Use of Time-Course Measurements For Functional Analysis

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Two peak-procedure experiments with rats asked how seven performance measures were influenced by (a) time within the 6-hr session and (b) the presence or absence of food on preceding trials. The number of different time courses observed suggest that the underlying mechanism can be divided into at least six separately-changeable parts--including a part that generates the initial responses that are increased by reward ("curiosity"), and a part responsible for increased effort after non-reward ("frustration").

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Outline of Talk

This talk is about an unusual way of interpreting psychology experiments. I'll describe the method, which I call time-course analysis, and briefly remind you about the peak procedure. Then I'll describe two applications of the method--one simple, one more complicated. Finally I'll draw some conclusions.

Diagram of basic idea

The approach I want to tell you about is a method of dividing a mechanism into parts--parts that can be separately changed. This transparency illustrates the basic idea. Suppose you are measuring a response that's generated by a mechanism with two parts. You use a treatment that changes both parts. You apply the treatment for a short time, then measure how long it takes for the effect of the treatment to wear off. Because the two parts are different, the treatment is likely to affect them differently. In particular, the aftereffects of the treatment are likely to last different amounts of time in the two parts. For example, in one part the effect of the treatment might last a day; in the other part, it might last a week.

In other words, from the theory that the mechanism has two parts comes the prediction that the treatment effects will show two different time courses. In practice, the direction of inference is reversed: If you observe two different time courses, you infer that the underlying mechanism has at least two parts.

Peak-procedure PROCEDURE

The data I am going to tell you about come from the peak procedure. The subjects were rats. This diagram illustrates the general procedure. Trials were signalled by light or sound. There were two types of trials: food trials and empty trials. On food trials, food was given for the first bar press after a fixed time, say 40 seconds, and the trial ends. On empty trials, no food was given. The trial lasted a long time, say 3 minutes, and ended regardless of what the rat did.

Peak-procedure RESULTS

This transparency shows the typical results. The first experiment I'm going to tell you about involved five measures of performance. One was iti rate, the response rate during the intertrial interval. We calculate this as the response rate during the 20 s before the trial begins. The other measures of performance were peak rate, which is the maximum response rate; tail rate, which is the response rate at which the function levels off; peak time, which is the time of the maximum response rate; and relative spread, which is a measure of the width of the function divided by peak time.

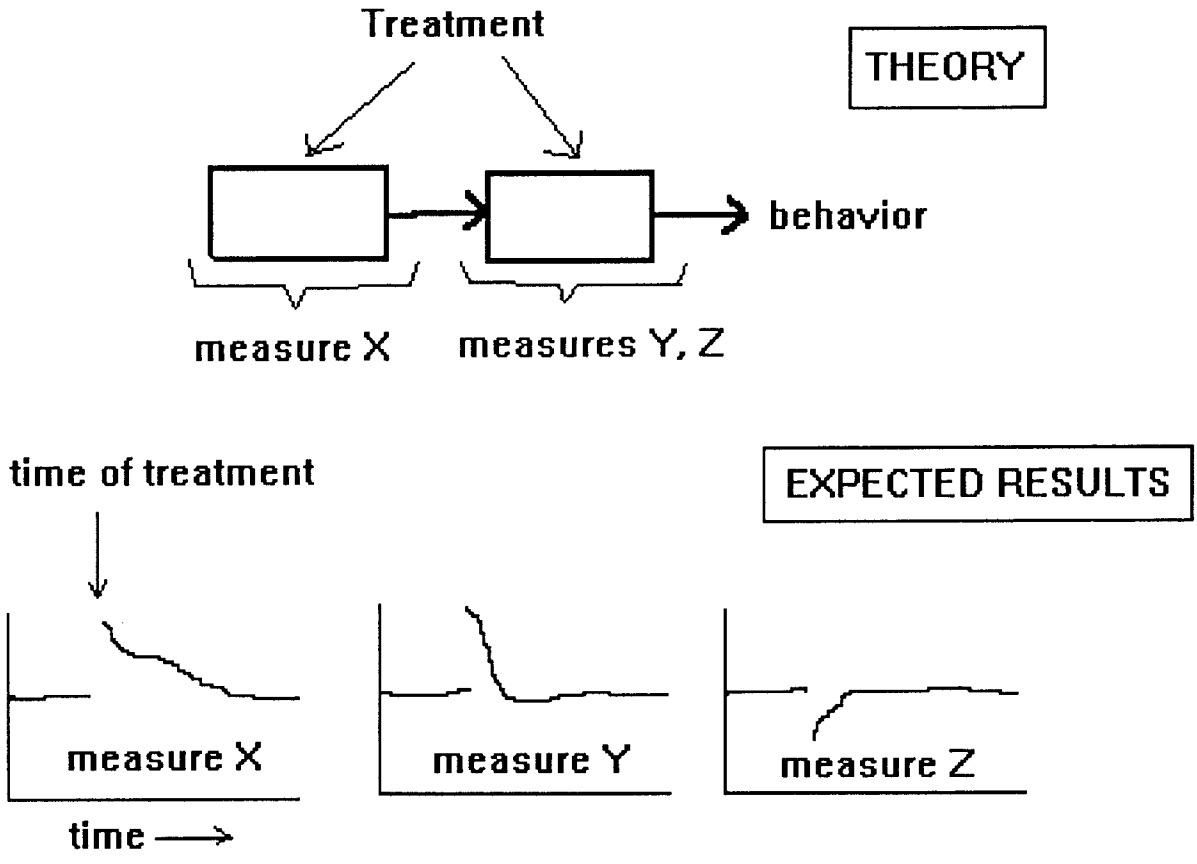
Outline of Talk

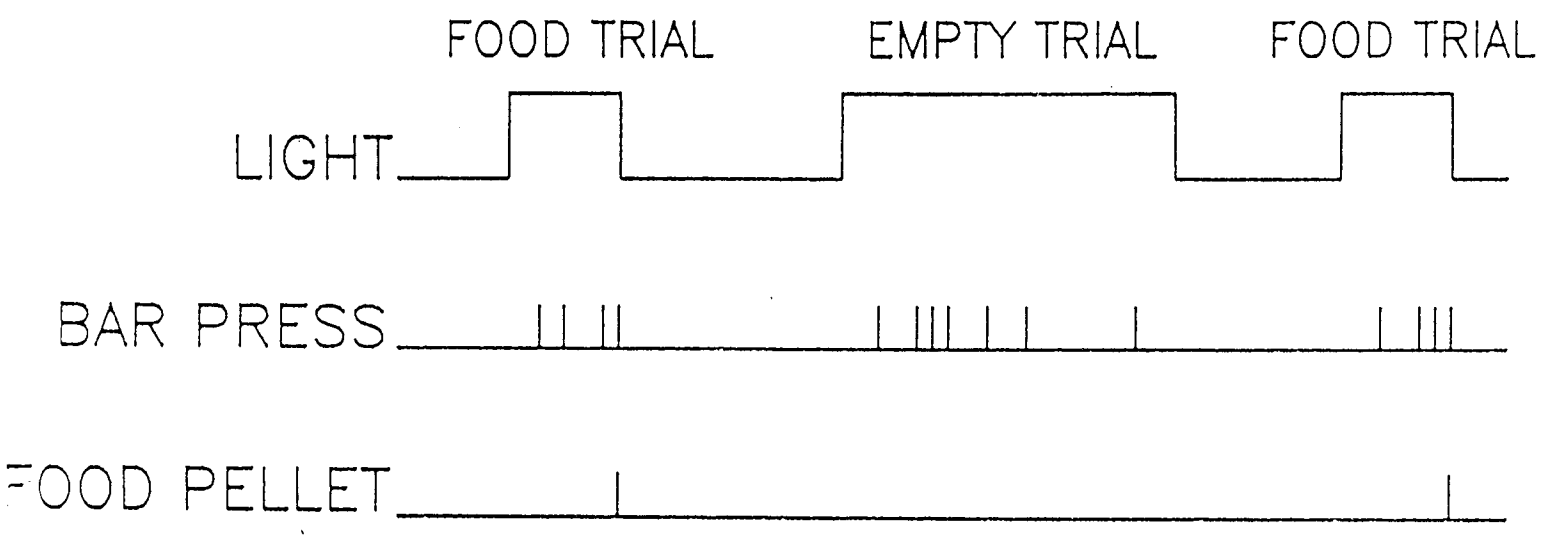
1. Tools
   - time-course analysis
   - the peak procedure

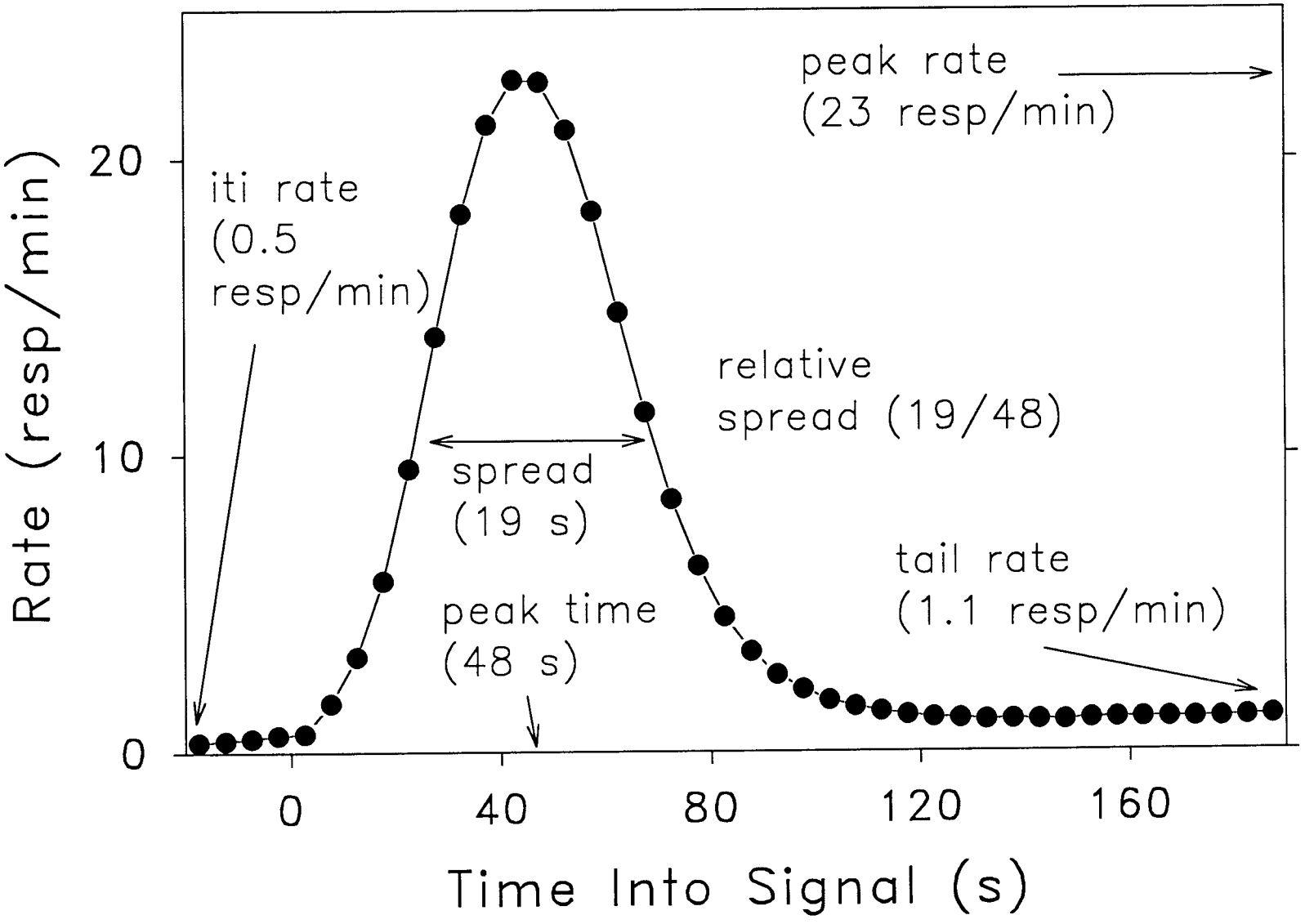
2. Simple Application (Expt. 1)

3. More Complex Application (Expt. 2)

4. Conclusions


Treatment
THEORY
behavior
measure X
measures Y, Z
time of treatment
EXPECTED RESULTS
measure X
measure Y
measure Z
time


FOOD TRIAL
EMPTY TRIAL
FOOD TRIAL
LIGHT
BAR PRESS
FOOD PELLET


peak rate
(23 resp/min)
iti rate
(0.5
resp/min)
relative
spread (19/48)
spread
(19 s)
tail rate
(1.1 resp/min)
peak time
(48 s)
Rate (resp/min)
20
10
0
0
40
80
120
160
Time Into Signal (s)

Peak-procedure THEORY

This is the theory we started with. It was based on the observation of dissociations and correlations in many experiments. It assumes that the underlying mechanism consists of basically three stages. The first stage analyses various dimensions of the stimulus; one part of the analysis is measured by peak time. The second stage decides which dimension is relevant. It's measured by relative spread and tail rate--in other words, changing the second stage will change relative spread and tail rate. The third stage chooses and executes the response. It's measured by peak rate and tail rate.

The first experiment I'll tell you about supports this model. But the second experiment shows that it's too simple.

Overview of Experiment 1 (procedure)

The first experiment was very simple. We used rats that already had had a lot of experience with the peak procedure. We just ran the peak procedure for 19 days. Sessions were six hours long; the question of interest was how performance changed during the session. We measured the time of each response on empty trials; we ended up with data for about 150,000 responses.

Experiment 1 response-rate functions

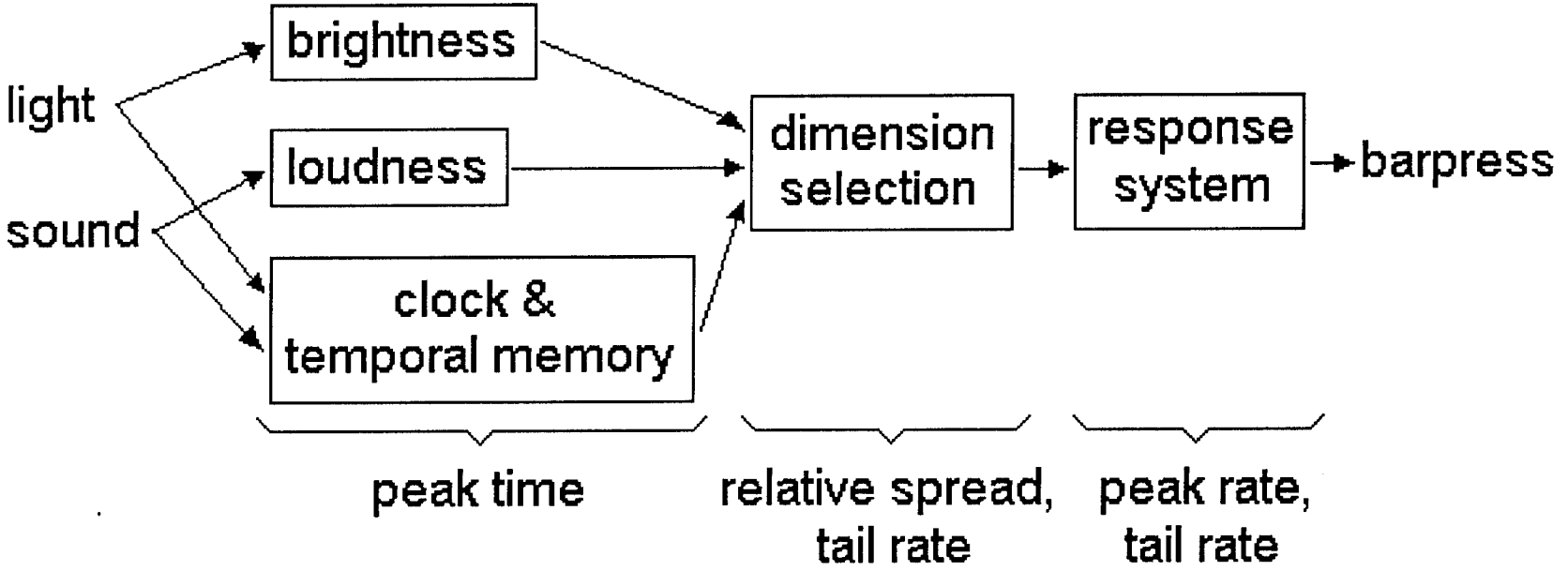
This gives a rough idea of how performance changed during the session. In general, response rate went down.

5 measures vs. time into session

This gives a more detailed view of the effect of session time. The measurements have been converted to logarithms to make it easier to compare different measures. The error bars on each graph show 95% confidence intervals for the difference between two data points; in other words, the difference between two points is reliable if it is greater than the error-bar distance.

There are a number of things to notice here. First, peak time was essentially constant throughout the session. Second, relative spread changed from the first hour to the second, but was constant after that. Peak rate, on the other hand, did just the opposite: It was constant from the first hour to the second, but changed after that. Tail rate and iti rate were like a combination of relative spread and peak rate: They changed from the first hour to the second, like relative spread, and they also changed every hour after that, like peak rate.

These results clearly suggest that the underlying mechanism has at least three separately-changeable parts. One part is measured by peak time; it doesn't change during the session. Another part is measured by relative spread; it changes during the first hour, but is constant after that. The third part is


light
sound
brightness
loudness
clock &
temporal memory
dimension
selection
response
system
barpress
peak time
relative spread,
tail rate
peak rate,
tail rate

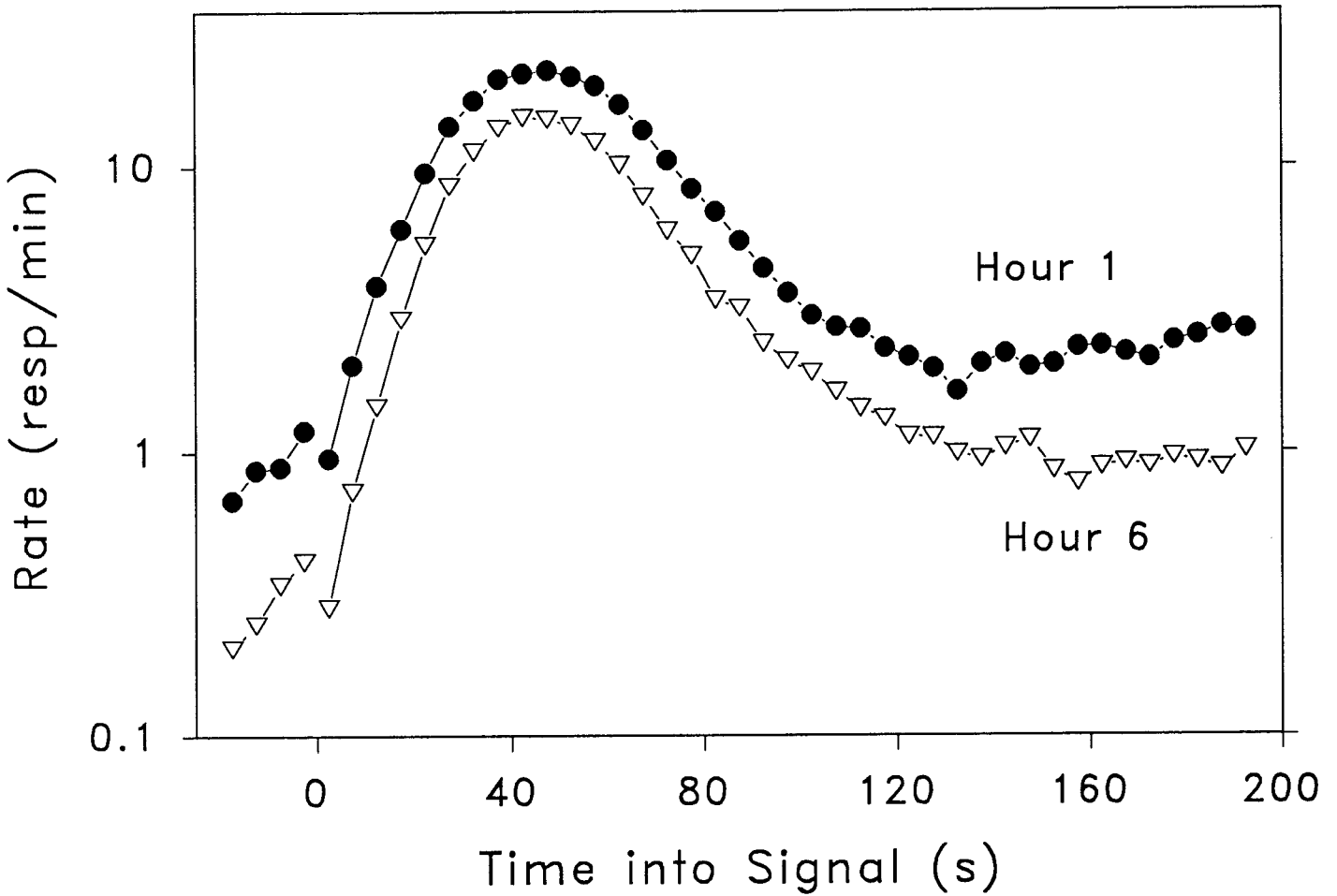
Overview of Experiment 1

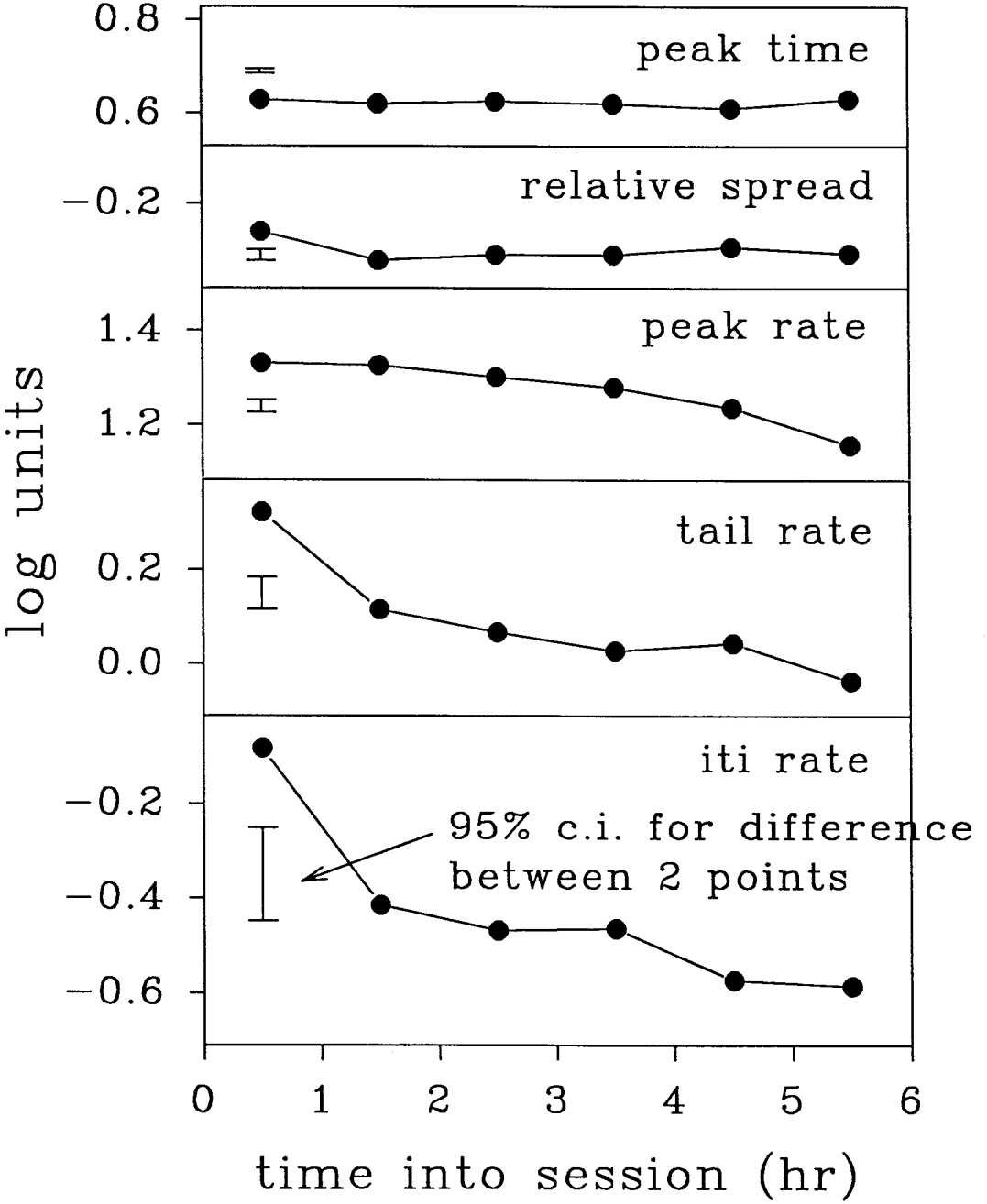
subjects: 18 rats. Well-trained at start of experiment.

procedure: the peak procedure. No treatments. 19 days, 6 hrs/day.

data: time of each response (empty trials only). About 150,000 responses total.

in short, a very simple situation


Rate (resp/min)
10
1
0.1
Hour 1
Hour 6
0
40
80
120
160
200
Time into Signal (s)


0.8
0.6
−0.2
1.4
1.2
0.2
0.0
−0.2
−0.4
−0.6
log units
peak time
relative spread
peak rate
tail rate
iti rate
95% c.i. for difference
between 2 points
0
1
2
3
4
5
6
time into session (hr)

measured by peak rate; it's constant during the first two hours, but changes after that. The tail-rate and iti-rate results may reflect a combination of two parts: the part measured by relative spread and the part measured by peak rate.

Summary of Experiment 1

This just sums up what I just told you. There were four different time courses. The fourth may have been a combination of the second and third. The results suggest that the mechanism has at least three separately-changeable parts. This conclusion is consistent with the theory I showed you earlier, which was based on entirely different data.

Peak-procedure THEORY

Here's that theory again, just to remind you. Notice that one part is measured by both relative spread and tail rate, and another part is measured by both peak rate and tail rate.

Overview of Experiment 2 (Procedure)

To learn more, we repeated Experiment 1 with a few changes. To find out if our results were repeatable, we used different rats, ran them at a different time of day, etc.--a variety of small differences. As a Greek philosopher said, you never step in the same experiment twice. Because we wanted to make finer distinctions, we made three changes in the procedure. One change was that we ran the experiment much longer--over 100 days. The second change was that we recorded responses from both food trials and empty trials. Both of these changes, of course, would give us more data, so our measurements would be more precise. The third change was that we recorded the duration of each response, not just its time of occurrence. The responses were bar-presses, of course; by the duration of a bar press, we mean the time that the rat holds the bar down. We hoped that response duration would reflect parts of the mechanism that did not influence response rate.

Rate and duration functions from Experiment 2

This gives an overview of what happened. It shows both response rate and response duration as a function of time into the signal. The response-rate results were just what you'd expect. The duration results, however, surprised me the first time I saw them. In this experiment, on food trials, food was given for the first response after 40 seconds. On empty trials, response duration increased sharply at about the time that food would have been given.

Duration before & after food omission

Summary of Experiment 1

Results

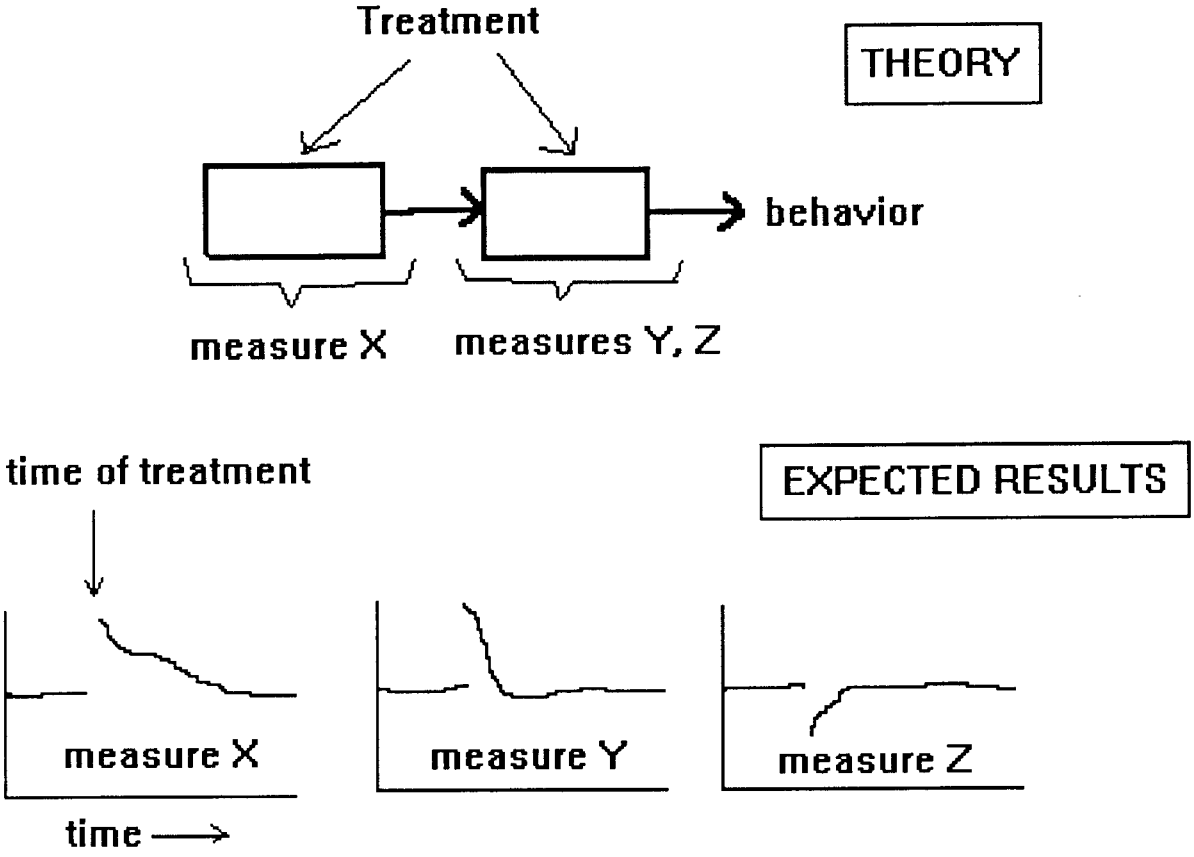
- Four time courses:

peak time	constant Hours 1→6
relative spread	changes Hours 1→2, constant Hours 2→6
peak rate	constant Hour 1→6, changes Hour 2→6
tail rate, iti rate	changes Hour 1→6

Conclusion

- Mechanism has at least 3 separately-changeable parts:

part	measured by
1	peak time
2	relative spread, tail rate, iti rate
3	peak rate, tail rate, iti rate


Treatment
THEORY
behavior
measure X
measures Y, Z
time of treatment
EXPECTED RESULTS
measure X
measure Y
measure Z
time

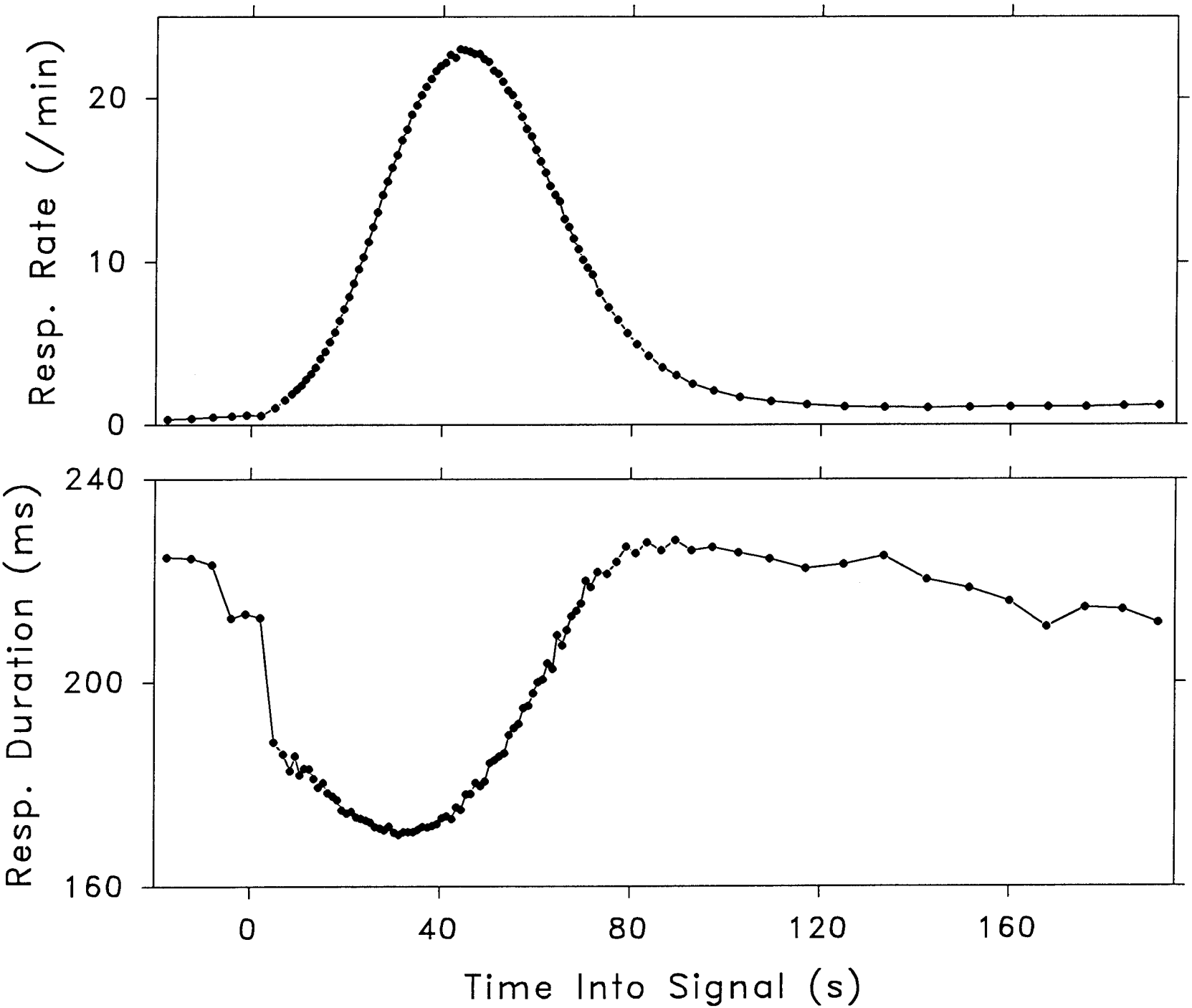
Overview of Experiment 2

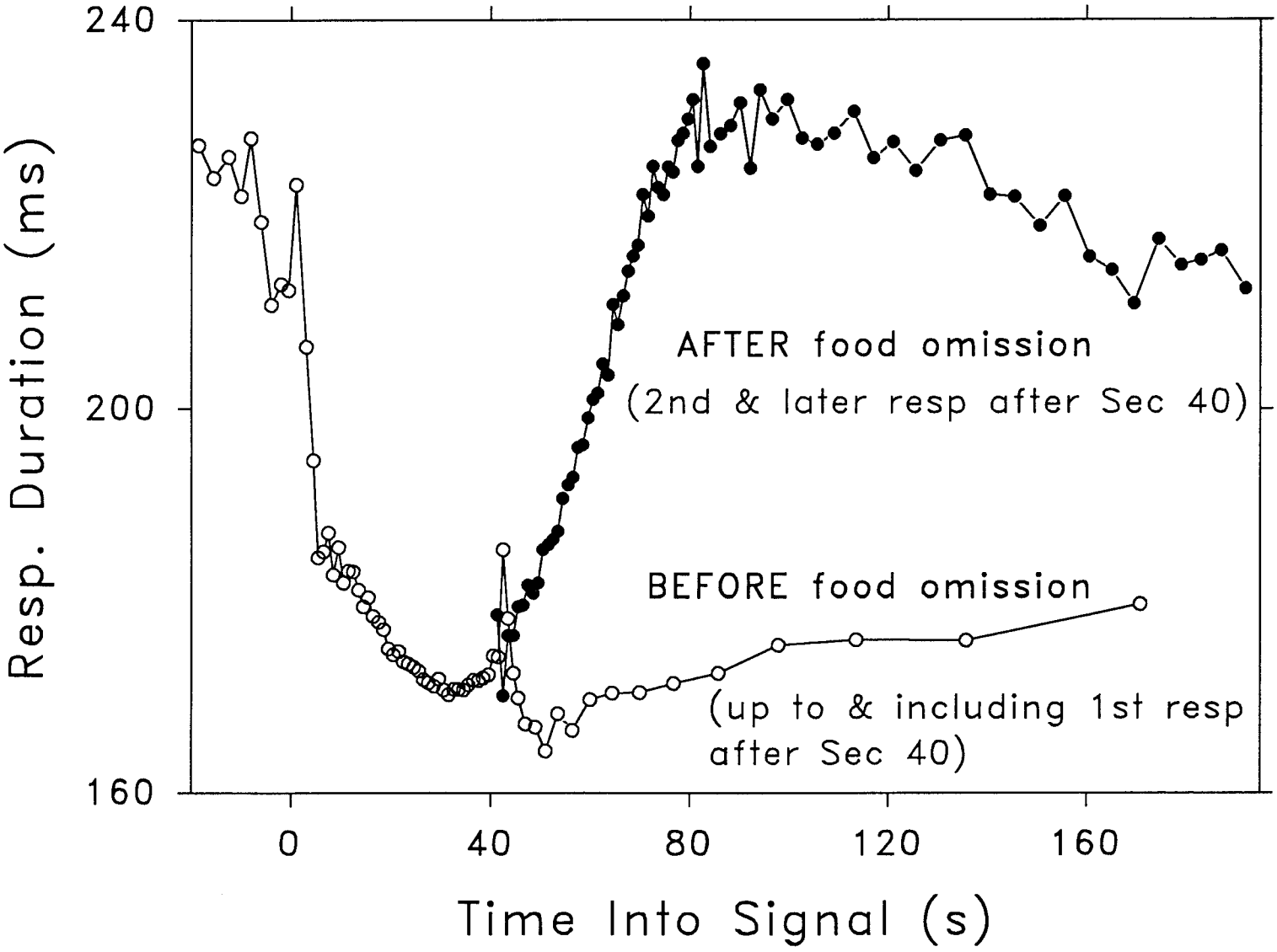
subjects: 18 rats. Well-trained at start of experiment.

procedure: the peak procedure. 112 days, 6 hrs/day.

data: time & duration of each response (all trials). About 3 million responses total.

in short, a very simple situation measured for a long time.


Resp. Rate (/min)
20
10
0
Resp. Duration (ms)
240
200
160
0
40
80
120
160
Time Into Signal (s)


240
200
160
Resp. Duration (ms)
AFTER food omission
(2nd & later resp after Sec 40)
BEFORE food omission
(up to & including 1st resp
after Sec 40)
0
40
80
120
160
Time Into Signal (s)

This shows what caused duration to increase late in the trial. It's what Amsel called frustration--the rat's reaction to the omission of expected food. At about Second 40 on empty trials, the rat realizes that the usual food is not there. This graph shows two functions based on different sets of responses. One function is based on all responses up to and including the first response after Second 40--in other words, all responses before the rat is disappointed. The other function is based on all responses after the first response after Second 40. In other words, all responses after the rat is disappointed. The graph shows that the responses before the rat is disappointed do not show the increase in duration late in the trial. This implies that the increase in response duration is due to the omission of expected food.

Two more measures of performance

We summarized the duration function with two measures. One was middle duration, defined as the average duration of responses between Second 10 and Second 40. The other was late duration, defined as the average duration of responses between Second 90 and the end of the recording interval. This gave us a total of seven measures of performance: the five I mentioned earlier--peak time, peak rate, and so forth--and these two.

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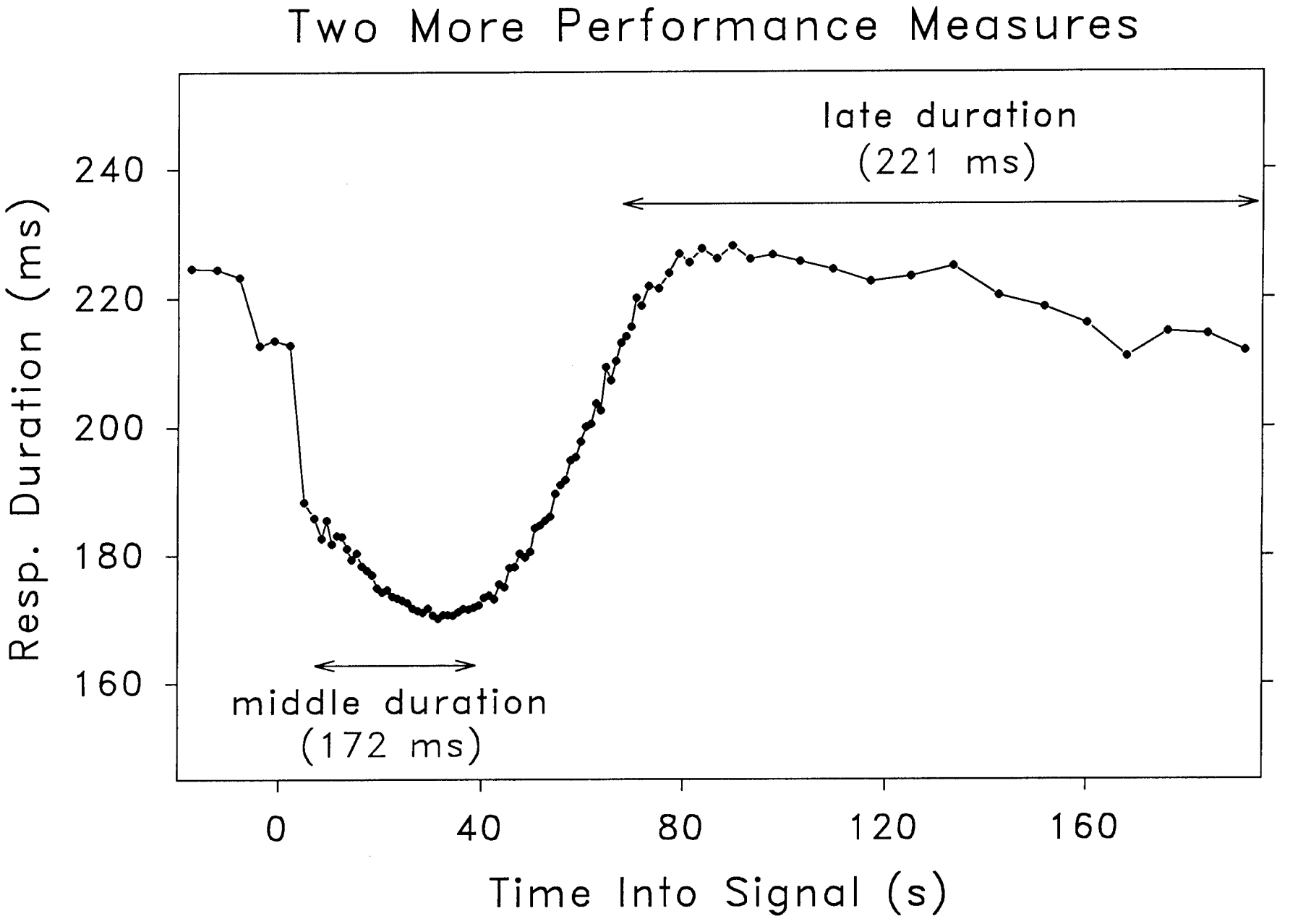
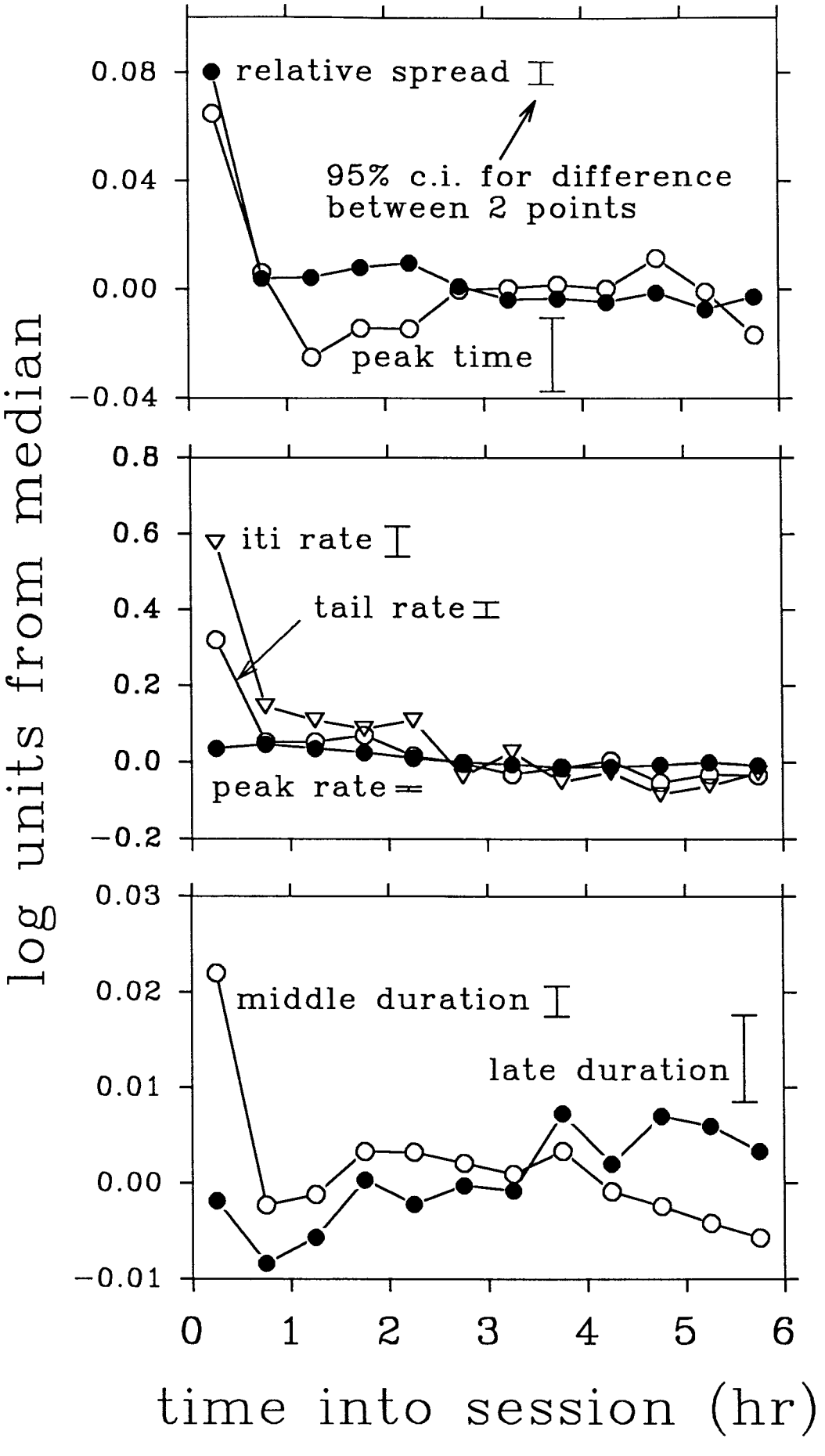
7 measures vs. time into session

This shows how the seven measures changed during the session. Each point is a different half-hour. The y axis is in log units; the various measures have been adjusted so that their medians coincide. The error bars, as before, show the 95% confidence intervals for the difference between two points; so two points are reliably different if their difference is more than the length of the error bar.

I'm going to go over the measures one by one. In the top panel, relative spread dropped a lot during the first hour, but it did not quite reach its final level until after about three hours--the drop from the third hour to the fourth is reliable. Peak time apparently reached its final level during the 2nd half-hour, but it is measured too imprecisely to put a lot of weight on this.

In the middle panel, peak rate declined gradually then levelled off shortly before Hour 4. It's hard to see on this scale, but it's quite clear when the y axis is expanded. Tail rate was clearly different from peak rate during the first half-hour, but followed peak rate after that. So the tail-rate results apparently reflect two mechanisms--one that changed during the first half-hour but was constant after that; and one that changed as long as peak rate changed. Iti rate behaved much like relative spread. It declined sharply from the first half-hour to the second, but apparently reached its final level toward the end of the third hour.


Two More Performance Measures
late duration
(221 ms)
middle duration
(172 ms)
Resp. Duration (ms)
240
220
200
180
160
0
40
80
120
160
Time Into Signal (s)


0.08
0.04
0.00
−0.04
relative spread
95% c.i. for difference
between 2 points
peak time
0.8
0.6
0.4
0.2
0.0
−0.2
iti rate
tail rate
peak rate
0.03
0.02
0.01
0.00
−0.01
middle duration
late duration
log units from median
0
1
2
3
4
5
6
time into session (hr)

In the bottom panel, middle duration shows a surprising pattern, going way down, then slightly up, then down again. It never levels off. Late duration is measured too imprecisely to be sure of much, but it seems to level off in the last few hours.

Summary of Expt. 2 session-time results

This summarizes the results I just showed you. There seem to be about four different times that measures reached their final levels. This suggests that the underlying mechanism has at least four different parts.

We can do a similar sort of analysis even when we are not looking at the time course of some effect. To illustrate this, I'll show you the effects of another factor--the effect of one trial on the next. Some trials were food trials, some were empty trials. The difference between the two types of trial had a big effect on the following trial. It turns out that it affected all seven measures of performance. But it affected different measures in different ways.

Effect of number of preceding food trials

This shows how the effect of one trial on the next varied with the number of preceding food trials. These graphs show the effect of the number of food trials in a row. Zero food trials in a row means, of course, that the preceding trial was an empty trial. The results for "1" preceding food trial come from cases where the previous trial was a food trial, and the trial before that was an empty trial.

The seven functions fall into two groups. For two of the measures, the effect of food is complete with just one food trial; additional food trials have no more effect. That was true for relative spread and tail rate. For the other five measures, multiple food trials had more effect than just one. It is also interesting that food trials had opposite effects on middle duration and late duration.

Summary of food-trial functions

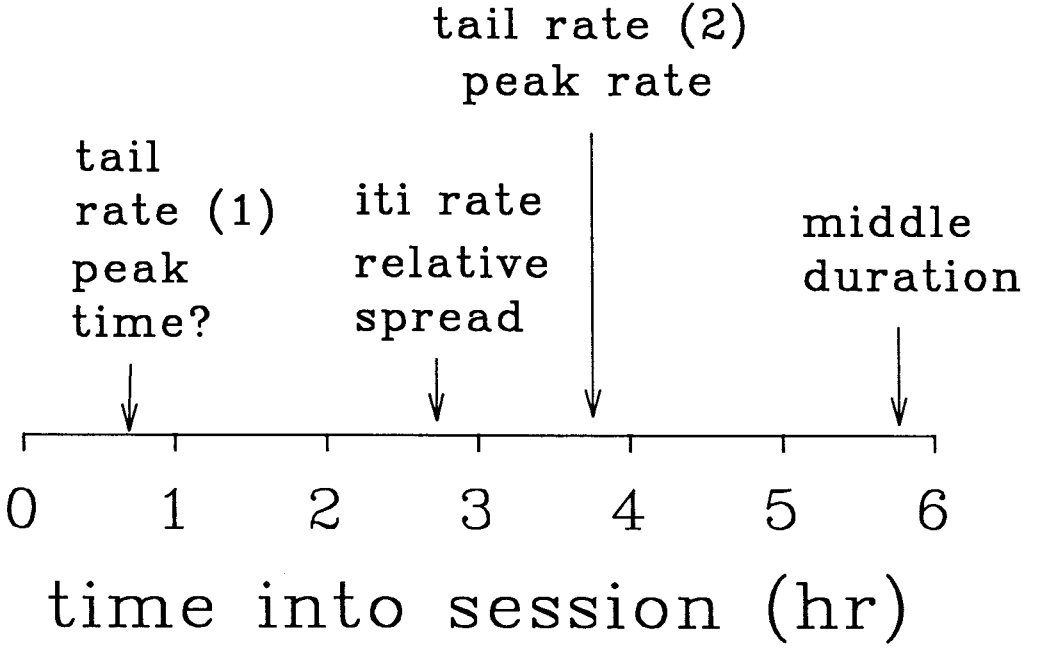
This summarizes the functions I just showed you. Two of the measures reached asymptote after just one food trial; the other five never reached asymptote. These results suggest, of course, that the underlying mechanism has at least two parts.

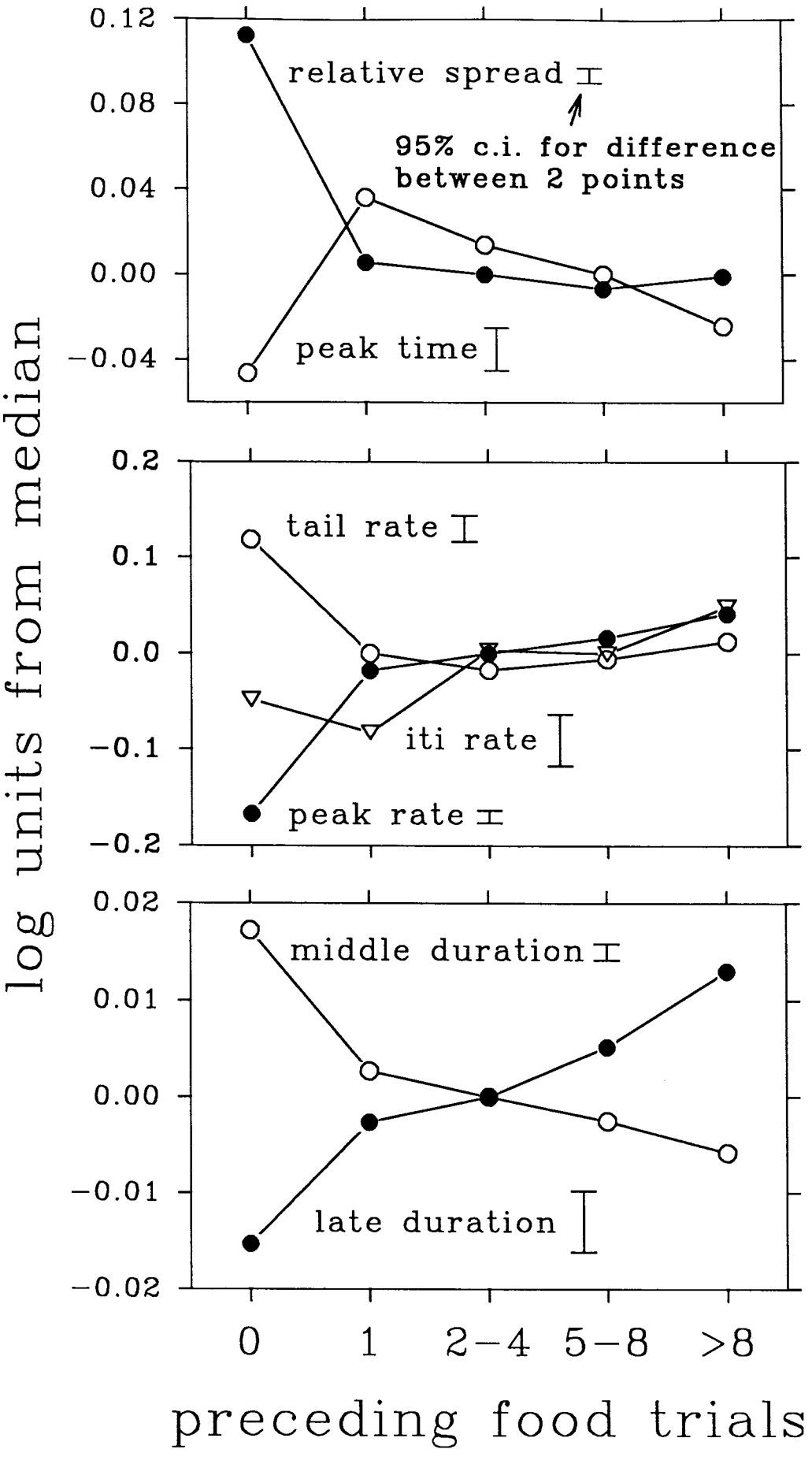
By looking at details of the food-trial effect, we can distinguish between many of the effects that are lumped together in this analysis.

Details of food-trial effects

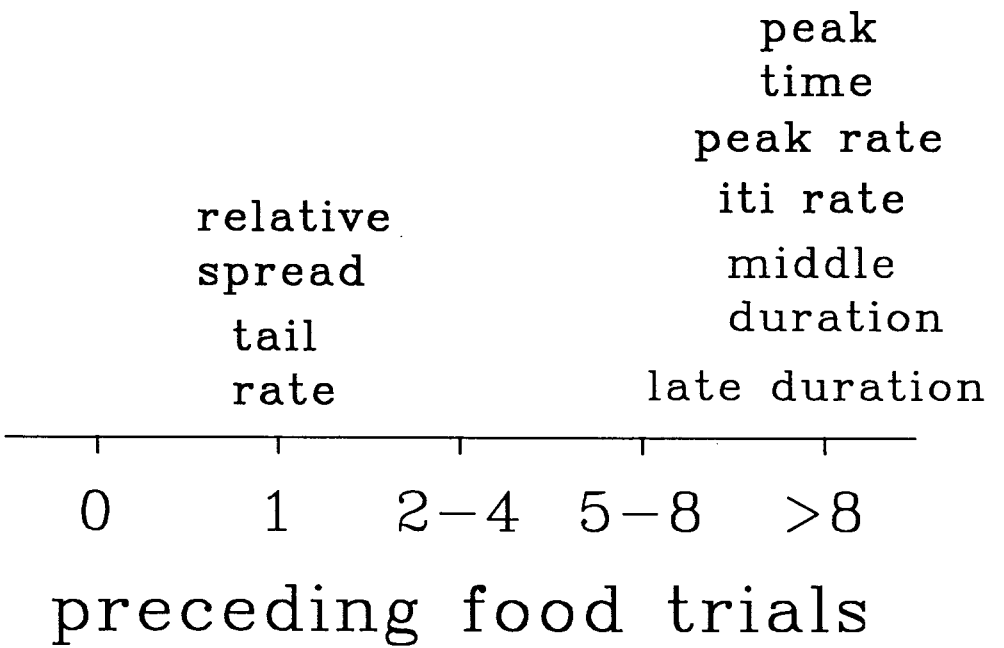
The first column of this table summarizes the data I just told you about--that looking at the number of food trials sorts the measures into two categories. The second column describes the

When each measure reached its final level




0.12
0.08
0.04
0.00
−0.04
relative spread
95% c.i. for difference between 2 points
peak time
0.2
0.1
0.0
−0.1
−0.2
tail rate
iti rate
peak rate
0.02
0.01
0.00
−0.01
−0.02
middle duration
late duration
log units from median
0
1
2−4
5−8
>8
preceding food trials

When each measure reached its final level



Details of Food-Trial Effect

measure	1 food trial same effect as >1 food trial?	interaction w/ same/different signal? (F ratio)	interaction w/ iti length? (F ratio)
relative spread	yes	yes (62)	yes (69)
tail rate	yes	yes (7)	no (1)
peak time	no	no (0)	yes (46)
peak rate	no	yes (92)	no (2)
iti rate	no	not meaningful	yes (38)
middle duration	no	yes (9)	no (3)
late duration	no	yes (6)	no (1)

results of an analysis that asked if the food-trial effect varied with the signal used on the preceding trial. Remember that half the trials were with sound, half with light. So the preceding trial could either be the same signal as the current trial, or a different signal. If the effect of one trial on the next depends on whether the signals of the two trials are the same or different, it's probably an associative effect. The numbers in parenthesis are the F ratios for the interaction. The F ratios show that in five cases, the effect did depend on the signal of the preceding trial. In one case--peak time--the effect did not depend on the preceding signal.

The third column describes the results of an analysis that asked if the size of the food-trial effect varied with the intertrial interval, that is, the time between the two trials. Intertrial intervals varied from 20 s to a few minutes. In three cases, the effect depended on the intertrial interval; in the other four cases, the effect was essentially the same regardless of the intertrial interval.

How many different processes are required to produce these results? The seven measures showed four different patterns of yes/no answers, so the nature of the preceding trial must affect at least four different parts of the mechanism. Because the effect on middle duration and the effect on late duration were in opposite directions, they are likely to be due to different mechanisms. That makes five parts.

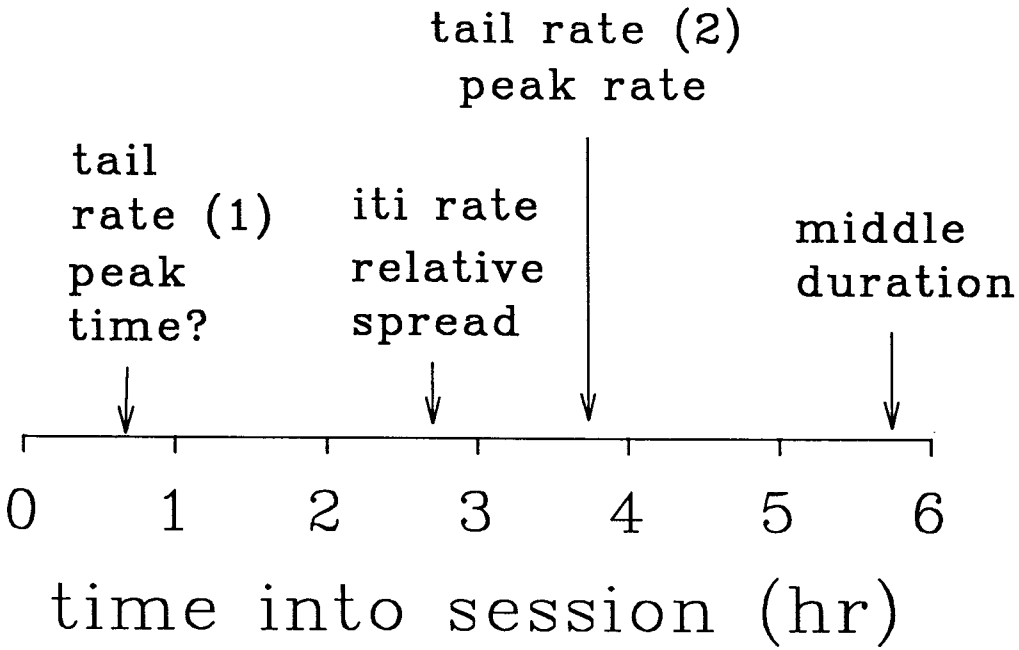
Two analyses combined

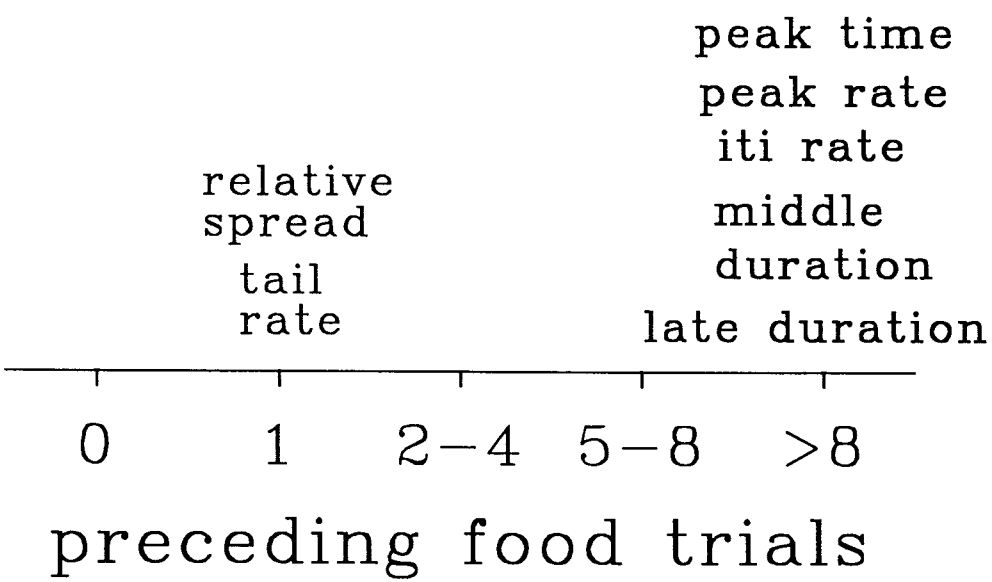
This shows the two analyses together--the analysis produced by session time and the analysis produced by the number of preceding food trials. Measures not distinguished by one analysis are distinguished by the other analysis. The effects of session time, taken alone, suggest four parts. But each of the pairs of measures that are not separated by session time are separated by the number of preceding food trials. For example, in the session-time analysis, tail rate and peak time are together, but in the food-trial analysis, they are apart. Likewise, iti rate and relative spread are together in the session-time analysis, but separated in the food-trials analysis. So, if the two analyses are taken together, the results suggest at least seven parts.

Summary of Experiment 2

These are the points I want to stress about this experiment. First, looking at the effects of session time we found four different time courses. This suggested the existence of four different parts. Second, whether a trial was food or empty affected behavior on the next trial, in fact affected all seven of our performance measures. Third, the details of these effects--how they depended on the number of food trials, the signal used on the preceding trial, and the amount of time between the trials--showed many differences between measures. There were five

When each measure reached its final level





Summary of Experiment 2

- four different time courses of session-time effects.

- all 7 measures influenced by trial type (food vs empty) of preceding trial. These seven effects (one per measure) varied in their dependence on the number of food trials, the signal (same or different) of the preceding trial, and the length of the intertrial interval.

- the trial-type results suggest that food influenced at least five different parts.

- The two analyses (session time and trial type) taken together suggest at least seven different parts.

different patterns of results, suggesting five different parts. And, finally, when the two analyses are combined--the effect of session time and the effect of the preceding trials--the results suggest at least seven different parts.

Conclusions

The main conclusion from this work, of course, is that the mechanism can be divided into many separately-changeable parts--apparently, at least six or seven. We often hear about multiple types of association, multiple types of memory, and so forth. Keep in mind however that conclusions that there are multiple types of memory, and so forth, have come from multiple tasks--the conclusion in these cases has been that <u>different</u> tasks involve separately-changeable processes. Here the conclusion is that <u>one</u> task involves separately-changeable parts.

The conclusion that food apparently changes at least five parts is in stark contrast to all learning theories. None of them proposes anything this complicated. It is also a problem for conventional learning procedures, such as autoshaping. At least four of the food effects appear to be associative. No conventional learning procedure allows the different effects to be measured separately.

The main methodological conclusion from this work is that the method used here has many advantages over the usual methods of dividing a mechanism into parts. That's often done with double dissociations, for example. To observe a double dissociation you need two selective treatments, and two selective measures of performance, which in practice are usually from different tasks. To use the method I've described here, you need only one task, no selective treatments, and no selective measures. Moreover, with two treatments, a double dissociation only suggests two parts; the method described here can identify many more than two.

Conclusions

- the mechanism has many separately-changeable parts--at least six or seven.

- food changes a number of parts--at least five. A problem for conventional learning procedures.

- method has advantages over other separation methods, such as double dissociations. Does not require multiple tasks, selective influence, or selective measurement.