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# THE EFFECT OF DURATION OF REINFORCEMENT ON RUNNING BEHAVIOR AND CONSUMMATORY ACTIVITY IN A RUNWAY

by

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Conditioning theorists have devoted considerable attention to the underlying variables responsible for the effect of "magnitude of reinforcement" on running behavior of rats, namely, faster running for groups of rats receiving larger magnitudes of reinforcement. Hull (1943) suggested that the effect of magnitude of reinforcement is due to the amount of physiological drive reduced and, hence to the nutritive value or to the actual weight of the reinforcer. Hull also assumed that the reinforcing substance served an incentive function. As a result a larger piece of food should lead to better conditioning than a small piece of food. The larger weight of reinforcement would lead to more drive reduction and would affect behavior through the habit strength construct. The appearance of the larger piece of food would have more potency as a secondary reinforcer and would induce a higher secondary drive or a higher level of "incentive motivation" and thus act on behavior by increasing the overall drive level.

In the 1943 version of the theory Hull made use only of the weight of reinforcement, which he built into the quantitative version of his theory, and failed to elaborate on the role of secondary or incentive motivation. To deal with the apparently rapid shifts in performance level exhibited in Crespi's (1942) data and in some latent learning data, Hull revised the theory in 1952. In that revision amount of reinforcement was no longer assumed to affect the habit construct but rather was to operate, like drive, as a multiplier of habit in producing performance. Specifically, Hull (1952) assumed that magnitude of reinforcement operated through "incentive motivation" (K), which was still assumed to be related to the actual weight of the reinforcer.

Hull (1943) cited Grindly's (1929) study as well as that of Wolfe and Kaplon (1941) as evidence for his views. Grindly gave chickens various quantities of boiled rice for traversing a four ft. runway while Wolfe and Kaplon gave chickens varying numbers of kernels of popcorn as a reinforcer. The results of both studies showed that a whole grain was more reinforcing than a quarter of a grain of rice or of popcorn. However, Hull pointed out a "paradox" in the data in that Wolfe and Kaplon found that four of the quarter-grains were more reinforcing than a single intact grain of popcorn. Hull explained this "paradox" by suggesting that the four quarters resulted in a larger increment in response strength than the one full grain by a "summation" process. An alternative interpretation would be that the four quarters resulted in a longer duration of reinforcement than the one full grain, and that the additional consummatory activity lead to the larger increase in response strength. Since Hull used the weight of reinforcement in his mathematical formulations, it follows that if the same quantity or amount of reinforcement is given over a short as opposed to a long duration of consummatory activity, no differences in response strength should result. Further, if the duration of the consummatory response is held constant, a large amount of reinforcement should result in a larger increase in response strength than a small amount of reinforcement.

Spence (1956) elaborated upon Hull's concept of incentive motivation by proposing a specific mechanism underlying K. Spence suggested that the goal response or consummatory response ($R_g$) gets classically conditioned to the stimulation in the goal box of a runway through drive reduction (presumably physiological). He further assumed that fractional anticpatory components ($r_g$) of the goal response get conditioned to stimuli at earlier points in the alley through generalization. These fractional anticpatory goal responses have stimulus consequences ($s_g$) which become part of the stimulation in the alley and therefore get conditioned to the running response. In addition Spence assumed that the $r_g$-$s_g$ mechanism had motivational properties which led to an increase in the level of K. The latter in turn, was assumed to increase instrumental response strength. It follows from this view that stronger $R_g$s should result in stronger $r_g$-$s_g$s and a higher level of K. This in turn should lead to increased response strength and specifically, for the runway, faster running speeds. It is interesting to note that Crespi (1942) apparently anticipated Spence when he suggested that the larger the incentive the more "eager" the organism is to get it. This "eagerness" was considered an emotional drive which added to the general drive level of the organism thereby increasing response strength.

Spence suggested that there are two ways that magnitude of reinforcement might affect the strength of $r_g$-$s_g$ and, therefore, the level of K. One was that it led to an increase in the number of consummatory responses made in the goal box and, in effect, more classical conditioning of the $R_g$ to the goal box stimuli. This view leads to the prediction that two groups receiving a small and a large amount of reinforcement respectively, should approach the same asymptotic speed in the alley as the number of trials became large since the differences due to the number of $r_g$s would become negligible. Goodrich (1960) gave rats training in a runway and combined, in a factorial design, sucrose concentration with the number of licks permitted. He fould significant effects due to concentration and number of licks on running speed. These effects appeared relatively early in training and persisted throughout the course of the study. Thus, Goodrich found no evidence for convergence at asymptote.

Spence's second suggestion was that the effectiveness of reinforcers was due to the vigor of the consummatory response they elicit. Presumably a more vigorous $R_g$ would lead to a "stronger" $r_g$ and, therefore, a higher level of incentive motivation. Goodrich (1960) found little relation between sucrose concentration and licking rates, although he did find that allowing <u>S</u>s a larger number of licks did result in faster licking rates. The overall licking rates were significantly affected by sucrose concentration but Goodrich's evaluation of the data was that this effect was due to the lower licking rates of a group receiving a 3% sucrose solution. "Pure" licking rates, that is rates determined when pauses of more than 200 ms. were omitted from drinking time, revealed no effect due to sucrose concentration. Goodrich concluded that the vigor hypothesis, originally proposed to account for quality of reinforcement effects, did not receive support from his data. However, the correspondence between the number of licks permitted and licking rates and the running speeds is consistent with the vigor hypothesis. In any event, Goodrich suggested that a more sensitive indicator of "response vigor", and therefore K, might be the pressure S exerted upon the drinking tube.

Spence (1956) cited two studies, one an unpublished doctoral dissertation by Swisher, the other an unpublished master's thesis by Czeh, which suggest that the duration of the consummatory response and not the amount of reinforcement is the critical variable in magnitude of reinforcement studies. Swisher, using a short alley with a lever protruding from the rear wall, gave one group of rats a food pellet weighing 2.5 gm. and a second group a .5 gm. pellet. Both groups were allowed to eat in the apparatus for 30 sec., which was not enough time to consume the 2.5 gm. pellet, and to complete eating in a carrying cage. Swisher found no differences between these groups in the latency to press the bar over 40 trials. Similarly, Czeh, using a similar apparatus, allowed one group of rats to consume a 2.4 gm. food pellet (which took an average of 240 sec.) in the goal box. Two additional groups were given a 30 sec. eating period in the goal box, one being given a 2.4 gm. pellet, the other a .1 gm. pellet. All groups were allowed to complete eating in a carrying cage. Czeh found no differences in reciprocal starting time between the two 30 sec. groups, both being considerably slower than the group allowed to consume the entire pellet in the goal box. An interesting observation reported by Czeh was that many of his Ss in the large pellet-30 sec. group picked up the pellet but did not eat until they were placed in the carrying cage. This observation suggests that the function of reinforcement may not be to reduce a physiological drive but rather to preserve prior conditioning by preventing responses incompatible with the running response from occurring.

The latter view is, of course, that of Guthrie (1940) who proposed that,

> "What encountering the food does is not to intensify a previous item of behavior but to protect that item from being unlearned." (page 144).

For Guthrie the consummatory response served to preserve prior conditioning, which was assumed to occur through contiguity. While Guthrie was not explicit on the point, it would seem to follow that a longer consummatory response, i.e. a longer duration of reinforcement, should more effectively remove an organism from the stimulation of the apparatus and therefore have a greater probability of preventing the previously learned response from getting unconditioned. Guthrie's position may also be taken to imply that a more vigorous consummatory response would lead to more effective reinforcement since it may be more effective in preventing incompatible responses from occurring.

Hellyer (1954) was the first theorist to make specific suggestions on the effects of duration of reinforcement. He elaborated on Guthrie's views by suggesting a stimulus trace theory, with the trace decreasing over time. Hellyer assumed that the organism has an opportunity to make competing responses in the presence of stimulus traces from the alley after consuming the reward but before being removed from the apparatus. As a result, when an organism spends much time engaging in consummatory responses, many stimulus traces from the alley will die out, so that the probability of a stimulus trace getting conditioned to a competing response will be small. On the other hand, if the duration of the consummatory response is small, the probability of a trace from the alley getting conditioned to a competing response will be higher since more traces will be available. Weinstock (unpublished) has recently offered a quantitative version of the Hellyer stimulus trace notion. The major difference is that Weinstock assumes that the sources of stimulus traces are kinesthetic or "movement produced" stimuli.

In the revised edition of his The Psychology of Learning Guthrie (1952) proposed what appears to be a strongly non-Guthrian view. In reply to a request by Neil Miller that he indicate how he would account for the gradual increase in speed of running in an alleyway Guthrie wrote that

> "...The presence of these goal responses may carry with it such attendant symptoms as increased energy. The zeal with which the sight of food is met by a hungry animal serves to energize eating." (pg. 230).

Presumably, gradual increases in what may be taken to be $r_g$-$s_g$s or in "excitement" would account for the increased speed in running.

Sheffield (Sheffield, Roby and Campbell, 1954) elaborated on this suggestion and proposed a "drive-induction" theory. He assumed that, the terminal $R_g$ gets conditioned to cues in the alley through generalization. Since the "arousal" of the $R_g$ in the early parts of the alley must, of necessity, be incomplete, the incomplete arousal of the $R_g$ produces excitement. The excitement in turn adds to the general drive level of the organism and results in faster running in the alley. According to this view the stronger or more vigorous $R_g$ evokes greater arousal, thereby increasing the organisms drive level and resulting in faster running. A number of studies by Sheffield and his associates (Sheffield and Roby, 1950; Sheffield, Roby and Campbell, 1954) supported this view. These studies showed that the strength of the instrumental response and the "vigor" of the consummatory response were strongly correlated.

Recently, Sheffield (1965) shifted his emphasis from consummatory response strength or vigor to consummatory stimulation. The shift was based on a study by Kraeling (1961) who found that varying the concentration of sucrose lead to differences in running behavior as well as licking behavior. However, as pointed out by Kraeling, the effects of sucrose concentration on licking behavior were much larger early in training than later in training. On the other hand the running speed differences were consistent throughout the course of the study. Kraeling concluded that the intensity of taste stimulation ( quality ) was critical and that the positive relation found between licking rates and running behavior showed that consummatory response vigor was an index of consummatory stimulation.

The prediction that faster running in an alley is due to consummatory behavior also follows from Premack's (1959) "prepotent response theory". Premack suggested that if a high rate response is made contingent upon the occurrence of a low rate response, the occurrence of the high rate response will serve to reinforce the low rate response, thereby increasing the response rate of the low rate response. Rather than being suggested as a "theory", this view was proposed as an empirical description of reinforcement. In a later paper Premack (1965) extended his "principle of reinforcement" to encompass, not only rate measures, but response probabilities as well. Presumably this "principle" should be applicable to any pair of response measures. Thus, if the consummatory response is an initially "stronger" response, a correspondence should be found between the strength of the $R_g$ and instrumental running behavior.

Thus, the major variables that have received attention with regard to the effect of reinforcement magnitude have been amount and the duration of reinforcement and the lick or ingestion rate, with the latter usually taken as measures of response vigor. The present series of studies proposes to investigate their effects on running behavior in an alleyway. One further variable that has received attention is the effect of the "quality" of the reinforcer. Although the effect of quality was not investigated in the present studies it may be of interest to clarify some of the issues raised.

Most studies show significantly faster running to increased concentrations of sucrose or saccharin (Collier, Knarr and Marx, 1961; Goodrich, 1960; Knarr and Collier, 1962; Kraeling, 1961; Snyder, 1962; Wist, 1962). Studies have also shown that the nutritional value of the substance and the total caloric intake or volume is not related to running behavior (Knarr and Collier, 1962; Kraeling, 1961; Sheffield and Roby, 1950; Sheffield _et_ _al_, 1954). Thus it appears that the taste of the substance is the critical variable in these studies. In addition all of these studies have revealed a correspondence between licking behavior, running behavior and concentration of the substance. However, Goodrich found that when interruptions of more than 200 ms. were eliminated from the drinking time records there were no differences in licking behavior. It should be noted that a "total" rather than a "pure" lick rate measure is usually used as an index of consummatory response strength. It has also been observed (Collier _et al_, 1961; Knarr and Collier, 1962; Kraeling, 1961) that differences in running behavior occur earlier and are more persistent, while consummatory response differences tend to get smaller during the course of training.

A relationship between consummatory behavior and speed of running appears to be found only with variations in the quality of reinforcement, e.g. the taste of sucrose, or dextrose or saccharin. Snyder and Hulse (1961), using a water reward, failed to find any relationship between running speed and a number of consummatory response measures, namely, total number of licks, total volume, volume per lick and licking rate. Also using a water reward, Hellyer (1954) found no relationship between running behavior and ingestion rate. Furchtgott and Widasin (1966), using a food reward, also failed to find the presumed relationship. However, Kling (1959), using water as reinforcement, reported a relationship between rate of ingestion and speed of running. Kling's data have been used to support theories which assign a large role to vigor of consummatory responding. Among other things the present series of studies will provide a replication of Kling's conditions and will, it is hoped, remove the apparent contradictions in results.

The correspondence between quality or taste of the reinforcer and consummatory response strength and running behavior may be related to the viscosity or sweetness of the substance used. Knarr and Collier (1962) suggest that the relation between consummatory and running behavior may be because both measures are "independent functions" of the same variables. They conclude that one of the determiners of the magnitude of reinforcement effect is the "sensory consequences of the reinforcing agent." The implication is that reinforcers that have specific sensory affects upon consummatory responses may have similar effects upon running behavior and that there is no causal relation between the two behaviors. The view proposed by Collier would also account for the failure to find differences in consummatory measures in studies in which amount of water reinforcement has been varied, since variations in amount of water presumably would not lead to differential "sensory consequences".

The studies of Crespi (1942) and Zeaman (1949), both of which found that groups of rats receiving larger amounts of reinforcement ran faster than groups of rats receiving smaller amounts, confounded the effects of amount and duration of reinforcement. The studies of Crespi and Zeaman had another source of confounding since they used a larger number of pellets or a larger sized pellet of food, respectively, as a method of varying amount of reinforcement. Thus, the appearance of their reinforcing substance and the amount given were confounded. Hellyer (1954) using access to a uniform appearing drinking tube removed the latter difficulty. The present study follows Hellyer's procedure in this respect. In addition Hellyer attempted to remove the confounding of amount and duration by combining the width of a drinking tube (1 mm. or 4 mm.) and the amount of water consumed (.1 cc. or 1.0 cc.) in a factorial design. In addition, he recorded drinking time, i.e. the amount of time the animal licked the drinking tube. He found a positive relation between speed of running and drinking time. Specifically, he found that those groups that took the longest to consume the water reward ran the fastest. When analyses of variance were performed a significant "amount" effect was found. However, when covariance analyses were performed, removing the effects of drinking time, differences due to amount disappeared in all but one case. On this basis Hellyer concluded that the duration of the consummatory response and not the amount consumed was the critical variable in the magnitude of reinforcement effect.

The difficulty with Hellyer's study is that duration and amount of reinforcement may be so highly correlated that removing the effects of duration of reinforcement (through a covariance analysis) may also serve to remove the effects of amount of reinforcement. The use of the covariance technique when the covariate and the independent variable are highly correlated has recently been severely criticized by Evans and Anastasio (1968). They pointed out that in this case removing the effects of the covariate may be the same as removing the effects of the independent variable. An improvement upon Hellyer's design might be to control the effects of reinforcement duration experimentally rather than to control for them statistically. If experimental manipulation resulted in a group of rats receiving say, twice as much water as a second group, but with both groups drinking for the same duration, then a firm conclusion might be drawn. For example, if the large amount group ran faster in the alley than the small amount group, the critical variable would then be seen to be amount and not duration of reinforcement. If, however, no differences were found in running speed between groups receiving large differences in amount, then, it would appear that duration and not amount of reinforcement is the critical variable. Furthermore, if some combination of duration and tube width resulted in a smaller amount consumed for a longer duration group than for a short duration group, then an extremely strong experimental test of the contribution of amount versus duration of reinforcement would result.

In Experiment 1 an attempt was made to improve upon Hellyer's design. To this end six groups of rats were given water reinforcement for traversing a runway. The reinforcement was presented through glass drinking tubes with a 1 mm. or 5 mm. hole for a fixed time period (8, 16 or 32 sec.). The results of preliminary work showed that the combination of tube width and reinforcement duration used should result in approximately a two-to-one difference in the amount consumed for the 5 mm. in contrast to the 1 mm. groups. By holding duration constant experimentally, the present design allows for an unconfounded assessment of the effects of amount of reinforcement.

It was anticipated that duration of reinforcement would be shown to be the major variable in the magnitude of reinforcement effect. As a result, in Experiment 2, a parametric study of the relationship between the duration of reinforcement and running speed was undertaken. Since amount of reinforcement varied perfectly with duration of reinforcement, no attempt was made in this part of the study to separate out the effects of duration and amount of reinforcement. To this end four groups of rats were given 4, 24, 48 or 64 sec. of water reinforcement through a 1 mm. tube. Since Experiments 1 and 2 were done concurrently, the 8, 16 and 32 sec.-1 mm. groups from Experiment 1 were included in the parametric analysis.

Both Hellyer and Kling gave their Ss training to drink from a tube in a box similar to the goal box prior to the introduction of runway training trials. Kling gave his groups 7 days of pretraining during which time they received water for various durations through a drinking tube different in size from that used in the runway. Hellyer gave his Ss 8 days of pretraining during which time they received the same amount they were to receive in the goal box through both tube widths used in his study. In an attempt to assess the effect of pretraining another group of rats was given drinking tube training in the goal box through a 1 mm. or 5 mm. tube at various durations prior to receiving runway trials.

The results of Experiment 1 and 2 suggested that when reinforcement quality and appearance are uniform little or no relation exists between running speed measures and a variety of consummatory response measures, namely, licking rate, ingestion rate, volume per lick or amount consumed. These data suggest that the consummatory response may be under the control of stimuli other than those that control the running response. Similarly, variables affecting behavior in the alley may be expected not to affect consummatory behavior. Hulse (1966) suggested that the onset of licking may be controlled by external stimulation but that once elicited the behavior is largely "involuntary". He presented data that reveal that licking behavior is largely determined by the size of the drop of water (Hulse, 1966; Snyder and Hulse, 1961). However, he has also shown that licking rates can be manipulated by varying the probability that a lick gets reinforced (Hulse, Snyder and Bacon, 1960; Hulse and Firestone, 1964).

## Experiment 1

Hellyer (1954) using a factorial design which combined drinking tube width (1 mm. or 4 mm.) with amount of water reinforcement (.1 cc. or 1.0 cc.), found a positive relation between running speed and drinking time. When the effects of drinking time were controlled statistically, through the use of analysis of covariance, effects due to amount were no longer significant. Hellyer interpreted these results as strong evidence that duration rather than amount of reinforcement was the operative variable in the magnitude of reinforcement effect. However, since amount and duration of reinforcement may be highly correlated, removing duration effects may be the same as removing amount effects. An improvement upon Hellyer's design may be to control experimentally, rather than statistically, the duration of reinforcement effects. Furthermore, Kling (1956), in a factorial design combining drinking tube width (2 mm. or 5 mm.) with duration of goal box confinement (15 sec. or 120 sec.), found a positive relationship between running speed and ingestion rate, but not between running speed and amount or duration of reinforcement. Inspection of Hellyer's data reveals no apparent relationship between ingestion rate and running speed. Thus, the results of Hellyer and Kling are in conflict regarding the contributions of duration of reinforcement and of ingestion rate to the magnitude of reinforcement effect.

An apparent contradiction has also resulted from studies using food reinforcement. Thus, Black and Elstad (1964) reported two studies in which they found faster running speeds for a group of rats allowed to eat for 10 sec. in contrast to a group allowed to eat for 30 sec. They reported that the 10 sec. group ingested their food faster than the 30 sec. group, thereby apparently replicating Kling's results using a food reward. On the other hand, Furchgott and Widasin (1966) found that the greater the duration of eating the smaller the latency of running. They found further that the group that ran faster had a lower ingestion rate.

In an attempt to clarify these discrepancies and to improve upon Hellyer's design, six groups of rats were given one trial per day in an alleyway and received either 8, 16 or 32 sec. of water reinforcement through a 1 mm. or 5 mm. glass drinking tube. In this manner, a group of rats drinking from a 5 mm. tube received approximately twice as much water as a group drinking from a 1 mm. tube for the same duration. Thus, the present experiment was designed primarily to detect the effects of amount of reinforcement which was varied by a factor of two while duration of reinforcement was held fixed. In addition, the experiment provides a replication of Kling (1959) with a possible improvement in procedure, namely the use of photocell-activated rather than electrically activated counters to measure the rate of licking.

# METHOD

## Subjects

Seventy-two female albino rats, 100-110 days old at the start of the experiment were acquired from Albino Farms, Little Silver, New Jersey.

## Apparatus

A straight runway, painted flat gray was used. It was 5 in. wide and 5 in. high except for the goal box which was 12 in. high. The start box, runway and goal box were 10, 44, and 18 in. long, respectively. The start box and runway were covered with hinge-mounted clear Plexiglas. A 4 x 5 in. recessed drinking area was attached at a right angle to the left end wall of the goal box. At the end wall of the drinking area was a 1 x 1 in. opening through which S gained access to the water tube. The start box, alley and goal box were separated from each other by guillotine doors. Lighting was provided by three 6w. flourescent bulbs spaced 17 in. apart and mounted 12 in. above the apparatus. An air conditioner was run continuously to provide a uniform masking noise.

Photocell beams were placed 1 in. past the start box door, 8 in. past the goal box door and ½ in. in front of the drinking area door and with associated photoelectric equipment (Farmer Electric Co. model PE-4), were used to record latency, running time and goal time, respectively. A fourth photocell circuit (Farmer Electric Co. model TRB) provided a flat beam of light across the opening of the drinking tube. The beam was interrupted by S's tongue and provided a measure of "first-lick latency", the time from interruption of the third beam to the first lick. The distance between the third photocell and the drinking tube was 2½ in. The interruption of the last photocell beam also activated a Farmer Electric Co. variable interval timer, which timed the reinforcement interval and signaled the end of the interval by a momentary flash of light.

Water reinforcement was provided through a glass drinking tube with either a 1 mm. or 5 mm. opening. The drinking tube was attached to a 50 ml. burette. The tube was placed ½ in. behind the 1 x 1 in. opening in the end wall of the goal box. The number of licks was recorded on a Sodeco print-out counter (25 impulses/sec., maximum) which was activated by interruption of the flat beam of light across the opening of the drinking tube. In addition, each interruption of this light beam activated a Standard Electric Timer. In this manner the total amount of time that the S's tongue was in contact with the drinking tube, or the duration of tube contact, was recorded. The 50 mL. burettes were scaled in .1-mL units permitting the recording of the amount of water consumed. All of the timers used were Standard Electric .01-sec. timers.

## Procedure

Two weeks before the beginning of the experiment Ss were gentled and habituated to a 20 hr. water deprivation schedule. Throughout the experiment Ss were given one trial per day under 19-22 hr. of water deprivation. Each group was divided into two squads and the squads were run in a different random order each day.

The Ss were randomly assigned to groups. Three durations of reinforcement, 8, 16 or 32 sec., were combined factorially with two different sized openings in the drinking tube, or tube width, 1 mm. or 5 mm. resulting in six groups of twelve Ss each. The six groups were designated 8-5, 16-5, 32-5, 8-1, 16-1 and 32-1, with the first digit referring to the reinforcement duration and the second to the tube width.

On runway training trial 1 the glass drinking tube projected through the opening into the drinking area. On subsequent trials the tube was gradually withdrawn so that by trial 4 the tip of the drinking tube was ½ in. behind the opening in the wall. The tube remained in this position for the remainder of the study.

It was planned to administer runway trials until the group curves appeared to level off and then give an additional twenty trials. It was planned to use these trials for asymptotic analyses regardless of the nature of the data collected. As a result 71 trials were given.

On each trial S was placed in the start box facing the guillotine door. The cover of the start box depressed a microswitch which activated a 5-sec. thermal-delay relay. When the relay closed the clutch of a Hurst synchronous motor was energized, raising the start box door and starting three timers. Interruption of the light beam 8 in. past the goal box door activated the clutch circuitry of the motor closing the start box door. When the beam ½ in. in front of the drinking area door was broken the goal box door was lowered. Interruption of this beam activated still another clutch-motor circuit automatically raising a door permitting S access to the water tube and starting another clock. When the light beam across the front of the drinking tube was broken the last clock was stopped. Each lick interrupted the light beam across the front of the drinking tube activating a Standard Electric timer and a Sodeco print-out counter. As a result the cumulative time on the drinking tube and the number of licks were recorded.

To check on the accuracy of the photocell-counter circuit four additional rats were given drinking tube training in the goal box. These rats were permitted to drink water for various durations through the 1 mm. and 5 mm. tubes. In addition to activating the photocell circuit, each lick activated a Grason-Stadler Drinkometer circuit. This circuit was completed through an aluminum plate on which the rat stood while drinking and a wire that was placed in the water tube. Almost a thousand such pairs of measures were taken. The results showed that approximately 98% of the time the number of licks recorded through both circuits were identical. At no time during the remaining 2% of the trials were differences even larger than 2%.

Finally, when *S*'s tongue broke the light beam across the front of the drinking tube a Farmer Electric variable interval timer that was preset for a fixed duration was started. When the interval ended a light bulb flashed momentarily. This was a signal to *E* to remove *S* from the goal box. After *S* was removed from the goal box it was returned to its home cage. Those *S*s who failed to leave the start box or to drink within 20 min. on two consecutive trials were discarded.

Five *S*s were discarded for failure to drink or run on the ealy training trials. Seven *S*s died or developed middle ear infection, leaving 10 each in Groups 8-1, 8-5, 32-1 and 32-5, 9 in Group 16-1, and 11 in Group 16-5, respectively.

## RESULTS

Latency, running time, goal time and time to the first lick were converted to reciprocals (10/sec.) throughout.

Inspection of Table 1 reveals that the 5 mm. groups consumed almost twice as much water as their 1 mm. counterparts. Specifically, Group 8-5 consumed 81% more water than Group 8-1, Group 16-5 consumed 94% more than Group 16-1 and Group 32-5 consumed 67% more than Group 32-1. Thus, the combinations of drinking tube width and reinforcement duration used in the present study were successful in yielding almost 2 to 1 differences in the amount consumed for the same duration of reinforcement.

### Runway Response Measures.

Mean reciprocal latency, running time and goal time for blocks of ten trials are presented in Figures 1, 2 and 3, respectively. Inspection of Figures 1, 2 and 3 revealed that there were apparently no differences between the 1 mm. and 5 mm. groups for a given reinforcement duration. Furthermore, it is clear from inspection of Figures 1, 2 and 3, that as the duration of reinforcement was increased the three reciprocal measures increased.

In accordance with the plan adapted in advance of the study the last twenty trials were taken as the asymptotic block. The mean reciprocal latency, running time and goal time for the last twenty trials are presented in Tables 2, 3 and 4, respectively. Inspection of Tables 2, 3 and 4 as well as Figures 1, 2 and 3 revealed that as the duration of the consummatory response was increased the three asymptotic mean reciprocal measures also increased. Furthermore, the 1 mm. groups ran somewhat faster than the 5 mm. groups on all three measures.

Three Duration by Tube Width two-way analyses of variance were performed on the last twenty trials for the three running measures. One S was randomly selected from Group 16-5 and excluded from the statistical analyses. In addition the mean reciprocal value for Group 16-1 was added to the analyses, although no increase in degrees of freedom was made. These two changes were made for all statistical analyses to equalize the n in each group. The results are presented in Table 5 and reveal a significant Duration effect for all three measures. However, neither the Tube Width nor the Duration by Tube Width interaction yielded significance on any of the three running measures.

Power analyses were performed (Feldt and Mahmound, 1958), using the Mean Square Within Groups as an estimate of $\sigma^2$, to determine the probability of finding various "true" differences between the 1 and 5 mm. conditions expressed as percentages of the Grand Mean. The probability of detecting various differences from the Grand Mean for the reciprocal latency, running time and

## Table 1

Mean Amount of Water Consumed per Trial (in cc.) in Experiment 1.

| Reinforcement Duration (in sec.) | 1 mm. Groups | 5 mm. Groups |
|---|---|---|
| 8 | .165 | .299 |
| 16 | .336 | .650 |
| 32 | .730 | 1.218 |

Figure 1

Mean Reciprocal Latency as a Function of Blocks of Ten Trials in Experiment 1.

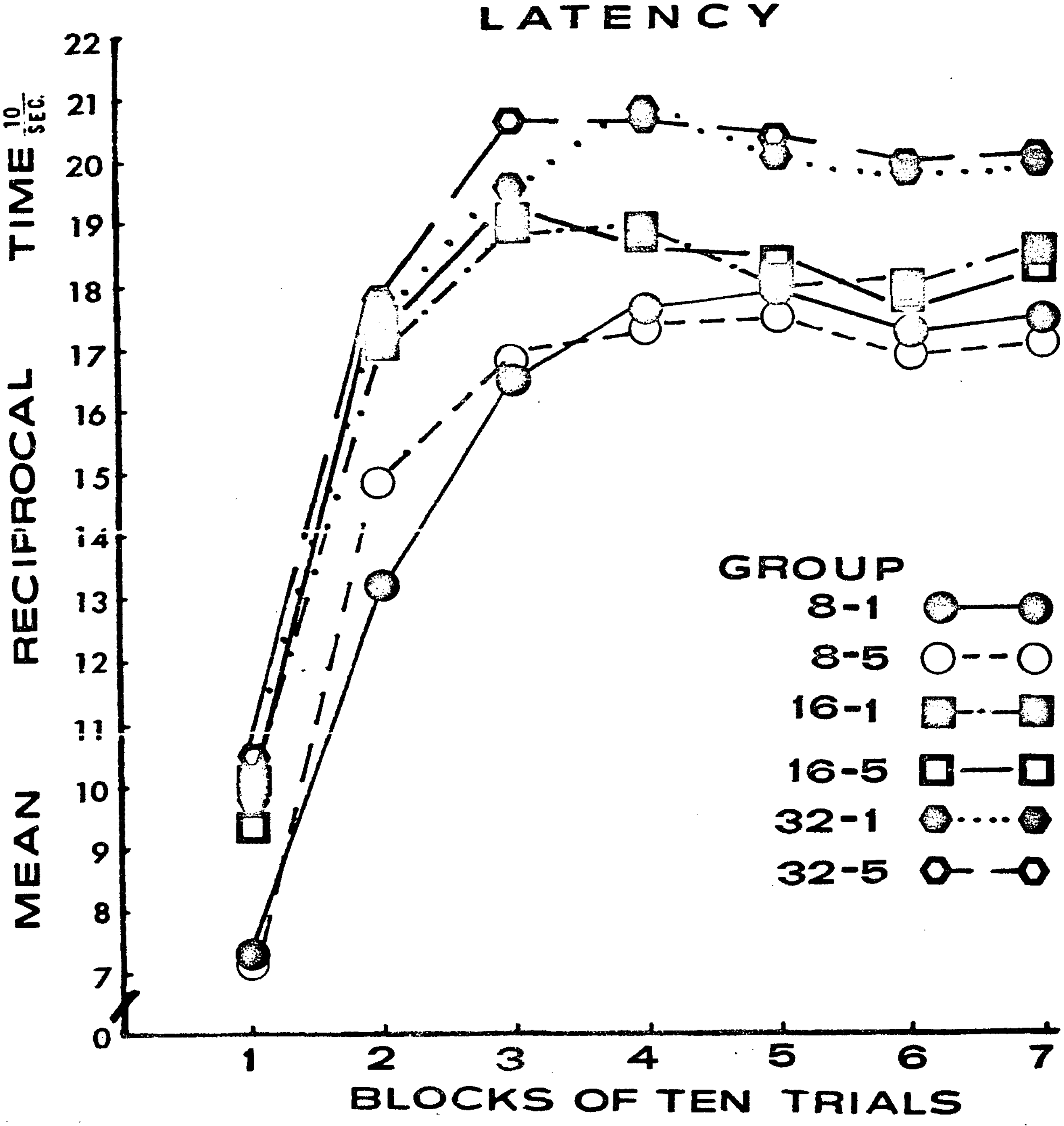

LATENCY
MEAN RECIPROCAL TIME 10/SEC.
0
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
8-1
8-5
16-1
16-5
32-1
32-5

Figure 2

Mean Reciprocal Running Time as a Function of Blocks of Ten Trials in Experiment 1.

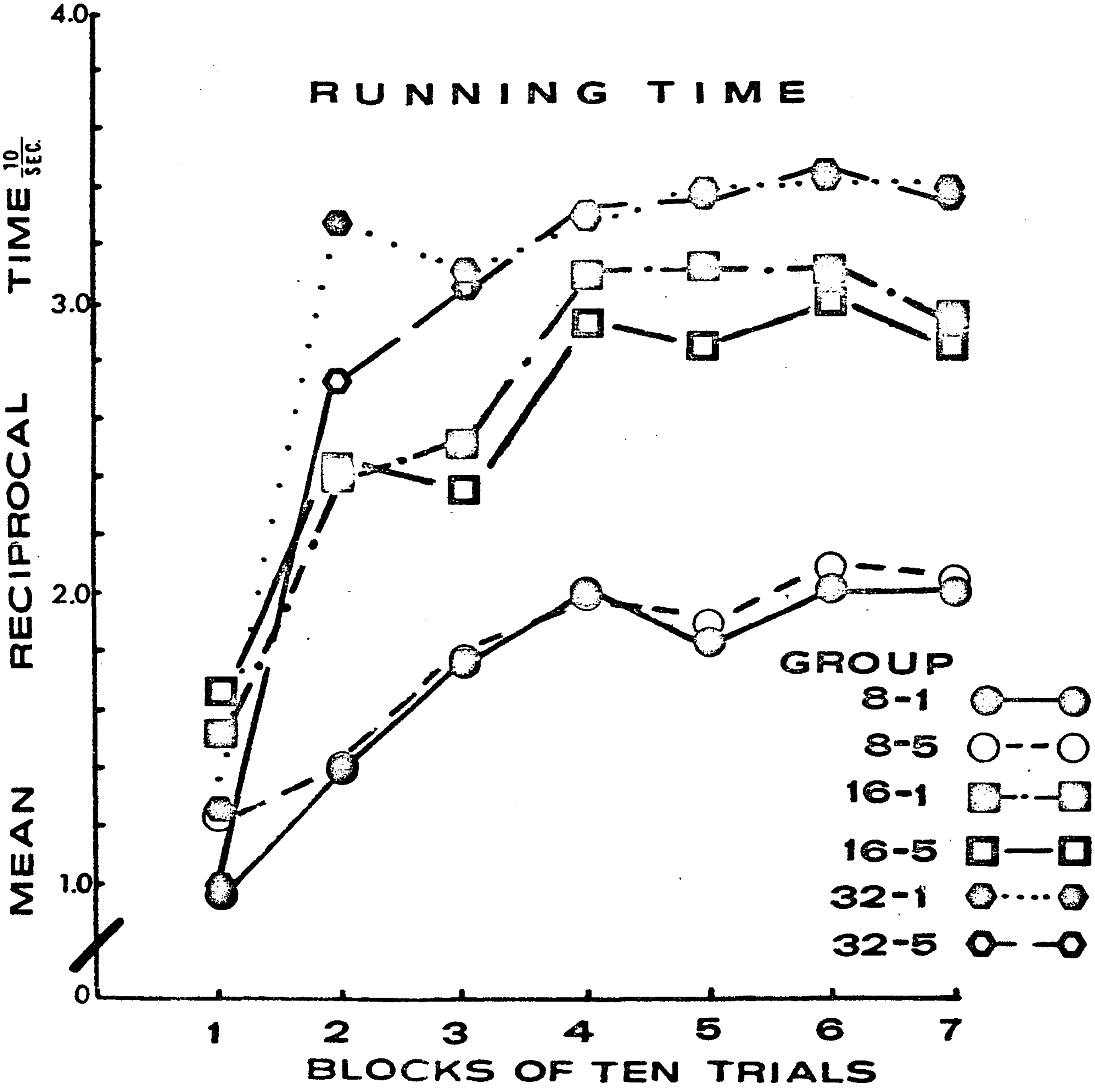

RUNNING TIME
MEAN RECIPROCAL TIME 10/SEC.
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
8-1
8-5
16-1
16-5
32-1
32-5

Figure 3

Mean Reciprocal Goal Time as a Function of Blocks of Ten Trials in Experiment 1.

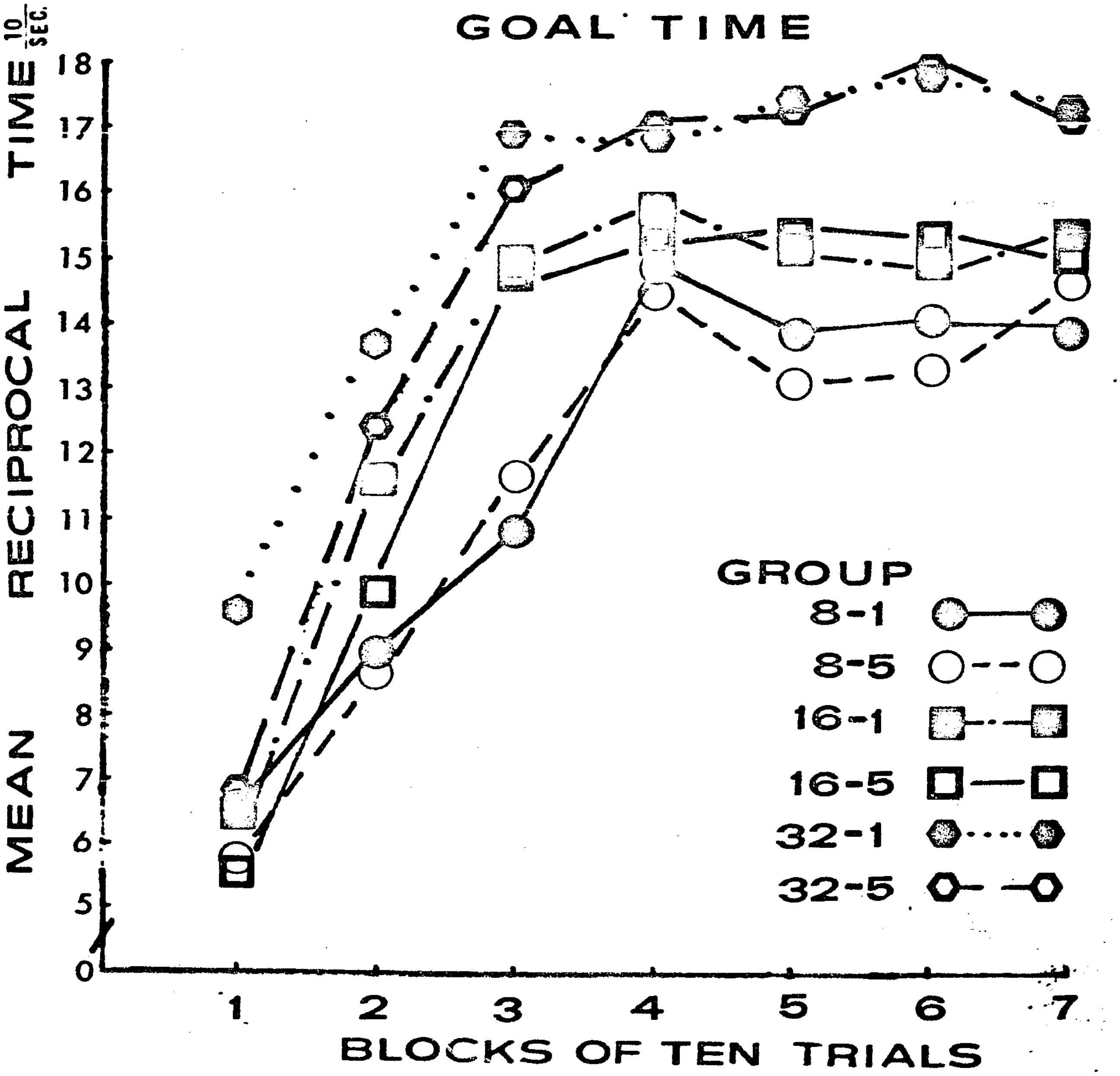

GOAL TIME
MEAN RECIPROCAL TIME 10/SEC.
18
17
16
15
14
13
12
11
10
9
8
7
6
5
0
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
8-1
8-5
16-1
16-5
32-1
32-5

Table 2

Mean Reciprocal Latency for the Last Twenty Trials in Experiment 1.

| Reinforcement Duration (in sec.) | 1 mm. Groups | 5 mm. Groups | Combined |
|---|---|---|---|
| 8 | 17.41 | 16.95 | 17.19 |
| 16 | 18.26 | 18.04 | 18.15 |
| 32 | 19.88 | 20.17 | 20.03 |
| Combined | 18.52 | 18.39 | 18.46 |

Table 3

Mean Reciprocal Running Time for the Last Twenty Trials in Experiment 1.

| Reinforcement Duration (sec.) | 1 mm. Groups | 5 mm. Groups | Combined |
|---|---|---|---|
| 8 | 2.07 | 2.06 | 2.07 |
| 16 | 3.02 | 2.96 | 2.99 |
| 32 | 3.42 | 3.43 | 3.43 |
| Combined | 2.84 | 2.82 | 2.83 |

## Table 4

Mean Reciprocal Goal Time for the Last Twenty Trials in Experiment 1.

| Reinforcement Duration (in sec.) | 1 mm. Groups | 5 mm. Groups | Combined |
|---|---|---|---|
| 8 | 13.90 | 13.97 | 13.94 |
| 16 | 15.24 | 15.29 | 15.27 |
| 32 | 17.66 | 16.07 | 16.80 |
| Combined | 15.60 | 15.11 | 15.36 |

# Table 5

Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials in Experiment 1.

|  | Latency |  |  |  |
|---|---|---|---|---|
|  | SS | df | MS | F |
| Source |  |  |  |  |
| Duration (D) | 83.51 | 2 | 41.76 | 3.95* |
| Tube Width (TW) | .89 | 1 | .89 | .08 |
| D x TW | .90 | 2 | .45 | .04 |
| Within | 560.69 | 53 | 10.58 |  |
| Total | 645.99 | 58 |  |  |

*$p < .05$

### Table 5
(Continued)

### Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials in Experiment 1.

|  | Running Time |  |  |  |
|---|---|---|---|---|
|  | SS | df | MS | F |
| Source |  |  |  |  |
| Duration (D) | 18.96 | 2 | 9.48 | 10.09* |
| Tube Width (TW) | .05 | 1 | .05 | .05 |
| D x TW | .09 | 1 | .05 | .05 |
| Within | 49.88 | 53 | .94 |  |
| Total | 68.98 | 58 |  |  |

$*p < .05$

### Table 5
(Continued)

### Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials in Experiment 1.

<u>Goal Time</u>

| | <u>SS</u> | <u>df</u> | <u>MS</u> | <u>F</u> |
|---|---|---|---|---|
| Source | | | | |
| Duration (D) | 88.04 | 2 | 44.02 | 3.37* |
| Tube Width (TW) | 4.33 | 1 | 4.33 | .33 |
| D x TW | 8.58 | 2 | 4.29 | .33 |
| Within | 691.50 | 53 | 13.05 | |
| Total | 792.45 | 58 | | |

$^*p < .05$

goal time measures for the Tube Width variable are presented in Table 6. Inspection of Table 6 reveals that the present study yielded an extremely sensitive design since the probability of finding approximately a 17% difference due to Tube Width, and therefore amount of reinforcement was .95, .5 and .8 for the latency, running time and goal time measures, respectively. Furthermore, there was more than a .6 probability of detecting a 10% difference between the two conditions for the reciprocal latency measure.

Since almost 2 to 1 differences were found in the amount consumed along with no differences in mean reciprocal measures it was decided to divide the six groups into two 2 x 2 analyses of variance to obtain 2 to 1 differences in reinforcement duration. That is, in one set of analyses the 8 and 16 sec. groups and in the other set the 16 and 32 sec. groups were combined factorially with the two tube widths. This was done to supplement the power analyses and answer the question of whether twofold differences in Duration were detectable within the present design. It should be noted that the 2 x 2 analyses were less sensitive than the overall design since the degrees of freedom of the error term are reduced by one-third. The results of these analyses are presented in Tables 7 and 8. Inspection of Table 7 revealed that, for the 8-16 sec. duration comparison, the Duration effect was significant for the running time measure. The 16-32 sec. Duration comparison as

Table 6

Power Analyses for the Tube Width Variable for Reciprocal Latency, Running Time and Goal Time Showing The Probability (P) of Detecting Differences Between the Population Means for the 1 and 5 mm. Conditions Expressed as Percentages of the Grand Mean in Experiment 1.

| *P* | Latency | Running Time | Goal Time |
|---|---|---|---|
| .50 | 9.2% | 17.9% | 12.2% |
| .60 | 9.7% | 19.0% | 12.9% |
| .70 | 11.8% | 23.1% | 15.7% |
| .80 | 13.2% | 25.9% | 17.6% |
| .90 | 15.2% | 29.7% | 20.2% |
| .95 | 16.9% | 33.1% | 22.5% |

Table 7

Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials for the 8 and 16 sec. Duration Groups in Experiment 1.

| | Latency | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | 9.36 | 1 | 9.36 | .78 |
| Tube Width (TW) | 1.22 | 1 | 1.22 | .10 |
| D x TW | .14 | 1 | .14 | .01 |
| Within | 419.21 | 35 | 11.97 | |
| Total | 429.93 | 38 | | |

$*p < .05$

Table 7
(Continued)

Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials for the 8 and 16 sec. Duration Groups in Experiment 1.

| | Running Time | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | 7.64 | 1 | 7.64 | 16.98* |
| Tube Width (TW) | .08 | 1 | .08 | .18 |
| D x TW | .01 | 1 | .01 | .02 |
| Within | 15.75 | 35 | .45 | |
| Total | 23.48 | 38 | | |

*$p < .05$

Table 7
(Continued)

Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials for the 8 and 16 sec. Duration Groups in Experiment 1.

Goal Time

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Duration (D) | 21.23 | 1 | 21.23 | 2.57 |
| Tube Width (TW) | .43 | 1 | .43 | .05 |
| D x TW | .03 | 1 | .03 | .004 |
| Within | 289.26 | 35 | 8.26 | |
| Total | 310.95 | 38 | | |

$^*p < .05$

Table 8

Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials for the 16 and 32 sec. Duration Groups in Experiment 1.

| | Latency | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | 35.14 | 1 | 35.14 | 4.29* |
| Tube Width (TW) | .01 | 1 | .01 | .001 |
| D x TW | .68 | 1 | .68 | .08 |
| Within | 287.04 | 35 | 8.20 | |
| Total | 322.87 | 38 | | |

$^*p < .05$

Table 8
(Continued)

Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials for the 16 and 32 sec. Duration Groups in Experiment 1.

| | Running Time | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | 2.00 | 1 | 2.00 | 1.55 |
| Tube Width (TW) | .27 | 1 | .27 | .21 |
| D x TW | 1.79 | 1 | 1.79 | 1.39 |
| Within | 45.19 | 35 | 1.29 | |
| Total | 49.25 | 38 | | |

$^{*}p < .05$

Table 8
(Continued)

Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials for the 16 and 32 sec. Duration Groups in Experiment 1.

| | Goal Time | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | 24.57 | 1 | 24.57 | 1.67 |
| Tube Width (TW) | .77 | 1 | .77 | .05 |
| D x TW | 9.39 | 1 | 9.39 | .64 |
| Within | 516.62 | 35 | 14.76 | |
| Total | 551.35 | 38 | | |

$^*p < .05$

shown in Table 8, revealed a significant Duration effect for the reciprocal latency measure only. None of the remaining comparisons were significant.

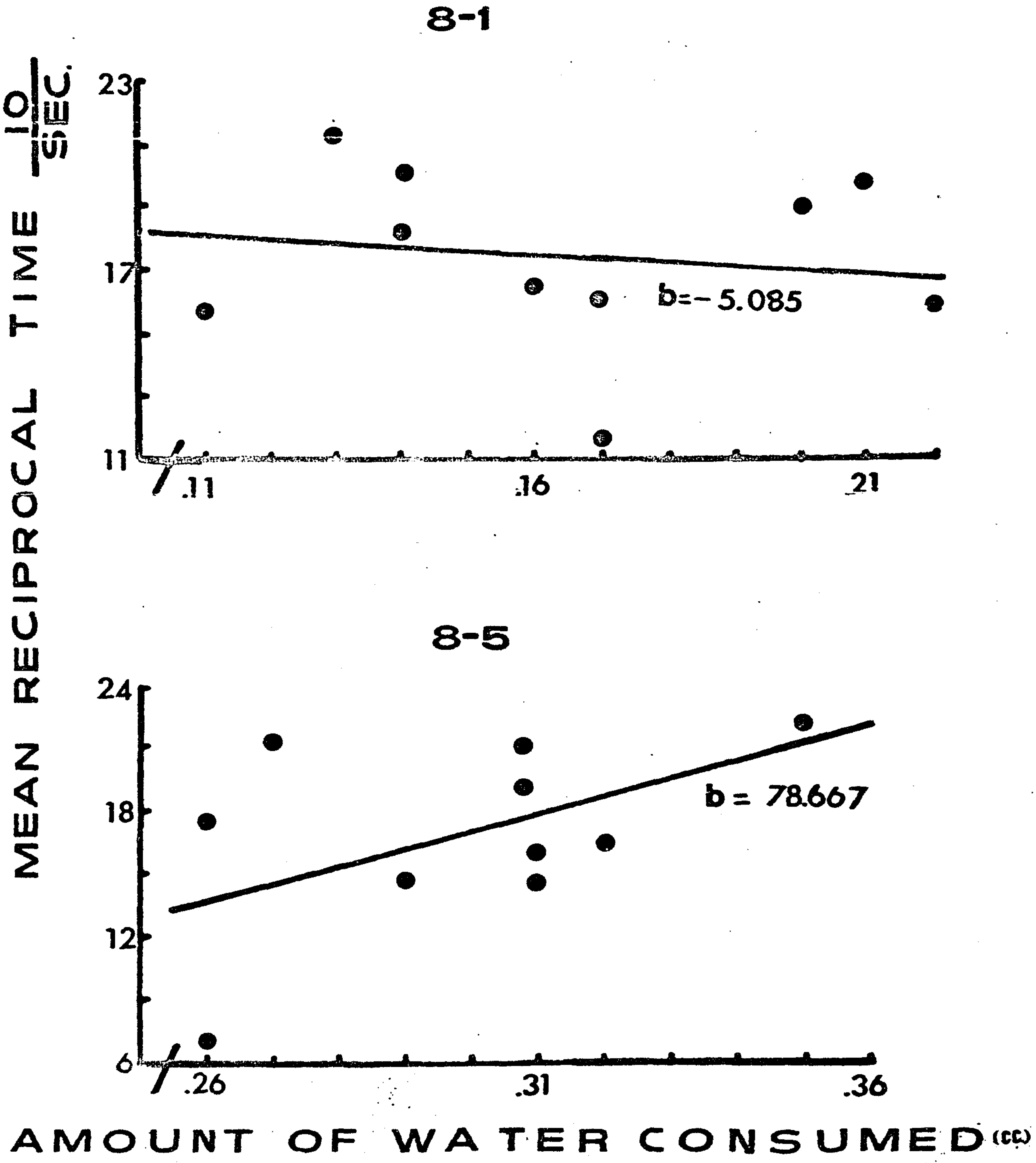
In Figures 4, 5 and 6 are plotted the relationships, within each group, between the amount consumed and the asymptotic mean reciprocal latency, running time and goal time, respectively. Inspection reveals little relation between the amount variable and asymptotic running speed. Pearson product-moment correlation coefficients were calculated based on all groups and revealed no significant correlations. Specifically, $r = .23$, .19, .03 for reciprocal latency, running time and goal time, respectively ($\underline{df} = 57$, $\underline{p} > .05$ in all three cases).

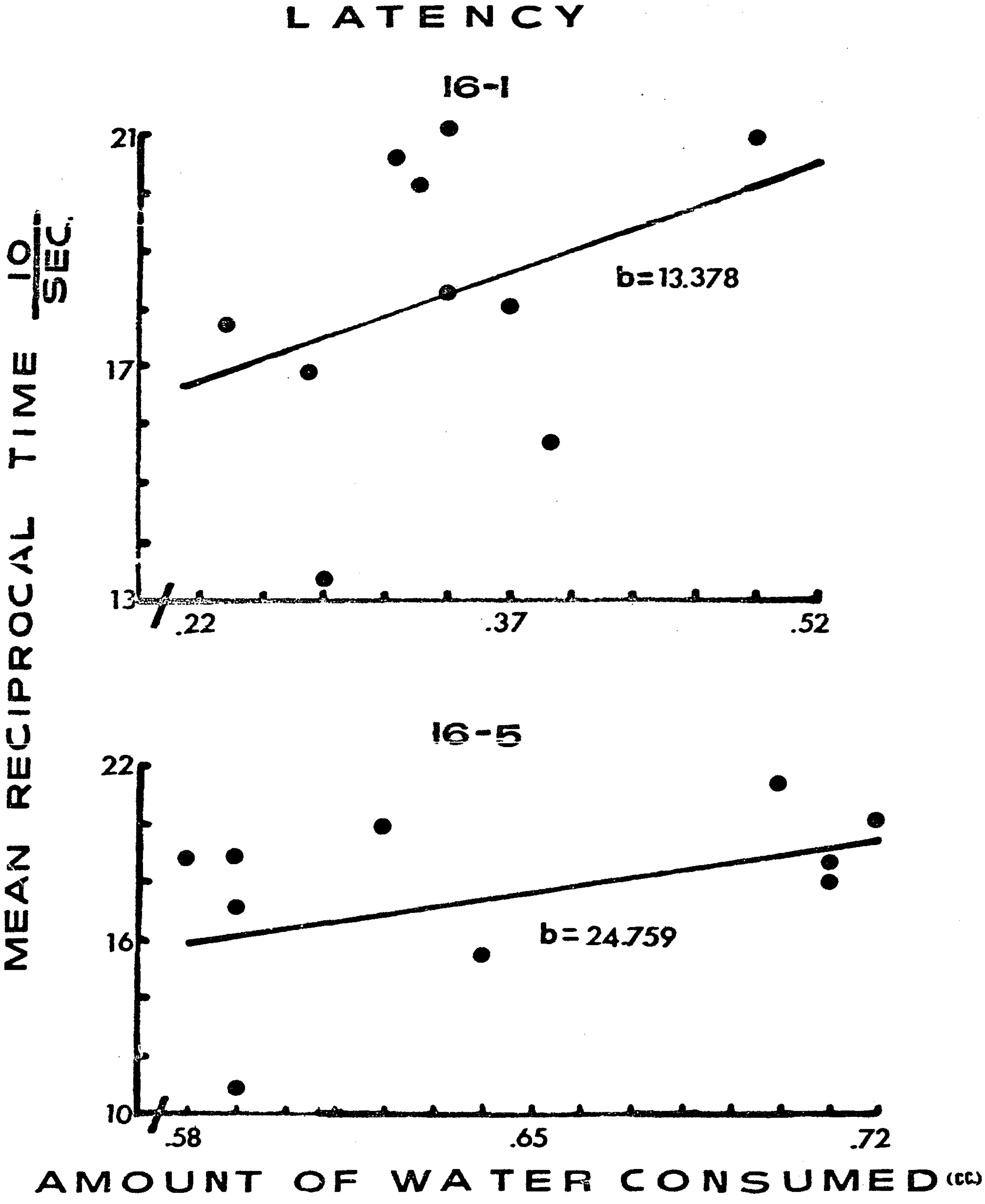
Hellyer (1954), as well as the present study, found a positive relation between duration of reinforcement and alleyway performance, whereas Kling (1959) did not. Hellyer conducted his study in two replications. The last five trials of the first, and the last eight trials of the second replication were regarded as the asymptotic trials. The asymptotic mean reciprocal latency (10/sec.) for Hellyer's groups, measured a distance of 6 in. from the start box, are plotted as a function of mean duration of tube contact in Figure 7. In addition, the mean reciprocal running time (a distance of 4½ ft.) for the last three trials of Kling's study is presented in Figure 7. Finally, the mean reciprocal latency for the last 20 trials of the present study is also plotted in Figure 7. Inspection of Figure reveals an almost linear

Figure 4

Scatterplots Showing the Relation Between Asymptotic
Mean Reciprocal Latency and Amount Consumed in Experiment 1.

# LATENCY


8-1
MEAN RECIPROCAL TIME 10/SEC.
23
17
11
.11
.16
.21
b=-5.085
8-5
24
18
12
6
.26
.31
.36
b = 78.667
AMOUNT OF WATER CONSUMED (cc)


LATENCY
16-1
21
17
13
b=13.378
.22
.37
.52
16-5
22
16
10
b=24.759
.58
.65
.72
MEAN RECIPROCAL TIME 10/SEC.
AMOUNT OF WATER CONSUMED (cc)

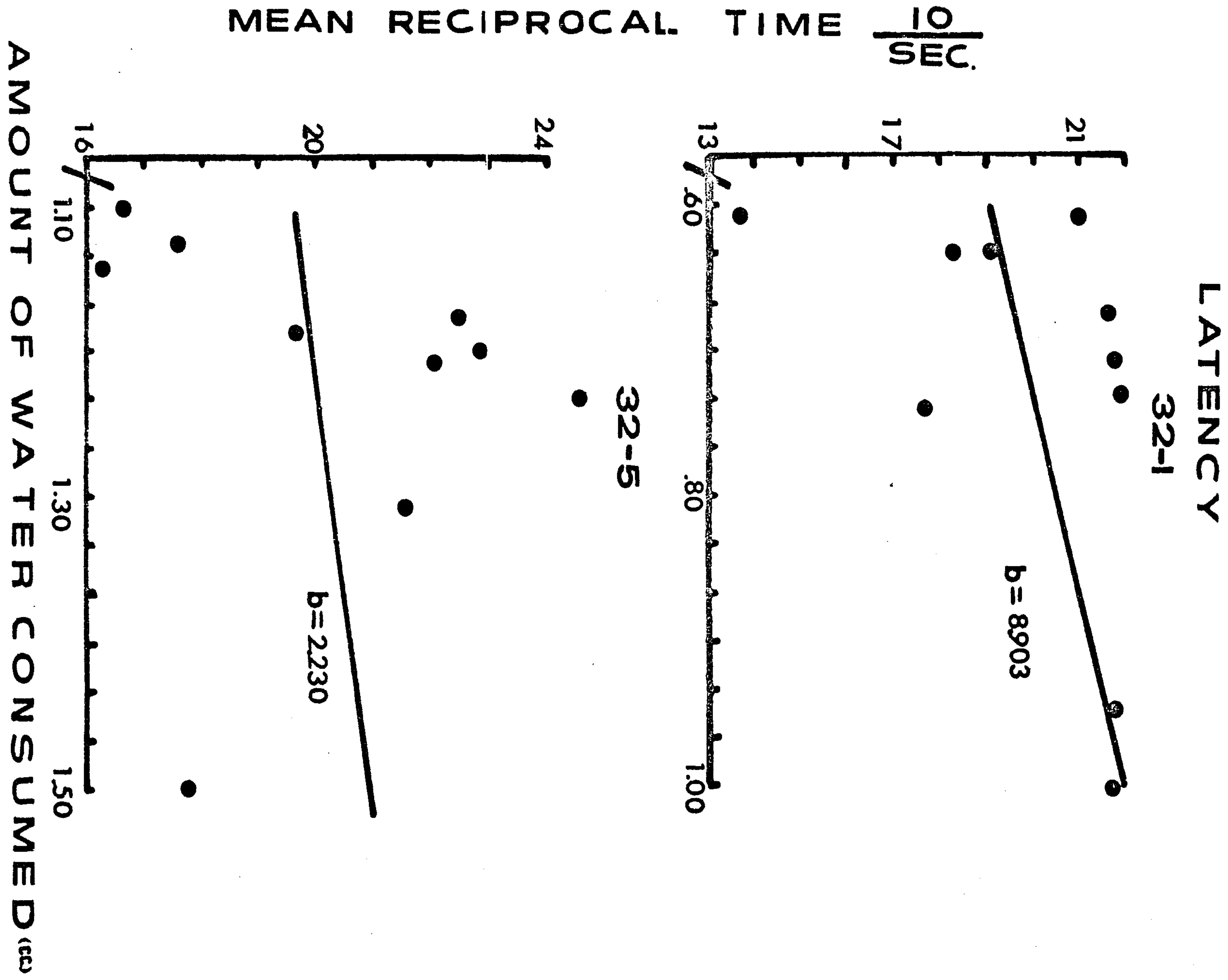
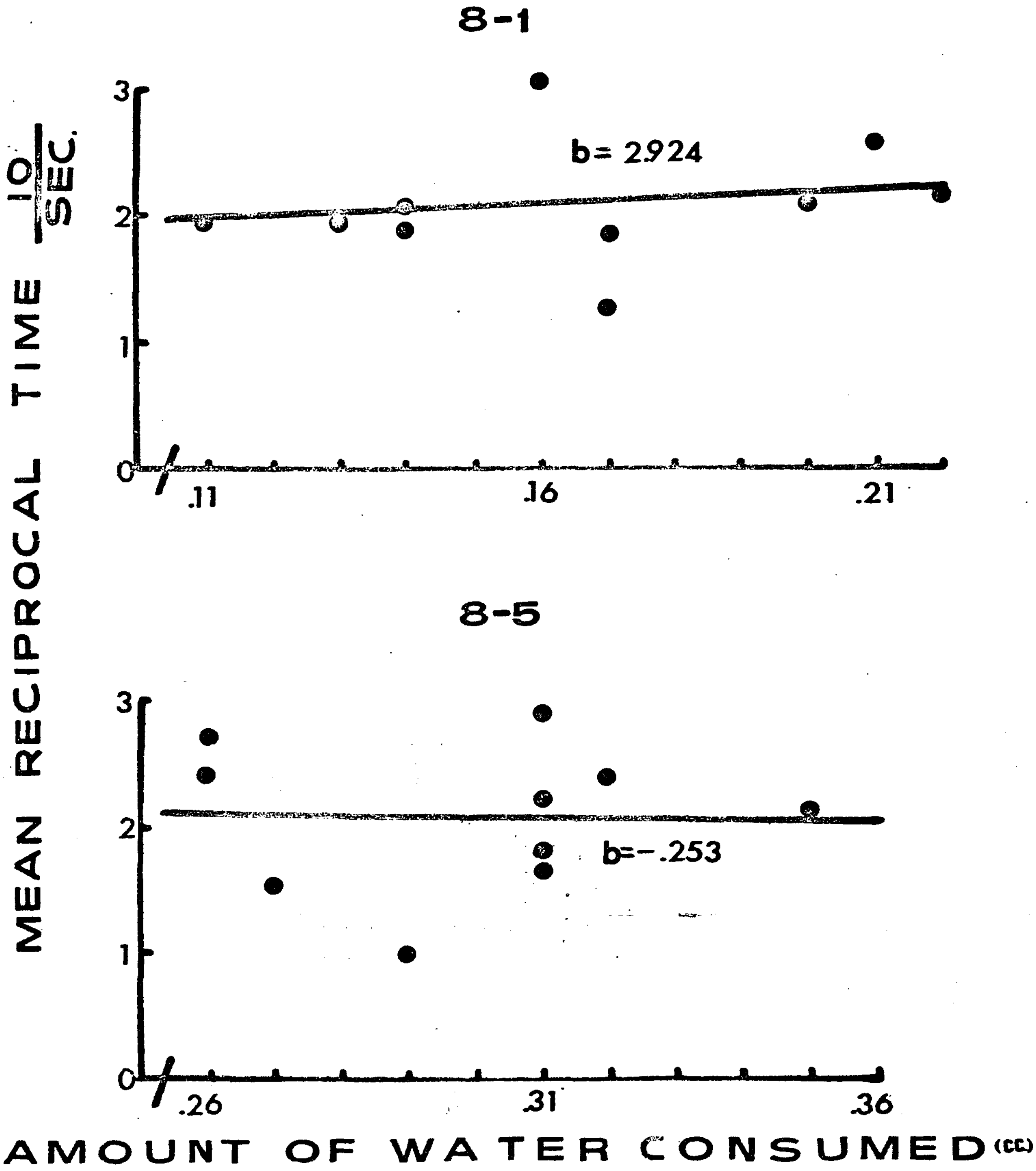

LATENCY
MEAN RECIPROCAL TIME 10/SEC.
AMOUNT OF WATER CONSUMED (cc)
32-1
b= 8.903
13
17
21
.60
.80
1.00
32-5
b= 2.230
16
20
24
1.10
1.30
1.50

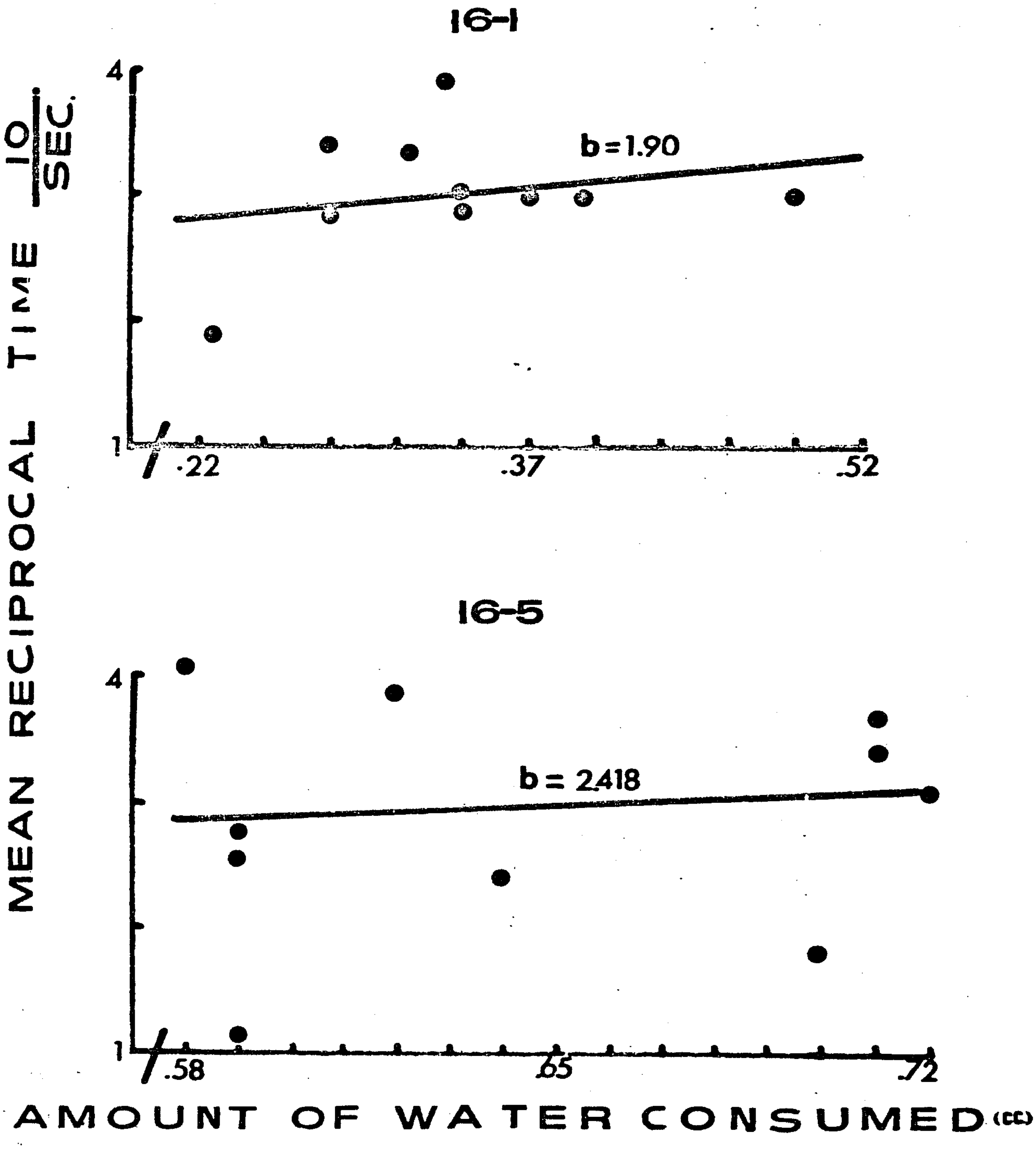
Figure 5

Scatterplots Showing the Relation Between Asymptotic Mean Reciprocal Running Time and Amount Consumed in Experiment 1.

RUNNING TIME



# RUNNING TIME



RUNNING TIME

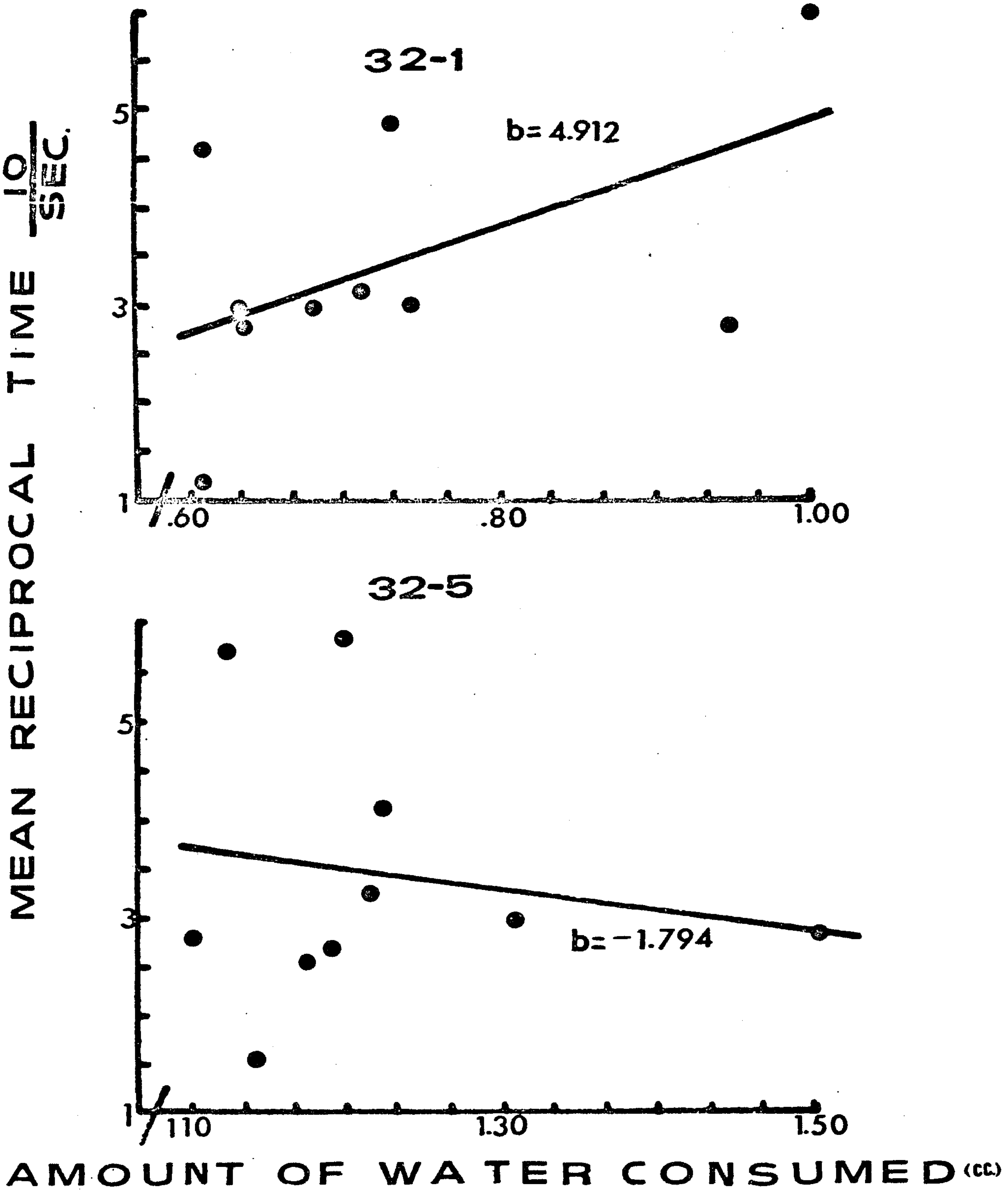
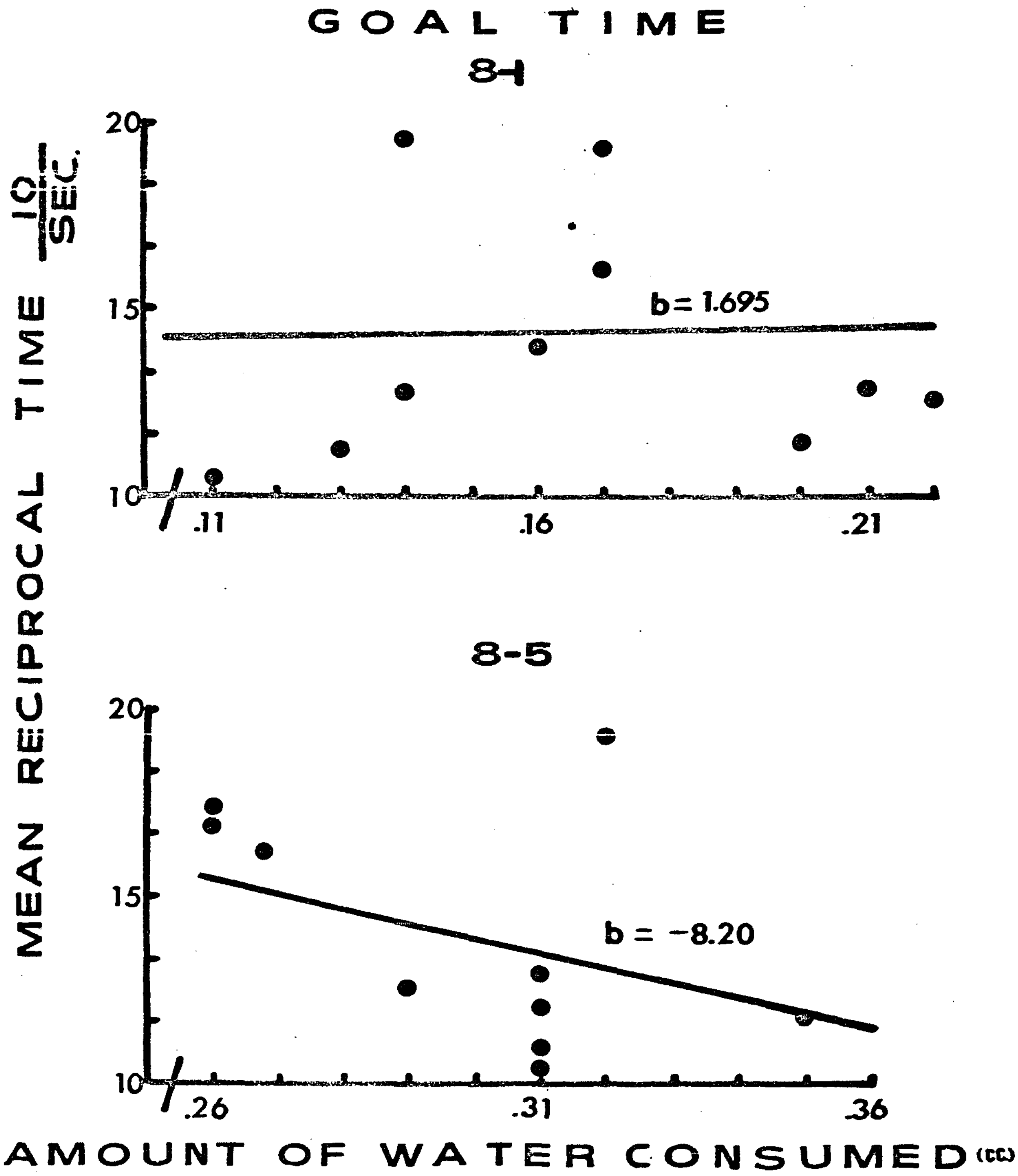
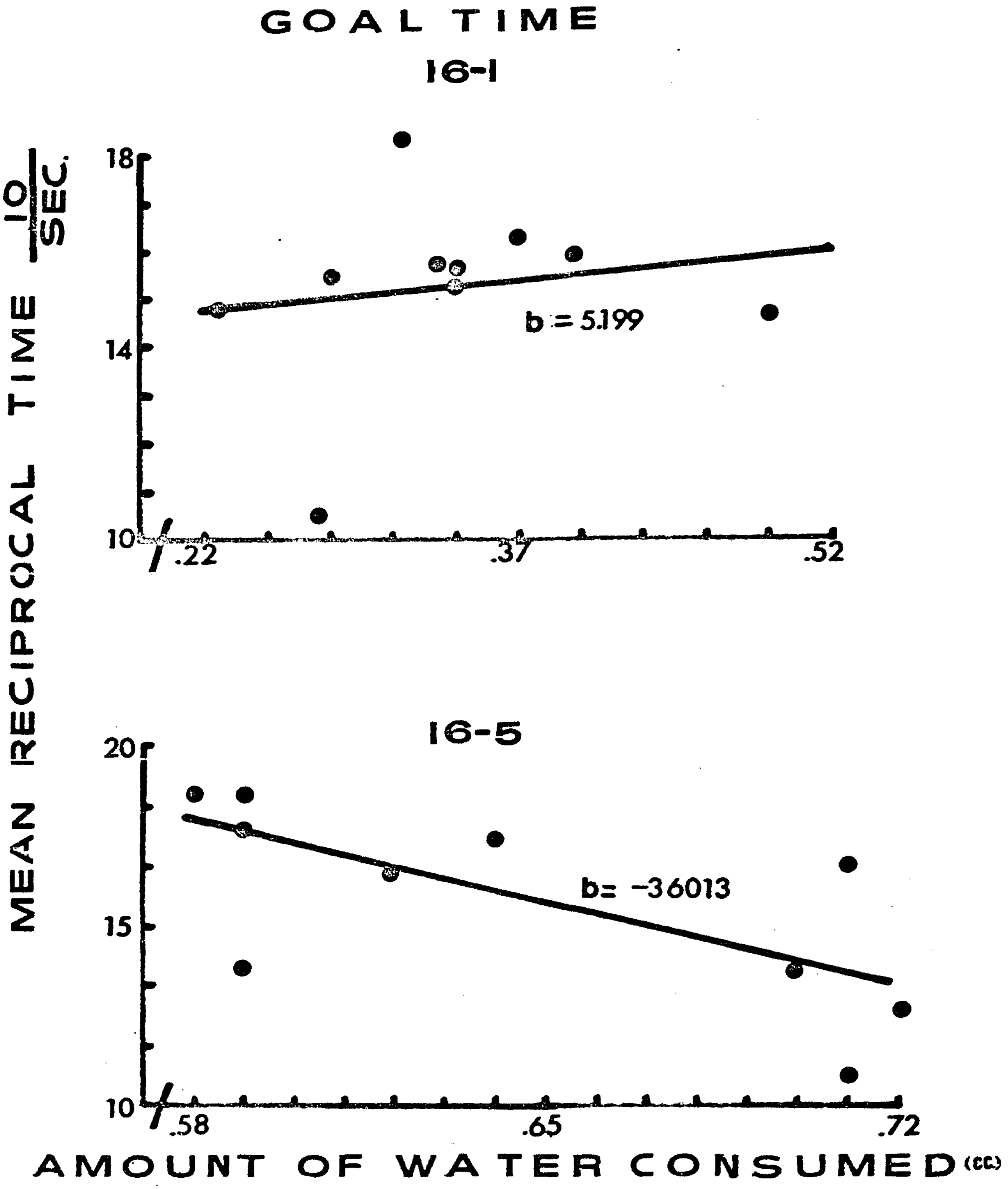


Figure 6

Scatterplots Showing the Relation Between Asymptotic Reciprocal Goal Time and Amount Consumed in Experiment 1.

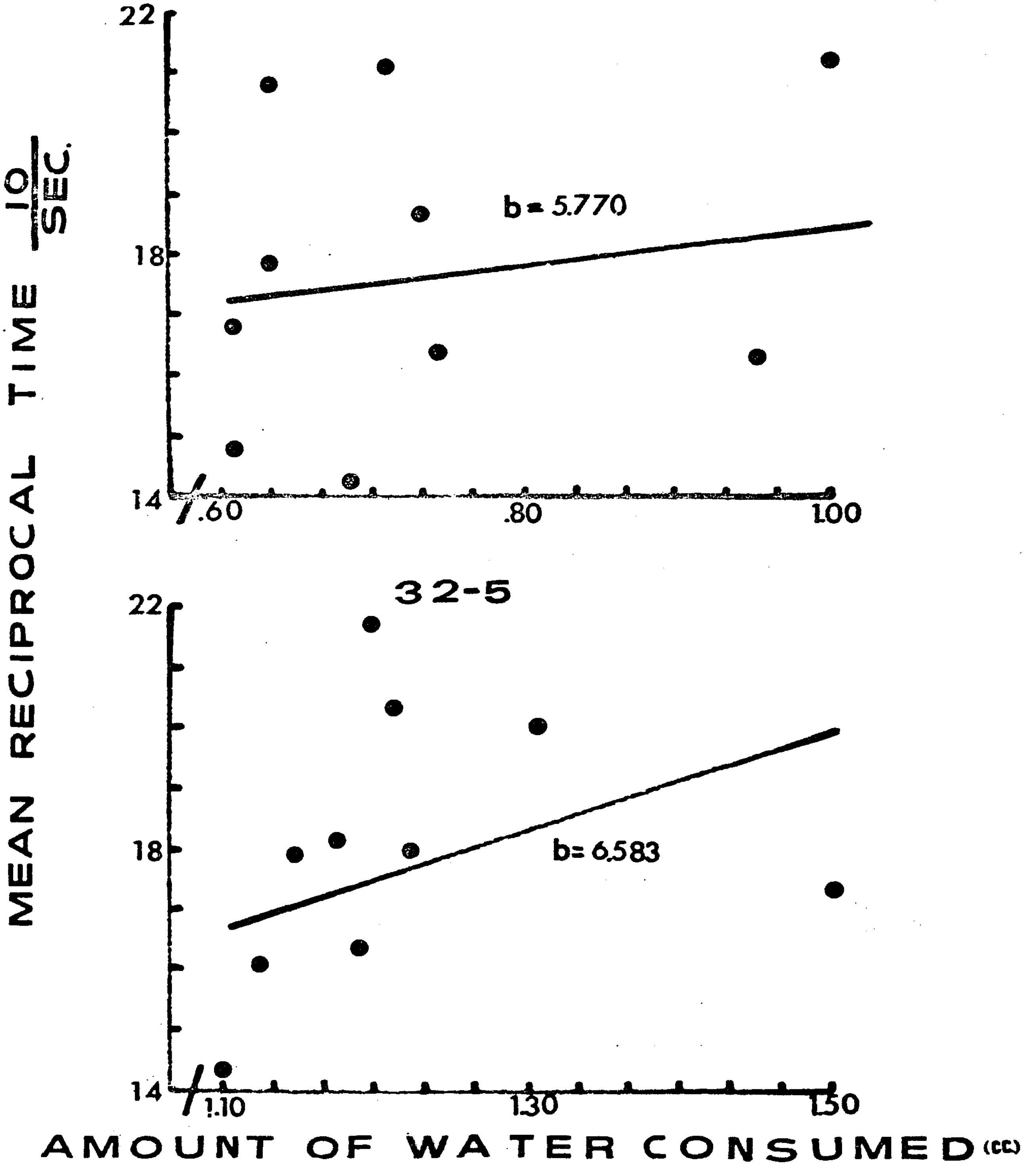

GOAL TIME
8-1
20
15
10
.11
.16
.21
b= 1.695
8-5
20
15
10
.26
.31
.36
b = −8.20
MEAN RECIPROCAL TIME 10/SEC.
AMOUNT OF WATER CONSUMED (cc)

GOAL TIME


16-1

16-5

# GOAL TIME

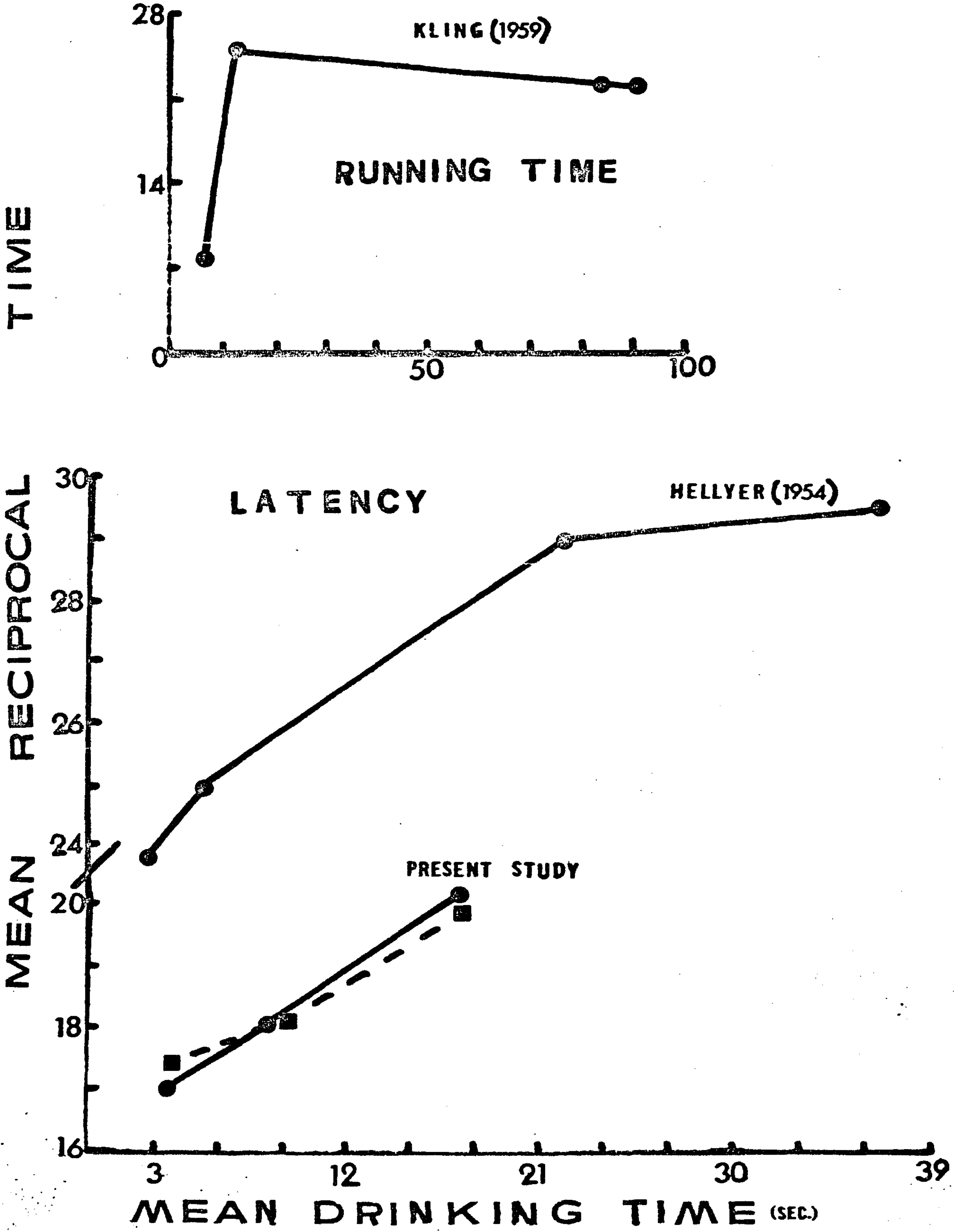


32-1

32-5

Figure 7

Mean Reciprocal Latency or Running Time as a Function of Duration of Mean Time on Drinking Tube in Experiment 1.


KLING (1959)
RUNNING TIME
TIME
28
14
0
50
100
LATENCY
HELLYER (1954)
PRESENT STUDY
MEAN RECIPROCAL
30
28
26
24
20
18
16
3
12
21
30
39
MEAN DRINKING TIME (SEC.)

relationship between the asymptotic speed and duration of time on the drinking tube for Hellyer's groups and those of the present study. Kling's data may also reflect the same relation with the exception of his 12 sec.-5 mm. group.

Anderson (1963) has suggested a general technique for assessing differences in resistance to extinction. This technique, the "shape function" method, can readily be adapted to assess differences in the rate of approach to different acquisition asymptotes. For each S̲ the ratio of the differences between the asymptotic speed and the mean speed over all trials to the difference between the asymptotic and initial speeds was computed. In general, the slower the rate of approach to asymptote, or rate of learning, the larger the resulting ratio, f(n). The data for the last 20 trials were used as an estimate of the asymptotic speed while the mean based on the first 10 trials was used as an estimate of the initial speed. The means for each group for each of the three speed measures using the shape function method are presented in Table 9. Inspection of Table 9 reveals no orderly relationships. Three two-way analyses of variance were performed on these data and the results are presented in Table 10 for the reciprocal latency, running time and goal time measures, respectively. Inspection of Table 10 reveals that no significant differences in the rate measure due to either Duration or Tube Width were found nor was the Duration by Tube Width interaction significant.

Table 9

Means of Shape Function Measure, f(n), for Reciprocal Latency, Running Time and Goal Time in Experiment 1.

| Group | Latency | Running Time | Goal Time |
|---|---|---|---|
| 8-1 | .198 | .161 | .255 |
| 8-5 | .191 | .167 | .248 |
| 16-1 | .134 | .169 | .248 |
| 16-5 | .147 | .196 | .238 |
| 32-1 | .164 | .154 | .231 |
| 32-5 | .171 | .178 | .259 |

## Table 10

Analyses of Variance Based on the Shape Function Measure for the Reciprocal Latency, Running Time and Goal Time Measures in Experiment 1.

| | Latency | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | .0257 | 2 | .0129 | 1.52 |
| Tube Width (TW) | .0006 | 1 | .0006 | .07 |
| D x TW | .0016 | 2 | .0008 | .09 |
| Within | .4491 | 53 | .0085 | |
| Total | .4770 | 58 | | |

Table 10
(Continued)

Analyses of Variance Based on the Shape Function Measure for the Reciprocal Latency, Running Time and Goal Time Measures in Experiment 1.

|  | Running Time |  |  |  |
|---|---|---|---|---|
|  | SS | df | MS | F |
| Source |  |  |  |  |
| Duration (D) | .0003 | 2 | .0002 | .01 |
| Tube Width (TW) | .0016 | 1 | .0016 | .05 |
| D x TW | .0025 | 2 | .0013 | .04 |
| Within | 1.7724 | 53 | .0334 |  |
| Total | 1.7768 | 58 |  |  |

Table 10
(Continued)

Analyses of Variance Based on the Shape Function Measure for the Reciprocal Latency, Running Time and Goal Time Measures in Experiment 1.

| | Goal Time | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | .0023 | 2 | .0012 | .07 |
| Tube Width (TW) | .0008 | 1 | .0008 | .05 |
| D x TW | .0034 | 2 | .0017 | .10 |
| Within | .9395 | 53 | .0177 | |
| Total | .9460 | 58 | | |

Consummatory Response Measures.

A measure comparable to Kling's "ingestion rate" was determined for each S for the last 20 trials by dividing the amount consumed by the measure time spent drinking (Kling, 1959). The mean ingestion rate for the six groups is presented in Table 11. Inspection of Table 11 reveals that the 5 mm. groups had an ingestion rate of almost twice that of the 1 mm. groups. This is not surprising since the 5 mm. groups consumed almost twice as much water for the same duration as their 1 mm. counterparts. A two-way analysis of variance was performed on the ingestion rate data and, as shown in Table 12, revealed a significant Tube Width effect.

Kling (1959) reported a positive relation between asymptotic running speed and ingestion rate. Kling's data and those of the present study are presented in Figure 8. In addition, ingestion rates for Hellyer's results, calculated from group means (since individual organism data were not available), are also presented in Figure 8. Inspection reveals no apparent relation between running speed and ingestion rate for either Hellyer's or the present data. Only Kling's data suggests such a relation. Kling's 15 sec.-2 mm. group consumed only approximately 20% as much water and drank for only half the amount of time as his 15 sec.-5 mm. group. As a result a much smaller ingestion was found for the 15 sec.-2 mm. group than the other groups. The data from the present study, as well as Hellyer's,

Table 11

Mean Ingestion Rate (cc. per sec.) Based on Last Twenty Trials in Experiment 1.

| Reinforcement Duration (in sec.) | 1 mm. Groups | 5 mm. Groups | Combined |
|---|---|---|---|
| 8 | .041 | .084 | .063 |
| 16 | .037 | .076 | .059 |
| 32 | .042 | .071 | .057 |
| Combined | .040 | .077 | .059 |

## Table 12

Analyses of Variance Based on Means of Consummatory Response Measures for the Last Twenty Trials in Experiment 1.

| | Ingestion Rate | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | .000600 | 2 | .000300 | 2.27 |
| Tube Width (TW) | .020400 | 1 | .020400 | 154.55* |
| D x TW | .000465 | 2 | .000230 | 1.74 |
| Within | .007019 | 53 | .000132 | |
| Total | .028484 | 58 | | |

*$p < .05$

## Table 12
(Continued)

## Analyses of Variance Based on Means of Consummatory Response Measures for the Last Twenty Trials in Experiment 1.

Reciprocal First Lick Time

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Duration (D) | .970 | 2 | .485 | .19 |
| Tube Width (TW) | .680 | 1 | .680 | .26 |
| D x TW | 9.130 | 2 | 4.565 | 1.77 |
| Within | 137.121 | 53 | 2.587 | |
| Total | 147.901 | 58 | | |

$^*p < .05$

Table 12
(Continued)

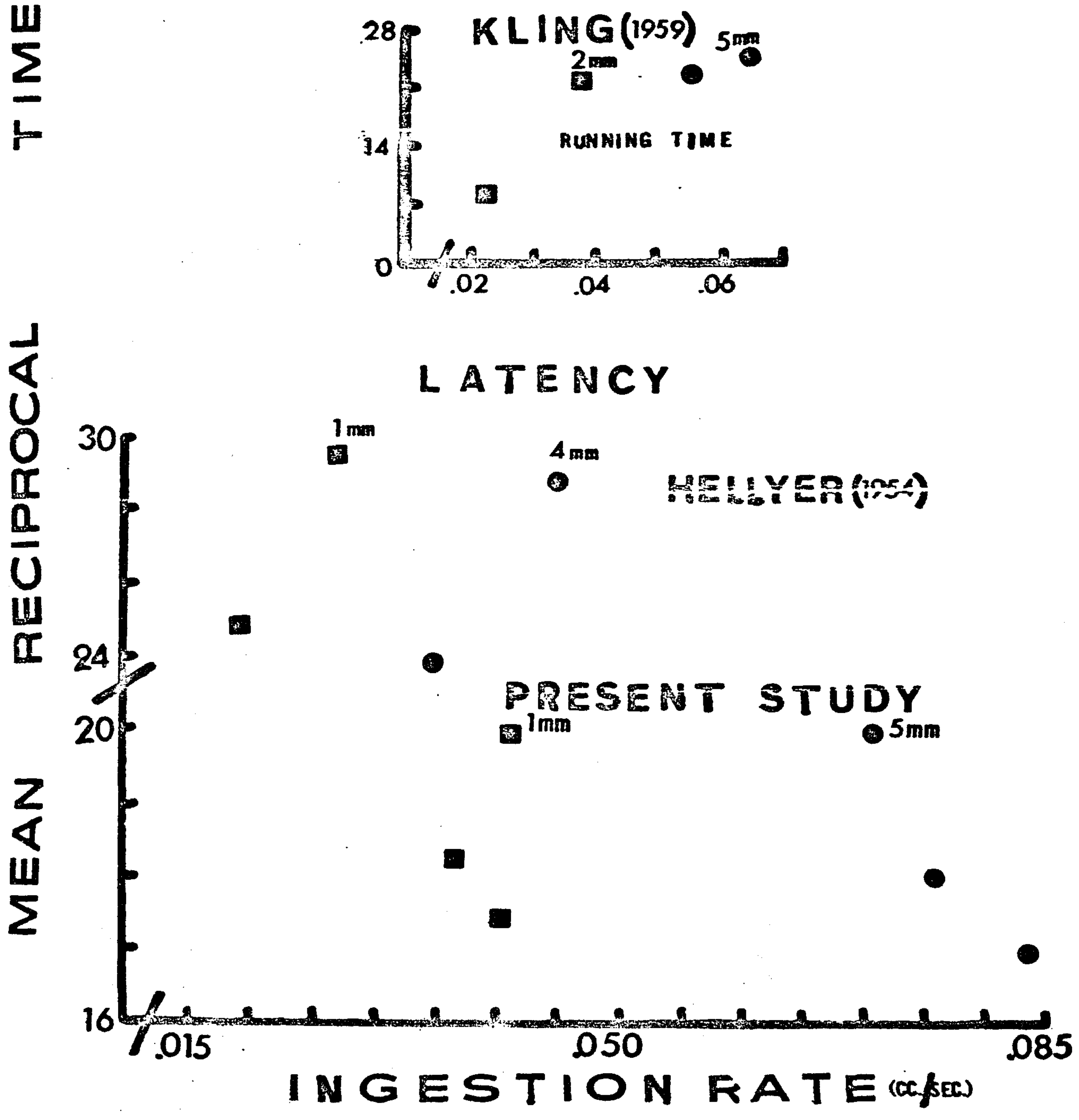
Analyses of Variance Based on Means of Consummatory Response Measures for the Last Twenty Trials in Experiment 1.

| | Lick Rate | | | |
|---|---|---|---|---|
| | SS | df | MS | F |
| Source | | | | |
| Duration (D) | .0090 | 2 | .0045 | .04 |
| Tube Width (TW) | 1.3601 | 1 | 1.3601 | 13.43* |
| D x TW | .0009 | 2 | .0005 | .005 |
| Within | 5.3701 | 53 | .1013 | |
| Total | 6.7401 | 58 | | |

*$p < .05$

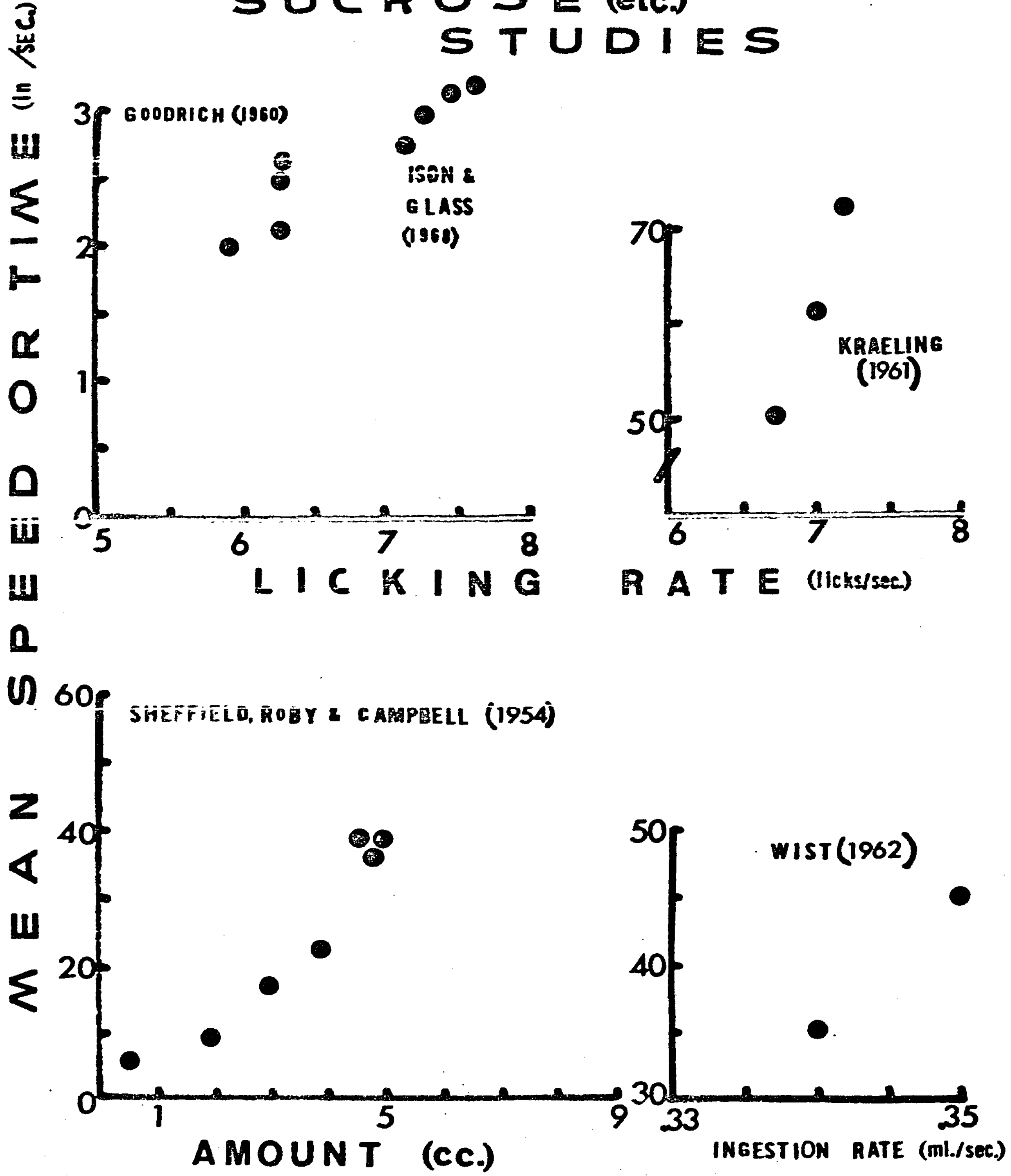
Figure 8

Asymptotic Mean Reciprocal Latency or Running Time as a Function of Ingestion Rate in Experiment 1.



KLING(1959)
28
14
0
2mm
5mm
RUNNING TIME
.02
.04
.06
LATENCY
HELLYER(1954)
1mm
4mm
PRESENT STUDY
1mm
5mm
30
24
20
16
.015
.050
.085
MEAN RECIPROCAL TIME
INGESTION RATE (CC./SEC.)

# SUCROSE (etc.) STUDIES



cluster about a horizontal line. Kling's 15 sec.-2 mm. group is the only one that shows any departure from a horizontal line. Included in Figure 8 are the results of a number of studies that varied the quality of the reinforcer. Almost all revealed a positive relation between ingestion rate and running speed.

The mean number of licks per sec. for blocks of ten trials is presented in Figure 9. Inspection of Figure 9 shows a faster licking rate for the 5 mm. groups over that of the 1 mm. groups. This is compatible with the results of the ingestion rate measure which revealed faster ingestion for the 5 mm. than for the 1 mm. groups. As may be seen from Table 12, which presents the results of a two-way analysis of variance for the lick rate data of the last 20 trials, the Tube Width effect was significant.

If we assume that the amount of water obtained per lick is constant, then the amount consumed divided by the number of licks will yield a volume per lick measure. The volume per lick measure was calculated in this manner for each S based on the last 20 trials and the results are presented in Table 13. Inspection of Table 13 reveals that the 5 mm. groups received approximately 50% more water per lick than the 1 mm. groups. This is not surprising since the 5 mm. groups consumed more water and licked or ingested faster for the same duration of reinforcement than the 1 mm. groups. These differences confirm the previous findings of Snyder and Hulse (1961) who found that the average lick rate increased with increasing volumes per lick up to approximately

Figure 9

Mean Lick Rate as a Function of Blocks of Ten Trials in Experiment 1 (Block 1 has 7 Trials).

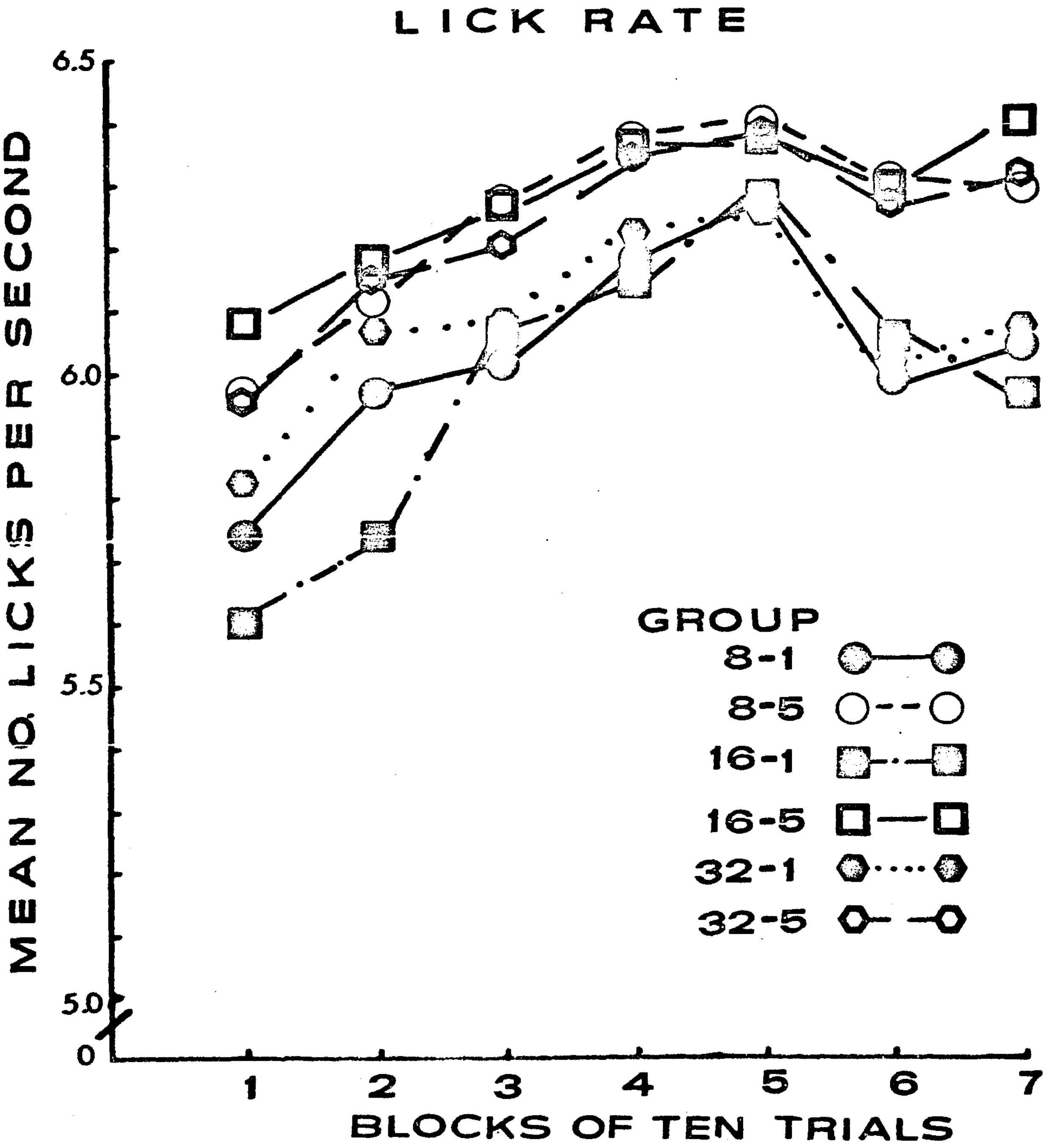

LICK RATE
MEAN NO. LICKS PER SECOND
6.5
6.0
5.5
5.0
0
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
8-1
8-5
16-1
16-5
32-1
32-5

Table 13

Mean Volume of Water (in cc.) Per Lick for the Last Twenty Trials in Experiment 1.

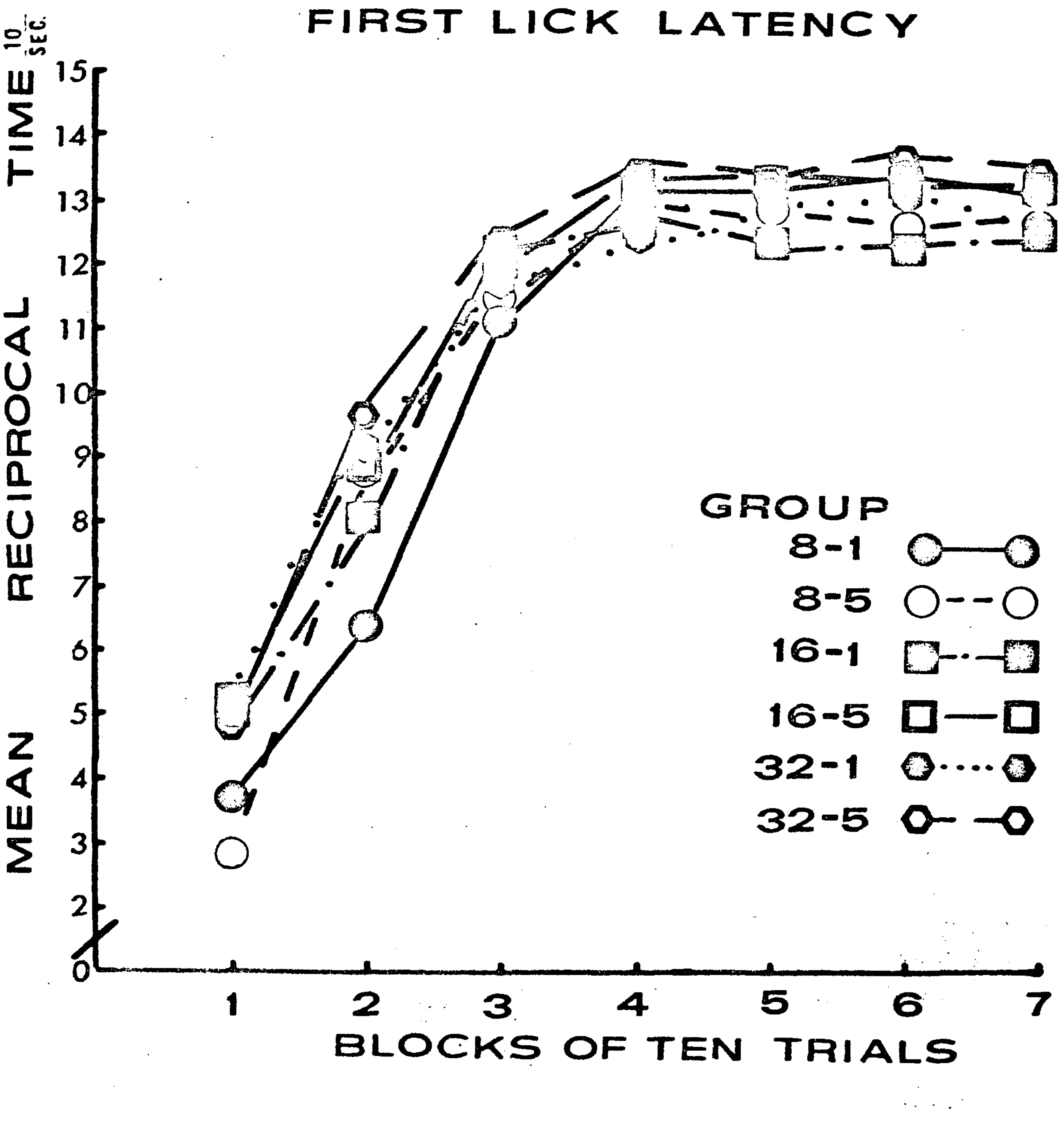
| Reinforcement Duration (sec.) | 1 mm. Groups | 5 mm. Groups | Combined |
|---|---|---|---|
| 8 | .0034 | .0060 | .0047 |
| 16 | .0035 | .0064 | .0050 |
| 32 | .0038 | .0060 | .0049 |
| Combined | .0036 | .0061 | .0049 |

.006 cc. per lick, which is close to the maximum volume found here.

The mean reciprocal first lick time in blocks of ten trials is presented in Figure 10. Inspection of Figure 10 reveals no apparent relation between this measure and Duration or Tube Width. A two-way analysis of variance was performed based on the mean reciprocal first lick time for the last 20 trials, and, as shown in Table 12, revealed no significant effects.

Figure 10

Mean Reciprocal First Lick Time as a Function of Blocks of Ten Trials in Experiment 1. (Block 1 has 7 Trials).


FIRST LICK LATENCY
MEAN RECIPROCAL TIME $\frac{10}{\text{SEC.}}$
0
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
8-1
8-5
16-1
16-5
32-1
32-5

# DISCUSSION

The major finding of the present study was that approximately 2 to 1 differences in the amount of water consumed lead to neglible differences in running behavior when the duration of reinforcement was held constant. In general, the small amount groups, the 1 mm. groups, ran faster than the large amount (5 mm.) groups. In addition, the power analyses revealed that the probability of detecting a difference between conditions of 15% of the Grand Mean due to Amount (Tube Width variable) was .9 for the reciprocal latency measure, while the probability of detecting a 19% difference was .6 for the reciprocal running time measure. Thus the present study was relatively "sensitive" to differences due to amount of reinforcement when duration of reinforcement was held constant.

The apparatus used in the present study was originally constructed to replicate the findings of Goodrich (1959) and Wagner (1961) who had found the reversal of the partial reinforcement acquisition effect in the goal box. As a result the goal time measure was taken in the present study. However, since the goal time measure has special significance only for the latter phenomena, and since most investigators studying magnitude of reinforcement effects do not take goal time measures, the major emphasis here will be on the traditional measures, namely, latency and running time.

Thus, groups of rats receiving 8, 16 or 32 sec. of water reinforcement through a 5 mm. drinking tube did not run faster than their 1 mm. counterparts. In addition, increasing the duration of reinforcement led to at least 10% differences in running speed with the larger duration groups always running the fastest. These results confirm the previous findings of Hellyer who found that larger durations of reinforcement led to faster running speeds. A two-way analysis of variance revealed a significant Duration effect. When the overall design was divided into two factorial designs with 2 to 1 differences in duration of reinforcement, the analyses revealed significant Duration effects in 2 of the 4 cases for the latency and running time measures. This is in line with the results of the power analyses since there was approximately a 50/50 chance of detecting the differences found between the 8-16 sec. and the 16-32 sec. comparisons. Thus, 2 to 1 differences in reinforcement duration did yield significant effects in half of the cases while comparable differences due to amount of reinforcement had no effect at all. In addition, the correlation between amount consumed and asymptotic running speed within each group was extremely low. The present study therefore demonstrates that holding duration constant experimentally leads to wide variations in the amount of water consumed but not in running speed. Thus, these results, along with Hellyer's, strongly support the suggestion that duration of reinforcement is the critical variable in the magnitude of reinforcement effect.

The results of the present study as well as Hellyer's results are not consistent with these of Kling. Kling failed to find a positive relation between running speed and duration of reinforcement. Inspection of Klings' data, as shown in Figure 7, revealed that only one group upset the relation between duration and speed. Specifically, a group that received an average of .79 cc. of water per trial through a 5 mm. hole and drank for 12 sec. ran faster than groups drinking for more than 83 sec. Inspection of Figure 7 also revealed that the form of the function relating speed to duration of reinforcement (as measured by duration of tube contact) was essentially the same for the present study and for that of Hellyer. The faster running found by Kling for a group drinking for 12 sec. compared to groups drinking for more than 83 sec. may be due to incompatible responses that may have occurred as a result of the relatively long duration of goal box confinement. In particular under 120 sec. confinement 83.9 sec. and 91.5 sec. were spent drinking or 36.1 and 28.5 sec. were spent in other activities by his 5 mm. and 2 mm. groups, respectively.

Kling also reported a positive relation between asymptotic running speed and ingestion rate. This finding was not confirmed in the present study nor in that of Hellyer. In fact, for both studies the function relating asymptotic speed to ingestion rate was essentially horizontal, implying no relationship. Examination of Kling's data reveals that his 15 sec.-2 mm. group had a much lower ingestion rate than his other three groups, all of which had similar ingestion rates. This group is the only one inconsistent with the results of the present study and that of Hellyer. Compared with the data from the other three groups of Kling's study it gives the appearance of a positive relation between speed and ingestion rate. The 15 sec.-2 mm. group consumed only .14 mL. of water in 6.3 sec. while the 15 sec.-5 mm. group consumed .79 mL. of water in 12 sec. The large difference in amount consumed and drinking time resulted in a much lower ingestion rate for the 2 mm. group than the 5 mm. group. This may have been as a result of the use of an electronic relay to record consummatory behavior. The Ss in the 2 mm. groups may have received some electrical shocks while licking and only those who received the longer duration may have "recovered" from the effects of "shock". This suggestion is supported by Kling's data since his 15 sec.-2 mm. group drank only half as long as the comparable 5 mm. group and consumed only 20% as much water. Weinstock (private communication) reported observing rats "pulling away" from the drinking tube and "shaking their heads" when an electronic relay was used to record consummatory behavior. In addition, in an unpublished pilot study, the present author found that licking rates of rats allowed to drink water for 30 sec. were affected by the recording technique. Specifically, those Ss licking from a drinking tube attached to a Grason-Stadler Drinkometer and a Farmer Electric photoelectric cicuit licked approximately 10% slower than Ss licking from a tube attached to a photoelectric circuit only. These differences, however, disappeared after 10 days of training. The electronic relay used by Kling probably delivered more shock than the Grason-Stadler Drinkometer and may have created a "conflict" which was expressed in the running data. It should be noted that Kling gave his Ss only 13 trials (n = 6 per group) and they may have just been recovering from the effects of shock when he terminated the study. The observations of the effects of using electronic circuits on consummatory behavior led to the use in this study of a photocell circuit suggested by Collier with the consequence that the present data are free from contamination by electrical shocks. Thus Kling's finding of a positive relation between ingestion rate and running speed may be an artifact due to the use of an electronic relay to record consummatory behavior.

Groups of rats who drank through a 5 mm. tube had significantly faster rates of licking and significantly higher ingestion rates than groups of rats drinking through a 1 mm. hole. These findings replicate Snyder and Hulse (1961). However, no differences were found in these measures as a function of the duration of reinforcement. Hellyer reported similar findings. Thus the present study supports the view that there is no relation between consummatory responding and running behavior when the quality of reinforcement is held constant.

There results are not in accord with those obtained by varying the quality of reinforcement. The apparent contradiction may perhaps be resolved by the argument of Knarr and Collier (1962) that varying the quality of a reinforcing substance may result in different "sensory consequences" which affect running and consummatory behavior independently. Since different durations of water reinforcement may be expected not to yield differential sensory consequences, their argument would predict no correlation between consummatory and running behavior in this case.

The results of studies in which the quality of reinforcement is varied are generally in line with theories that emphasize vigor of consummatory responding. Clearly such theories fail to account for the lack of a relation between consummatory responding and running behavior when the quality of reinforcement is held constant. No relation was found in the present study between licking rates and other measures of consummatory behavior and running speed. This replicates the previous findings of Snyder and Hulse (1961) who also used a variety of consummatory response measures. Taken together they suggest that Spence's view that differences in the "vigor" of the consummatory response lead to differences in running behavior through the $r_g$-$s_g$ mechanism may be in error. Spence also proposed that longer durations of reinforcement may also lead to a stronger $r_g$-$s_g$ and thereby to faster running. However instrumental response strength for different reinforcement durations should converge since large numbers of trials should eventually lead to the same level of classical conditioning of $r_g$s. No such convergence was found due to reinforcement duration in the present study. The failure to find any differences in consummatory responding due to Duration further weakens the argument.

The lack of a correspondence between consummatory responding and running is not disturbing from a contiguity viewpoint, since the consummatory response may be assumed to be under the control of internal stimulation whereas the running response may be largely dependent upon external stimulation. A similar line of reasoning has recently been suggested by Hulse (1966).

In conclusion, groups receiving the same duration of reinforcement did not differ in running behavior, although approximately 2 to 1 differences in the amount consumed were found. Furthermore, a very low and non-significant correlation was found between amount consumed and running behavior within each group. In addition, it was revealed that when a water reinforcement is used, no relationship exists between running speed and a variety of measures of consummatory activity, namely, lick rate, ingestion rate, volume per lick and latency to the first lick. However, comparable variation in the duration of reinforcement did produce significant differences in running behavior but not in consummatory behavior. These results can be interpreted as providing strong support for Hellyer's stimulus trace interpretation of the effect of reinforcement magnitude.

# EXPERIMENT 2

It was considered likely that the results of Experiment 1 would indicate that duration rather than amount of reinforcement is the major variable in magnitude of reinforcement studies. Since amount and duration of reinforcement have typically been confounded, studies purporting to demonstrate the effects of amount of reinforcement also demonstrate the effects of reinforcement duration. Thus the studies of Crespi (1942) and Zeaman (1949) can readily be interpreted in terms of duration of reinforcement. Only Slough (1959) varied reinforcement duration directly and found significantly faster running for a group of rats receiving 30 sec. than for a group receiving 5 sec. of water reinforcement. It was therefore decided to perform a parametric study of the effects of duration of reinforcement on running behavior.

A major goal of the present study was to determine a specific functional relationship between magnitude of reinforcement and running behavior. Estes (1950) presented a response model relating probability of response, p, to response latency. He assumed that latency is recorded after the completion of the first occurrence of an R response. As a result, behavior on any given trial can be viewed as a string of $\bar{R}$s (any response other than an R until one R occurs). If it is assumed that an R or an $\bar{R}$ takes h sec. to complete the following expression for average latency is obtained

$$(1) \quad \bar{L}=h/p.$$

Bush and Mosteller (1955) extended the Estes model by assuming that k "steps" or successive Rs are necessary before the organism traverses the distance corresponding to the response latency. They showed that the distribution of "waiting times" or latencies is a gamma distribution where the average latency is

$$(2) \quad \bar{L}=c + k/(sp),$$

where k is the number of steps, s is a "scale factor" and c is the minimum time to make a response. Thus, probabilistic learning theories provide a response model which relates its theoretical dependent variable of probability of a response, p, to an experimental dependent variable, the average latency of the response, $\bar{L}$.

One of the major shortcomings of the theories of Hull (1943) and Spence (1956) was the failure to carry through a program relating the theoretical dependent variable, excitatory potential, $\bar{E}$, to experimental dependent variables. Burke (1948) attempted to provide the needed relation. A combination of empirical and mathematical considerations led him to assume that

$$(3) \quad \bar{L}=c + c'/\bar{E}.$$

Using (3) and parameter values estimated from asymptotic data in the runway, Burke "predicted" the behavior during acquisition. Furthermore, Cotton (1955) used the same relation between $\bar{E}$ and $\bar{L}$ to deal with data from an experiment in which drive level was varied. If they are not the only studies, these two are among the few performed from a Hullian viewpoint for which it can be claimed that "parameter recovery" was achieved or that quantitative predictions were made. The above borrows heavily from Weinstock (unpublished) who observed that the equations (2) and (3) differ only in the replacement of p by $\bar{\bar{E}}$ and who therefore urged theorists working within a Hullian framework to adopt the probabilistic response model.

Spence (1954) suggested two models to relate $\bar{\bar{E}}$ to latency, one comparable to Estes' (1950) one-step model, the other to Bush and Mosteller's (1955) k-step model. He also derived relations between speed and $\bar{\bar{E}}$ which were similar in form to equations (1) and (2). In this analysis Spence apparently assumed that $(1/\bar{L})$ was equal to $(\overline{1/L})$. As a result theoretical predictions regarding the relationship of $(1/\bar{L})$ to various independant variables could be related to most of the experimental literature, since $(\overline{1/L})$ is the response measure that is usually employed experimentally. It is interesting to note that theories stressing extremely different mechanisms result in the same quantitative form. Weinstock (unpublished) developed a stimulus sampling model for asymptotic probability of responding, $p_\infty$, based on Hellyer's stimulus trace interpretation of reinforcement magnitude. At asymptote the resulting probability of response as a function of reinforcement duration is

$$(4) \quad p_\infty = c_2 - c_3 (1 - \beta)^{c_1 t_1},$$

where $c_2$, $c_3$ and $(1 - B)^{c_1}$ are constants and $t_1$ is reinforcement duration. Substituting (4) in (2) and combining certain constants, yields the following expression for average asymptotic latency:

$$(5)\quad \bar{L}_{\infty} = c + 1/\left[c_4 - c_5(1 - \beta)^{c_1 t_1}\right].$$

Thus, average asymptotic latency should be a decay function of duration of reinforcement. It should be noted that Hullian theory would result in the same functional relation if the assumption were made that $\bar{\bar{E}}$ is a growth function of duration of reinforcement.

Thus, in the present experiment it was decided to attempt to fit a function relating reinforcement duration to asymptotic latency using equation (5). Since Bush and Mosteller's response model assumes that S cannot retrace, a latency measure 1 in. past the start box door was taken here to meet this assumption. Experiment 2 represents an attempt to evaluate the quantitative relation between asymptotic running behavior and reinforcement magnitude. Four groups of rats were given 4, 24, 48 or 64 sec. of water reinforcement through a 1 mm. tube. Since Experiments 1 and 2 were done concurrently the 8, 16 and 32 sec.-1 mm. groups from Experiment 1 were included in the parametric analysis. In addition, another group of rats was given pretraining to drink in the goal box through a 1 mm. or 5 mm. tube using various durations of reinforcement prior to receiving runway trials as a procedural control. Specifically, it was feared that the 4 sec.-1 mm. group would not develop stable drinking behavior and that its running behavior would not be interpretable.

Furthermore, combinations of tube width and duration of reinforcement might exist so that a group given a longer duration through a 1 mm. tube would consume a smaller amount of reinforcement than a group given a shorter duration through a 5 mm. tube. If the larger duration group ran faster than the larger amount group, this would provide extremely strong support for a consummatory time interpretation of the magnitude of reinforcement effect.

# METHOD

## Subjects

Fifty female albino rats, 100-110 days old at the start of the experiment were acquired from Albino Farms, Little Silver, New Jersey.

## Apparatus

The apparatus used and the response measures recorded were the same as in Experiment 1.

## Procedure

The gentling and adaptation to deprivation procedure used was the same as that in Experiment 1. Specifically, two weeks before the beginning of the experiment Ss were gentled and habituated to a 20 hr. water deprivation schedule. Throughout the experiment Ss were given one trial per day under 19-22 hr. of water deprivation. Each group was divided into two squads and the squads were run in a different random order each day.

Four groups of ten rats each received 4, 24, 48 or 64 sec. of water reinforcement through the 1 mm. tube and were designated as Groups 4-1, 24-1, 48-1 and 64-1, respectively. Another group of ten rats (Group 4C) received 18 days of pretraining to drink in the goal box prior to the introduction of running trials. The six combinations of reinforcement duration and tube width were given in a different random order for each S. This procedure was repeated three times so that each S in Group 4C had three trials at each of the combinations of reinforcement duration duration and tube width. On the first pretraining trial the glass drinking tube projected into the drinking area and on subsequent trials the tube was gradually withdrawn so that by trial 4 the tip of the drinking tube was ½ in. behind the opening in the wall. The remaining Ss received equivalent handling during this time. All Ss were then given runway training trials. All Ss received 100% reinforcement throughout the course of the study. The Ss in group 4C were given 4 sec. of water reinforcement through the 1 mm. tube during the runway trials.

The runway training procedures used were the same as in Experiment 1 except that for Group 4C the tip of the glass drinking tube was placed ½ in. behind the opening in the end wall of the goal box at the outset of training. Since Experiments 1 and 2 were done concurrently, 71 trials at 100% reinforcement were given.

Five Ss were discarded for failure to drink or run on the early training trials and ten Ss died or developed middle ear infection. This left 6 Ss in Group 48-1, 8 in Group 64-1 and 7 Ss each in Groups 4C, 4-1 and 24-1.

## RESULTS

Latency, running time, goal time and first lick time were converted to reciprocals (10/sec.) throughout.

### Runway Response Measures.

In Figure 11 is presented the mean asymptotic reciprocal latency, $(\overline{1/L})$, as a function of duration of reinforcement for the present data as well as those of Hellyer. In addition, the mean asymptotic reciprocal latencies for Grindly's and Crespi's data are also presented. Inspection of Figure 11 reveals a fairly linear relation for the present as well as for Hellyer's data. Since at zero "reinforcement magnitude" some variables may have much larger effects than at non-zero values (e.g. runway width) the zero point may be eliminated from the functional relation. Ignoring the zero group in Grindly's data results in a straight line function for the remaining points. Inclusion of the zero point gives rise to a negatively accelerated function such as the one Hull (1943, page 126, Figure 28) fitted to Grindly's data. Crespi's data reveal a similar relation when the zero point is eliminated, although inclusion of the largest value of reward magnitude (256 gm.) shows that the function begins to level off there.

In Figure 12 the mean latency is plotted as a function of

Figure 11

Mean Asymptotic Reciprocal Latency ($\overline{1/L}$) or Reciprocal Mean Asymptotic Latency ($1/\overline{L}$) as a Function of Duration of Reinforcement in Experiment 2.

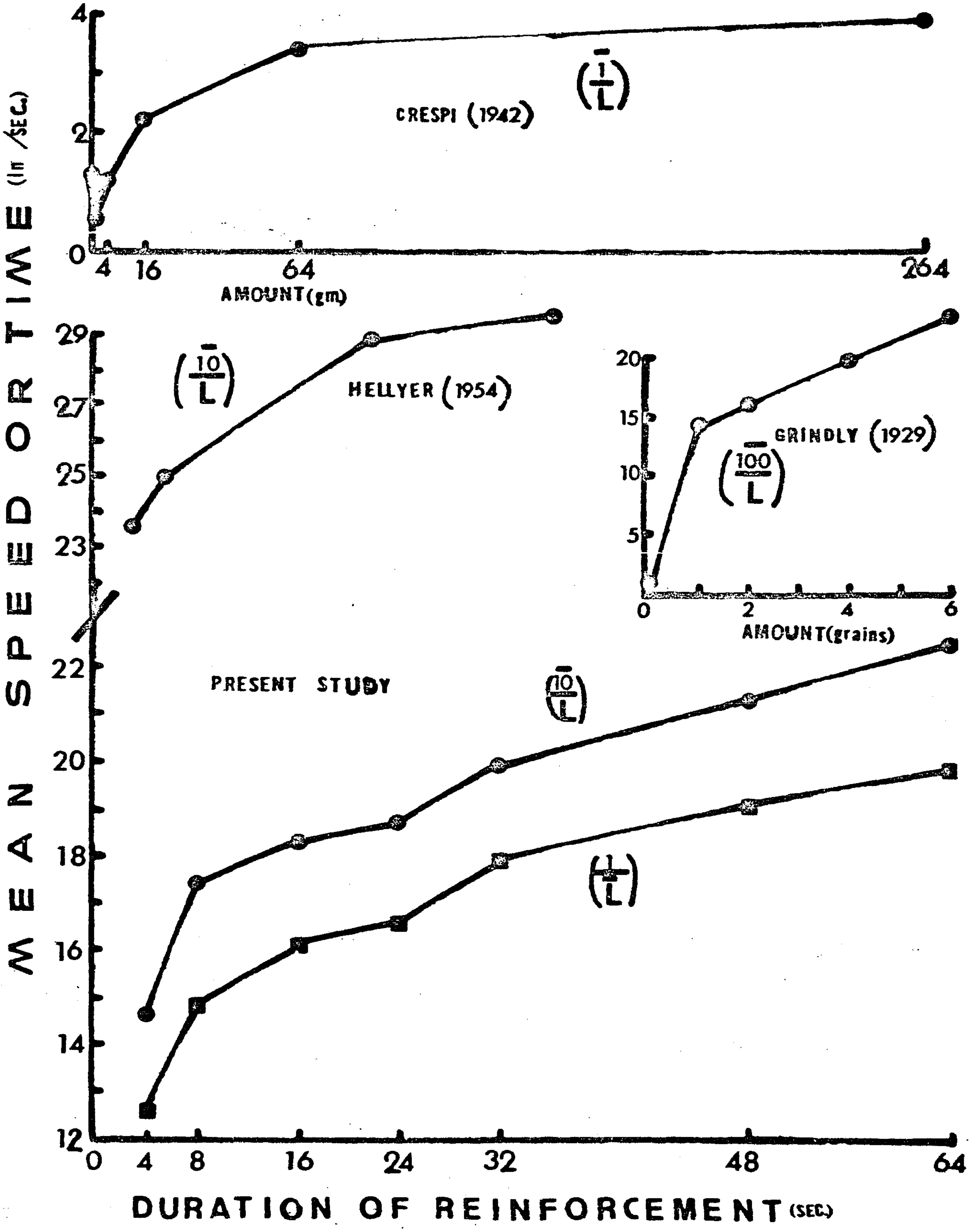
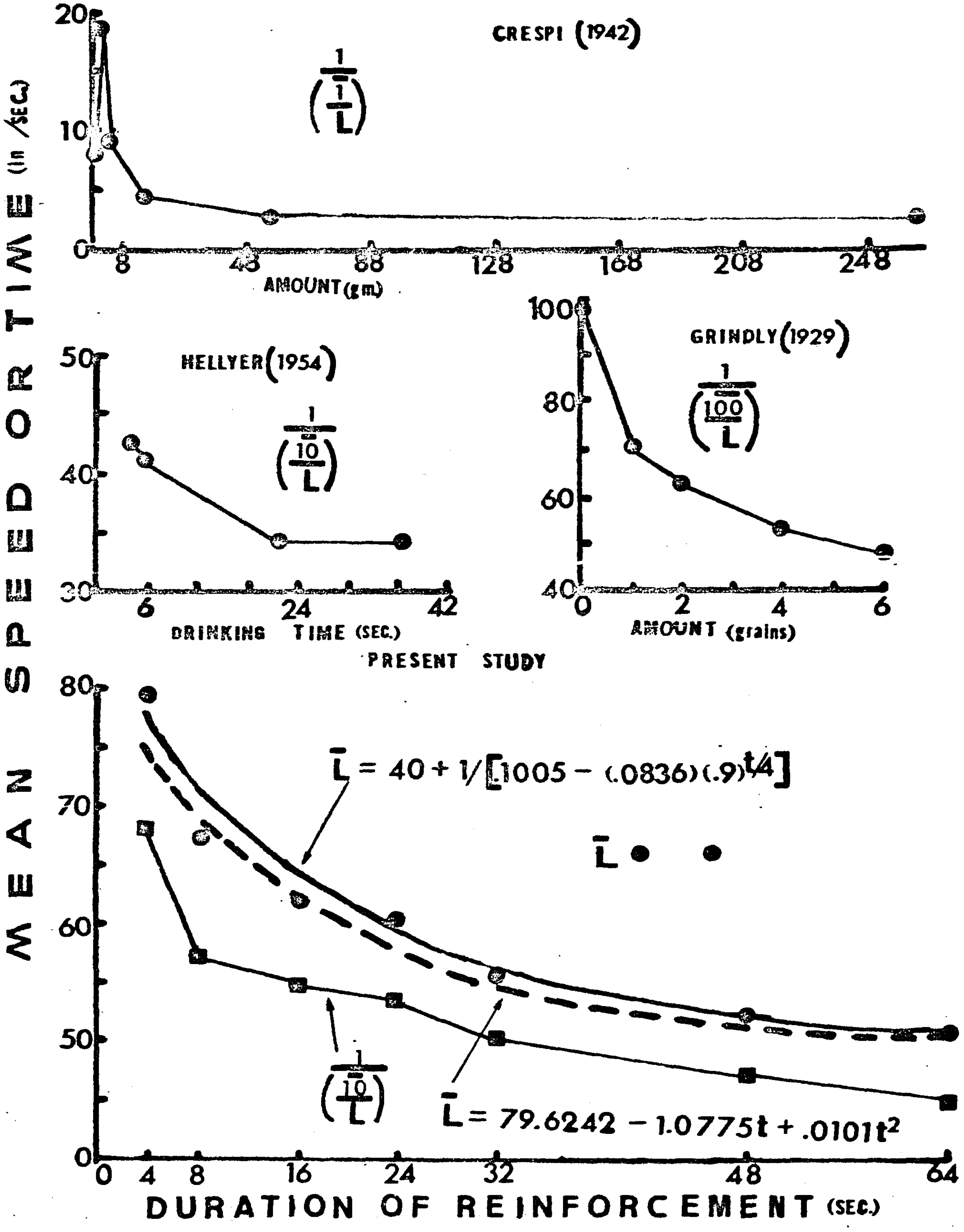

MEAN SPEED OR TIME (In /SEC.)
4
2
0
4
16
64
264
AMOUNT(gm)
CRESPI (1942)
$\left(\frac{\bar{1}}{L}\right)$
29
27
25
23
$\left(\frac{\bar{10}}{L}\right)$
HELLYER (1954)
20
15
10
5
0
2
4
6
AMOUNT(grains)
GRINDLY (1929)
$\left(\frac{\bar{100}}{L}\right)$
PRESENT STUDY
$\left(\frac{\bar{10}}{L}\right)$
$\left(\frac{\bar{1}}{L}\right)$
22
20
18
16
14
12
0
4
8
16
24
32
48
64
DURATION OF REINFORCEMENT (SEC.)

Figure 12

Mean Asymptotic Latency ($\overline{L}$) or Reciprocal of the Mean Asymptotic Reciprocal Latency $1/(\overline{1/L})$ as a Function of Duration of Reinforcement in Experiment 2.


MEAN SPEED OR TIME (in /SEC.)
CRESPI (1942)
$\frac{1}{\left(\frac{1}{L}\right)}$
20
10
0
8
48
88
128
168
208
248
AMOUNT (gm)
HELLYER (1954)
$\frac{1}{\left(\frac{10}{L}\right)}$
50
40
30
6
24
42
DRINKING TIME (SEC.)
GRINDLY (1929)
$\frac{1}{\left(\frac{100}{L}\right)}$
100
80
60
40
0
2
4
6
AMOUNT (grains)
PRESENT STUDY
80
70
60
50
0
$\bar{L} = 40 + 1/[1005 - (.0836)(.9)^{t/4}]$
$\bar{L}$ ● ●
$\frac{1}{\left(\frac{10}{L}\right)}$
$\bar{L} = 79.6242 - 1.0775t + .0101t^2$
0
4
8
16
24
32
48
64
DURATION OF REINFORCEMENT (SEC.)

reinforcement duration and inspection reveals a negatively decelerating function. In Figure 11 is presented the reciprocal mean latency $(1/\bar{L})$, for the present study, as a function of reinforcement duration. Inspection of Figure 11 reveals that when the reciprocal of the mean latency is plotted a relatively linear function results. Similarly, as shown in Figure 12, when the reciprocal of the mean reciprocal latency is plotted, $1/(\overline{1/L})$, a negatively decelerated function results. In Table 14 is shown the mean reciprocal latency $(\overline{1/L})$, the reciprocal mean latency $(1/\bar{L})$ and the difference between the two measures for the 1 mm. and 5 mm. groups of Experiments 1 and 2. Inspection of Table 14 reveals no relation between the difference and reinforcement duration. Thus the difference appears to be fairly constant. As a result the relation between the two measures for the present data may be expressed as

$$(6) \quad (\overline{1/L}) = (1/\bar{L}) + k,$$

where k is a constant.

The data from the seven 1 mm. groups were used to estimate the four "free" parameters, $c$, $c_4$, $c_5$ and $(1 - \beta)$, of the theoretical function for $\bar{L}$ (equation 6). This was done using the method of selected points and an iterative procedure suggested by Williams (1959). The resulting function,

$$(7) \quad \bar{L} = 40 + 1/\left[.1005 - (.0836)(.9)^{t/4}\right],$$

is presented graphically in Figure 12 and reveals a very close correspondence between the observed and theoretical functions

Table 14

Mean Reciprocal Latency ($\overline{1/L}$), Reciprocal Mean Latency ($1/\overline{L}$) and Difference Between the Measures Based on the Last Twenty Trials in Experiment 2.

| Group | ($\overline{1/L}$) | ($1/\overline{L}$) | Difference |
|---|---|---|---|
| 1 mm. Groups | | | |
| 4-1 | 14.65 | 12.57 | 2.08 |
| 8-1 | 17.41 | 14.83 | 2.58 |
| 16-1 | 18.26 | 16.16 | 2.10 |
| 24-1 | 18.63 | 16.58 | 2.05 |
| 32-1 | 19.88 | 17.98 | 1.90 |
| 48-1 | 21.28 | 19.09 | 2.19 |
| 64-1 | 22.40 | 19.77 | 2.63 |
| 5 mm. Groups | | | |
| 8-5 | 16.95 | 13.89 | 3.06 |
| 16-5 | 18.04 | 15.65 | 2.39 |
| 32-5 | 20.17 | 17.99 | 2.18 |

may be observed. The theoretical function removes approximately 97% of the original variance of the group means about the Grand Mean.

A trend analysis (Robson, 1959) was performed on the relation between the asymptotic mean latency and reinforcement duration. Using the Within Group Variance as an estimate of the error term, a significant linear component (_F_ = 21.96, _df_ = 1/50, $p < .05$) and a significant quadratic component (_F_ = 4.07, _df_ = 1/50, $p < .05$) was revealed. Approximately 77.7% and 14.3% of the SS of the group means about the Grand Mean was accounted for by the linear and quadratic components, respectively. Since only 8% remained, the cubic component would obviously not be statistically significant.

Since the trend analysis revealed a significant linear and quadratic component, the three free parameters of a second degree polynomial were estimated. The resulting function,

$$(8) \quad \bar{L} = 79.6242 - 1.0775t + .0101t^2,$$

is presented in Figure 12. Inspection of Figure 12 reveals a fairly close correspondence to the present data, although not as close as that resulting from the theoretical expression. This is not surprising since the theoretical expression involved four free parameters, while the polynomial involved only three.

Mean reciprocal latency, running time and goal time as functions of blocks of ten trials are presented in Figures 13, 14 and 15, respectively. Inspection reveals that as the duration of reinforcement increased, the three reciprocal measures

Figure 13

Mean Reciprocal Latency as a Function of Blocks of Ten Trials in Experiment 2.

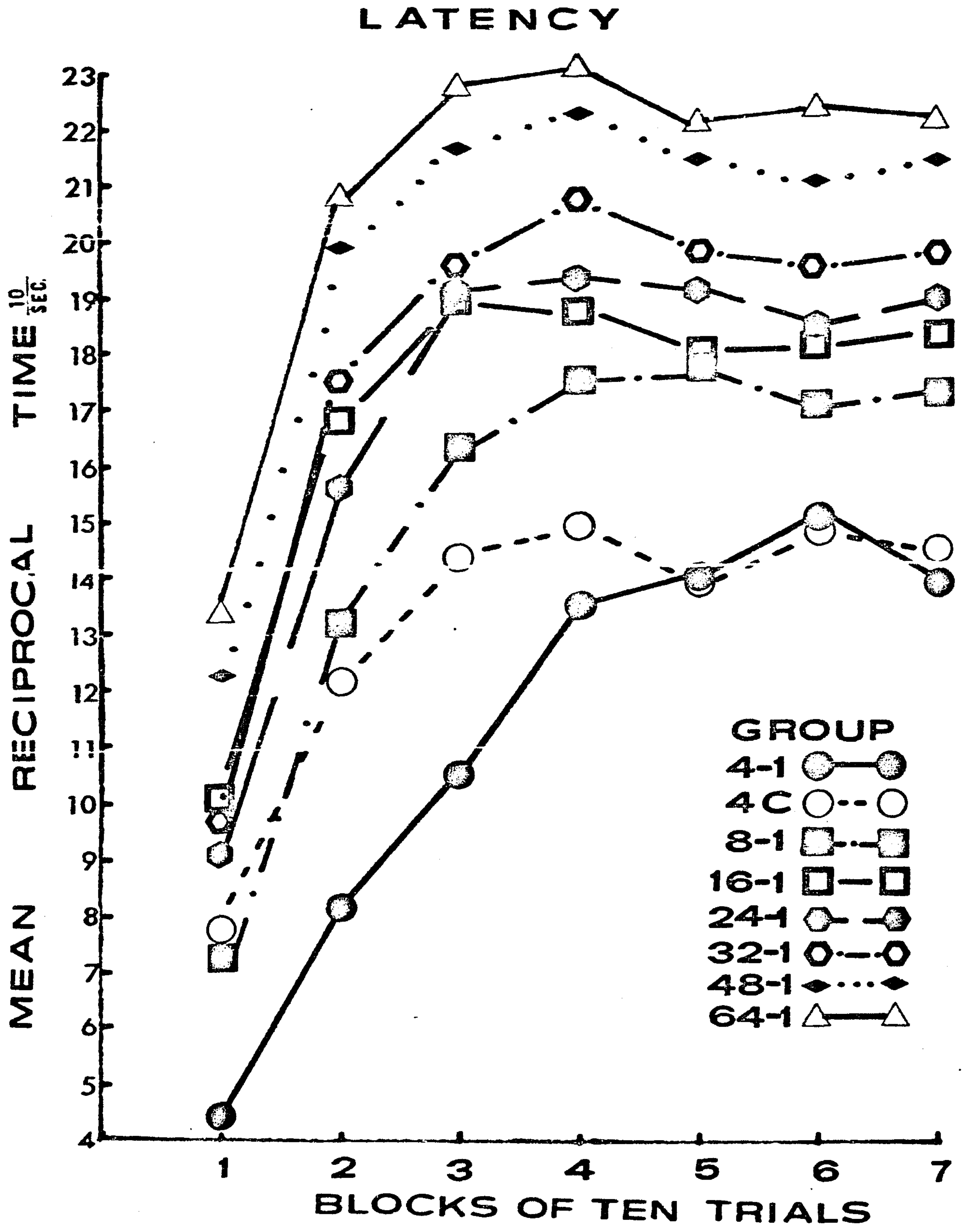

LATENCY
MEAN RECIPROCAL TIME 10/SEC.
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
4-1
4C
8-1
16-1
24-1
32-1
48-1
64-1

Figure 14

Mean Reciprocal Running Time as a Function of Blocks of Ten Trials in Experiment 2.

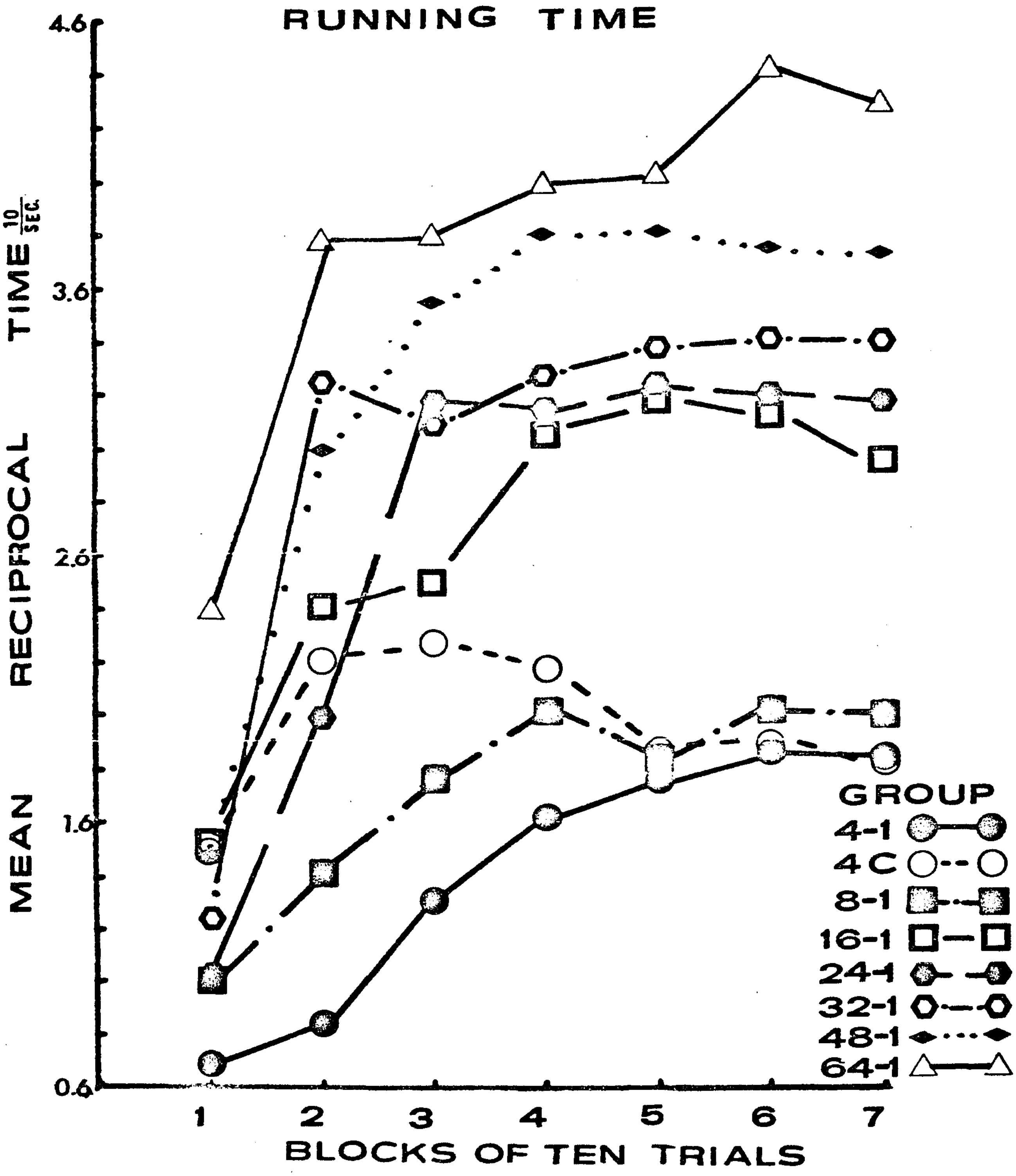
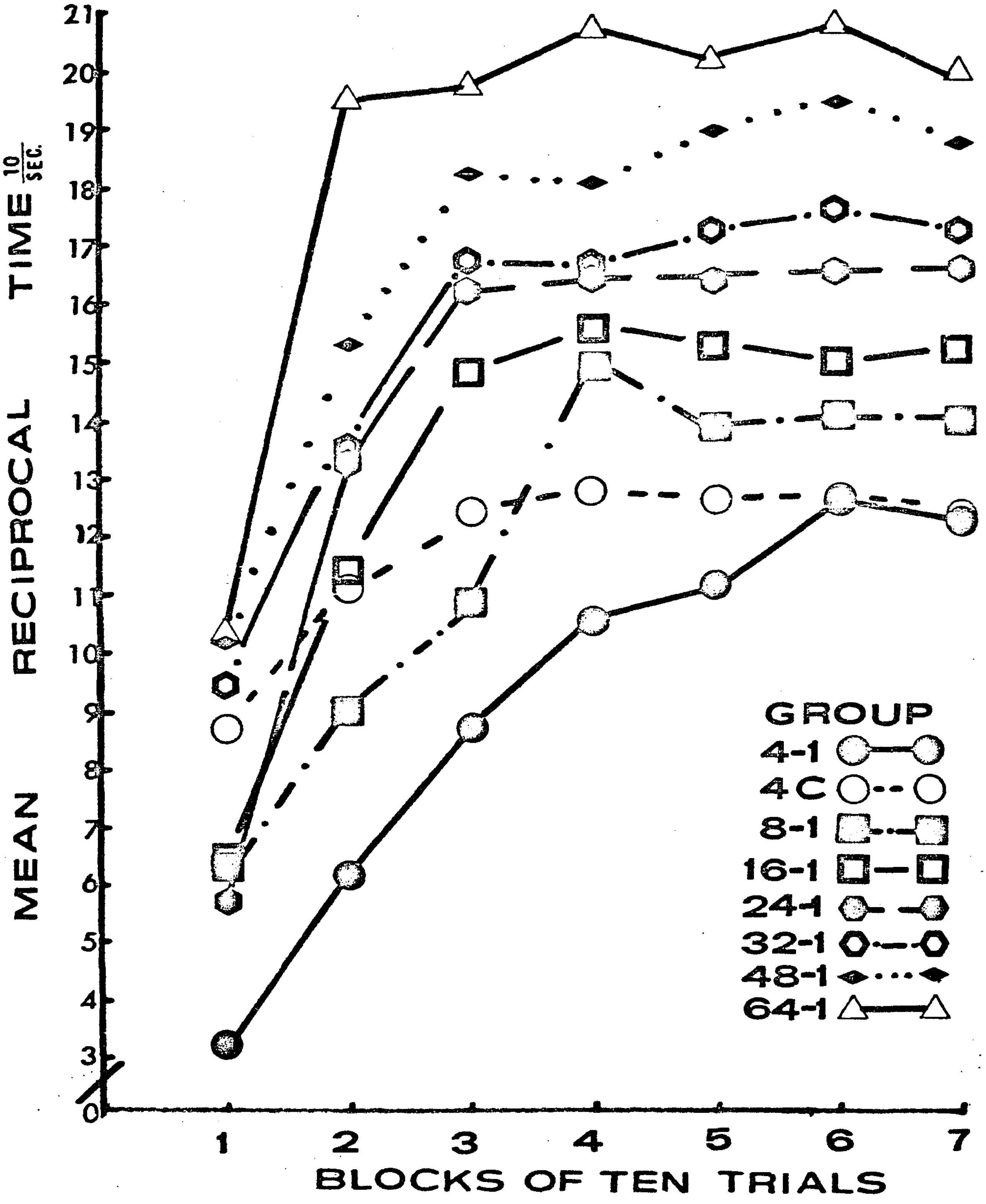

RUNNING TIME
MEAN RECIPROCAL TIME $\frac{10}{SEC.}$
4.6
3.6
2.6
1.6
0.6
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
4-1
4C
8-1
16-1
24-1
32-1
48-1
64-1

Figure 15

Mean Reciprocal Goal Time as a Function of Blocks of Ten Trials in Experiment 2.



GOAL TIME

MEAN RECIPROCAL TIME 10/SEC.
0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
4-1
4C
8-1
16-1
24-1
32-1
48-1
64-1

increased. In addition, Group 4C appeared to be running faster than Group 4-1 through the first half of the study, although the two groups responded at the same speed during the last 20 or 30 trials on all three measures. Three *t*-tests were performed comparing the last 20 trials of Groups 4C and 4-1 and revealed no significant between group differences ($t < 1$, $df = 12$, $p > .05$ for all three measures). In addition, three analyses of variance were performed on the last 20 trials for the running measures based on all 1 mm. groups excluding Group 4C and revealed, as shown in Table 15, significant differences between groups for all three measures.

Scatterplots depicting the relation between asymptotic running behavior and amount of water consumed for Groups 4-1, 24-1, 48-1 and 64-1 are presented in Figures 16, 17 and 18 for reciprocal latency, running time and goal time, respectively. Pearson product moment correlation coefficients were calculated based on the within group relations for the 1 mm. groups excluding Group 4C and revealed no significant correlations for the three speed measures ($r < .24$, $df = 55$, $p > .05$ in all three cases). The relationship between amount and duration of reinforcement, presented in Figure 19, is seen to be a linear function. Therefore, eliminating amount effects through a covariance analysis would have been the same as eliminating Duration effects.

As in Experiment 1, Anderson's (1963) shape function method was used to assess differences in learning rates. The

Table 15

Analyses of Variance Based on Mean Reciprocal Latency, Running Time and Goal Time for the Last Twenty Trials in Experiment 2.

Latency

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | 294.24 | 6 | 49.04 | 5.87* |
| Within | 418.16 | 50 | 8.36 | |
| Total | 712.40 | 56 | | |

Running Time

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | 36.12 | 6 | 6.02 | 6.02* |
| Within | 49.86 | 50 | 1.00 | |
| Total | 85.98 | 56 | | |

Goal Time

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | 382.24 | 6 | 63.71 | 8.30* |
| Within | 384.24 | 50 | 7.68 | |
| Total | 766.48 | 56 | | |

*$p < .05$

Figure 16

Scatterplots showing the Relation Between Mean Asymptotic Reciprocal Latency and Amount Consumed for Experiment 2.

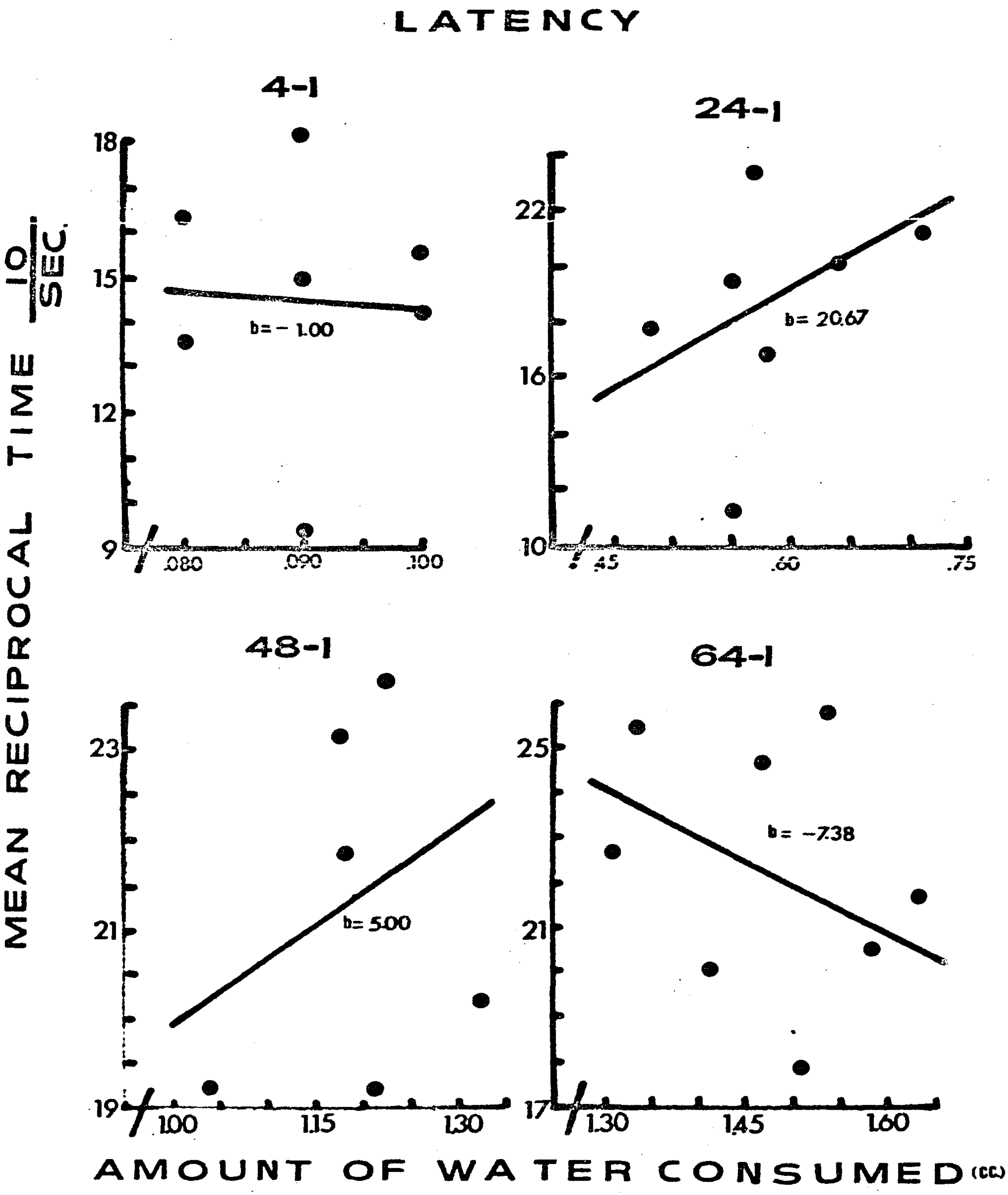

LATENCY
MEAN RECIPROCAL TIME 10/SEC.
AMOUNT OF WATER CONSUMED (CC)
4-1
18
15
12
9
.080
.090
.100
b= - 1.00
24-1
22
16
10
.45
.60
.75
b= 20.67
48-1
23
21
19
1.00
1.15
1.30
b= 5.00
64-1
25
21
17
1.30
1.45
1.60
b= -7.38

Figure 17

Scatterplots Showing the Relation Between Mean Asymptotic Reciprocal Running Time and Amount Consumed for Experiment 2.

RUNNING TIME

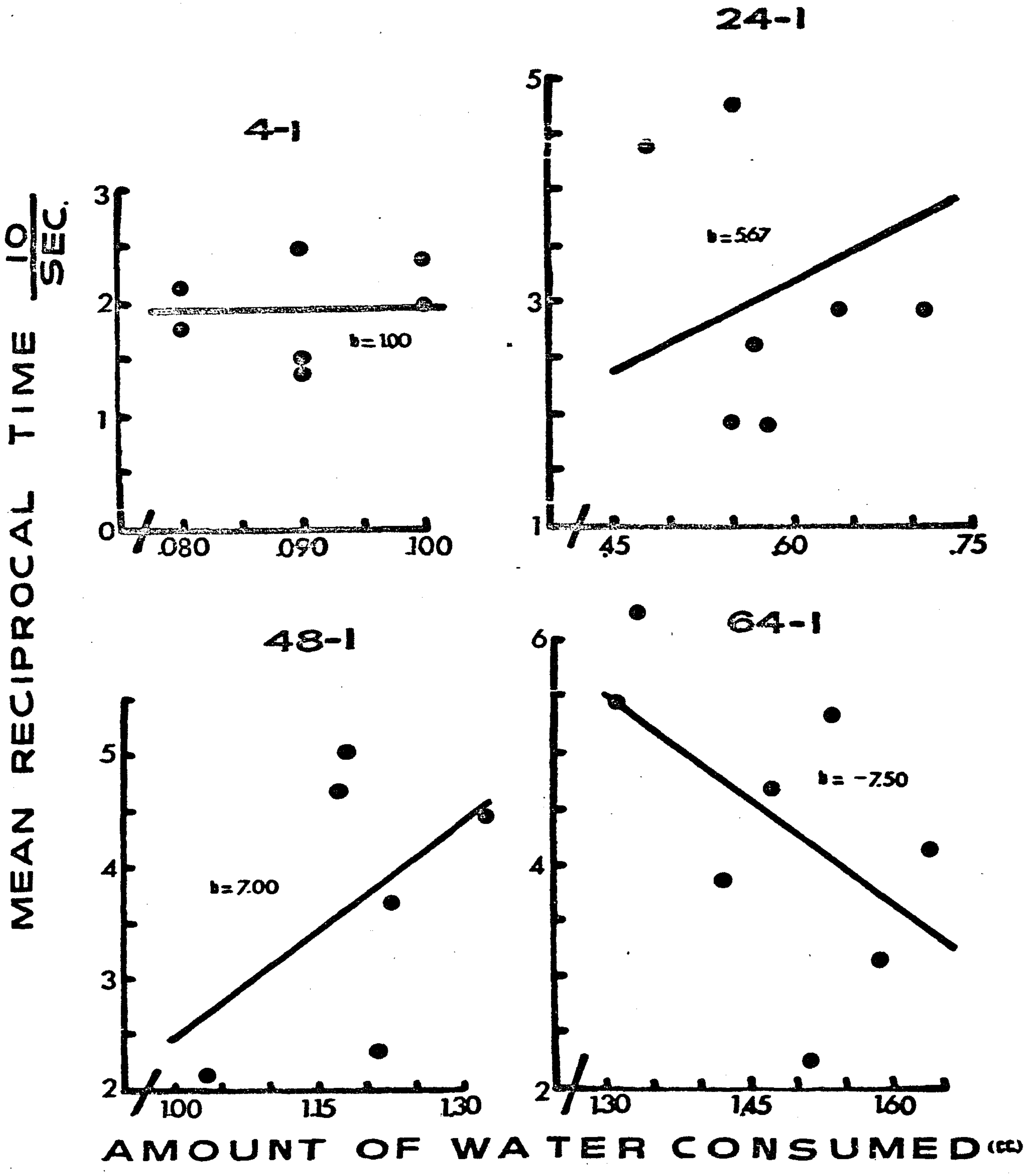


Figure 18

Scatterplots Showing the Relation Between Mean Asymptotic Reciprocal Goal Time and Amount Consumed for Experiment 2.

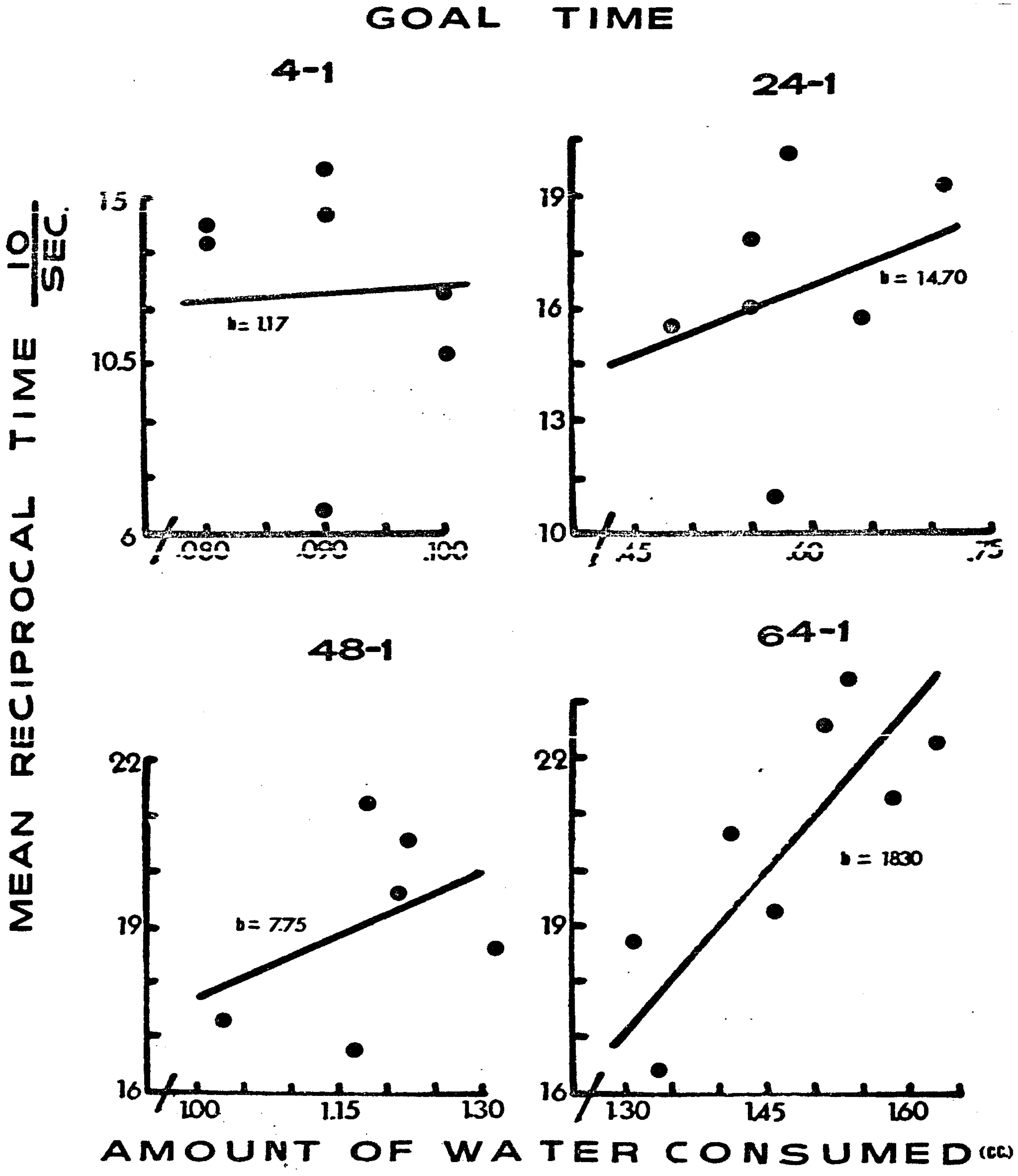
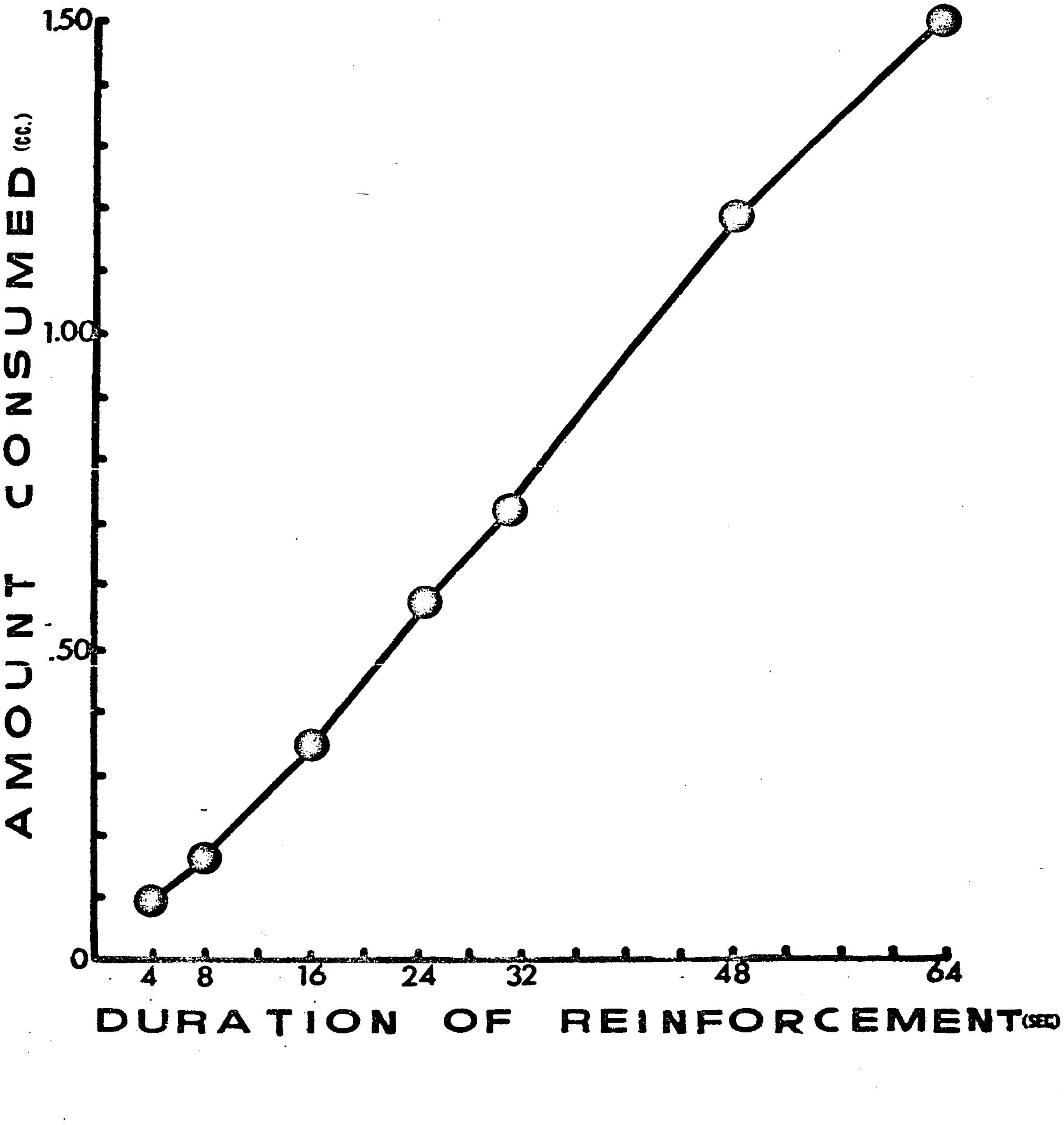

GOAL TIME
4-1
24-1
48-1
64-1
MEAN RECIPROCAL TIME 10/SEC.
15
10.5
6
.080
.090
.100
b= 1.17
19
16
13
10
.45
.60
.75
b= 14.70
22
19
16
1.00
1.15
1.30
b= 7.75
22
19
16
1.30
1.45
1.60
b= 1830
AMOUNT OF WATER CONSUMED (cc.)

Figure 19

Mean Amount of Reinforcement Consumed per Trial as a Function of Duration of Reinforcement in Experiment 2.


1.50
1.00
.50
0
AMOUNT CONSUMED (cc.)
4
8
16
24
32
48
64
DURATION OF REINFORCEMENT (SEC)

means for each group for the three speed measures based on the shape function method are presented in Table 16. Inspection reveals that Group 4-1 appeared to have the slowest learning rate with no orderly relation among the remaining groups. Three $t$-tests were performed comparing the learning rate measures of Groups 4C and 4-1 and revealed significant differences for the reciprocal latency ($t = 4.01$, $df = 12$, $p < .05$), running time ($t = 2.18$, $df = 12$, $p < .05$) but not the goal time measure ($t = 1.34$, $df = 12$, $p > .05$). Furthermore, six analyses of variance were performed based on the data from the 1 mm. groups, three without Group 4C and three without Groups 4C and 4-1. As shown in Table 17, the analyses including Group 4-1 but not 4C yielded significant between group differences for the reciprocal latency and running time measures. No other comparison yielded a significant difference.

### Consummatory Response Measures.

As in Experiment 1 ingestion rates were determined for each S for the last 20 trials and resulted in values ranging from .037 to .046 cc of water consumed per sec. A $t$-test comparing the mean ingestion rates during the last 20 trials for Groups 4C and 4-1 failed to yield significance ($t < 1$, $df = 12$, $p > .05$), as did an analysis of variance, as shown in Table 18, based on all groups excluding Group 4C.

In Figure 20 is presented the relation between ingestion rate and mean asymptotic reciprocal latency, running time and

## Table 16

Means of Shape Function Measure, f(n), Based on Reciprocal Latency, Running Time and Goal Time in Experiment 2.

| Group | Latency | Running Time | Goal Time |
|---|---|---|---|
| 4C | .218 | .201 | .255 |
| 4-1 | .305 | .332 | .322 |
| 8-1 | .198 | .161 | .255 |
| 16-1 | .134 | .169 | .236 |
| 24-1 | .188 | .153 | .219 |
| 32-1 | .164 | .154 | .231 |
| 48-1 | .122 | .185 | .227 |
| 64-1 | .139 | .192 | .236 |

### Table 17

### Analyses of Variance Based on the Shape Function Measure for Reciprocal Latency, Running Time and Goal Time in Experiment 2.

<u>1 mm. Groups (Excluding Group 4C):</u>

<u>Latency</u>

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | .1680 | 6 | .0280 | 3.33* |
| Within | .4223 | 50 | .0084 | |
| Total | .5903 | 56 | | |

<u>Running Time</u>

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | .8950 | 6 | .1492 | 6.69* |
| Within | 1.1162 | 50 | .0223 | |
| Total | 2.0112 | 56 | | |

<u>Goal Time</u>

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | .0528 | 6 | .0088 | 0.47 |
| Within | .9399 | 50 | .0189 | |
| Total | .9927 | 56 | | |

*$p < .05$

# Table 17
(Continued)

## Analyses of Variance Based on the Shape Function Measure for Reciprocal Latency, Running Time and Goal Time in Experiment 2.

### 1 mm. Groups (Excluding Groups 4-1 and 4C):

### Latency

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | .0367 | 5 | .0073 | 0.78 |
| Within | .4142 | 44 | .0094 | |
| Total | .4509 | 49 | | |

### Running Time

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | .0664 | 5 | .0133 | 0.58 |
| Within | 1.0141 | 44 | .0230 | |
| Total | 1.0805 | 49 | | |

### Goal Time

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Between | .0065 | 5 | .0013 | 0.08 |
| Within | .7563 | 44 | .0172 | |
| Total | .7628 | 49 | | |

$*p < .05$

## Table 18

## Analyses of Variance Based on Means of Consummatory Response Measures for the Last Twenty Trials in Experiment 2.

### Reciprocal First Lick

#### Time

| | SS | df | MS | F |
|---|---|---|---|---|
| Source | | | | |
| Between | 16.22 | 6 | 2.70 | 1.05 |
| Within | 128.25 | 50 | 2.56 | |
| Total | 144.47 | 56 | | |

#### Lick Rate

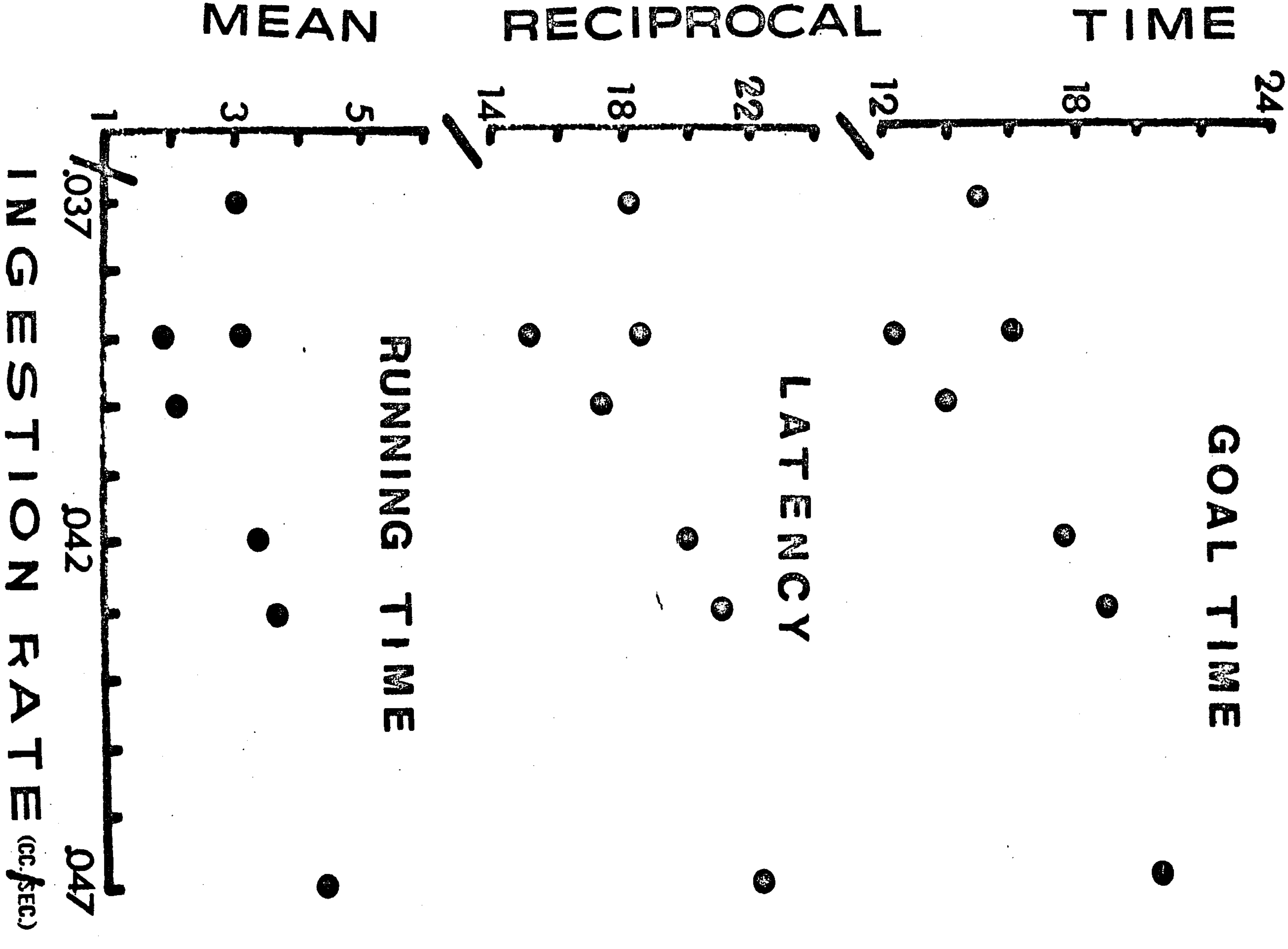
| | SS | df | MS | F |
|---|---|---|---|---|
| Source | | | | |
| Between | 0.18 | 6 | 0.030 | 0.435 |
| Within | 3.44 | 50 | 0.069 | |
| Total | 3.62 | 56 | | |

#### Ingestion Rate

| | SS | df | MS | F |
|---|---|---|---|---|
| Source | | | | |
| Between | .000240 | 6 | .000040 | 0.60 |
| Within | .003349 | 50 | .000067 | |
| Total | .003589 | 56 | | |

Figure 20

Mean Asymptotic Reciprocal Latency, Running Time and Goal Time as a Function of Ingestion Rate in Experiment 2.


MEAN RECIPROCAL TIME
RUNNING TIME
LATENCY
GOAL TIME
1
3
5
14
18
22
12
18
24
.037
.042
.047
INGESTION RATE (CC./SEC.)

goal time. Inspection reveals no orderly relation.

The mean reciprocal first lick time as a function of blocks of ten trials is presented in Figure 21. Inspection reveals that Group 4-1 appeared to be responding slower than the remaining groups who did not differ from each other. A t-test comparing the mean reciprocal first lick time during the last 20 trials for Groups 4C and 4-1 revealed a significant difference ($t = 3.43$, $df = 12$, $p < .05$) with Group 4-1 responding slower. However, as shown in Table 18, an analysis of variance excluding Group 4C failed to yield any significant difference.

The number of licks per sec. as means of blocks of ten trials is presented in Figure 22. Inspection reveals faster lick rates for Group 4C initially, although all groups appeared to converge at asymptote. Furthermore, the "acquisition" curve for Group 4C was flat while that of the other groups was typically negatively accelerated. A t-test comparing the mean lick rates during the last 20 trials between Groups 4C and 4-1 failed to reveal a significant difference ($t < 1$, $df = 12$, $p > .05$) nor did the analysis of variance, as shown in Table 18, which excluded Group 4C.

The amount of water consumed per lick or volume per lick was calculated for each S, as in Experiment 1 based on the last 20 trials, and yielded values between .0034-.0041 cc. of water per lick, with no orderly relation among the 1 mm. groups. These values were considerably below that for the 5 mm. groups

Figure 21

Mean Reciprocal First Lick Time as a Function of Blocks of Ten Trials in Experiment 2 (Block 1 has 7 Trials).

FIRST LICK LATENCY

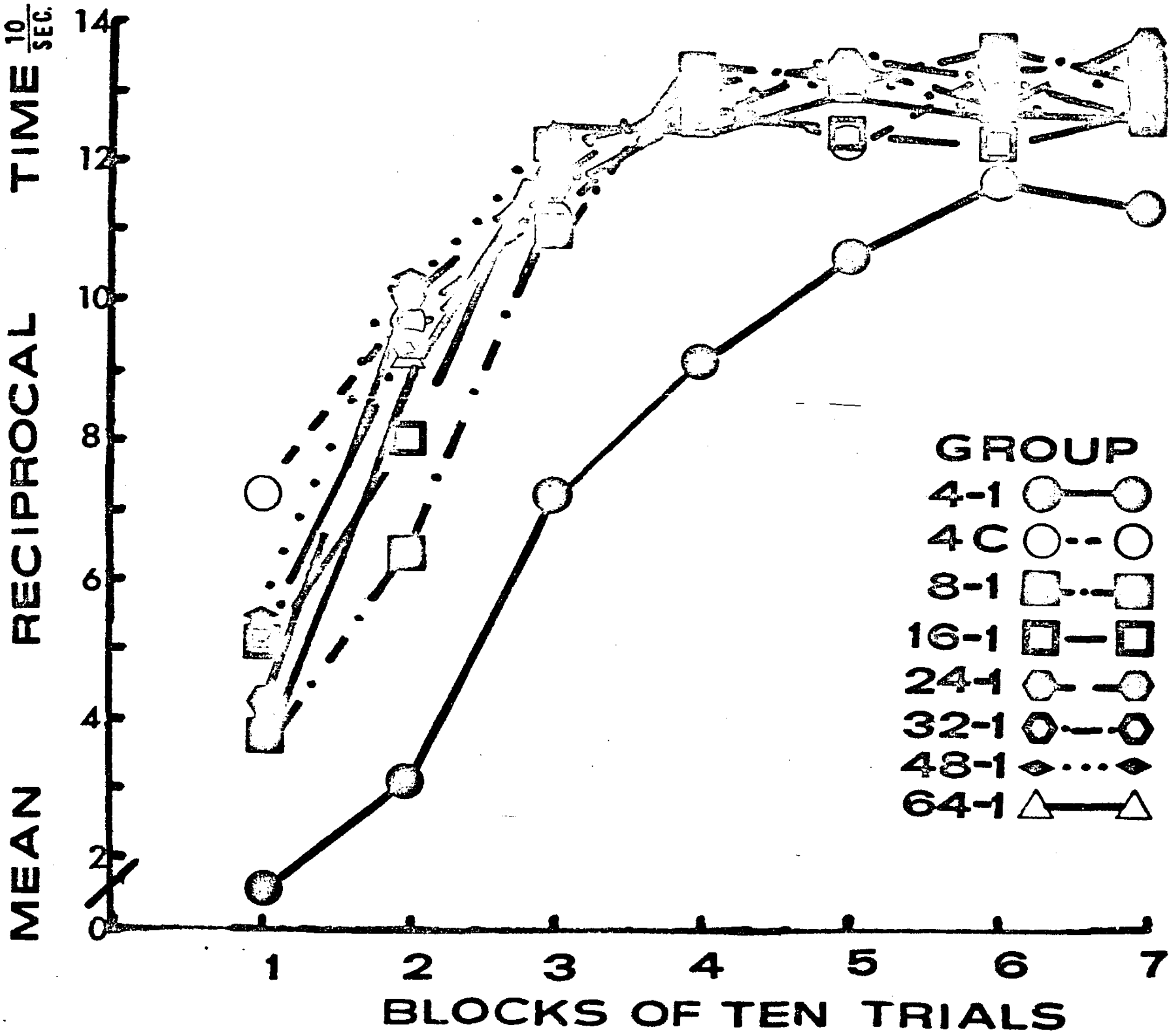
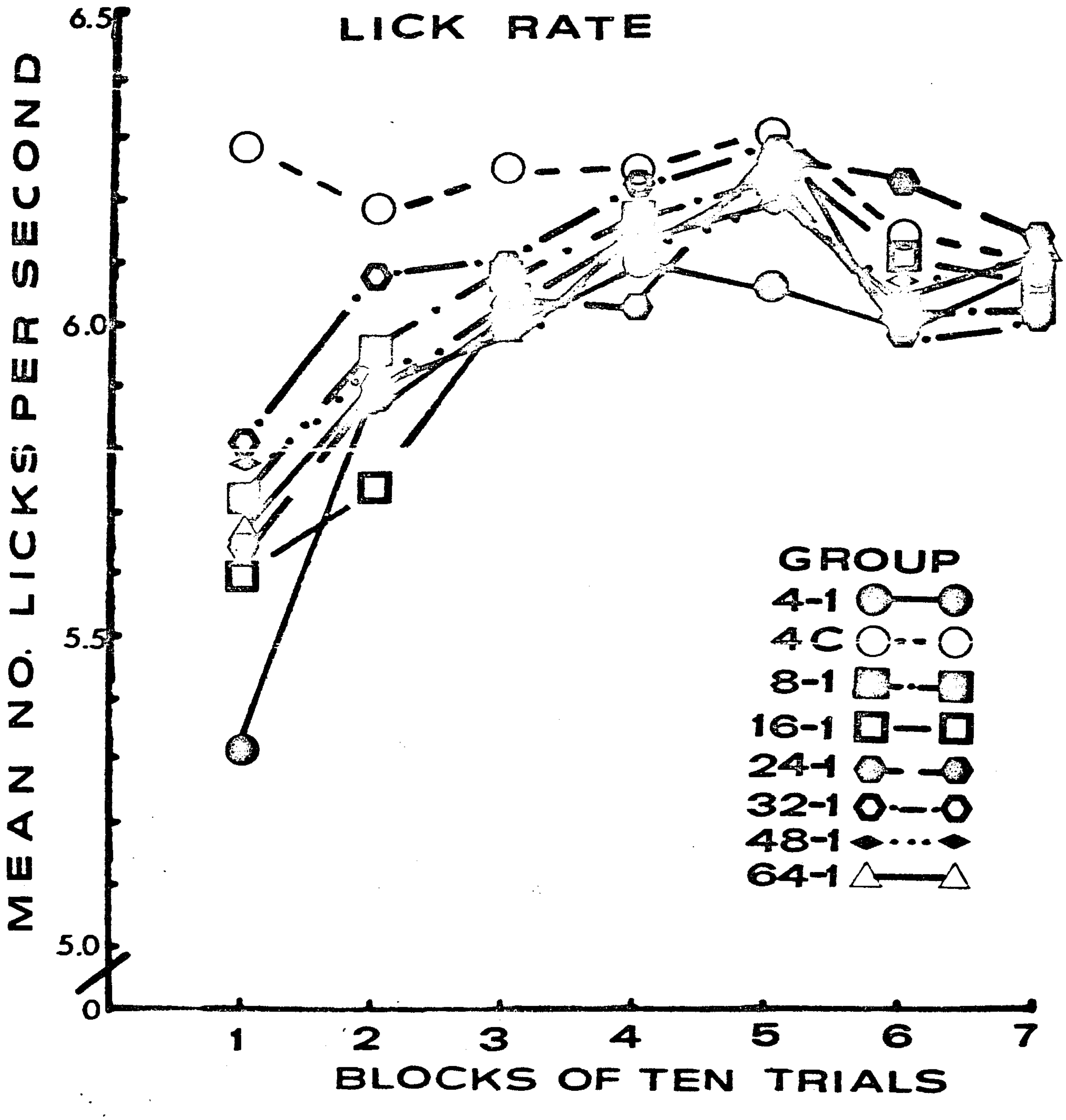


Figure 22

Mean Lick Rate as a Function of Blocks of Ten Trials in Experiment 2 (Block 1 has 7 Trials).


LICK RATE
MEAN NO. LICKS PER SECOND
6.5
6.0
5.5
5.0
0
1
2
3
4
5
6
7
BLOCKS OF TEN TRIALS
GROUP
4-1
4C
8-1
16-1
24-1
32-1
48-1
64-1

in Experiment 1.

### A Further Test of Reinforcement Duration Versus Amount of Reinforcement.

The results of Experiments 1 and 2 yielded two instances in which a longer duration group consumed less water than a shorter duration group, and these are presented in Table 19. Specifically, Group 24-1 drank 50% longer but consumed 10% less water per trial than Group 16-5. Group 48-1 also drank 50% longer than Group 32-5 but consumed slightly less water per trial. In both cases the longer duration group ran 3-5% faster than the short duration group. Not surprisingly, none of the differences were statistically significant ($t < 1.15$, $p > .05$ in all six cases).

### Table 19

### Mean Asymptotic Reciprocal Speeds, Amount Consumed and Reinforcement Duration for the Four Groups Comprising the Two Cases Where Longer Duration Groups Consumed Less Water Than Short Duration Groups in Experiments 1 and 2.

| | | | Mean Asymptotic Reciprocal | | |
|---|---|---|---|---|---|
| Group | Reinforcement Duration (in sec.) | Amount Consumed (in cc.) | Latency | Running Time | Goal Time |
| Case I: | | | | | |
| 24-1 | 24 | .583 | 18.63 | 3.05 | 16.18 |
| 16-5 | 16 | .650 | 18.04 | 2.96 | 15.29 |
| Case II: | | | | | |
| 48-1 | 48 | 1.190 | 21.28 | 3.70 | 19.00 |
| 32-5 | 32 | 1.218 | 20.17 | 3.43 | 16.07 |

# DISCUSSION

The major finding of the present study was that mean asymptotic latency was a decay function of duration of reinforcement. In addition, the function relating asymptotic mean reciprocal latency to reinforcement duration was a straight line. These findings are in agreement with those of Hellyer, Crespi and Grindly. This apparent "contradiction" is resolved when one considers the transformation involved. The analysis of the present data revealed that the relation between the mean asymptotic reciprocal latency and reciprocal asymptotic mean latency is linear, the one being displaced from the other by a constant. Similarly the reciprocal of the asymptotic mean reciprocal latency was negatively decelerated, being fairly similar to the relation between mean latency and reinforcement duration. This finding is important from the point of view of quantitative theories. Specifically, quantitative theories of runway behavior have all predicted behavior in terms of latency (Burke, 1948; Estes, 1950; Spence, 1954; Weinstock, unpublished). However, almost all studies have used reciprocal latency as a response measure. This has largely been done to achieve homogeneity of variance, since latency distributions almost always have some extreme values which result in large amounts of variance. If the relationship between $(\overline{1/L})$ and $(1/\overline{L})$ found in the present study is typical, than much of the data in the literature can be used to assess quantitative theories.

An extremely close correspondence was found between the theoretical and observed function relating asymptotic latency to reinforcement duration. Even though the decay function fitted to the data removed more than 97% of the variance, the use of four "free" parameters detracts appreciably from the support given to the underlying theory. This is not surprising since, as pointed out by Brody and Weinstock (1962), almost any function with four free parameters can adequately fit orderly data. This was illustrated by the fit obtained with a second degree polynomial which has no apparent theoretical significance. This function accounted for some 92% of the variance and involved just three free parameters. This demonstrates that when the number of free parameters is greater than two, caution must be exercised in concluding that good fits represent strong support for the underlying model. Perhaps when the number of parameters becomes large (greater than two) and parameters cannot be estimated from independent situations, other techniques must be used to evaluate quantitative theory. Sternberg (1963) has suggested that one method of assessing quantitative theory might be to compare different models. The "comparison of models" technique has been used by a number of investigators with reasonable success (e.g. Bush and Mosteller, 1959; J. Robbins, 1968). Another technique is to investigate the "fine structure" of the data (e.g. Bush and Mosteller, 1955; Weinstock _et al_, 1965). In any event the danger of drawing too strong a conclusion when a model has three or four free parameters is clear. It is nevertheless the case that the present data do conform to a decay function and that they provide some support for a quantitative version of Hellyer's stimulus trace theory and for a modified Hullian theory. The modification of Hull's theory referred to is one in which $\bar{E}$ is taken to be a growth function of duration rather than amount of reinforcement.

The group that received preliminary drinking training (Group 4C) prior to receiving runway trials acquired the running response considerably faster than the group that had no preliminary drinking training (Group 4-1). Both groups received reinforcement through the 1 mm. tube for 4 sec. on runway trials. However, at asymptote the groups responded at the same speed. Specifically, Group 4-1 had a slower learning rate than any of the other groups, who did not differ from one another. Informal observation revealed that the _S_s in Group 4-1 became somewhat "emotional" when being removed from the goal box, and, in general, were not as tame as the remaining _S_s. Group 4C also showed a fairly flat licking rate "acquisition" curve, while the other groups all had fairly negatively accelerated functions. These results suggest that early in training runway measures may be somewhat contaminated by interfering responses that arise as a result of learning to drink in the situation.

As found in Experiment 1, none of the consummatory response measures, namely, ingestion rate, lick rate, volume per lick, reciprocal first lick time or amount consumed, were related to running behavior. In addition, low and nonsignificant within group correlations were found between amount consumed and asymptotic running behavior.

In conclusion, the results of both studies suggest strongly that the duration of reinforcement is the critical variable in the magnitude of reinforcement effect. Further, no relation was found between consummatory behavior and running behavior when a water reinforcement was used. Finally, as expected by a quantitative version of Hellyer's stimulus trace hypothesis and a modified Hullian theory, the relation between asymptotic latency and duration of reinforcement was found to be a decay function.

# SUMMARY

In Experiment 1 six groups of rats (n = 10 each) were given 71 trials in an alleyway with continuous reinforcement using a factorial design in which duration of reinforcement and width of drinking tube were combined. Specifically, Ss received 8, 16 or 32 sec. of water reinforcement through a glass drinking tube with a 1 mm. or 5 mm. hole (tube width).

The apparatus was a straight runway, painted flat gray and covered with hinge-mounted clear Plexiglas, except for the goal box which was not covered. It was 5 in. wide and 5 in. high except for the goal box, which was 12 in. high. The start box, runway, and goal box were 10, 44, and 18 in. long, respectively. A 4 x 5 in. recessed drinking area was attached at a right angle to the end of the goal box. The start box, alley, goal box, and drinking area were separated from each other by guillotine doors. Photocell beams were placed 1 in. past the start box door, 8 in. past the goal box door, and ½ in. in front of the drinking area door to record latency, running time and goal time, respectively. A fourth photocell timer circuit measured first-lick latency, the time from interruption of the third beam to the first lick (a distance of 2½ in.). The number of licks was recorded on a Sodeco print-out counter which was activated by interruption of a light

beam across the front of the glass drinking tube. The glass drinking tube was attached to a 50 ml. burette, which permitted the recording of the amount consumed.

The Ss were given one trial per day under 20-22 hr. of water deprivation.

The results indicated that the 5 mm. groups consumed almost twice as much water as their 1 mm. counterparts. The major finding was that the differences in the amount consumed did not lead to differences in latency or running speed. Furthermore, as the duration of reinforcement increased the asymptotic reciprocal latency and running speed increased, independent of the amount consumed. The correlation based upon the within group relationship between amount consumed and asymptotic running speed was low and non-significant for the running behavior measures. No relation was found between running behavior and a number of measures of consummatory behavior, namely, lick rate, ingestion rate, first-lick latency, volume per lick and amount consumed. It was concluded that the duration of reinforcement, rather than either amount of reinforcement or ingestion rate, is the critical variable in magnitude of reinforcement studies when a water reinforcer is used.

In Experiment 2, four groups of rats were given 4, 24, 48 or 64 sec. of water reinforcement through a 1 mm. drinking tube. Since Experiments 1 and 2 were done concurrently the 8, 16 and 32 sec. 1 mm. groups were included to complete a parametric study of the effect of duration of reinforcement on running behavior. In addition another group was included as a pretraining control. Specifically, in previous studies *S*s usually received preliminary drinking training in a box similar to the goal box. However no preliminary drinking training was given in the present study. As a result an additional group (4C) was given preliminary drinking training in the goal box following by 71 trials under continuous reinforcement in an alleyway on which these *S*s received 4 sec. of water reinforcement through a 1 mm. tube.

The same apparatus, response measures and procedures as these used in Experiment 1 were used.

The results indicated an almost linear relationship between duration of reinforcement and mean asymptotic reciprocal running speed $(\overline{1/L})$. However, the function relating reinforcement duration to mean asymptotic latency, $(\bar{L})$, was, as predicted by a number of theories, a decay function. It was observed that the relationship between these two measures is such that, $1/\bar{L}$ plus a constant is approximately equal to $(\overline{1/L})$. This observation removed the apparent "contradiction" in results between a linear function for the reciprocal measure and a decay function for the latency measure and brought the findings of Crespi and Grindly into line with the present findings. Again, no relation was found between running behavior and the various measures of consummatory behavior, namely, ingestion rate, licking rate, volume per lick and first lick time.

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# AUTOBIOGRAPHICAL STATEMENT

The candidate, Donald Robbins, was born in New York City on March 20, 1939. He attended the City College of New York and received a B.B.A. in 1959 with a major in Public Accounting. In 1962 he received a license to practice in New York State as a Certified Public Accountant. Subsequently, he received an M.A. in Psychology from Brooklyn College in 1965. While obtaining his graduate education at Brooklyn College he was a Research Assistant, a Departmental Fellow, held a United States Public Health Pre-Doctoral Fellowship and later taught at the college. During the last year he was a Research Associate in the Department of Psychology.

Publications:

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