floor level on the same end wall, delivered 0.1 cc of a sweet liquid containing, by weight, 15% Sustagen (Mead-Johnson), 0.5% NaCl, 14.5% sucrose, and 70% water. The walls, lever, and grids were wired to deliver brief (0.25 sec) shocks of scrambled polarity and 1.5 mA intensity, controlled by a Foringer constant-current shock generator. A white pilot light was mounted 7 cm above the response lever. As an additional manipulandum, a ball-chain (3 mm diameter) was suspended from a microswitch, hanging through a hole in the ceiling, and reaching to within 7 cm of the grid floor. The chain required a pull of 0.05 N to close the microswitch; the mass of the chain and the switch characteristics were such that a single pull was always recorded as a single response. A relay was mounted on the outside of the metal wall to provide auditory feedback, as specified below.

Each conditioning chamber was enclosed in a sound- and light-resistant chest, which also contained a 10-W houselight and an audio speaker. White noise was supplied continuously to the room that contained the enclosures, and the electromechanical control equipment was located in a separate room. The experiment was monitored with cumulative recorders and with counters that accumulated events over individual sessions. A printing counter recorded sub-totals every 10 min during a session; the sessions were staggered so that the same printer could record data for all animals. Due to printer limitations, intersession intervals could be manipulated for only one animal at a time.

Procedure

Phase I. The following appetitive procedure was designed to produce steady but slow responding throughout each of four daily sessions: after deprivation and magazine training, the response of chain-pulling was established with food reinforcement and then placed on a differential-reinforcement-of-low-rate (DRL) schedule. Each pull of the chain was counted, and produced the click of the microswitch, but only a response more than 4 sec after the preceding response resulted in the louder click of the feedback relay and operation of the dipper. After four 1-hr sessions, a second-order schedule was introduced. As before, each chain-pull that satisfied the 4-sec DRL requirement produced a click from the feedback relay. However, only every Nth click was accompanied by food delivery. Initially N was 2, producing the second-order schedule, FR 2 (DRL 4-sec). After a few sessions, N was increased by increments of one, to a value that resulted in persistent responding throughout the sessions (N = 3 for Rat 10-4; N = 5 for Rat 2-4; N = 6 for Rat 2-3; N = 5 for Rat 2-2).

The scheduling of sessions for Rats 2-2, 2-3, and 2-4 is diagrammed in Part I of Figure 1. Each of these three rats was given four daily 1-hr appetitive sessions, separated by intervals of 2, 4, and 2 hr, in that order. The chamber

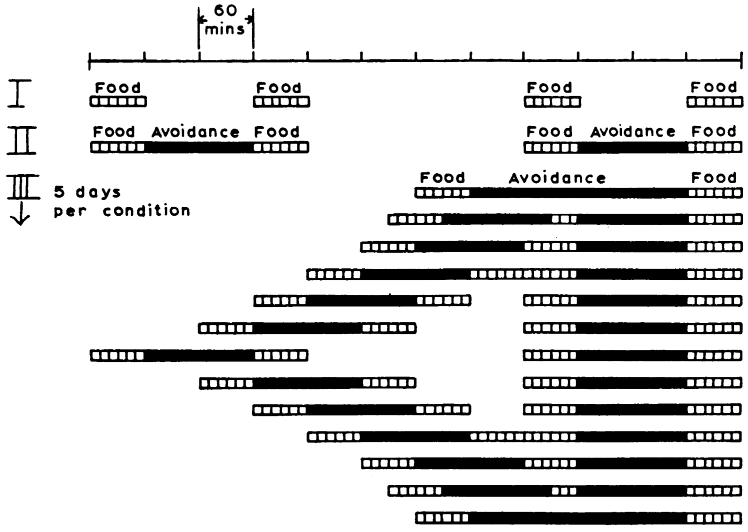


Fig. 1. Diagram of daily sequences of appetitive and avoidance sessions. Part I indicates the establishment of baselines of appetitive responding in each of four daily sessions. Part II indicates the daily sequence for establishing avoidance baselines while examining the effects of avoidance training on appetitive behavior in adjacent sessions. Part III indicates the manipulation of intersession times, where the sequence was changed after every fifth day. The 10-min divisions within food sessions correspond to the sampling of data over successive 10-min periods. Avoidance data were sampled in comparable 10-min periods. Rat 2-4 followed the procedures as shown, whereas the procedures were modified for Rats 2-2, 2-3, and 10-4. See text for details.

was dark except during these sessions, when the houselight provided dim background illumination. Stability of performance was assessed by examining rates of responding for successive 10-min periods in the sessions. Medians were taken for each 10-min period, over blocks of five consecutive days. When there was no systematic change over three successive blocks, avoidance training was begun.

Phase II. As shown in Part II of Figure 1, the avoidance sessions occurred twice each day; they were 2 hr long, filling the 2-hr gaps between food sessions. A rat's daily sessions thus formed two clusters; the two avoidance sessions were 6 hr apart, and each was preceded and followed by a session of appetitive conditioning of the chain-pull response. Avoidance sessions were accompanied by one-per-second flashes of the pilot light, along with the dim background illumination that was present during appetitive sessions. The avoidance response was lever pressing; the procedure was that devised by Sidman (1953). Initially, the shock-shock (SS) interval was 2 sec, with a response-shock (RS) interval of 20 sec. After 55 sessions, the shock-shock interval was increased to 20 sec, and the resulting schedule, SS = RS = 20, remained in effect for the rest of the experiment.

This phase of the experiment provided the opportunity to examine the initial and the steady-state effects of avoidance training on appetitive behavior in adjacent sessions. At the same time, a main purpose of this phase was to produce stable baselines of both appetitive behavior and avoidance, in preparation for manipulating intersession time. Patterns of within-session performance change were assessed by plotting response rates for consecutive 10-min periods within food sessions, and shock rates for consecutive 10-min periods within avoidance sessions. The first animal to show stable patterns of both appetitive responding and avoidance performance for three consecutive blocks of five days (Rat 2-4), was advanced to Phase III, where intersession time was manipulated.

Limitations of the apparatus for data recording required that Rats 2-2 and 2-3 be held in Phase II, even when they had reached stability, while Rat 2-4 progressed through Phase III. During this time, Rat 2-2 was sacrificed due to an ear infection, and was replaced by a younger animal, Rat 10-4. Rat 10-4 was trained on procedures identical to those described above, except that during the first 68 days (28 days in Phase I and the first 40 days of Phase II), the appetitive sessions were only 30 min long, and the second and fourth appetitive sessions of each day were accompanied by a 600-Hz tone instead of by the houselight (reported in Hineline, 1972). Thereafter, appetitive sessions were 60 min long and accompanied by the houselight, as for the other animals.

Phase III. Rats 2-4 and 10-4 served in this phase. The time between avoidance sessions was manipulated by changing the starting time for the first cluster of daily sessions, while the second avoidance session continued to occur at the same time each day. The change occurred every fifth day, providing a five-day block of sessions for each intersession value. The sequence of intersession times for Rat 2-4 is shown in Part III of Figure 1. Starting with an intersession time of zero, there was first an increasing, and then a decreasing series. Figure 1 also shows the relations between appetitive and avoidance sessions. When the time between avoidance sessions was 120 min, the intervening appetitive procedure ran for a continuous 120-min session, instead of the two separate 60-min sessions that occurred at longer intersession values. When the interval between avoidance sessions was less than 120 min, the intervening appetitive session was shortened so as to not overlap with the avoidance sessions.

When Rat 2-4 had completed Phase III, Rat 10-4 was selected for Phase III manipulations because it was the youngest and showed the most distinct warmup effects. The manipulations for 10-4 resembled those portrayed in Part III of Figure 1, except that the sequence of intersession times (in minutes) was: 360, 240, 60, 120, 240, 120, 60, 40, 30, 20, 15, 10, 5, 0, 5, 10, 15, 20, and 30.

RESULTS

Figure 2 presents data for Rats 2-2 and 2-3 during Phases I and II, showing effects of avoidance training on appetitive behavior in sessions that routinely preceded and followed the avoidance sessions. The figure presents for individual animals some effects that have been described with group data in a brief report elsewhere (Hineline, 1972). The appetitive data are included here because they provide

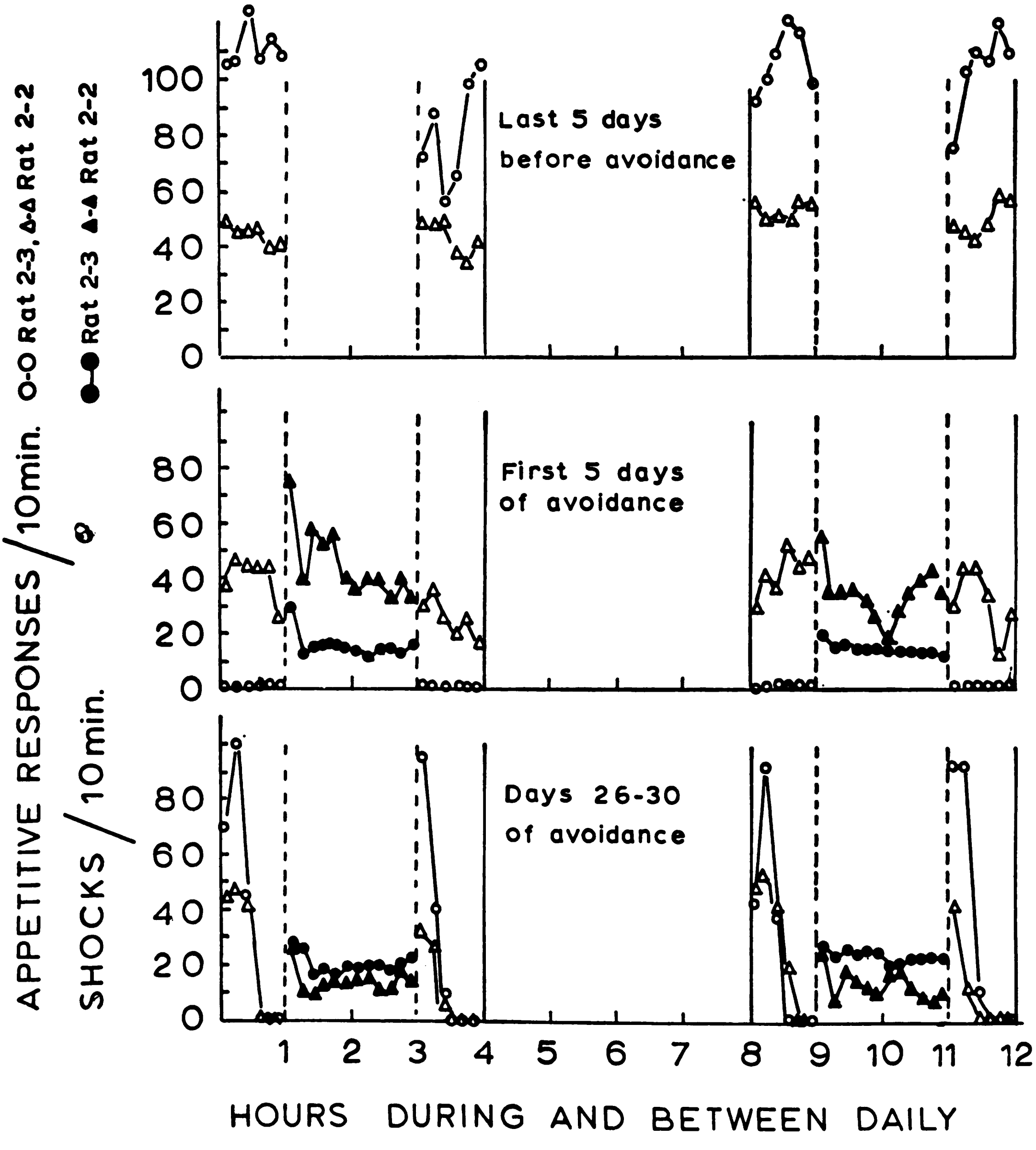


Fig. 2. Within-session performance changes are shown for Rats 2-2 (triangular data points) and 2-3 (circular data points), during the five days of 60-min appetitive sessions that immediately preceded avoidance conditioning, during the first five days with avoidance conditioning, and during Days 26 to 30 with avoidance conditioning. Medians were taken for each successive 10-min period of the daily sessions. Thus, the open symbols indicate appetitive responses per 10 min; the filled symbols indicate shocks received per 10 min during the avoidance sessions. The vertical dashed lines mark boundaries between food sessions and avoidance sessions; vertical solid lines mark boundaries between conditioning sessions of whatever kind and intersession intervals during which the chamber was dark.

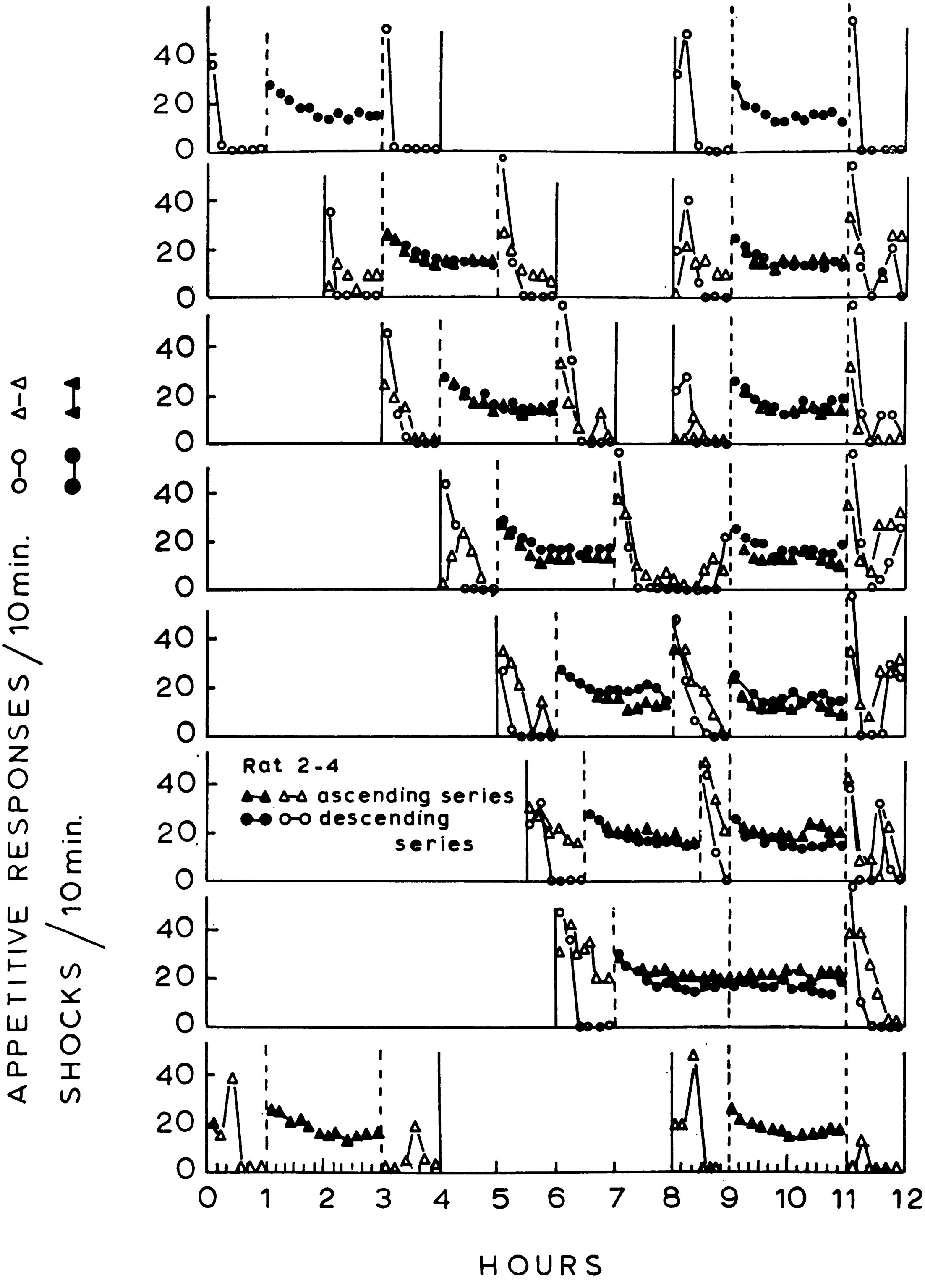
part of the context of the intersession manipulations, which have not been described before, and because the initial effects followed two distinct patterns that were not evident in the group data. Response rates during successive 10-min periods of the appetitive sessions are indicated by the open symbols, with shock rates during avoidance indicated by filled symbols. The top panel of the figure shows responding before the first exposure to avoidance training. Clearly, the rates of chain-pull responding did not vary systematically within the daily 1-hr sessions of food reinforcement. The center panel of the figure shows that when avoidance conditioning was first introduced, the effects were substantial but not consistent across animals. The appetitive response rates of Rat 2-3, which had been the highest, now dropped to near zero. Rats 2-2 and 2-4, with lower appetitive response rates also showed substantial reductions, but as shown for Rat 2-2, these rates did not drop so drastically as those of 2-3. However, with continued exposure to the avoidance procedure, a common pattern of appetitive responding was obtained for all four animals on this procedure, including Rat 10-4, which had previously received shorter sessions with differing stimuli (Hineline, 1972). As shown in the bottom panel of Figure 2, appetitive response rates were substantial early in each 1-hr session and decreased to near zero during the final 30 min. There were occasional departures from this pattern when low early-session rates were followed by a mid-session peak or, less often, a late-session rise.

The avoidance performances, shown by the plots of shock rates within the avoidance sessions, revealed warmup effects, with highest rates at the beginnings of sessions. This characteristic was more pronounced for Rats 2-2 and 2-4 than for 2-3, but was present in all animals.

To provide an overview of Phase III and to illustrate some features of the warmup, Figure 3 shows the performances of Rat 2-4 as the time between avoidance sessions was varied. As in Figure 2, the open symbols indicate appetitive responding during successive 10-min periods preceding and following the avoidance sessions, and the filled symbols indicate shocks in successive 10-min periods during avoidance sessions. The bottom row of the figure corresponds to the final five days of Phase II, where the two daily avoidance sessions were 6 hr apart, each preceded and followed by a food session. Next, as shown by successive ascending rows, the two avoidance sessions were juxtaposed and then gradually moved apart. The data from this series of increasing intersession times are plotted with triangular data points. When a 6-hr separation was reached, the sequence was reversed, to produce a decreasing series of intersession times. The results are plotted with circular data points, with successive intersession times in the series represented by successive graphs as one moves back down the figure. Each plot shows medians taken over five successive days at a given intersession time; the resulting graphs are similar to those that were obtained for individual days.

The shock rates plotted in Figure 3 indicate a consistent pattern of avoidance for Rat 2-4, showing that the warmup can be a gradual change in performance, rather than the abrupt change from nonavoidance to avoidance that is more easily identified in cumulative records. Day after day, this rat systematically improved over the first hour, gradually approaching the late-session performance level. When the two avoidance sessions were juxtaposed, there was no warmup apparent in the second session. However, when the two avoidance sessions were as much as 30 min apart, performance consistently decreased at the beginning of the second session. The varying intersession time was accompanied by greater variation in the patterns of appetitive responding than had been observed with extended exposure to constant intersession intervals. However, the changes in appetitive behavior were appar-

Fig. 3. Median response rates within appetitive sessions, and median shock rates within avoidance sessions, for successive 10-min periods of these sessions as the intersession times were manipulated for Rat 2-4. The bottom panel indicates the initial training conditions, with two daily 2-hr avoidance sessions separated by 6 hr, each preceded and followed by a 1-hr appetitive session. Vertical dashed lines indicate transitions from avoidance to food, or from food to avoidance sessions. Vertical solid lines mark the transitions from blackout (where all lights were off and neither schedule was in effect) to food or from food to blackout. Open symbols indicate median appetitive responses per 10 min, based on the five days at a given intersession interval. Filled symbols indicate shocks per 10 min, also based on five-day samples. Triangular symbols represent data from initial baseline sessions (intersession interval of 6 hr), and from an increasing series in which the time between avoidance sessions was increased every five days, from 0 to 0.5, 1, 2, 3, 4, and 6 hr. These are shown in ascending panels in the figure. The circular symbols represent comparable data from a descending series using the same set of values, and again changed every five days. When the avoidance sessions were less than 120 min apart, the appetitive sessions were shortened accordingly, to form a continuous appetitive session between the avoidance sessions.


APPETITIVE RESPONSES / 10min. ○-○ △-△
SHOCKS / 10min. ●-● ▲-▲
Rat 2-4
▲-▲ △-△ ascending series
●-● ○-○ descending series
0
20
40
0 1 2 3 4 5 6 7 8 9 10 11 12
HOURS

ently unrelated to changes in avoidance. An examination of day-to-day variations revealed no strong or consistent correlation between response rate in the last 10 min of an appetitive session and the shock rate in the 10 min of avoidance that immediately followed. Similarly, there was no strong correlation between shock rate in the last 10 min of an avoidance session and the response rate in the 10 min of appetitive conditioning that immediately followed it.

Rat 10-4 was exposed to a series of weekly changes of intersession time covering the same range as for Rat 2-4. Although the duration of warmup was much briefer than that of Rat 2-4, the appetitive effects were similar to those already shown, so detailed plots of 10-min samples are not included here. What differences there were in the warmup effects are assessed below with derived measures.

To describe changes in the warmup as a function of some variable, one or more indices of the degree of warmup are needed. Previous reports (*e.g.*, Leander, 1973; Powell, 1970) used the per cent of total shocks that occur early in sessions. However, this percentage is affected by session length and especially by changes in asymptotic performance, as well as by warmup. Two other indices are presented here: one based on the magnitude of performance change within experimental sessions and the other on the duration over which the change occurred. These indices equal zero when there is no warmup and are relatively unaffected by differing late-session levels of performance.

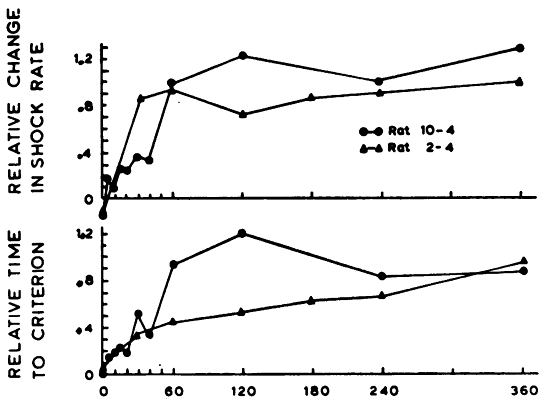


Fig. 4. Two measures of relative degree of warmup as a function of time between avoidance sessions. Circular symbols show data for Rat 10-4; triangles show data for Rat 2-4. The data points represent medians taken over all sessions at a given intersession value, except the occasional five-day blocks that included apparatus failures. The upper graph is based directly on changes in shock rate, showing between-session changes ("warmup decrement") as a proportion of within-session change. If the first 10 min of the first and second sessions of the day are labelled (a) and (c) respectively, and the last 10 min of the first session is labelled (b), then the "relative change in shock rate" is given by c-b/a-b. The lower graph is based on measurements of time from the start of sessions until the beginning of the first 42-sec shock-free interval. This measure for the second session of the day was divided by the comparable value for the first of the day, to obtain the index, "relative time to criterion".

Duration of warmup for Rats 2-4 and 10-4 was assessed by recording the elapsed time from the beginning of a session until a 42-sec shock-free interval occurred. The 42-sec interval was then subtracted, leaving the elapsed time to the beginning of the interval. Since the shock-shock and response-shock intervals were both 20 sec, a 42-sec shock-free interval could not occur without at least two well-placed responses, so shock-elicited bursts of responding could not result in the criterion being met. The duration measure for the second session was expressed as a proportion of the duration measure for the first session of the day. This proportion, indexing relative duration of warmup, is plotted for each intersession in the lower panel of Figure 4.[2]

For both animals, this measure indicated no recurrence of warmup if the second session immediately followed the first session. Substantial second-session warmup was seen when the intersession interval was as long as 30 min. Rat 10-4 was exposed to several smaller intersession values and showed a systematic increase up to this point. Beyond 30 min, the two animals differed somewhat. Rat 10-4 showed virtually complete recovery of the warmup with intersession intervals of 60 min or more, while Rat 2-4 showed a more gradual change from intersession intervals of 30 to 360 min. It should be noted that the absolute durations of warmup differed substantially for the two animals. Pooling the absolute time to criterion in the first session of each day over all sessions contributing to Figure 4, the mean value for Rat 10-4 was 7.9 min, while that for Rat 2-4 was 40.2 min.

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[2] The absolute values used for computing all relative indices presented in this report will be supplied by the author on request.

To obtain the second index of warmup, based on magnitude of performance change, the reference point was the shock rate during the final 10 min of the first session for each day. This value was subtracted from early-session shock rates of both sessions, with the value for the second session then expressed as a proportion of that for the first session. Thus, the between-session change ("warmup decrement") is expressed as a proportion of the immediately preceding within-session change.

This proportion is the index plotted in the upper panel of Figure 3. Again, substantial increase in warmup was indicated over the first 30 min of intersession time. However, with this measure, both animals reached full recovery of warmup (or full decrement in performance) with an intersession time of 60 min.

EXPERIMENT II

Housing animals full-time in experimental chambers is an inefficient use of equipment and while the inefficiency can be justified for the study of intersession effects, an alternative, more efficient method is worth seeking. Hence, an alternative method was attempted here: housing animals in home cages between avoidance sessions. All rats were tested daily in a single conditioning chamber. Once stable avoidance with reliable warmup had been established, timeout periods were introduced midway in each avoidance session. The duration of these periods was manipulated in a way comparable to the manipulation of intersession intervals in Experiment I. Besides testing a more efficient procedure, this systematic replication (Sidman, 1960) permitted examination of the recovery-of-warmup function with no appetitive conditioning during the intervals between periods of avoidance conditioning.

METHOD

Subjects

Three Long-Evans male rats, designated 8-1, 8-3, and 8-4, were housed in individual home cages, with free access to food (Purina Lab Chow) and water, except during experimental sessions.

Apparatus

The conditioning chamber was of the same dimensions of those used in Experiment I, differing only in that the response chain mounted in the ceiling and the water bottle were removed, and the dipper was not used. The enclosure and other equipment were also comparable to Experiment I. The numbers of avoidance responses and shocks were printed out every 10 min during each session.

Procedure

Avoidance sessions were 100 min long, and were accompanied by the lighted houselight. Each animal was tested five days per week, Monday through Friday. The procedure, with avoidance contingent on the lever-press response, was similar to that of Experiment I, except that during initial training the SS interval was 10 sec instead of 2 sec. As before, the RS interval was 20 sec. After persistent responding was established, with the cumulative records showing occasional shock-free intervals of a minute or more, the SS interval was changed to 20 sec. The resulting schedule, SS = RS = 20, was in effect for the remainder of the experiment. Stability of performance was assessed as in Experiment I, using plots of shocks per 10 min and responses per 10 min, pooled over blocks of five sessions. When these plots of within-session change were stable over three successive weeks, the main manipulation was begun. Timeout periods were introduced at midsession, during which the chamber was dark and the avoidance apparatus inactive. The timeout period thus divided the avoidance sessions into two 50-min sub-sessions. The duration of timeout was changed every five days, first through a sequence ranging from 0 to 240 min and then back to zero for all animals, using the following intervals: 0, 15, 30, 60, 90, 120, and 240 min. Then, each animal received a shorter sequence that included additional intervals between zero and 15 min. Each animal received two exposures to nearly all durations of timeout, with additional exposures to some values.

RESULTS

Figures 5 and 6 illustrate the patterns of within-session shock rate for Rats 8-3 and 8-4 as the duration of midsession timeout was varied. Performances of Rat 8-1 closely resembled those of 8-4 and are not included here. As in Figure 3, these figures indicate warmup by high shock rate at the beginning of a conditioning period, with decreasing shock rate during successive periods of continuous con-

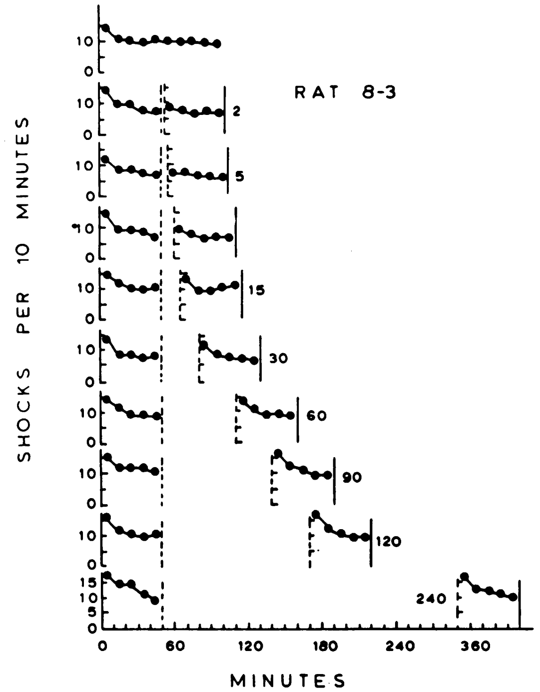

Fig. 5. Shock rates for successive 10-min periods of avoidance sessions for Rat 8-3, as the duration of midsession timeout was varied. Each data point indicates performance during a particular 10-min portion of sessions with a given duration of timeout. Medians were taken over the five consecutive sessions of exposure to a given timeout duration; then means were taken, representing the medians for all exposures to a given value. The abscissa includes duration of timeout as well as time within sessions.

ditioning. Indeed, with continuous 100-min sessions, the highest shock rate always occurred in the first 10 min, as shown in the top plot of each figure. For Rat 8-3, most of the change in performance occurred early in the session, whereas for Rat 8-4 (and 8-1, which is not shown) the shock rate decreased through more of the session. For all animals, insertion of a midsession timeout resulted in a reliable warmup effect in the second half. For Rats 8-4 and 8-1, this was evident with timeout durations as short as 2 min, whereas for Rat 8-3 the posttimeout warmup did not reliably occur at timeout durations under 10 min. At larger timeout durations, the warmup was consistently large in all animals, even to the extent that the range of shock rates within each of two widely separated half-sessions was greater than the range within a continuous 100-min session. In addition, Rats 8-1 and 8-4 often showed greater warmup in the second half than in the first half of the session, as is evident in Figure 7, which presents derived measures of the warmup.

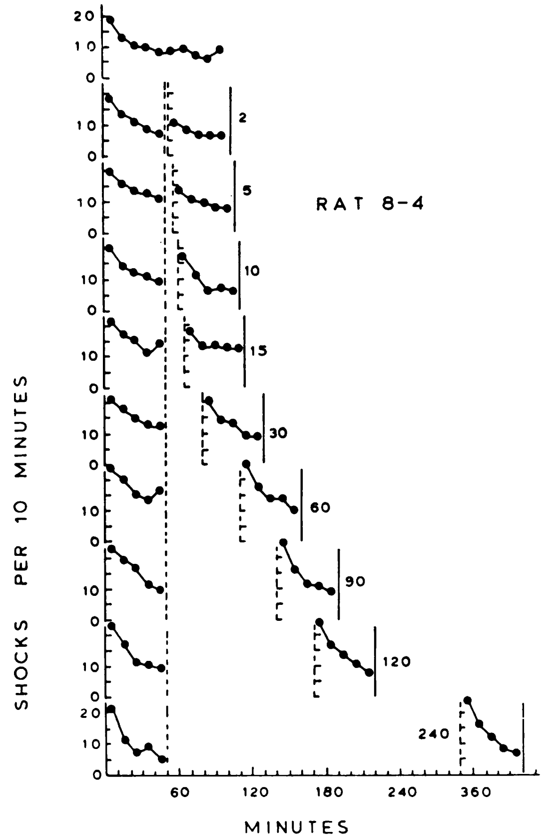

Fig. 6. Shock rates for successive 10-min periods of avoidance sessions for Rat 8-4, as the duration of midsession timeout was varied. Each data point indicates performance during a particular 10-min portion of sessions with a given duration of timeout. Method of computation was the same as that for Figure 5. The abscissa includes duration of timeout as well as time within sessions.

The top and bottom panels of Figure 7 are comparable to the top and bottom panels of Figure 4, which presented results from Experiment I. In Figure 7, the abscissa scale is changed to accommodate a smaller range of time values, representing timeout durations instead of intersession intervals. As in Figure 4, the ordinate of the top panel of Figure 7 is based on changes in shock rate; the decrement in performance over the timeout is expressed as a proportion of the improvement in performance that had occurred during the half-session just preceding the timeout. A measure of relative duration of warmup is shown on the ordinate of the bottom panel;

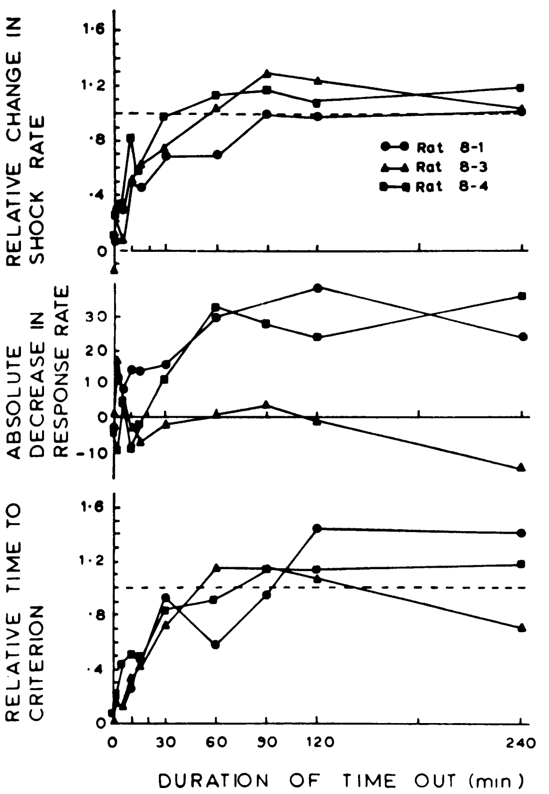

Fig. 7. Three measures of warmup in the second half of an avoidance session, as a function of the duration of the midsession timeout that divided sessions into two equal halves. The top graph is based directly on changes in shock rate ("relative change in shock-rate"), as in Figure 4. The second graph shows the difference between response rates immediately before and immediately after the timeout, with the latter subtracted from the former. The bottom graph is based on measurements of time from the onset of a half-session until the beginning of the first 42-sec shock-free interval in each half-session. The median time to 42-sec criterion in the second half-session was divided by the comparable value for the first half-session. Each data point represents all sessions at a given duration of timeout. Medians were taken over each group of five consecutive sessions at a given timeout duration; then, means were used to pool the medians of the multiple five-day exposures to each value. The dashed lines identify the index value of 1.0, which would be obtained if there were no difference between warmup effects in the two half-sessions.

it was computed exactly as for Figure 4. The center panel of Figure 7 is based on response rates, which had not been printed out in Experiment I.

As in Experiment I, substantial recovery of warmup occurred with intervals as short as 30 min. The top panel of Figure 7 shows further, that for Rats 8-4, 8-3, and 8-1, the index based on shock rates reached 1.0 at intervals of 30, 60, and 90 min, respectively. For Rat 8-4 at all timeout durations of 60 min or greater, and for Rat 8-3 at the timeout durations of 90 and 120 min, the shock-rate index exceeded 1.0, *i.e.*, shock rates were higher immediately after the timeout than at the beginning of the session. These "overshoot" effects were reliable for the animals in which they occurred: the overshoot was indicated by the median measures for every block of five exposures to the intervals specified above, including those blocks that were separated by exposures to other intervals that did not produce the overshoot.[3]

The relative duration of warmup (bottom panel of Figure 7) also increased systematically with increasing timeout intervals between 0 and 30 min. At intervals exceeding 30 min, there was greater variability among animals. The index exceeded 1.0 at several values for each of the three rats, but this evidence for "overshoot" was weaker than that from shock-based measures, for there was greater variability in the duration measures.

While all three animals showed substantial within-session changes in response rates, these were often unsystematic and were inconsistent across animals. The response-based measure included in the center panel of Figure 7, of several that were examined, was the measure that gave most orderly results; it is the absolute difference between response rates just

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[3] While one cannot use statistics based on multiple repeated measures from two subjects to infer the likelihood of other subjects behaving similarly, one can use such measures to assess the likelihood that these two subjects would behave in the same way if exposure to the procedures was continued (actual continuation was not feasible within the time constraints on this study). A nonparametric test, the Wilcoxon matched-pairs signed-ranks test (two-tailed), was employed for this latter purpose. The shock rates at the beginnings of the two half-sessions provided a matched-pair of observations for each day's session. Using the difference scores for individual days as independent observations, the reliability of the overshoot effects shown in the top panel of Figure 6 for Rats 8-4 and 8-3 were assessed. For Rat 8-4, the overshoot was statistically significant at timeout values of 90 and 120 min (0.05 and 0.01 levels, respectively). With only five sessions of exposure to the timeout of 240 min, statistical inference could not be used, but the overshoot occurred in four of the five sessions. Pooling the data for all timeout values of 60 min or greater, the level of statistical significance exceeded 0.001. For Rat 8-3 the overshoot at 90 and at 120 min was statistically significant at the 0.05 level.

before and just after timeout. While this measure gave great variability with timeout values below 30 min, it showed systematic increases for two of the three rats at longer intervals. The third animal, Rat 8-3, showed no consistent differences between response rates before and after timeout, even though the rat's responding produced the orderly changes in shock rate that are portrayed in the top and bottom panels of Figure 7.

GENERAL DISCUSSION

When avoidance training was resumed after brief interruptions, warmup effects were evident after interruptions as short as 2 or 5 min. With longer intervals of interruption, the effects were greater, both in terms of the degree of decrement in performance, and in terms of duration of warmup when training resumed. That is, the shock rate just after a 30-min interruption was substantially higher than that just before the interruption, and shock rates after interruptions of 60 or 120 min were as high or higher than at the beginning of the first avoidance period of the day. The duration of the warmup effect after a 30-min interruption was at least half as long, and after 60 or 120 min it reached or exceeded the duration of warmup earlier in the day. In most respects, the warmup effects reappeared to similar degrees, whether the reappearance was produced by a midsession timeout period for an animal that was in the conditioning chamber for only a few hours per day, or whether it was produced by an intersession interval for an animal that lived full-time in the conditioning chamber.

Compared to the other subjects, Rat 2-4 showed a slower increase in relative duration of warmup as a function of interruption time. This difference may be related to the fact that this rat had the longest absolute duration of warmup, for the rat with smallest absolute duration of warmup (8-3) showed the most rapid reappearance of warmup with increasing interruption time. The remaining three animals' data do not support a relationship between absolute duration of warmup and speed of its recovery, but this may be because their absolute durations of warmup were all within a fairly narrow range.

When avoidance sessions were introduced adjacent to sessions of food reinforcement, responding decreased late in the food sessions. This decrease is suggestive of the phenomenon of conditioned suppression (Estes and Skinner, 1941), commonly studied with stimuli of a few minutes' duration that terminate with brief inevitable shocks. The present results differ from the usual demonstrations of conditioned suppression in that the effect occurred on an expanded time scale; the inevitable events were entire avoidance sessions instead of individual shocks. Two other differences are also relevant to whether the two phenomena are related. First, in the usual conditioned suppression effect, response rates decrease in the presence of stimuli that precede shock, but not after the shock has passed. In the present case, decreases in food-reinforced responding occurred both in the food sessions that preceded and that followed avoidance sessions. However, in the usual paradigm for producing conditioned suppression, the aversive stimulus is followed by an "inter-stimulus interval" during which the preshock stimulus is absent. In the present case, the stimulus situation immediately after the avoidance session was, except with respect to time, identical to the stimulus situation that routinely preceded the avoidance situation. Hence, the similarity of patterns of responding in the food sessions both before and after the avoidance sessions probably reveals a generalization between the two kinds of food sessions. Supporting this interpretation is the finding (Hineline, 1972) that when differing stimuli accompanied the two kinds of food sessions, there was less suppression in the food sessions that followed avoidance sessions. The second main difference between the present results and the usual demonstrations of conditioned suppression was that the present decreases in appetitive responding resulted in substantial reductions in frequency of reinforcement. Conditioned suppression is not usually so severe as to reduce the rate of reinforcement (Geller, 1960; Lyon, 1963; Lyon and Felton, 1966). In relation to this, it should be noted that the present effects are not peculiar to the DRL schedules used in the present experiment; similar effects were observed in preliminary work, using fixed-interval and variable-interval schedules (Hineline, 1966). It is not surprising that whole sessions of aversive conditioning should have greater suppressive effects on appetitive responding than do individual shocks.

Effects of food sessions on avoidance cannot be completely assessed, since the food sessions were never deleted in Experiment I. However, it is clear that routinely preparing the animals with appetitive conditioning before avoidance sessions did not eliminate the warmup in avoidance. In addition, warmup was unaffected by the onsets and offsets of interposed appetitive sessions; the measures of warmup showed no discontinuity between intersessions of 120 and 180 min, where there was a change from continuous appetitive conditioning to separate sessions of appetitive conditioning between the daily avoidance sessions. A further indication of independence of the warmup from the appetitive effects is the similarity of results obainted in Experiments I and II.

The present procedures can be described as multiple schedules with components of avoidance, food reinforcement, and extinction in Experiment I, and components of avoidance and extinction in Experiment II. Thus, one might hope to compare these experiments to other experiments that used multiple schedules of avoidance and food or extinction. However, the existing reports of such experiments do not permit meaningful comparison. Herrnstein and Brady (1958) used a multiple schedule involving components of food reinforcement, avoidance, and extinction, but their schedule components were too brief to allow analysis of warmup effects. In experiments studying multiple schedules of avoidance and extinction (Appel, 1960; Emurian and Weiss, 1972), as well as in those with differing avoidance schedules in each component (Wertheim, 1965*a;* deVilliers, 1972, 1974) the components were again relatively brief. In addition, all of these investigators except Herrnstein and Brady, excluded the data from the first hour (or more) of each session, specifically to eliminate warmup effects from consideration.

The present procedure of interrupting avoidance training suggests that the present results may be related to the "vacation effect" first reported by Clay-Findley (1971). She found that after rats were trained to stable avoidance performance, an interruption in training (from one to six days of "vacation") resulted in substantially improved performance when training was resumed; the greatest facilitative effects were obtained with vacations of four and six days. However, her data presentation used response rates and shock rates based on entire sessions, so one cannot determine whether warmup effects were affected in that experiment. Manning, Jackson, and McDonough (1974) carried out a set of manipulations similar to those of Clay-Findley, using vacation lengths of 19, 15, and 7 days, and found improved performances when training was resumed. However, they did examine warmup effects by means of shock rates in successive 10-min periods, as in the present experiments, and found that the postvacation shock rates were lower over the entire sessions. The long-duration vacations did not selectively affect the warmup, as did the shorter interruptions of training used in the present experiment.

Most attempts to interpret the warmup have attributed the within-session improvements in performance to increases in some underlying motivational/emotional state that is said to mediate avoidance (Anderson and Nakamura, 1964; Dinsmoor, 1962; Hoffman, Fleshler, and Chorny, 1961; Nakamura and Anderson, 1962; Powell, 1971, 1972). However, these interpretations have been offered only with terms of vague plausibility, and hence are difficult to assess. If an explanation in terms of motivational concepts is to be made viable, it must be spelled out in detail as it applies to warmup in free-operant avoidance, as well as in discrete-trial avoidance. It must also account for characteristics of intersession change, such as those delineated in the present experiments. Since I have not found these motivational explanations convincing (Hineline, 1976), I shall not attempt to spell one out here.

An alternative way to interpret the warmup is to compare it with other phenomena that have similar characteristics. Recovery from punishment, the Kamin effect, and habituation will be considered below: other authors have suggested or proposed that two of these phenomena are related to warmup effects. The third is suggested here for the first time.

1. Several investigators have reported that when positively reinforced responses produce shock of an intensity sufficient partially to suppress but not to eliminate responding, the greatest suppression occurs at the beginnings of sessions. Azrin, Holz, and Hake (1963) and Hake, Azrin, and Oxford (1967) referred to such recovery from punishment as a warmup effect, noting that it, like the warmup in avoidance, was a within-session recovery of per-

formance. The recovery from punishment has been observed most frequently in pigeons (Azrin *et al.,* 1963; Azrin, 1959, 1960), but also in squirrel monkeys (Hake *et al.,* 1967) and rats (Appel and Peterson, 1965). Using pigeons, Azrin (1960) found that when a 20-min timeout was imposed part way through a 60-min punishment session, there was a renewed suppression after the timeout period; the suppression lasted for about a fourth as long as at the beginning of the session. This manipulation resembles the manipulations of warmup in the present Experiment II, and the resulting recovery from punishment was of the same order of magnitude as the recovery of warmup with a 20-min timeout from avoidance shown here. However, comparison of timeout effects with the two phenomena would best be done within a single species; either pigeons or rats would be appropriate.

2. Spear (1973) and Spear, Gordon, and Martin (1973) suggested that warmup effects in avoidance may be based on mechanisms very similar to those that underlie the Kamin effect, which is observed with discrete-trial shuttle avoidance procedures. Kamin (1957) found that when conditioning is interrupted early in acquisition, and then continued after varying periods of time, the resumed performance is less proficient after interruption of 1 hr than after no interruption or after an interruption of 24 hr. In a further analysis, Kamin (1963) found indications that warmup effects contributed to the first part of the effect—the increasing decrement in performance with increasing length of interruption. He attributed the subsequent improvement in performance to another, unspecified factor. Some features of the present results also support a similarity between the Kamin effect and the warmup. First, the time courses of the two phenomena are similar, since in the present experiments the warmup reappeared and was substantially full-blown with intersessions of 1 hr, the point of maximal deficit in Kamin's situation. Also, with interruptions of 30 min, Denny and Ditchman (1962) and Kamin (1957) observed partial deficits roughly comparable to the partial reappearance of warmup after 30-min interruptions in the present experiments. A second similarity is that the response of freezing has been observed to occur frequently during the warmup (Hineline, 1966) and during performance deficits in Kamin's type of situation (Denny and Ditchman, 1962). A third similarity can be suggested only tentatively, since it appeared in only two of five animals in the present experiments. At timeout values ranging from 60 to 120 min, two rats persistently showed greater warmup in the second part of each day's avoidance than at the beginning of the session. Thus, the deficits in performance were greater after intervals of 60 and 120 min than after intervals of 21 or 22 hr (the overnight intervals), a nonmonotonicity that resembles the complete Kamin effect, instead of just the initial half.

Despite these similarities, differences between the Kamin effect and warmup effects advise caution in relating them. First, the Kamin effect is apparently eliminated by overtraining (Anderson, Johnson, Schwendiman, and Dunford, 1966; Bryan and Spear, 1976). In contrast, while there is some evidence of warmup early in avoidance training (Spear, Gordon, and Martin, 1973), the warmup is commonly observed in animals that have, for months of daily sessions, avoided most shocks late in sessions. Second, Anisman and Waller (1971) found that confinement in the test chamber for 5 min before the resumption of avoidance training eliminated the Kamin deficit, while Hoffman, Fleshler, and Chorny (1961) found that time in the chamber did not eliminate the warmup in signalled lever-press avoidance. Third, stimulus-shock pairing is apparently a primary determinant of the Kamin effect (Brush, 1971), whereas this appears to play only a minor part, if any, in experiments on the warmup. It is possible that these differences result from reconcilable differences of procedure, such as differing shock-shock or intertrial intervals. However, pending the isolation of specific bases for major observed differences, the characteristics of one phenomenon should not be used to evaluate an interpretation of the other, as has sometimes been done (Spear, 1973; Spear *et al.,* 1973).

3. Finally, when viewed as disrupted performance, the warmup bears some resemblance to phenomena of habituation. Habituation is usually defined in terms of specific elicited responses, where frequently repeated stimulation results in decreased responding to that stimulation. In the warmup, the habituating responses could be shock-elicited bursts of re-

sponding, freezing, or aggressive responses such as biting. Each of these response patterns could produce a decrement in avoidance performance. Wertheim (1965*b*) reported a preponderance of response bursts during the warmup, and freezing often is displayed by rats in situations where shocks occur, including periods of avoidance warmup (Hineline, 1966). Pear, Moody, and Persinger (1972) showed that some rats bite the lever during avoidance procedures. However, biting may also be directed toward objects other than the lever, competing with the avoidance response. Azrin, Rubin, and Hutchinson (1968) found within-session changes in shock-elicited biting that resemble warmup. When provided with a rubber target during 3.5-hr sessions in which shock was delivered every 30 sec, rats showed the greatest amount of biting during the first 20 min of the session. Hutchinson, Renfrew, and Young (1970) found with squirrel monkeys that habituation or sensitization of biting depend critically on both intensity and frequency of shocks, two variables that could be used to test the relation between biting and the warmup.

Reviews of habituation research provide evidence that habituation and the warmup may be related, but they also indicate that the relationship may be difficult to verify and study. According to Thompson and Spencer (1966), the time course of recovery from habituation (comparable to the timeout and intersession effects in the present experiments) varies widely, and may depend on a great many variables. The recovery rates in the present experiments lie within the range of rates reported by Thompson and Spencer. Ratner (1970) proposed that there are systematic differences between types of response with respect to the time-course of recovery. He asserted that habituation takes the form of systematic disappearance of components of the elicited response, and noted that large individual differences in habituation are often observed between identically treated animals. The latter observation corresponds well with the observation of large individual differences in warmup. However, Ratner's observations point to a difficulty. The avoidance chamber is a relatively unconstrained situation for the study of elicited behavior; Azrin *et al.* (1968) constrained their rats in a closely fitting cylinder to study biting. If different animals show different patterns of competing behaviors and these patterns habituate at differing rates, it may be necessary to observe and record several responses simultaneously for each animal, rather than depending solely on functional similarities based on experiments like the present one. Nevertheless, the warmup merits further systematic study and may be a key to understanding other aspects of avoidance as well.

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