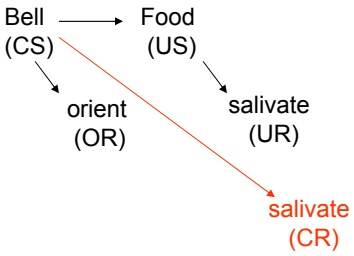
Introduction to Learning

Associative learning

- Event-event learning (Pavlovian/classical conditioning)
- Behavior-event learning (instrumental/ operant conditioning)

- Both are well-developed experimentally and theoretically
- Note confusion in usages as *procedures*, *outcomes*, and *processes*

Pavlovian conditioning



CS = conditioned stimulus
US = unconditioned stimulus
OR = orienting response
CR = conditioned response
UR = unconditioned response

Note limiting nature of defined properties of these events

Important consequences of Pavlovian conditioning

- Behavioral
  - Reflexes vs behavior systems
  - Regulatory systems; anticipatory homeostasis (allostasis)
- Affective
  - Motivational states and modulation of other behavior
  - Reinforcement power
- Cognitive
  - Attention
  - Representation

Learning theory

- What are the conditions of learning?
- What are the contents of learning?
- What is the relation of learning to behavior?

Conditions for learning

- External (environmental) vs internal (organismic) conditions
  - External
    - Time
    - Reinforcement (do you need it; what is it?)
  - Internal
    - Motivation (drive)

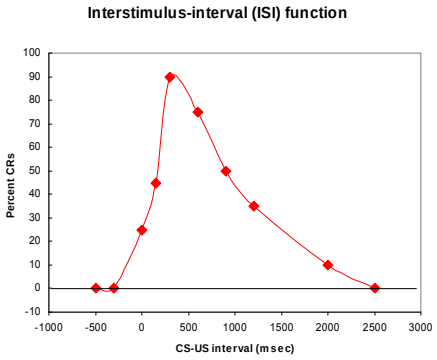
Conditions for learning

- External (environmental) vs internal (organismic) conditions
  - External
    - Time, information
    - Reinforcement (do you need it; what is it?)
  - Internal
    - Motivation (drive)
    - Attention
    - other hypothetical variables
    - Function and evolutionary history

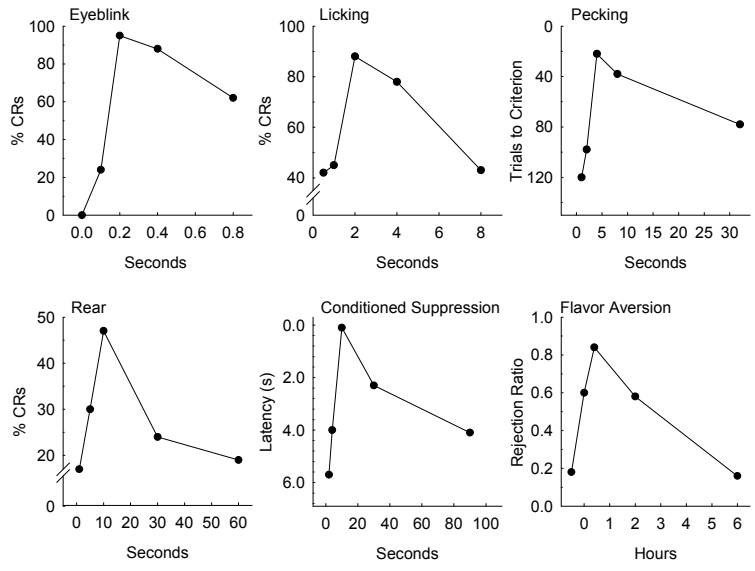
Conditions for learning

- Time
  - Inter-stimulus interval (ISI)

Acquisition of Pavlovian associations: interstimulus interval



Condition for learning or content of learning?

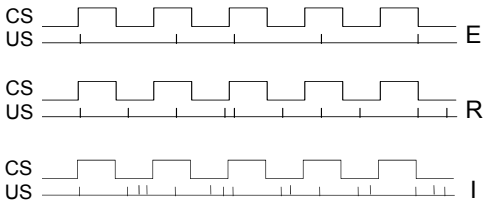


Important variables

- Time
  - Inter-stimulus interval (ISI)
  - Inter-trial interval (ITI)
  - Ratio of ITI/ISI
  - Condition for learning or content of learning?

Important variables

- Time
  - Inter-stimulus interval (ISI)
  - Inter-trial interval (ITI)
  - ITI/ISI
- Information
  - Contingency/correlation



Important variables

- Time
  - Inter-stimulus interval (ISI)
  - Inter-trial interval (ITI)
- Information
  - Contingency/correlation
    - Excitation and inhibition
  - Blocking

Blocking experiment

B:	Light → food	light + tone → food	tone?
C:	Light / food	light + tone → food	tone?

Many theories

- Most common & successful are contiguity theories: Learning-induced variations in processing of USs and CSs
  - Reinforcement theories: USs change effectiveness; unpredicted USs more effective
  - Attention theories: CSs change effectiveness; good (or poor) predictors processed better

Learning-induced variations in processing of USs

- Rescorla-Wagner model: $\Delta V_A = \alpha_A \beta_1 (\lambda_1 - V_{\Sigma A \ldots X})$
  - Reinforcing event is error signal (discrepancy between expected and actual value of US)
    - If US underexpected (error>0) learning is excitatory
    - If US overexpected (error < 0) learning is inhibitory
    - Thus, excitation & inhibition tied to change/contrast rather than absolute events
    - Symmetry of conditions for, and content of, excitation and inhibition
  - Error signal is aggregate error (all sources)
  - Rate parameters for CS and US (constants) determine how fast things happen, and sometimes how big the differences are but otherwise not typically critical

Learning-induced variations in processing of USs

- Rescorla-Wagner model: $\Delta V_A = \alpha_A \beta_1 (\lambda_1 - V_{\Sigma A \ldots X})$
  - Became a standard in behavioral psychology because it did a great job of modeling a large number of odd (counterintuitive) findings as well as obvious ones, with minimum complexity of representation and computation (will demonstrate)
  - later became a standard in neuroscience because it is easy to implement and because midbrain dopamine neurons seemed to show requisite properties to be R-W teaching signals (aggregate prediction error)
    - delivery of unexpected rewards ("positive prediction error") produces rate increases
    - omission of expected rewards ("negative prediction error") produces rate decreases
    - as reward becomes expected on the basis of a cue or response, the increases come under control of that cue/response, and fail to occur to reward delivery itself
    - (will say more on this later, too)

Learning-induced variations in processing of USs

- Rescorla-Wagner model: $\Delta V_A = \alpha_A \beta_1 (\lambda_1 - V_{\Sigma A \ldots X})$
  - Apply to blocking
  - Apply to conditioned inhibition procedure (A+, AX-)
  - Apply to overexpectation (A+, B+ | ABX+| X?)
  - Apply to contingency (AC+, C-) (AC+, C+) (AC-, C+)
  - Not the last word; many intolerable flaws and wrong predictions
    - Symmetry of excitation and inhibition elusive (e.g., extinction of inhibition and excitation)
    - Aggregate error may not be the whole story; constrained error terms
    - Retrieval effects
    - Evidence for more detailed representation of world ("model-based learning", e.g., Rescorla, 1973)
    - No role for changes in CS processing (attention)

Learning-induced variations in processing of CSs

- Passive (limited resource) models (e.g. Suthreland & Mackintosh, 1971)
- Active models (must learn to distribute resources)
  - Mackintosh: α increases to better predictors, decreases to worse predictors
  - Pearce-Hall model: $\Delta V_A = \alpha_A \lambda_1$, where $\alpha_A \sim |\lambda_1 - V_{\Sigma A...X}|$. (Unsigned) reinforcement error signal determines processing of CS (learning rate parameter). Attends more to bad predictors.

Pearce-Hall model

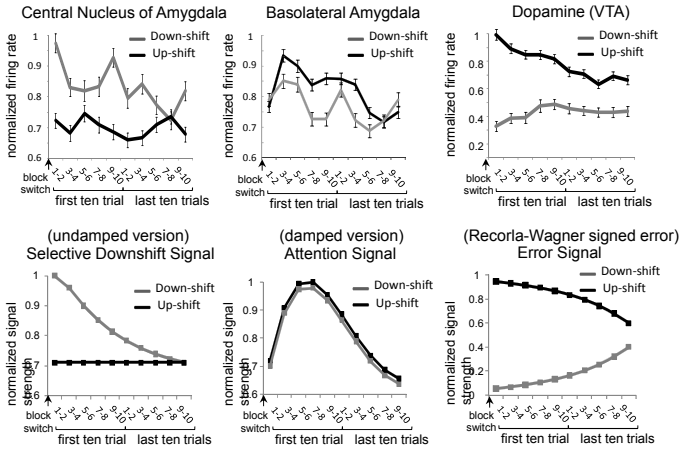
- Contrast learning and action (controlled and automatic)
- Apply to blocking
- Apply to cases in opposition to R-W
  - Unblocking: A++ | AX+ | X?
  - Hall-Pearce negative transfer & rescue
    - A+ | A- | A++
    - A+ | A++ | A-

Pearce-Hall model

- Works in principle, but usually a problem with speed of process
  - in simple acquisition to one cue, would be gradual loss of α (OK)
  - if added another cue, as in blocking experiment, such that $|\lambda - V_{agg}| = 0$, change in α would be instantaneous
  - if changed or removed reinforcer, change in α would be instantaneous
- Added dampening factor, such that $\alpha_A = \gamma|\lambda - V_{agg}| + (1-\gamma)\,\alpha_A$
- When combined with R-W term for variations in reinforcer effectiveness, accounts for nearly everything

Any evidence for an unsigned Pearce-Hall-like error signal?

establish learning with one reinforcer and then shift to a bigger or smaller one



More complex theories

- Contingency theories: Learn individual event relations and compute contingencies
  - Learning based (frequentist & Bayesian)
  - Performance-based (Comparator theory)
- Learn everything and compute whatever needed

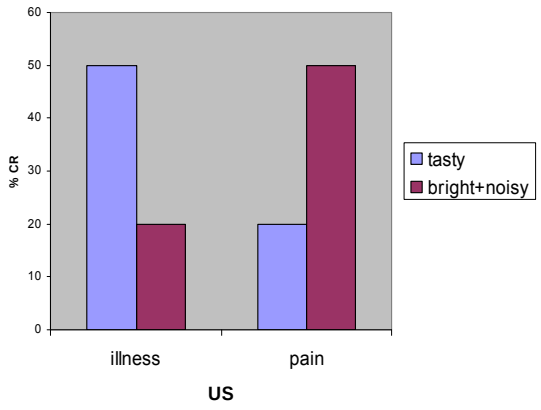
Non-arbitrary nature of events

- Identity of associates matter
  - Engage different neural and behavioral systems for learning
  - Both CS and US individually, and their combination
    - Garcia example

Acquisition of Pavlovian associations: cue to consequence

Garcia Experiment

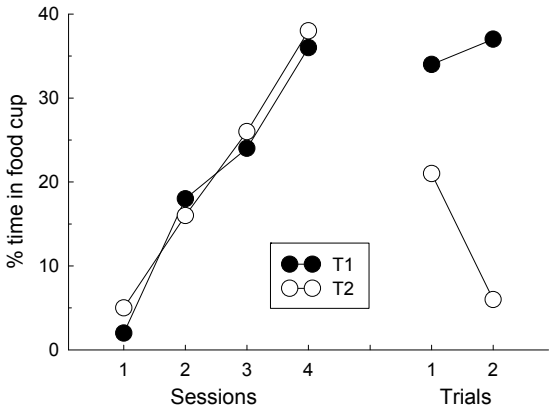
Bright+Noisy+Tasty -- illness
-or-
Bright+Noisy+Tasty -- pain



Content of learning: Pavlovian conditioning as knowledge acquisition

- Stimulus-stimulus (S-S) vs stimulus-response (S-R) associations
  - Learning how vs. learning what (procedural vs declarative)
  - Model-free vs model-based learning
  - Light means slobber vs Light means food
  - Devaluation experiment ("behavioral syllogism"):
    - Light—food men are mortal
    - Food—illness Peter is a man
    - Light? Peter is mortal

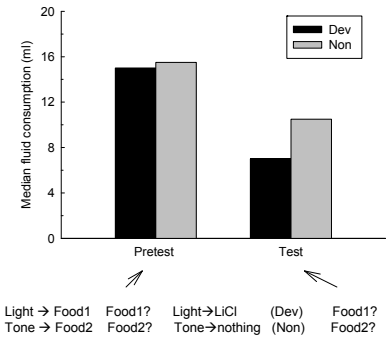
Mediated Performance (devaluation)



T1 --> flavor1 T1?
T2 --> flavor2 flavor2 --> LiCl T2?

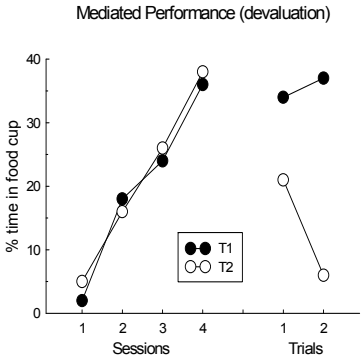
Holland, 1975;1990

Mediated learning



Holland, 1981

Sensory processing of absent events



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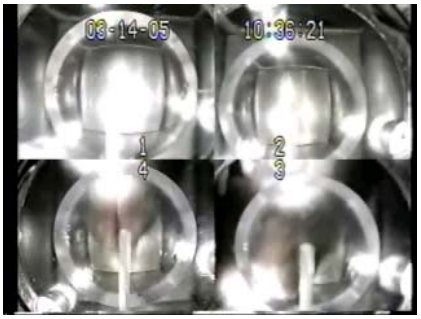
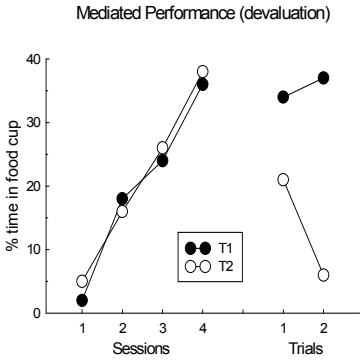


continue testing T1 and T2, with unflavored sucrose in cup

Sensory processing of absent events

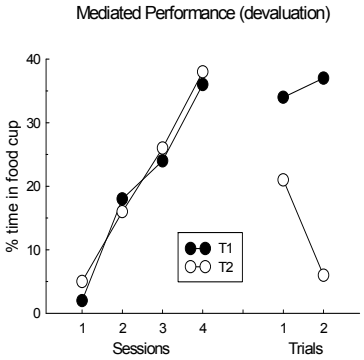


T1 --> flavor1 T1?
T2 --> flavor2 flavor2 --> LiCl T2?

T1

continue testing T1 and T2, with unflavored sucrose in cup

Sensory processing of absent events

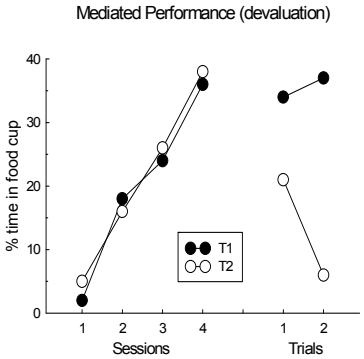


T1 --> flavor1 T1?
T2 --> flavor2 flavor2 --> LiCl T2?

T2

continue testing T1 and T2, with unflavored sucrose in cup

Sensory processing of absent events



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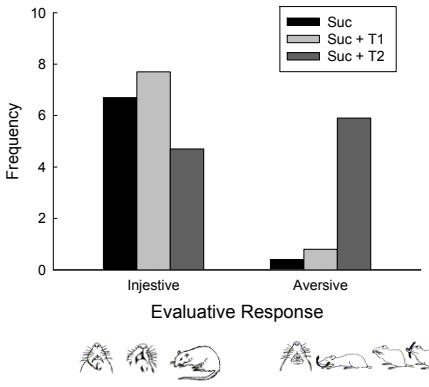

Group Maintain	Tone→sucrose	sucrose//LiCl	tone?
Group Devalue	Tone→sucrose	sucrose→LiCl	tone?
Group CTL	Tone//sucrose	sucrose→LiCl, or sucrose//LiCl	tone?

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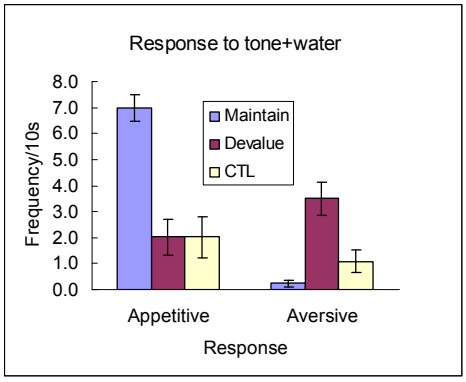
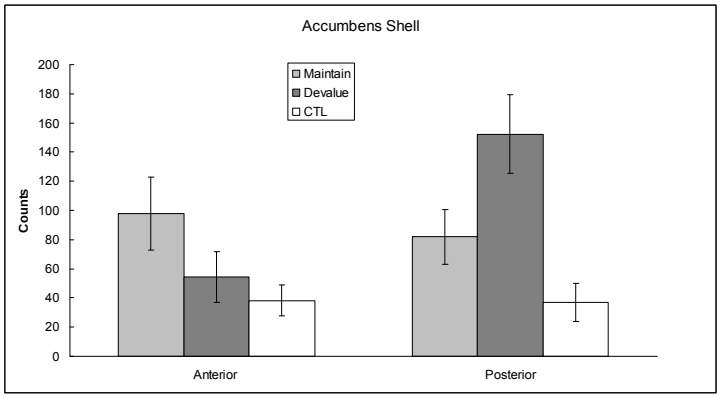
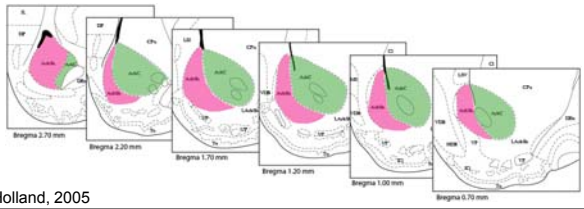


Kerfoot, Agarwal, Lee, & Holland, 2004

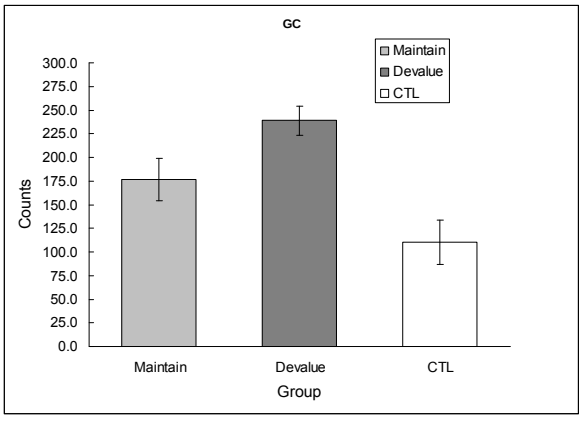
FOS expression in nucleus accumbens





Kerfoot, Agarwal, Lee, & Holland, 2005

FOS expression in gustatory cortex



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