King Saud University

College of Engineering

IE – 341: "Human Factors Engineering"

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Chapter 3. Information Input and Processing

Part – 3: Choice Reaction Time Experiments

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Chapter Overview

Information Processing and Compatibility

1. Information Display – Coding (Ch. 3)
2. Fitts' Law (Ch. 3, Ch. 9)
3. Hick Hyman Law (Ch. 3, Ch. 9)
4. Signal Detection Theory (Ch. 3)
5. Memory - Attention (Ch. 3)
6. Compatibility - Part 1 - Spatial Compatibility (Ch. 10)
7. Compatibility - Part 2 - Movement - Modality Compatibility (Ch. 10, Ch.3)

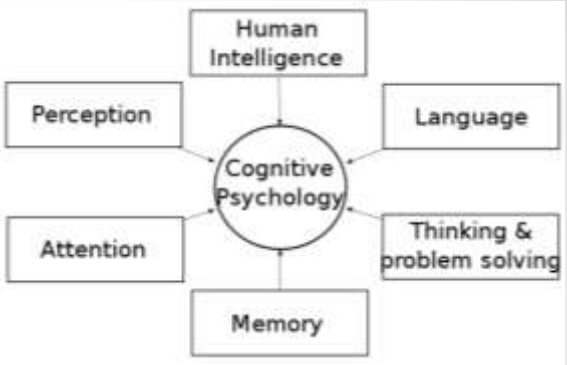
Contents

- Information Theory
  - Unit of Measure of Information
- Reaction Time Experiments
  1. Simple reaction time tasks (SRT)
  2. Choice reaction time tasks (CRT)
  3. Hick's Law
  4. Hick-Hyman Law
- Summary

Information Theory

Information Theory

- Information Processing is AKA:
  - Cognitive Psychology
  - Cognitive Engineering
  - Engineering Psychology



- Objectives of Information Theory:
  - Finding an operational definition of information (1948)
  - Finding a method for measuring information
  - Note, most concepts of Info. Theory are descriptive (i.e. **qualitative** vs. **quantitative**)

Claude Shannon

- Information (Definition):
  - "Reduction of Uncertainty"
  - Emphasis is on "highly unlikely" events
  - Example (information in car):
    - "Fasten seat belt": likely event ⇒ not imp. in Info. Th.
    - "Temperature warning": unlikely event ⇒ imp.

Unit of Measure of Information

- Case 1: **≥ 1 equally likely alternative events**:

$$H = \log_2 N = \frac{\log N}{\log 2}$$

  - *H* : amount of information **[Bits]**

  - *N*: number of equally likely alternatives
  - e.g.: 2 equally likely alternatives ⇒ $H = \log_2 2 = 1$

    ⇒ **Bit** (Def^n): "amount of info. to decide between **two** equally likely (i.e. 50%-50%) alternatives"

  - e.g.: 4 equally likely alternatives⇒ $H = \log_2 4 = 2$

  - e.g.: equally likely digits (0-9) ⇒$H = \log_2 10 = 3.32$

  - e.g.: equally likely letters (a-z) ⇒$H = \log_2 26 = 4.70$

Note, for each of above, unit [bit] must be stated..

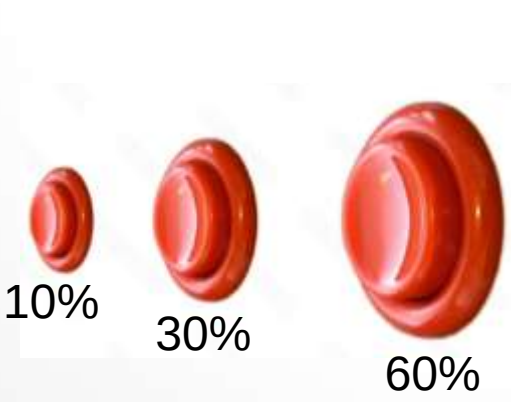
Cont. Unit of Measure of Information

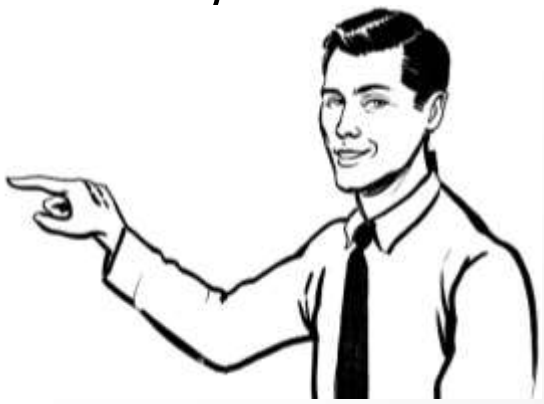
- Case 2: **≥ 1 non-equally likely alternatives**:

$$h_i = \log_2 \frac{1}{p_i}$$

  - h_i: amount of information [Bits] for single event, i
  - p_i: probability of occurrence of single event, i
  - Note, this is not usually significant

    (i.e. for individual event basis)





Cont. Unit of Measure of Information

- Case 3: **Average info. of non-equally likely series of events**:

$$H_{av} = \sum_{i=1}^{N} p_i \left(\log_2 \frac{1}{p_i} \right)$$

  - H_{av}: average information [Bits] from all events
  - p_i: probability of occurrence of single event, i
  - *N* : num. of non-equally likely alternatives/events
  - e.g.: 2 alternatives (*N* = 2)
    - Enemy attacks by land, $p_1 = 0.9$
    - Enemy attacks by sea, $p_2 = 0.1$

    - ⇒

$$H_{av} = \sum_{i=1}^{2} p_i \left(\log_2 \frac{1}{p_i} \right) = p_1 \left(\log_2 \frac{1}{p_1} \right) + p_2 \left(\log_2 \frac{1}{p_2} \right)$$

$$= 0.9 \left(\log_2 \frac{1}{0.9} \right) + 0.1 \left(\log_2 \frac{1}{0.1} \right) = 0.47$$

Cont. Unit of Measure of Information

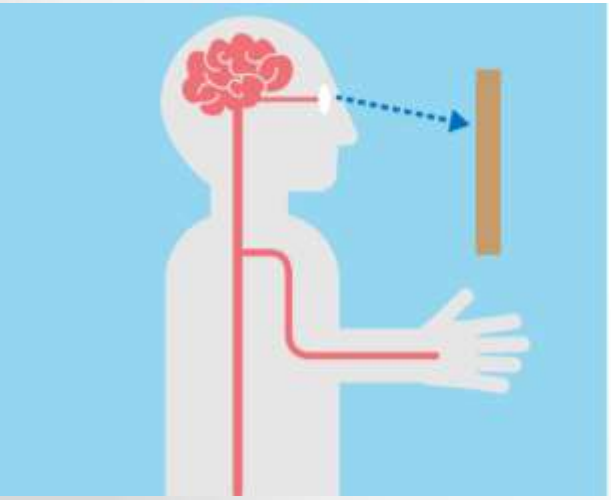
- Case 4: **Redundancy**:
  - If 2 occurrences: equally likely ⇒
    - $p_1 = p_2 = 0.5$ (i.e. 50% each)
    - $\Rightarrow H = H_{max} = 1$
  - In e.g. in last slide, departure from max. info.
    - = 1 – 0.47 = 0.53 = 53%
  - $$\%\ Redundancy = \left(1 - \frac{H_{av}}{H_{max}}\right) * 100$$
  - Note, as departure from equal prob. ↑ ⇒ %Red. ↑
  - e.g.: not all English letters equally likely: "th","qu"
    - ⇒ %Red. of English language = 68 %
    - ps. how about Arabic language?

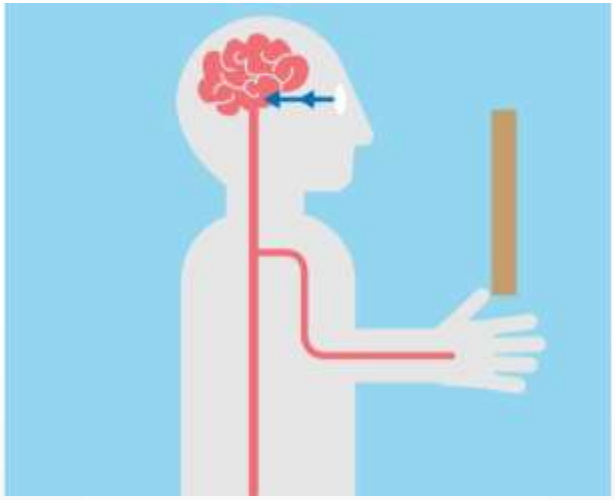
1. Simple Reaction Time

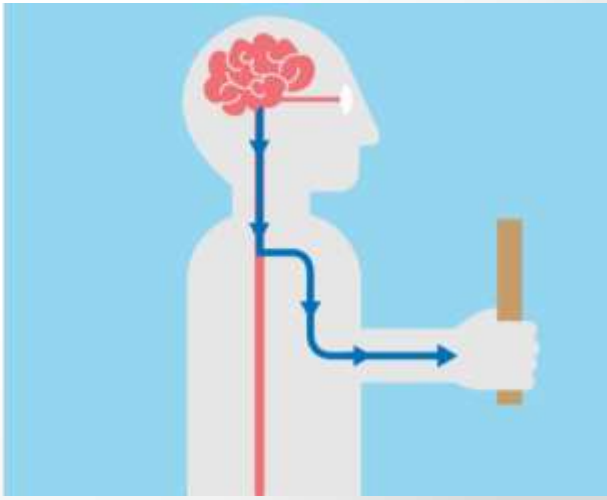
Reaction Time Experiments

- Remember:
  - Total Response Time =

    Reaction Time (RT) + Movement Time (MT)
- Reaction time is used,
  - as a means to explain complex mental events,
  - as a practical measure of performance

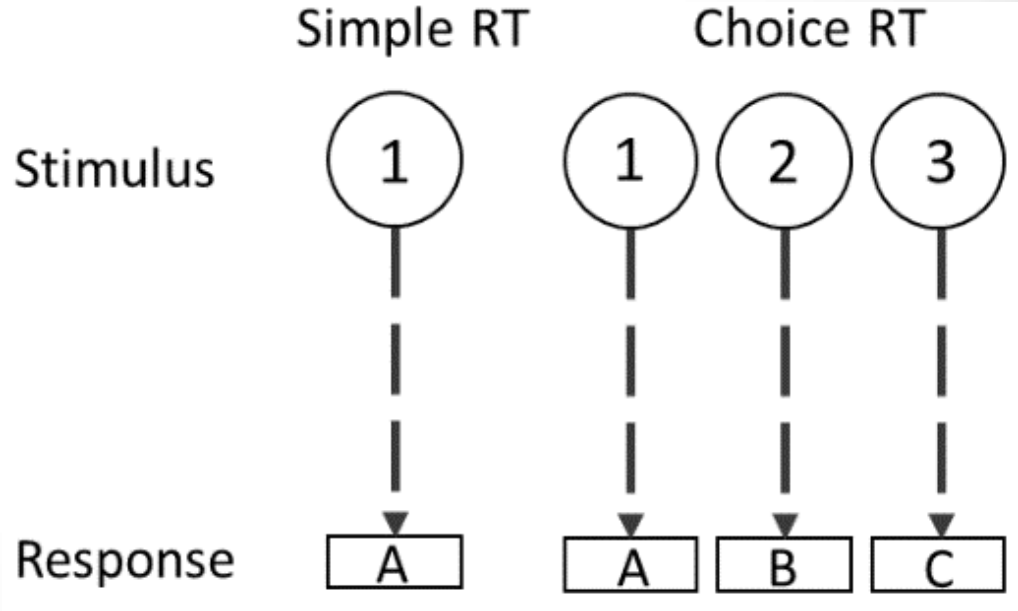






Reaction Time Experiments

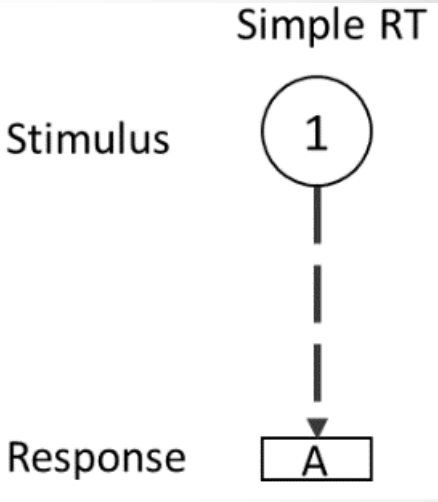
- We now discuss imp. info. theory applications
- Types of reaction time:
  - Note, this depends on the nature of the task:
  1. Simple reaction time (SRT) task
  2. Choice reaction time (CRT) task:
     a) Hick's Law
     b) Hick-Hyman Law



Cont. Reaction Time Experiments

1. Simple Reaction Time Tasks (SRT)
   - Used to test how fast human responds in presence of 1 stimulus
   - It is time to initiate a response, when:
     - only one particular stimulus can occur
     - same response is always required

   - Example:
     - starting to run when hearing starting gun in a race
   - Person usually knows that the stimulus will occur within:
     - short time
     - specific spatial area
   - Typical SRT:
     - 150 – 200 ms (0.15 – 0.20 s)
     - 200 ms is commonly a representative value

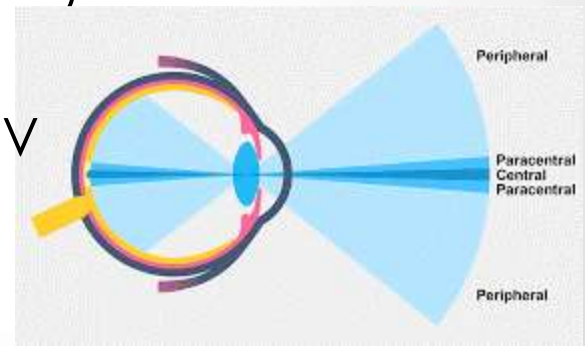


Cont. Reaction Time Experiments

1. Simple Reaction Time Tasks (SRT) – Cont.

- Variables that can influence SRT (by <100 ms):
  1. Stimulus modality:
     - auditory/tactual RT is ~40 ms faster than simple visual RT

  2. Stimulus detectability:
     - Experiment (Teichner, 1972):
     - for very dim flash (<3 cd/m^2): RT reaches 500 ms
     - for brightness >3 cd/m^2 (visual threshold): RT ~ 200 ms
  3. Stimulus location
     - RT for stimuli in the peripheral (45˚) FOV
     - =~ 20 ms < than for central vision



  4. Age
     - Very little changes in SRT from ~15-60 years
     - Much slower at <15 years; some slowing >60

Cont. Reaction Time Experiments

1. Simple Reaction Time Tasks (SRT) – Cont.

- Variables that can influence SRT (cont.):
  5. Preparedness/expectancy of stimulus
     - SRT ↑ when stimulus is unexpected and/or infrequent
     - Experiment (Warrick, 1965):
     - "press a button when buzzer sounds"
     - Only: 1-2 times/week over 6-months
     - RT for "unexpected" signals:
       ~100 ms > than when subjects
       received a warning 2-5 s before buzzer

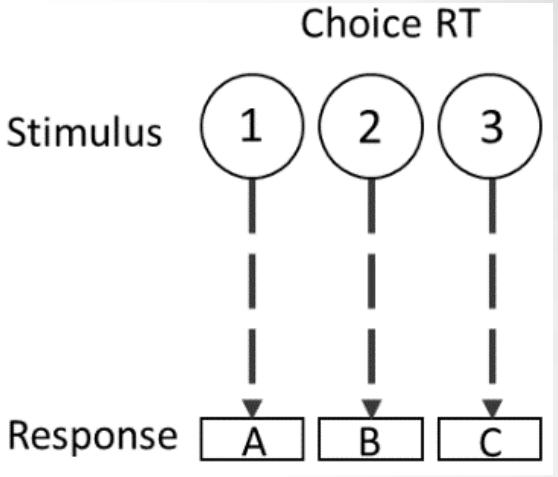
Cont. Reaction Time Experiments

1. Simple Reaction Time Tasks (SRT) – Cont.
   - Try experiment (aka *Deary-Liewald task*): as fast as you see icon on screen, press 'space bar':
   - Note, how this tests has two aspects:
     - Correct response rate
     - How fast you respond (ms)
   - How much did you score?
     - Experiment shows: humans can score for 1 choice: $\sim 200\ ms$
     - How much do you expect when there is more than one choice?

2. Choice Reaction Time

Cont. Reaction Time Experiments

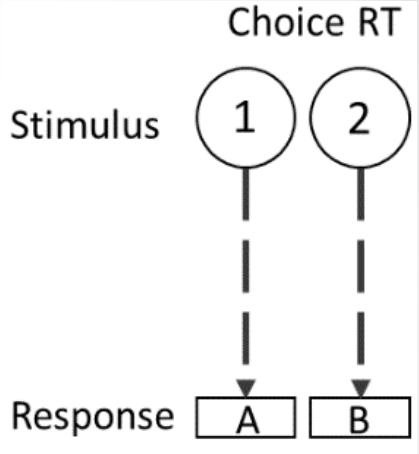
2. Choice Reaction Time task (CRT)
   - SRT is not usu. relevant in practical situations
   - In most real-life situations:
     - there are several different stimuli,
     - requiring different responses, and
     - occurrence of stimulus is unexpected



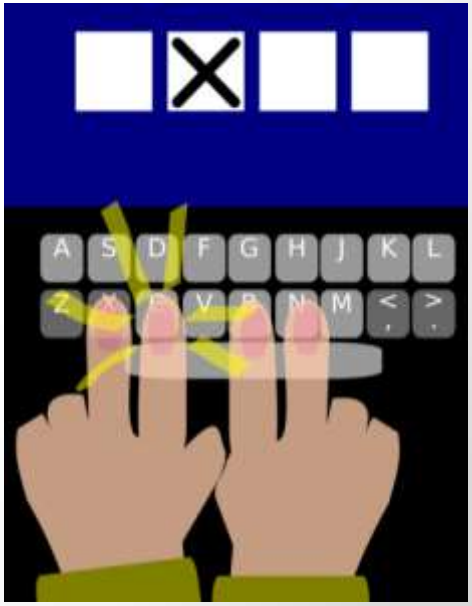
   - i.e. used to test how fast human responds in presence of *more* than 1 stimulus, i.e. multiple stimuli
   - Example:
     - choosing a digit on keyboard from '0' to '9',
     - each stimulus requires a different response
   - In general, more stimuli/responses ⇒ slower RT

Cont. Reaction Time Experiments

2. Choice Reaction Time task (CRT) – Cont.
   - *Simplest* CRT experiment:
     2 stimuli/responses ⇒
     - minimum RT =~ $250\ ms$
     - typical average: $350 - 450\ ms$

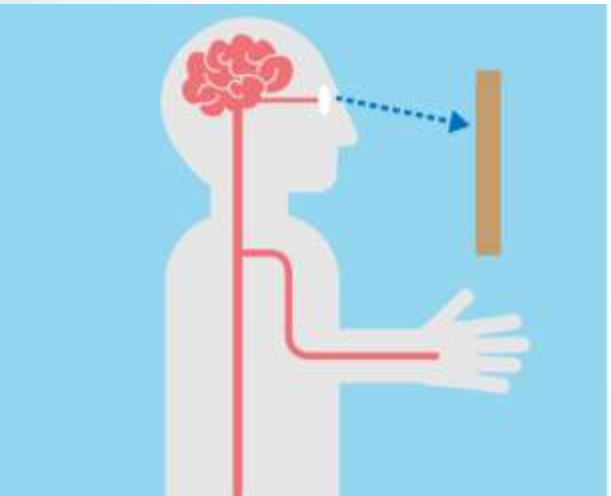
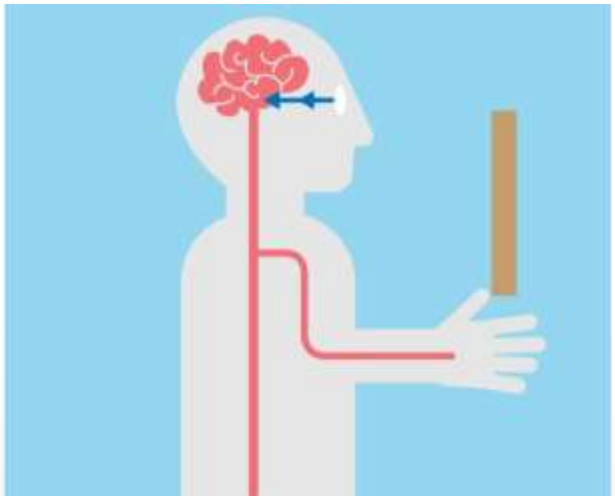
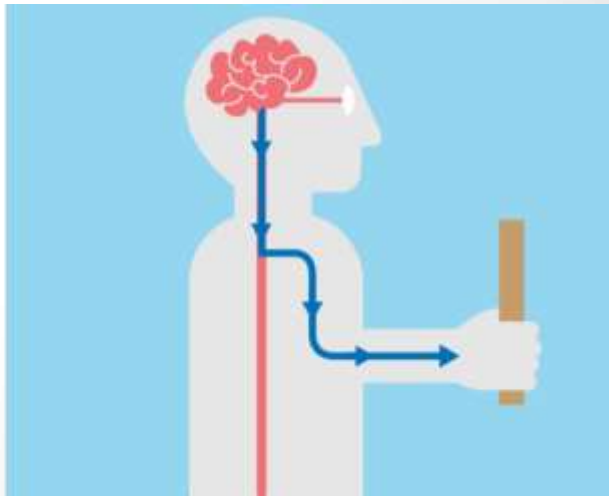


   - Try 2nd experiment:
     - there are now 4 blocks,
     - with '**X**' appearing in either of 4 possible positions (i.e. 4 stimuli)
     - as fast as you see '**X**' come on, press letter on keyboard that corresponds to it
   - Note how RT/error rate are now greater



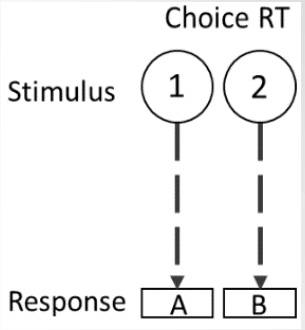
Cont. Reaction Time Experiments

2. Choice Reaction Time task (CRT) – Cont.
   - So what is the significance of measuring CRT?
   - RT is indication of time required to
     - Process/interpret information (i.e. stimuli)
     - Retrieve information from memory
     - Initiate muscle responses
     - i.e. gives good indication of time required to "think" (basic thought process)
   - This is important part of "cognitive psychology" field

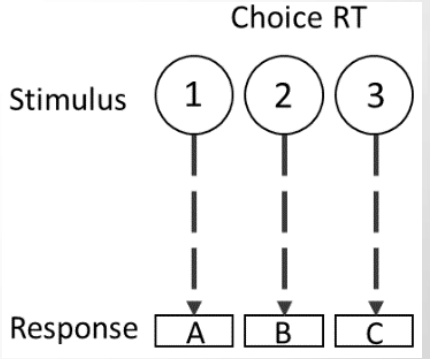




Cont. Reaction Time Experiments

2. Choice Reaction Time task (CRT) – Cont.



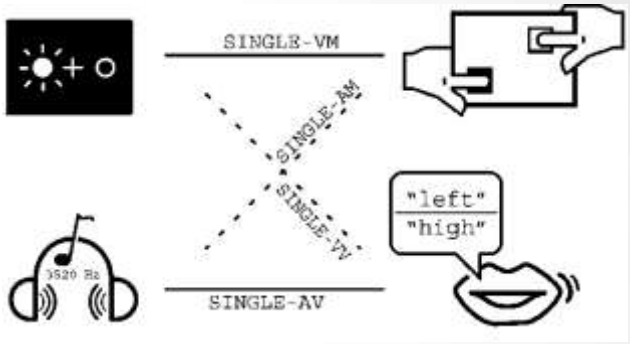
- Variables that can influence CRT:
  1. Number of responses/stimuli, *N* (main factor)
     - When *N* is small,
       ⇒ each stimulus has high prob. (e.g. 50-50),
       i.e. highly expected stimulus
       ⇒ response is already retrieved from memory
       ⇒ CRT is fast
     - But when *N* ↑,
       ⇒ prob. of anyone alternative ↓
       ⇒ there's no highly expected stimulus
       ⇒ it takes more time to retrieve
       appropriate response from memory
       ⇒ CRT ↑

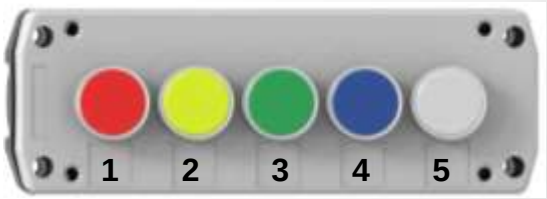


Cont. Reaction Time Experiments

2. Choice Reaction Time task (CRT) – Cont.

- Variables that can influence CRT – Cont.:
  2. Compatibility between stimuli and responses
     - when relationship bet. stimuli & responses is more natural ⇒ CRT is faster
     - e.g. 5 lights vs. 5 buttons: CRT will be fastest when correct responses to the lights are compatible (e.g. light C is on ⇒ press button 3)
     - what do you expect happens if the correct button-press response to each light was selected randomly?
     - also note, when comp. ↑ ⇒ difference in CRT is negligible (e.g. 2 vs. 10 alternatives), and vice versa





Cont. Reaction Time Experiments

2. Choice Reaction Time task (CRT) – Cont.

- Variables that can influence CRT – Cont.:

3. Practice
   - when amount of practice ↑ effect of incr. *N* ↓
   - at 10^6 trials ⇒ *N* no longer affects CRT
4. Type of movement
   - as complexity of movement ⇒ CRT ↑ (but effect is very small)
5. Age
6. Conditions
   - rested vs. tired
   - hungry or not, etc.

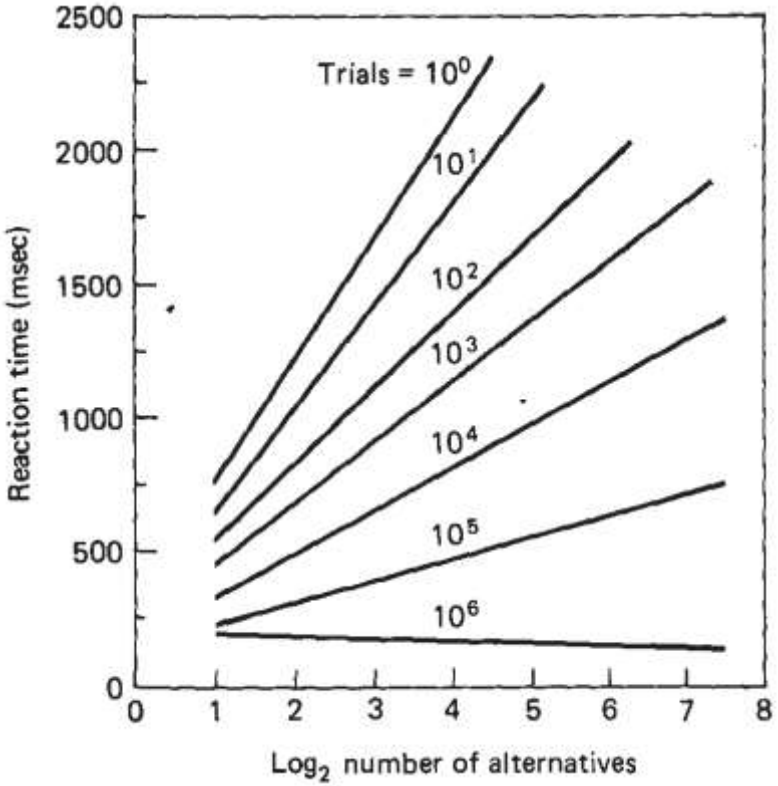
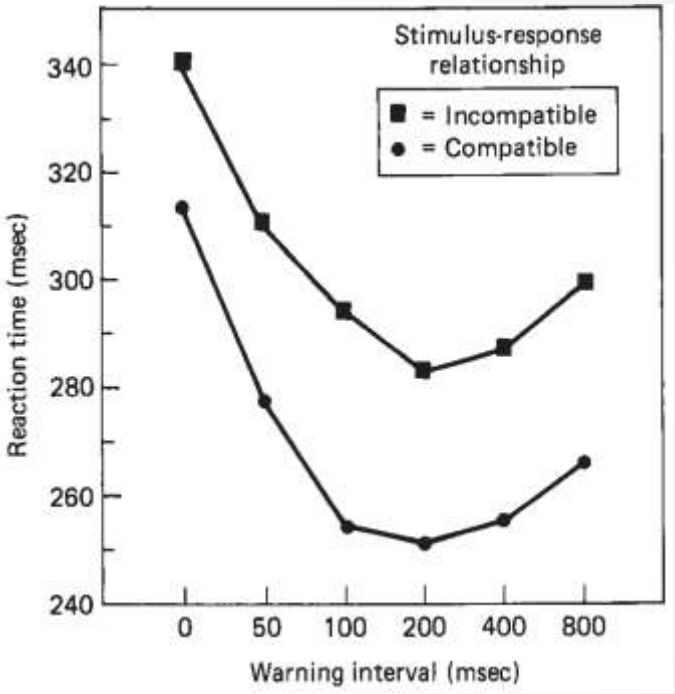


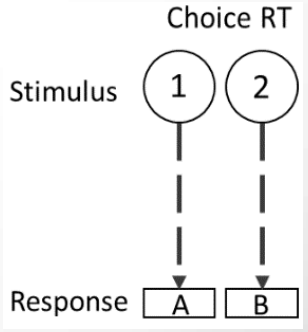
FIGURE 9-6
Choice reaction time as a function of number of alternatives and amount of practice. Based on data from several studies. (*Source: Teichner and Krebs, 1974. Copyright 1974 by the American Psychological Association. Reprinted by permission.*)

Cont. Reaction Time Experiments

2. Choice Reaction Time task (CRT) – Cont.

- Variables that can influence CRT – Cont.:
  7. Warning
     - CRT ↓ using a warning signal
     - depends on the interval bet. warning and signal
     - Posner (1973): for 2-choice task, when using warning (optimum at 200 ms) vs. no warning, ⇒ CRT improved: ~50 – 80 ms



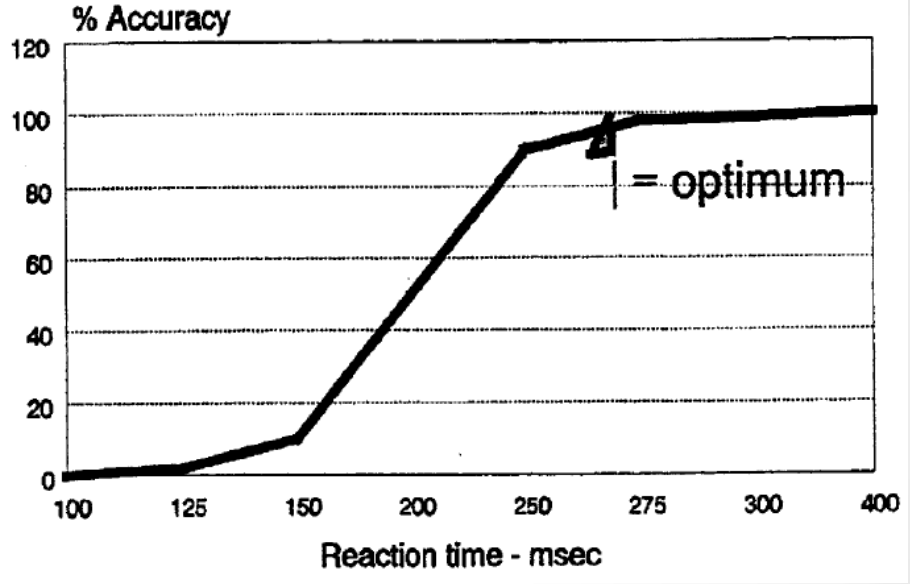


Cont. Reaction Time Experiments

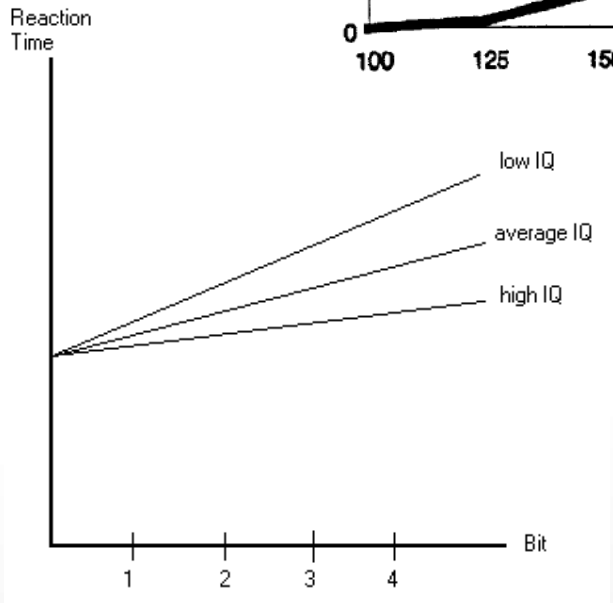
2. Choice Reaction Time task (CRT) – Cont.

- Variables that can influence CRT – Cont.:

8. Speed-accuracy tradeoff
   - if you aim to make less mistakes ⇒ accuracy ↑ but CRT ↑
   - and vice versa



9. Intelligence



Cont. Reaction Time Experiments

2. Choice Reaction Time task (CRT) – Cont.

- Variables that can influence CRT – Cont.:

10. More than one stimulus

    - When 2 successive stimuli require separate responses, if the 2nd stimulus occurs before response is made to the 1st signal ⇒ RT to 2nd stimulus ↑

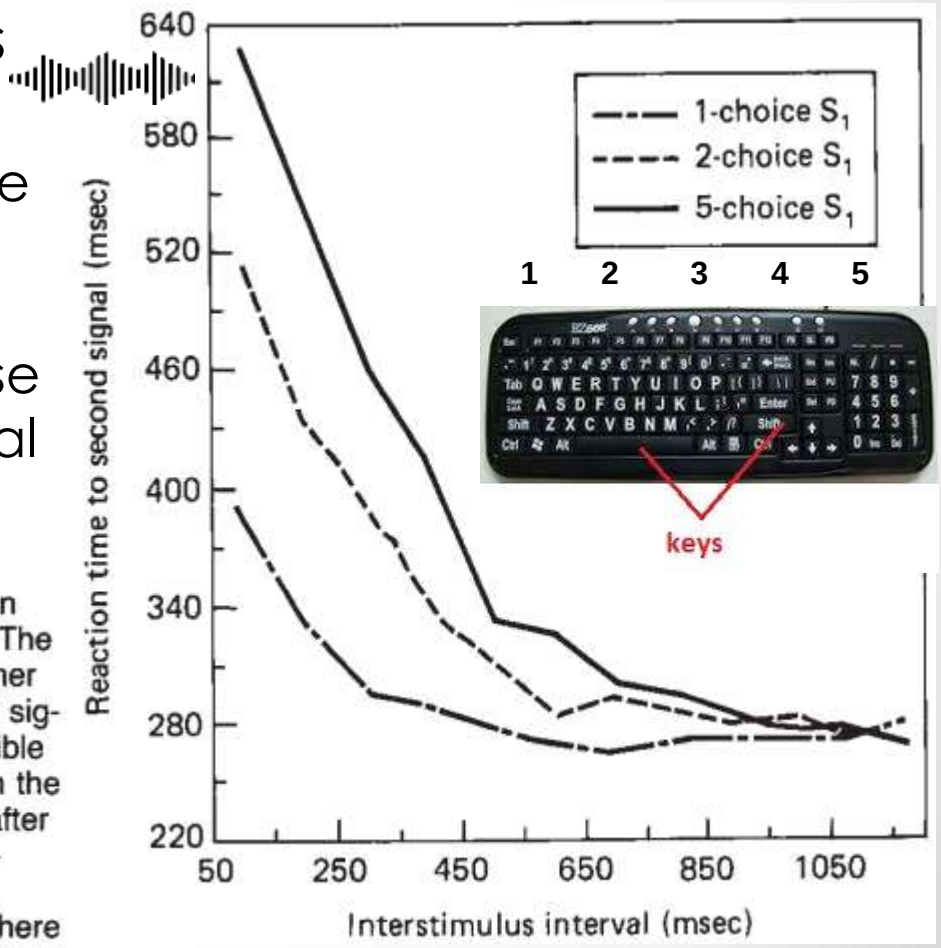


FIGURE 9-8
Reaction time to a second signal soon after the occurrence of a first signal. The first signal required a keypress to either 1, 2, or 5 possible digits. The second signal, a tone, required one of two possible responses with the other hand. When the second signal occurred very shortly after the first signal and before the first response, reaction time to the second signal increased. The more choices there are in the first signal, the greater the delay in responding to the second signal. (*Source: Karlin and Kestenbaum, 1968.*)

3. Hick's Law

Hick's and Hick-Hyman Laws

3. Hick's Law
   - Named after British psychologist *William E. Hick*
   - Conducted experiments on CRT in 1950's
   - He found (1952):
     - cognitive information capacity:
       is assessed as rate of gain of information
     - as # of equally likely stimuli alternatives ↑
       ⇒ CRT to stimuli ↑ logarithmically (next slide)
     - i.e. doubling N:
       1 to 2, 2 to 4, 4 to 8, 3 to 6, 5 to 10, etc.
       ⇒ increases CRT by a constant
     - several studies: CRT ↑ ~150 ms for each doubling of N
       (note, this is added to SRT of ~200 ms)
     - ⇒ RT ↑ ~ linearly with the $\log_2$ of N
     - ⇒ RT vs. # stimuli (H) [Bits]: ~ linear function
       (amazing find!)

Hick's and Hick-Hyman Laws

3. Hick's Law – Cont.

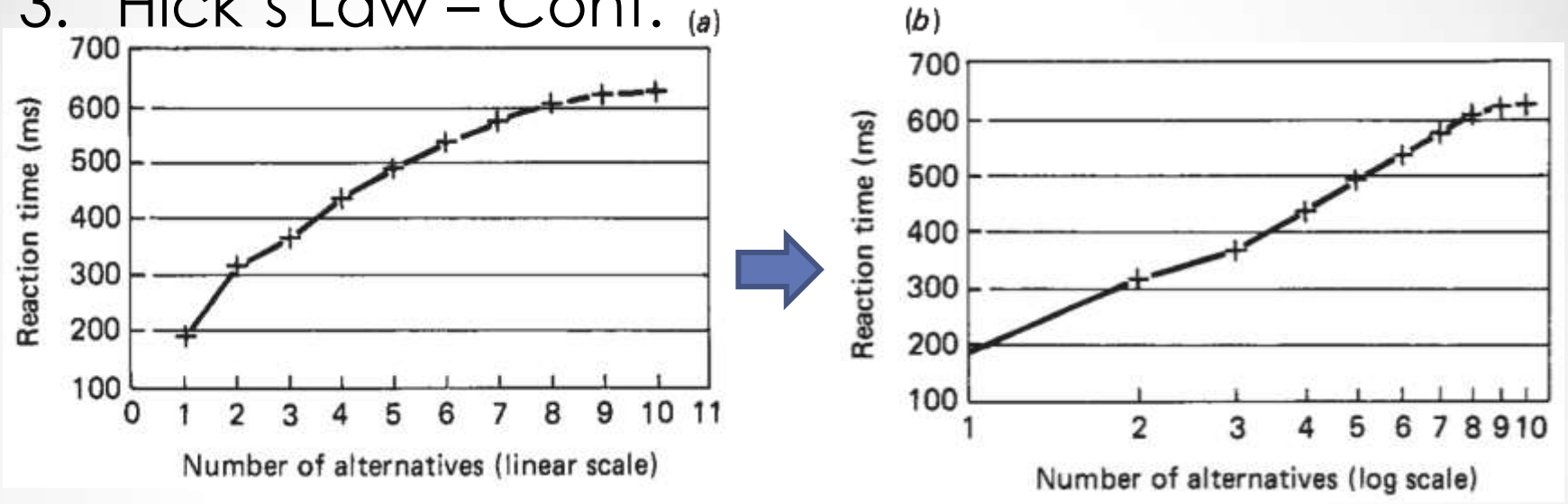
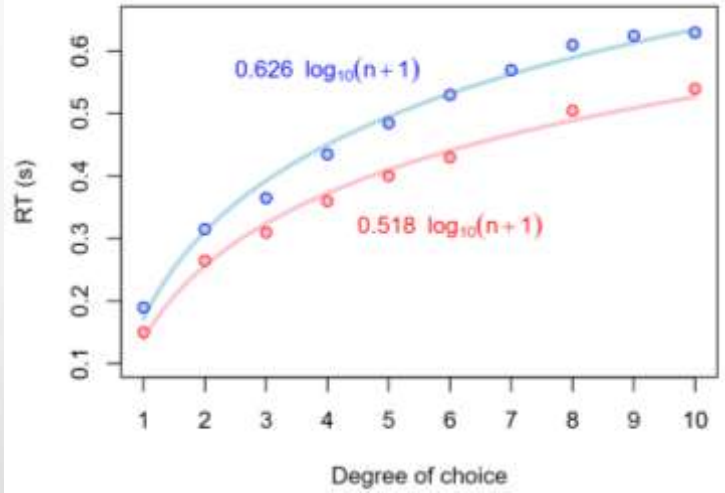
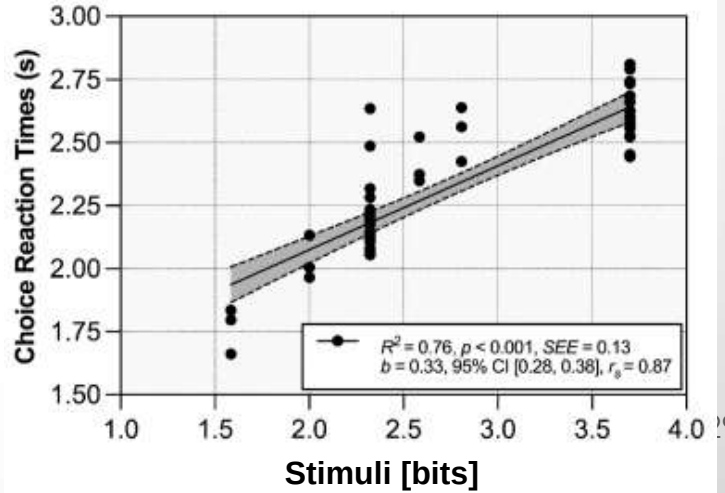


FIGURE 9-5
Logarithmic relationship between number of alternatives (choices) and choice reaction time. Number of alternatives is shown on a linear scale (*a*) and on a logarithmic scale (*b*). Panel (*b*) shows a linear relationship between reaction time and the log of the number of alternatives.





Hick's and Hick-Hyman Laws

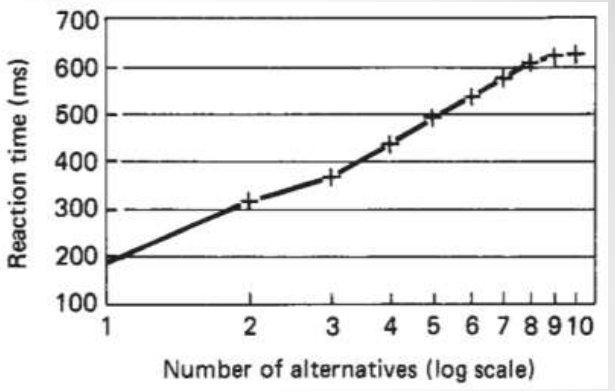
3. Hick's Law – Cont.
   1. Hick's Law (first version): Given *N equally likely* choices, $\overline{RT}$ required to choose among the choices is:

$$RT = b \cdot \log_2(N + 1) = b \cdot H$$

- *RT*: choice reaction time [ms]
- *b*: empirical constant [ms/Bit]
- $\log_2$ indicates that "binary" search is performed
- note how "+1" is used to account for 1 choice*
- *N*: number of equally likely alternatives
- *H*: amount of information (stimuli) [Bits]

Cont. Choice Reaction Time Experiments

3. Hick's Law – Cont.
   2. Alternative version of Hick's Law:



$$RT = a + b \cdot H$$

   - *a*: time passed without decision-making [ms]
   - *b*: how fast it takes to evaluate each option [ms/Bit]

   - More recent research (*E. Roth*, 1964): RT affected by IQ:
   3. Time (*RT*) required to make a decision,

$$RT = a + H/(Processing\ Speed)$$

   - Note how proc. speed = 1/b [Bits/ms], aka channel/information capacity

4. Hick-Hyman Law

Cont. Choice Reaction Time Experiments

4. Hick-Hyman Law (1953):
   - Hick's law further analyzed by US psychologist: *Ray Hyman*
   - Kept number of stimuli/alternatives (*N*) fixed
   - Varied prob. (p_i) of occurrence of events/choices (e.g. size of targets)
   - When stimuli occur with different prob.,
     - CRT ↓ for the more probable ones and
     - ↑ for the less probable ones

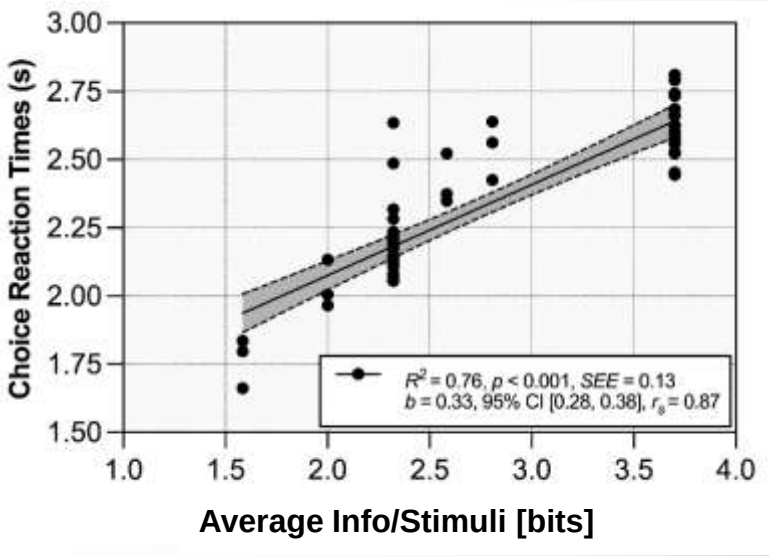
Cont. Choice Reaction Time Experiments

4. Hick-Hyman Law – Cont.
   - He found: "Hick-Hyman Law", generalized as follows:

$$RT = a + b \cdot H_{av}$$

$$H_{av} = \sum_{i}^{N} p_i \log_2 \left(\frac{1}{p_i} + 1 \right)$$

   - AGAIN: CRT vs. Stimulus [Bits] is a linear function



SUMMARY

4. Hick-Hyman Law – Cont.
   - Compare Hick-Hyman Law(s) and Fitts's Law:

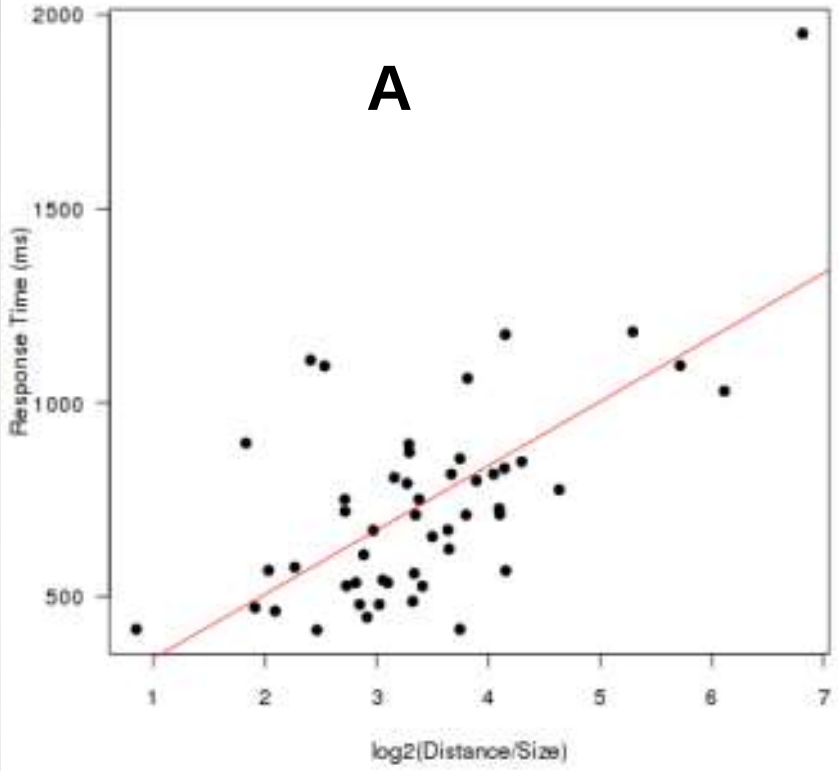
$$MT = a + b \cdot ID$$

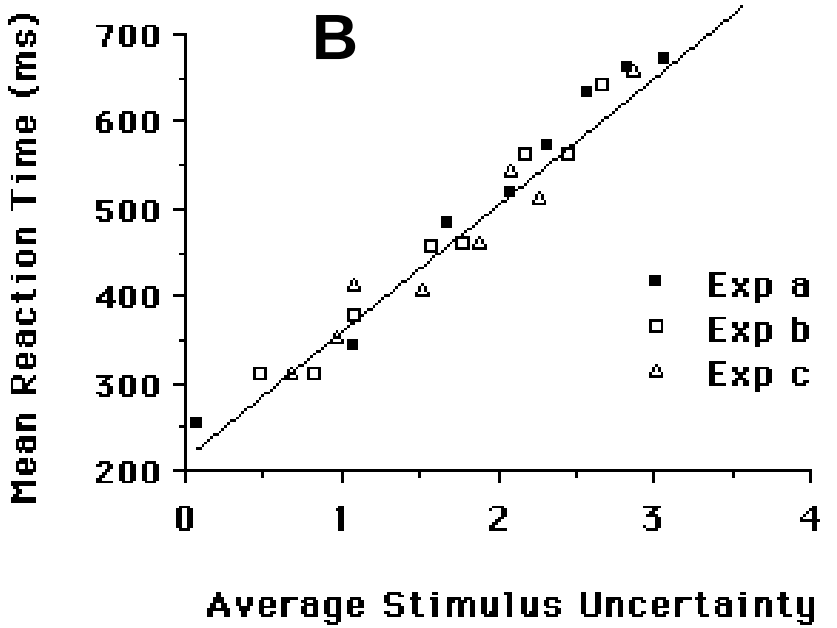
$$RT = a + b \cdot H$$

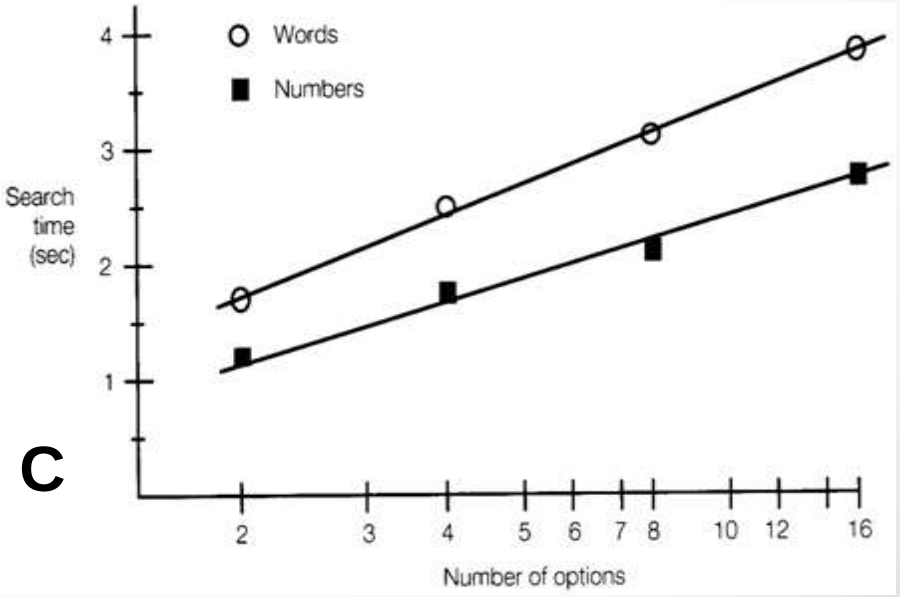
   - Note, *H* could mean either,
     - H_{max} (Hick's Law) or
     - H_{ave} (Hick-Hyman Law)

   - Compare Hick, Hick-Hyman, Fitts's Laws in next slide

SUMMARY


A
Response Time (ms)
2000
1500
1000
500
1
2
3
4
5
6
7
log2(Distance/Size)


B
Mean Reaction Time (ms)
700
600
500
400
300
200
0
1
2
3
4
Exp a
Exp b
Exp c
Average Stimulus Uncertainty


C
Search time (sec)
4
3
2
1
Words
Numbers
2
3
4
5
6
7
8
10
12
16
Number of options

Videos

- Watch the following videos (applications in HCI):
  - ***Hick's law***: https://youtu.be/ttw5nditisQ?si=BZSRb5LfZyST0anT
  - ***Hick-Hyman Law***: https://youtu.be/558s2nkmdA4?si=E6m1hhhYGr_yWhST

References

- ***Human Factors in Engineering and Design***. Mark S. Sanders, Ernest J. McCormick. 7th Ed. McGraw: New York, 1993. ISBN: 0-07-112826-3.
- ***Simple and choice reaction time tasks***. From: PsyToolkit. Available at: http://www.psytoolkit.org/lessons/simple_choice_rts.html
- For more **simple reaction time tasks**: https://www.humanbenchmark.com/tests/reactiontime
- ***Hick's law***. From Wikipedia, the free encyclopedia. Available at: https://en.wikipedia.org/w/index.php?title=Hick%27s_law&redirect=no