Where Do New Responses Come From?

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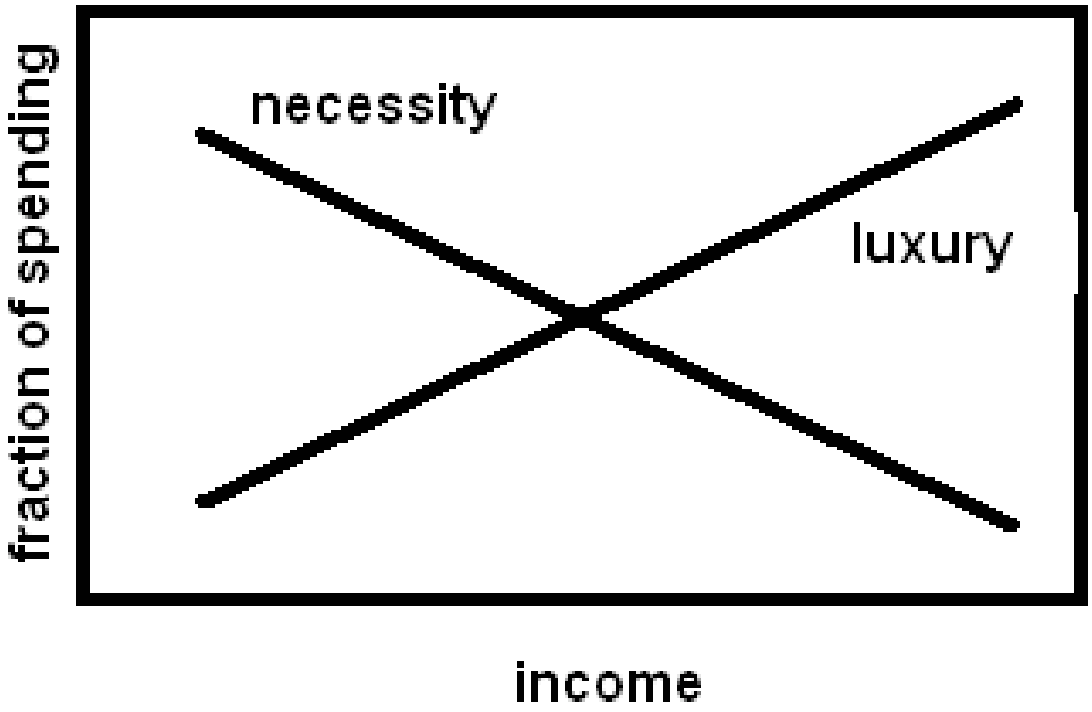
Outline of talk

- Question: What controls the variation from which reward selects?
- Experiment 1: a mystery
- Experiment 2: wrong answer
- Experiment 3: right answer?
- Experiment 4: yes, right answer
- Overall conclusions

instrumental learning = variation
+ selection

Variation: necessity or luxury?



Two Plausible Answers

- *Necessity*. Required for learning.
- *Luxury.* Variation is costly.

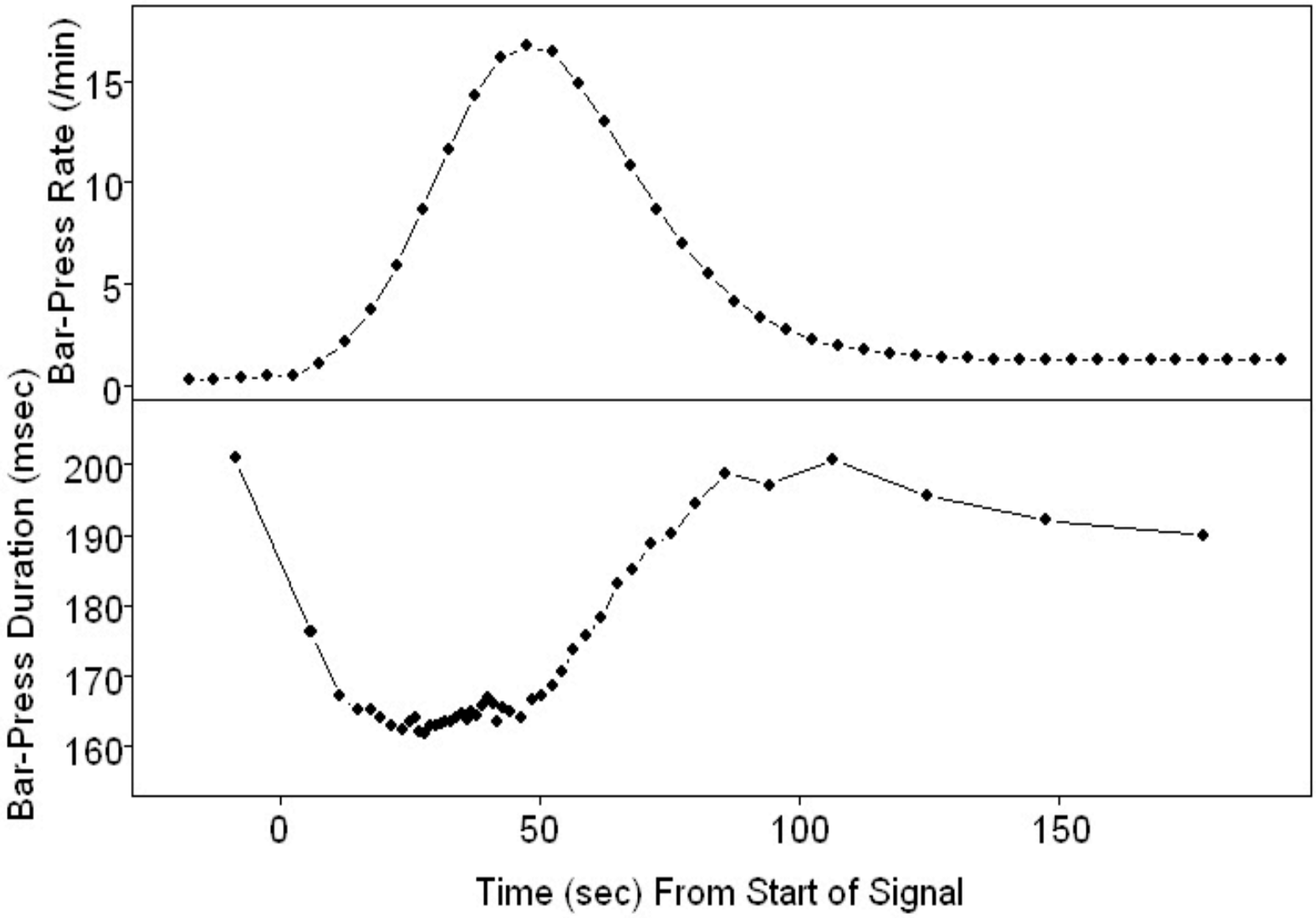
Factual Background

- Variation of form increases during extinction (i.e., as income declines). But there are many differences between training and extinction.

How this work began

- Measured bar-press duration (how long the rat holds down the bar) with peak procedure
- Surprising result: Sharp increase in middle of trial, triggered by absence of reward
- Not due to frustration (another surprise)

Expt 1: Peak Procedure



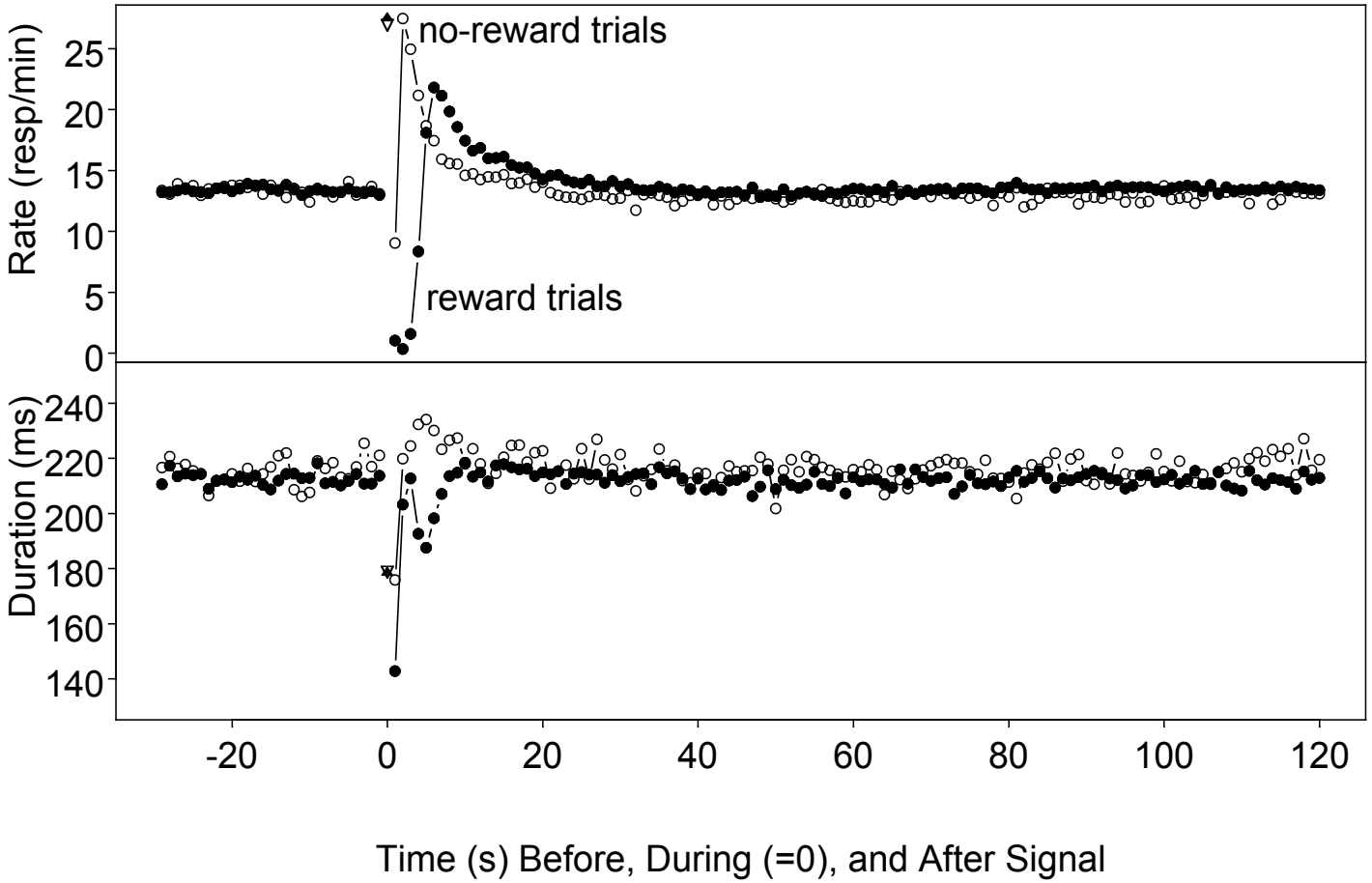
Expt 1: Why did bar-press duration increase?

- Increase was large (25%) and very clear (t = 18).
- For years, assumed that increase was due to frustration – failure to get expected food. Frustration studied in many runway studies by Amsel. Rats run faster after failure to get expected food.
- Submitted paper to *JEP:ABP* with this explanation. Editor suggested we do another experiment.

Expt 2: Test of frustration explanation

- Tried to do simplest possible experiment that would show effect of frustration on bar-press duration.
- Rats press bar for low probability of reward (food). Now and then, light turned on. 1st bar press turns off light. On 80% of trials, food given; on 20% of trials, no food given.
- Non-reward at end of trial should produce frustration. We compared bar-press duration after reward and non-reward.

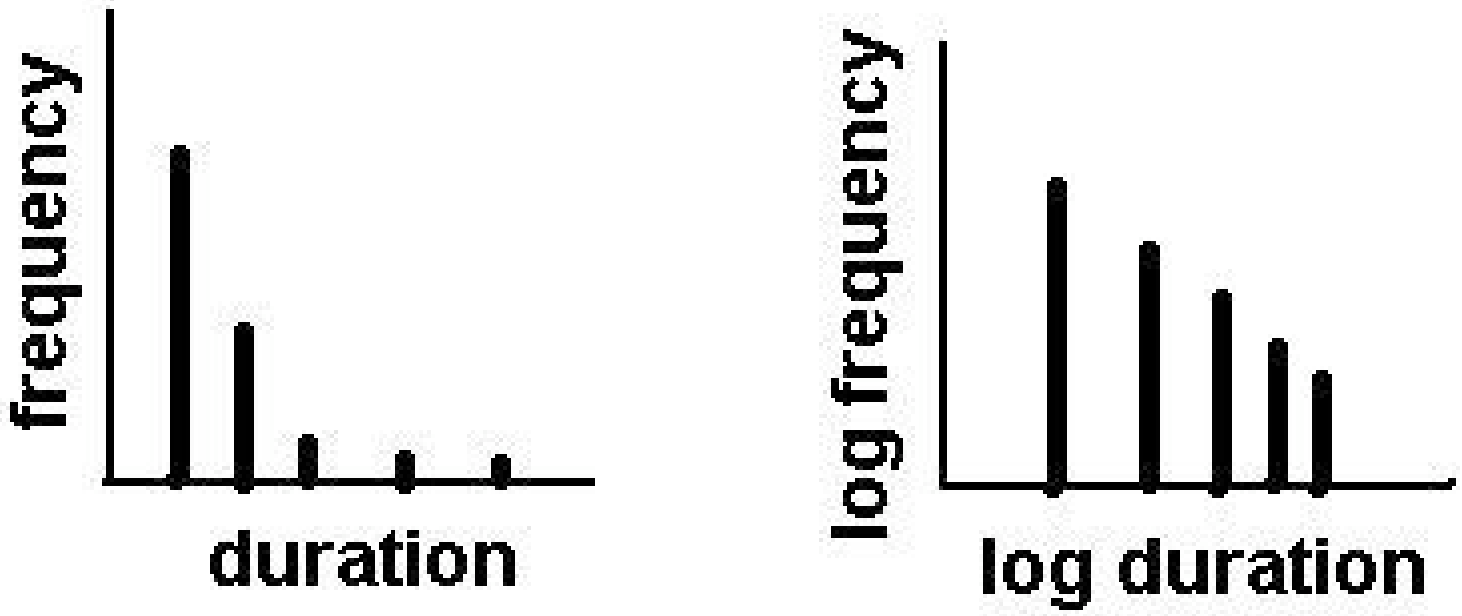
Expt 2: Effect of reward omission



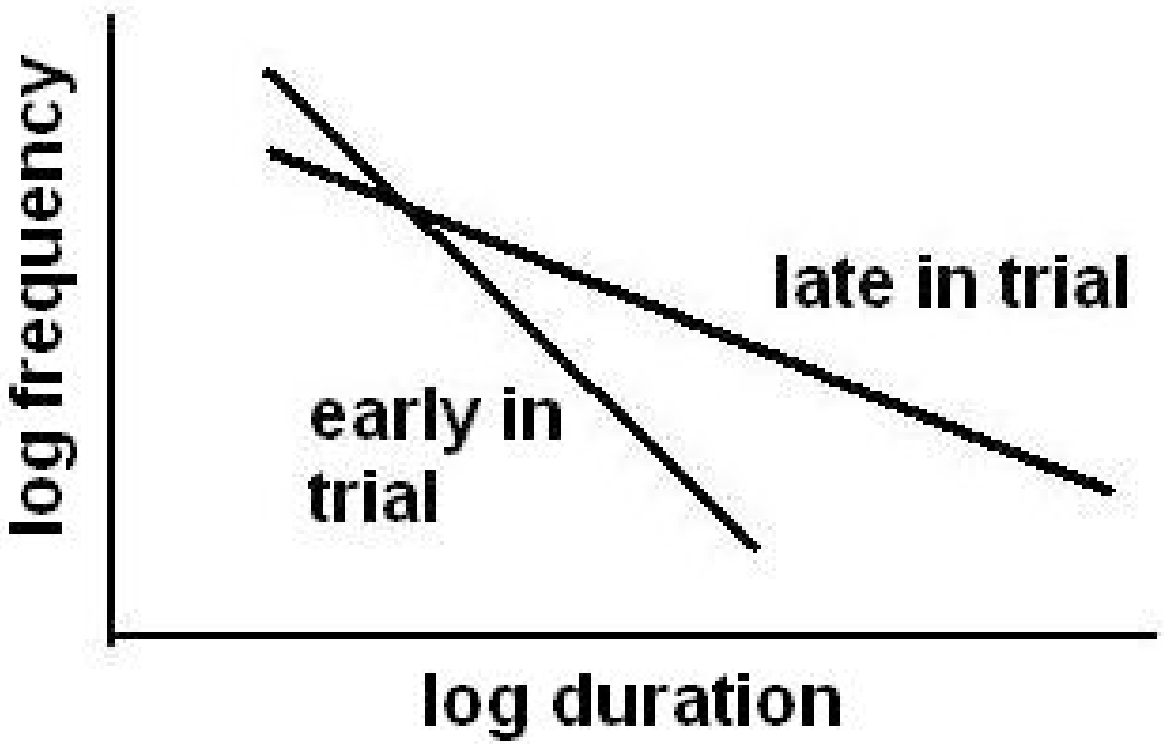
Expt 2: Conclusion

- Omission of expected reward produced small, short-lived increase in bar-press duration. Much different than peak-procedure results.
- Peak-procedure results not due to frustration.

Distribution of bar-press durations: straight line on log-log coordinates



Change in distribution of bar-press durations during peak-procedure trial



New Explanation of Increase in Bar-Press Duration

- Distribution change = increase in variability
- Variability increased when rat figured out there would be no reward on that trial
- Instance of general rule: less expectation of reward, more variation in response form. Rule makes sense: less expectation of reward, less lost by “wrong answers”
- Test of rule: change expectation of reward in a different way

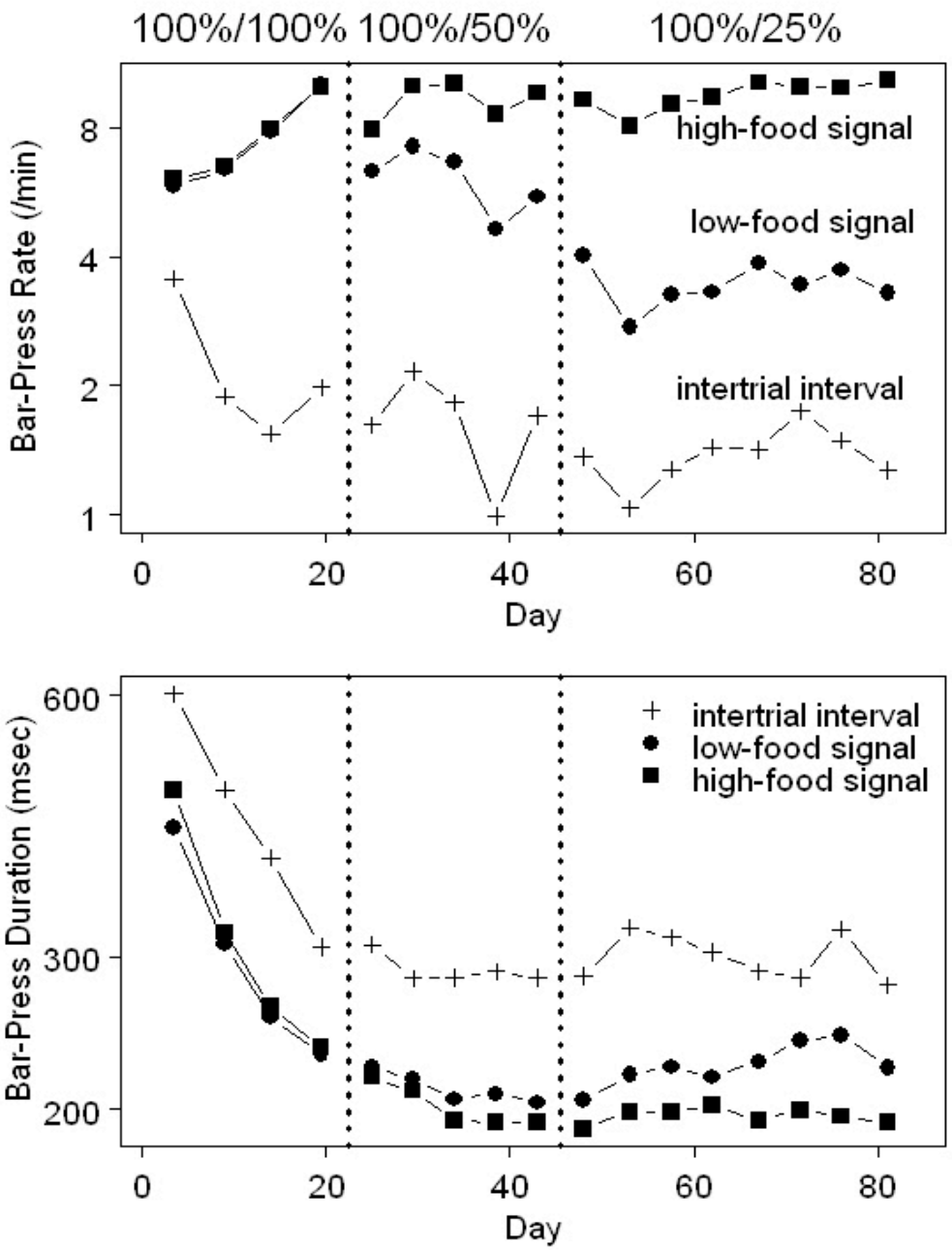
Experiment 3: Test new explanation

- **Purpose:** test prediction that less expectation of food produces more variation of bar-press duration
- **Procedure:** 2 signals (light and sound) with high & low probability of reward. Trials separated by intertrial interval (iti).
- **Prediction:** Pattern of variation:

  high-food signal < low-food signal < iti

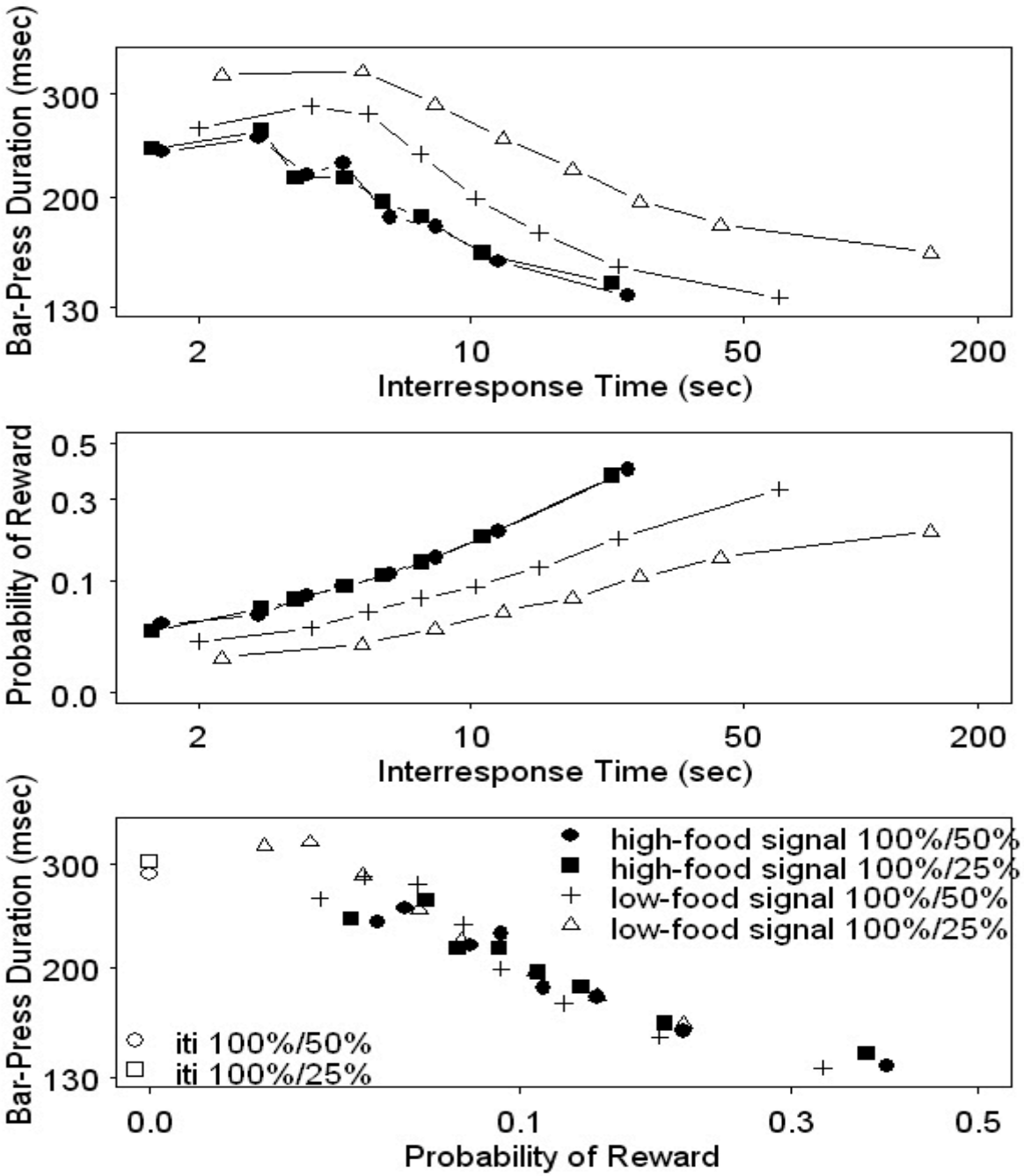
Details of Procedure of Experiment 3

- **Subjects**: 14 rats
- **Both signals**: Trial starts with signal onset. End of trial "primed" each second with probability 1/60. After end of trial primed, next bar press ends trial (turns off signal).
- **High-food signal**: all trials end with food
- **Low-food signal**: trials end with food with probability 100% (1st phase), 50% (2nd phase), or 25% (3rd phase).
- **Intertrial intervals**: 60 sec long.

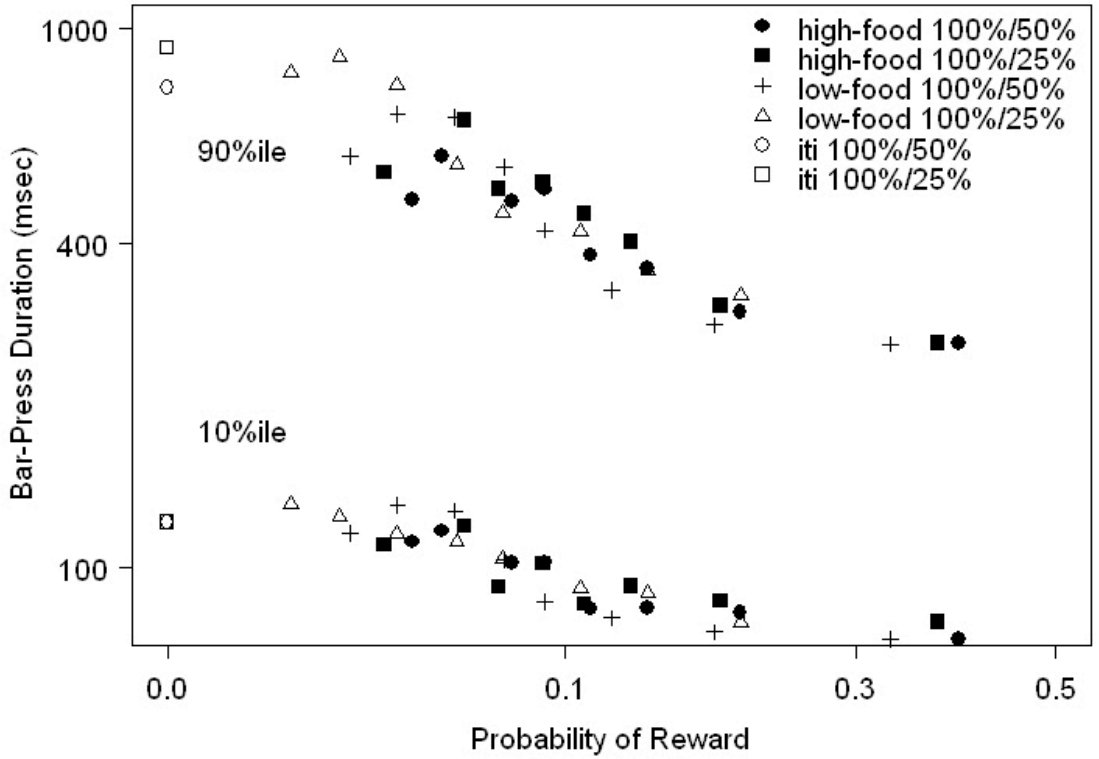

100%/100%
100%/50%
100%/25%
high-food signal
low-food signal
intertrial interval
Bar-Press Rate (/min)
1
2
4
8
0
20
40
60
80
Day
Bar-Press Duration (msec)
200
300
600
intertrial interval
low-food signal
high-food signal
0
20
40
60
80
Day

Results of Experiment 3

- Predictions confirmed but . . .
- Effects smaller than expected.
- Realized that variable-interval schedule causes probability of reward to depend on time since last bar press: the longer the time, the greater the probability of reward.
- If rats measured time since last bar press, they could adjust expectation of reward


Bar-Press Duration (msec)
300
200
130
2
10
50
200
Interresponse Time (sec)
Probability of Reward
0.5
0.3
0.1
0.0
2
10
50
200
Interresponse Time (sec)
Bar-Press Duration (msec)
300
200
130
high-food signal 100%/50%
high-food signal 100%/25%
low-food signal 100%/50%
low-food signal 100%/25%
iti 100%/50%
iti 100%/25%
0.0
0.1
0.3
0.5
Probability of Reward

Variability of bar-press durations depends on probability of reward



More results of Experiment 3

- Bar-press durations in all conditions well-predicted by probability of reward of each bar-press
- The lower the probability of reward, the greater the variation in duration

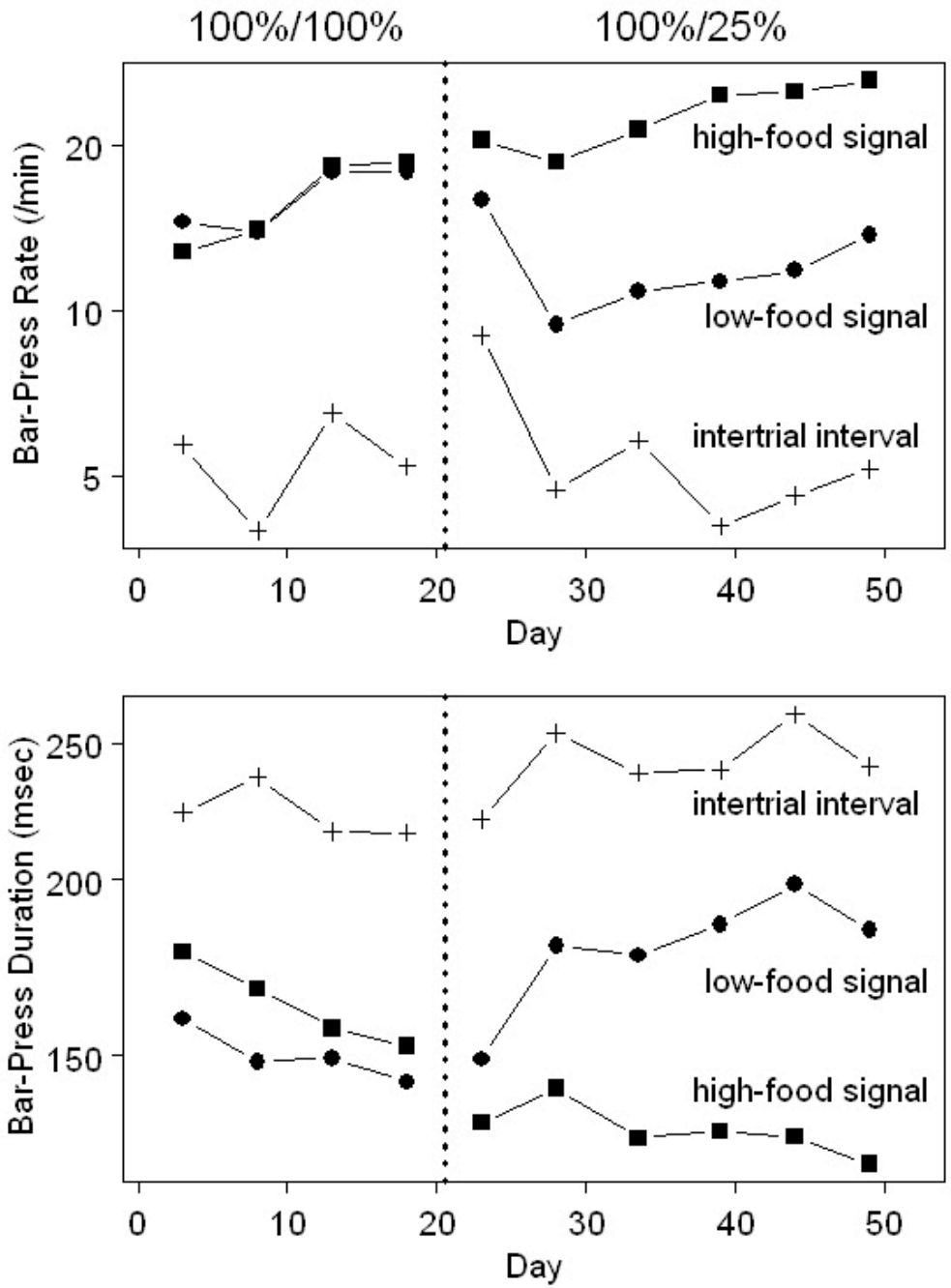
Experiment 4: Test new explanation again

- **Purpose:** retest rule (less expectation of food causes more variation in bar-press duration) taking into account that rats can measure time between bar presses
- **Procedure:** Basic plan same as Expt 1: 2 signals (light and sound) with high & low probability of reward. Signals separated by intertrial interval (iti).
- **Prediction:** Pattern of variation:

  high-food signal < low-food signal < iti

Details of Procedure of Experiment 4

- **Subjects**: 14 rats of Experiment 1
- **Both signals**: Main difference from Expt 1: *Trial ends with probability 25% after each bar press.*
- **High-food signal**: all trials end with food
- **Low-food signal**: trial ends with food with probability 100% (1st phase) or 25% (2nd phase)
- **Intertrial intervals**: 60 sec long.


100%/100%
100%/25%
Bar-Press Rate (/min)
20
10
5
high-food signal
low-food signal
intertrial interval
0
10
20
30
40
50
Day
Bar-Press Duration (msec)
250
200
150
intertrial interval
low-food signal
high-food signal
0
10
20
30
40
50
Day

Results of Experiment 4

- Predictions confirmed
- Large effect of reward probability on bar-press duration (high-food signal vs low-food signal, $t = 6$)
- Duration effect as clear as rate effect (high-food signal vs low-food signal, $t = 6$)

Overall Conclusions I

- Experiments 3 & 4 support general rule suggested by Experiments 1 & 2: *less expectation of reward, more variation of form*
- Variation behaves like a necessity, not a luxury. And variation *is* a necessity: without it, no learning.

Overall Conclusions II

- Easy to measure variation, at least in this situation. No need for special equipment.
- Variation – the importance of variation – has a funny way of being overlooked. Staddon, Neuringer, and Balsam stand out as exceptions. Not just psychology: economics, too. Not just academia: business, too.