햅틱 인터페이스 및 렌더링에 유용한 평가 방법
Evaluation Methods for Haptic Interface and Rendering

한국 HCI 학술대회
2009.1.27

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Haptics & Virtual Reality Lab., POSTECH

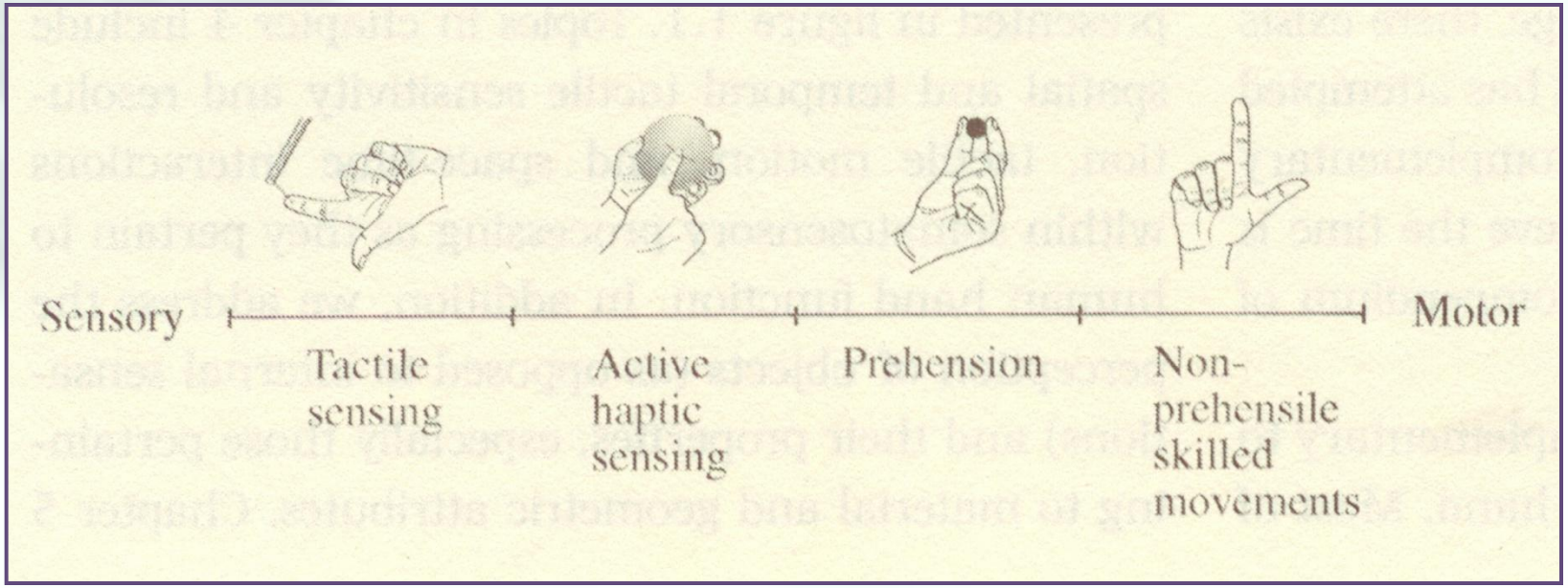
POSTECH

Overview

- Haptic Properties and What to Evaluate?
- Psychophysical Methods
- Task Performance
- Subjective Evaluation
- Advanced Topics

HAPTIC PROPERTIES AND WHAT TO EVALUATE?

Sensorimotor Continuum For Human Hand Function



[L. A Jones, and S. J Lederman, Human Hand Function, Oxford University Press, 2006]

Haptic Sensations

- Tactile (Cutaneous) Sensation
  - Spatial Tactile Sensation: e.g., shape
  - Temporal Tactile Sensation: e.g., vibration
  - Temperature
  - Pain
- Kinesthetic (Proprioceptive) Information
  - Position, velocity, and acceleration of the body
  - Orientation of the body
- Haptic Information
  = Tactile + Kinesthetic Information

Passive vs. Active Touch

- The haptic sensory channel is bidirectional.
  - Perception + Action
- Passive Touch
  - Haptic perception occurs while motor commands to muscles are absent
- Active Touch
  - Haptic perception occurs while the user intentionally moves the contacted body part.
  - Often results in better perceptual performance

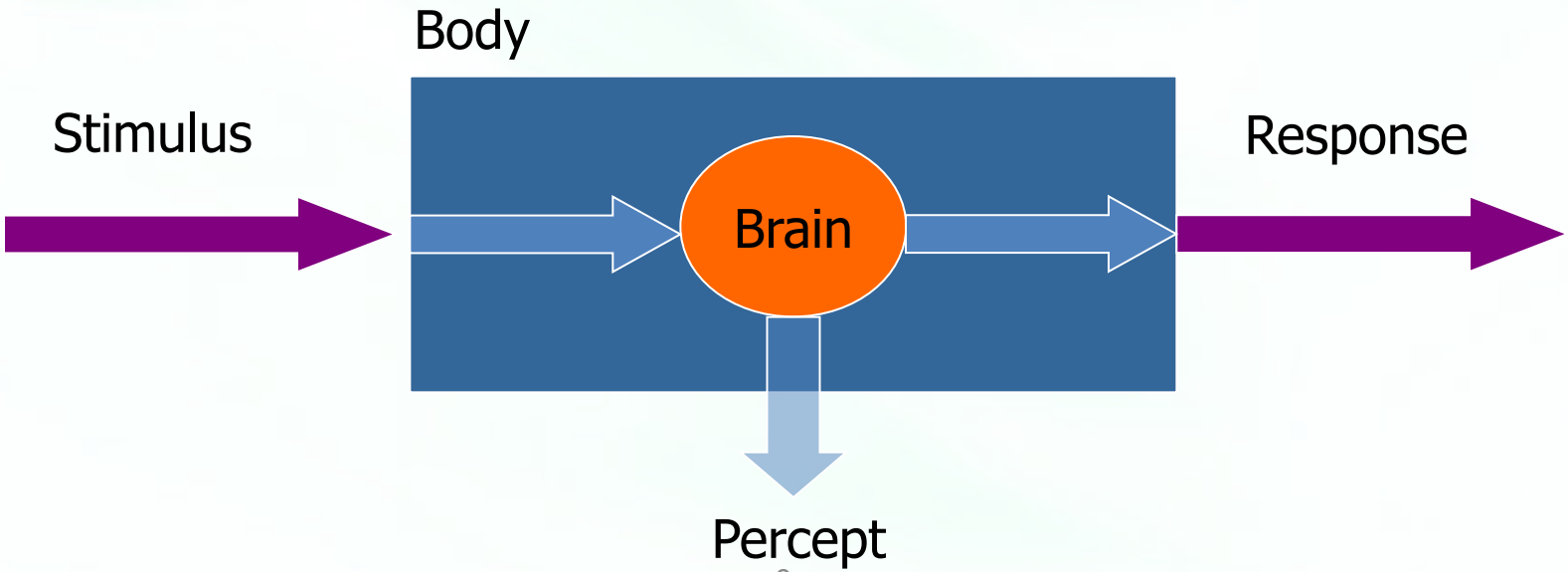
Tactile Sensations

- Vibration – Common in mobile devices
- Shape – Can be displayed using a tactile pin-array
- Texture – Can be displayed via both spatial and temporal displays
- Temperature – Can be displayed by a thermal display

PSYCHOPHYSICAL METHODS

Psychophysics

- Methodology for investigating relationships between sensations in the psychological domain and stimuli in the physical domain
- Central to experimental psychology

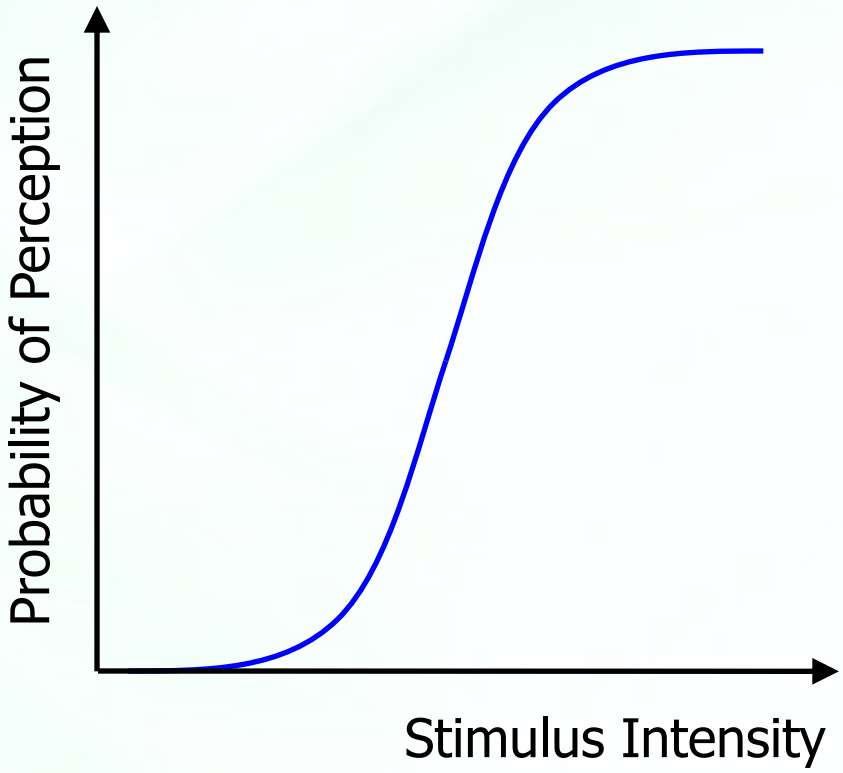


Two Regions of Interest

- Threshold level
  - Deals with stimuli that are barely perceivable
  - Related concepts
    - Psychometric function
    - Detection and difference thresholds
    - Weber's law
- Suprathreshold level
  - Deals with stimuli that are clearly perceivable
  - Related concepts
    - Perceived magnitude (perceived intensity)
    - Steven's power law

Psychometric Function

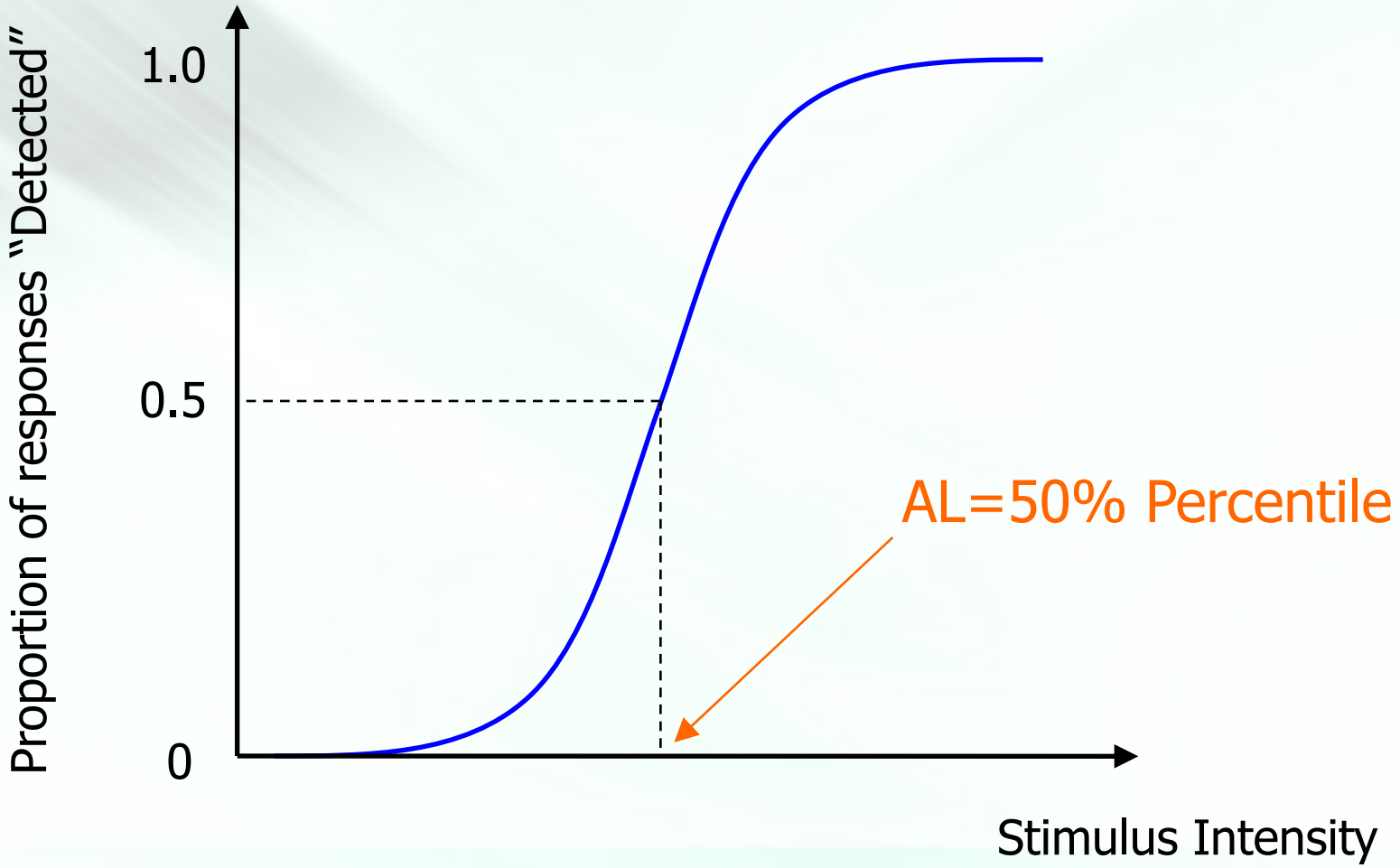
- A function between stimulus intensity and probability to perceive the stimulus
- Usually a S-shaped ogive (cumulative normal distribution)
- Due to the sensory noise of perception process



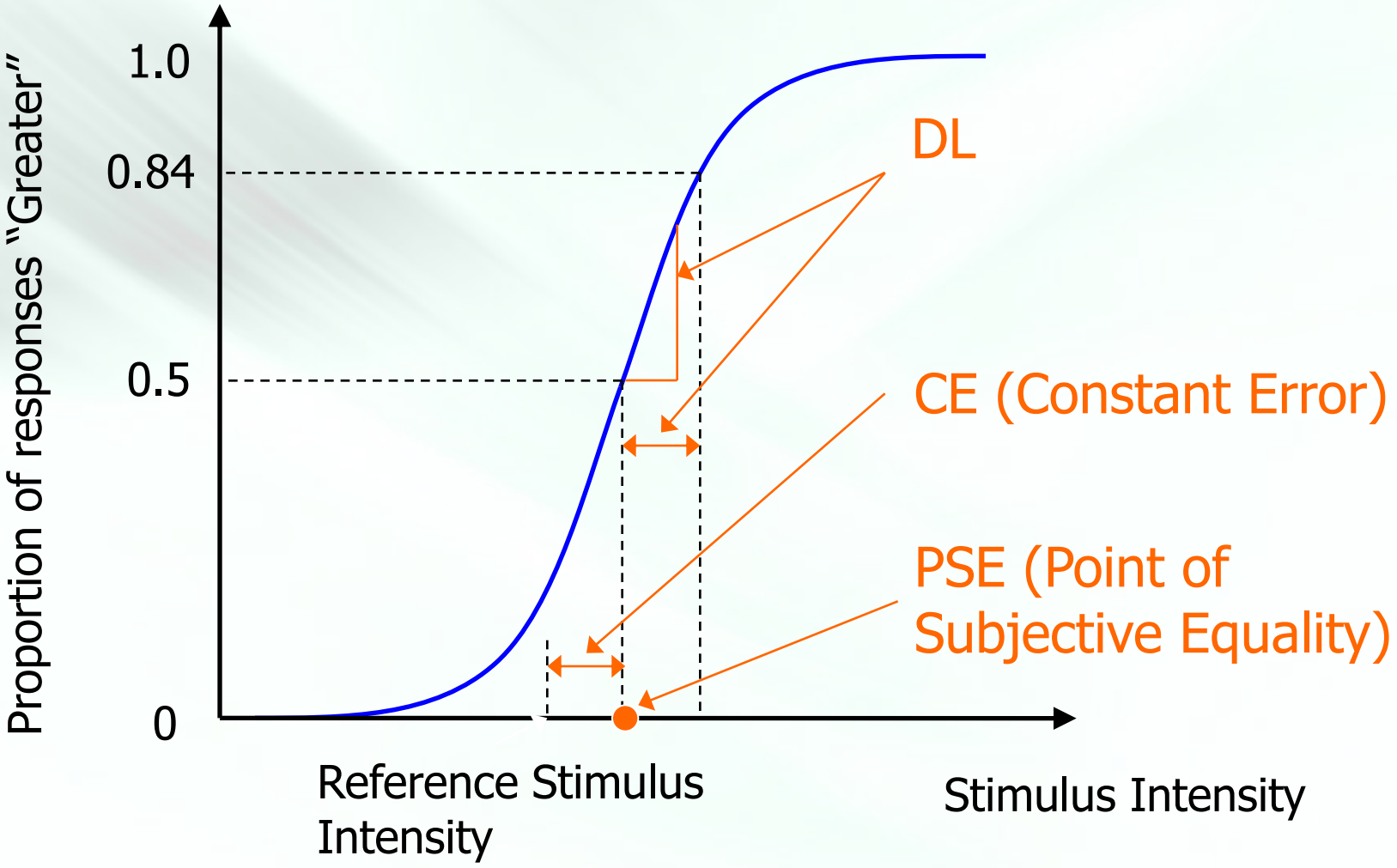
Two Thresholds

- Absolute Threshold
  - The smallest amount of stimulus energy to produce a sensation or that can be reliably detected
  - Often called AL (absolute limen) or RL (Reiz Limen)
- Difference Threshold
  - The smallest amount of stimulus energy change to produce a sensation or that can be reliably detected
  - Often called DL (difference limen or differenz limen)

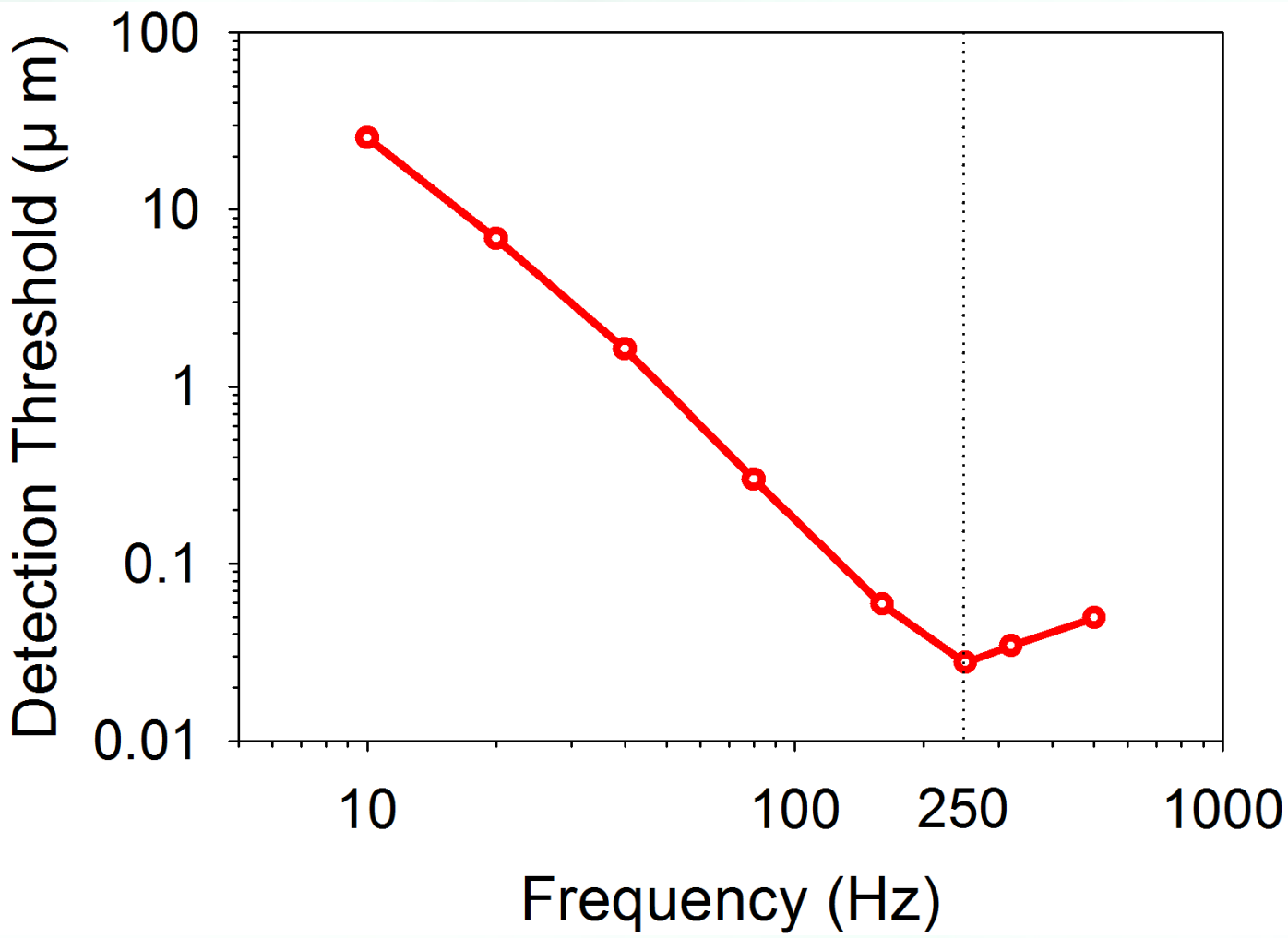
Absolute Threshold



Difference Threshold



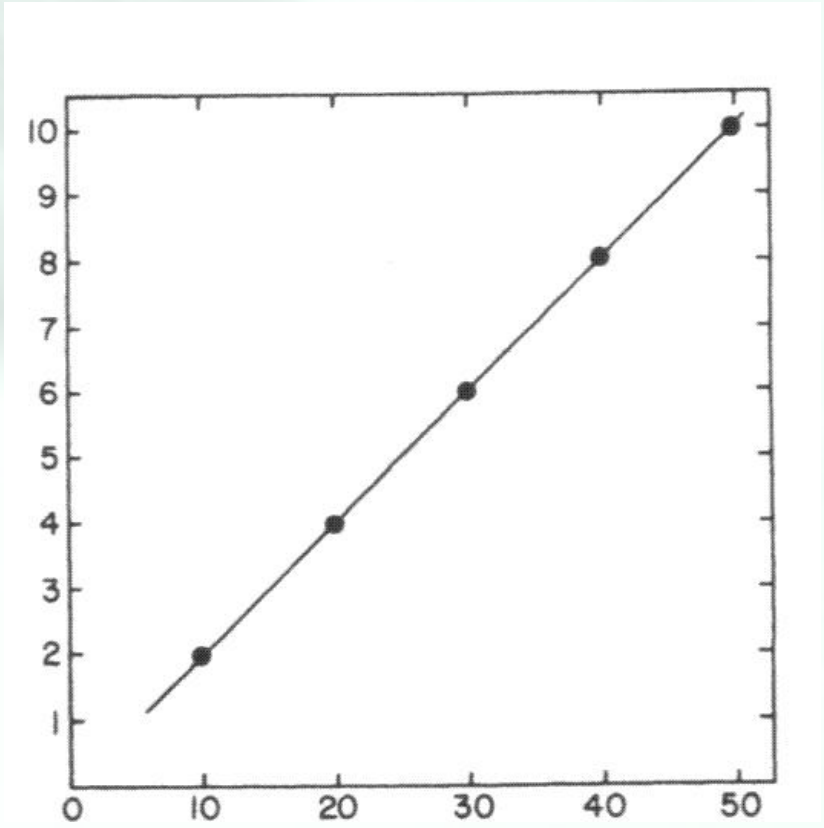
Detection Thresholds – Mobile Device

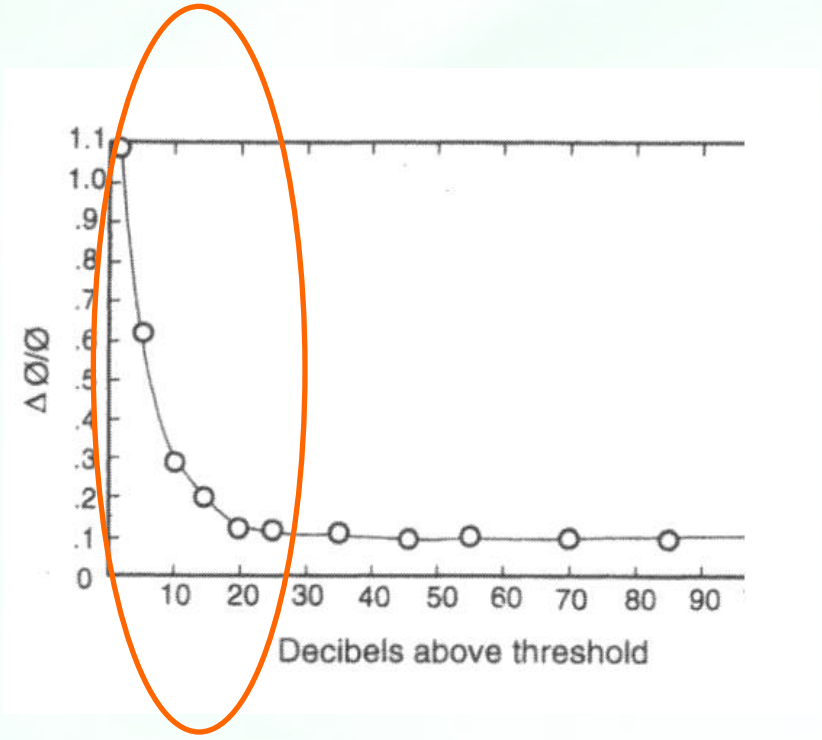


Weber's Law

- DL is proportional to reference stimulus intensity
- $DL = w \bullet I_{ref}$
  - w: Weber fraction
  - I_{ref}: Reference Stimulus Intensity
- Discovered in weight discrimination
- Note that Weber's Law is an empirical law

Weber's Law – Graphical Illustration





Does not work when reference stimulus intensities are close to the AL.

Steven's Power Law

- S. S. Stevens, 1957

- Power Law

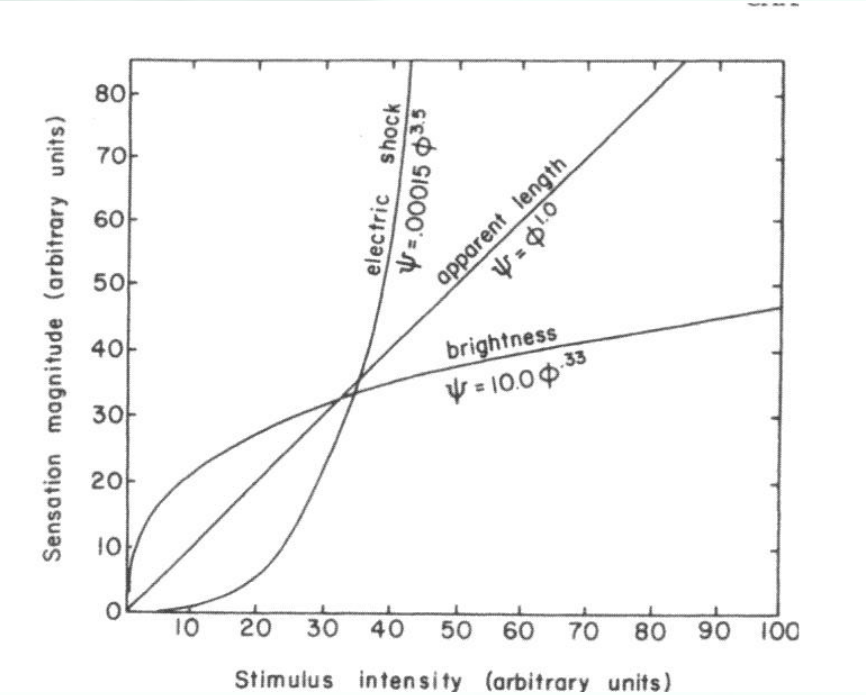
$$P = c\left(\frac{I}{I_0}\right)^n$$

$$\log P = n\log\left(\frac{I}{I_0}\right) + \log c$$

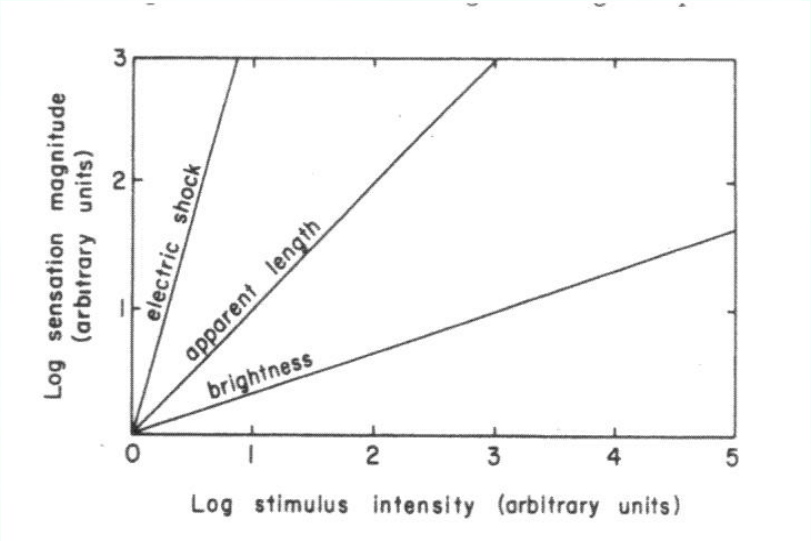
  - n depends on stimulus condition.
    - 0.33: Brightness
    - 3.5: Electric shock
  - One of the best established empirical laws in psychology

Steven's Power Law - Examples

Linear vs. Linear



Log vs. Log



How to Measure Thresholds

- Classical Psychophysical Methods

	Accuracy	Efficiency
Method of constant stimuli	Best	Worst
Method of limits	Middle	Middle
Method of adjustment	Worst	Best

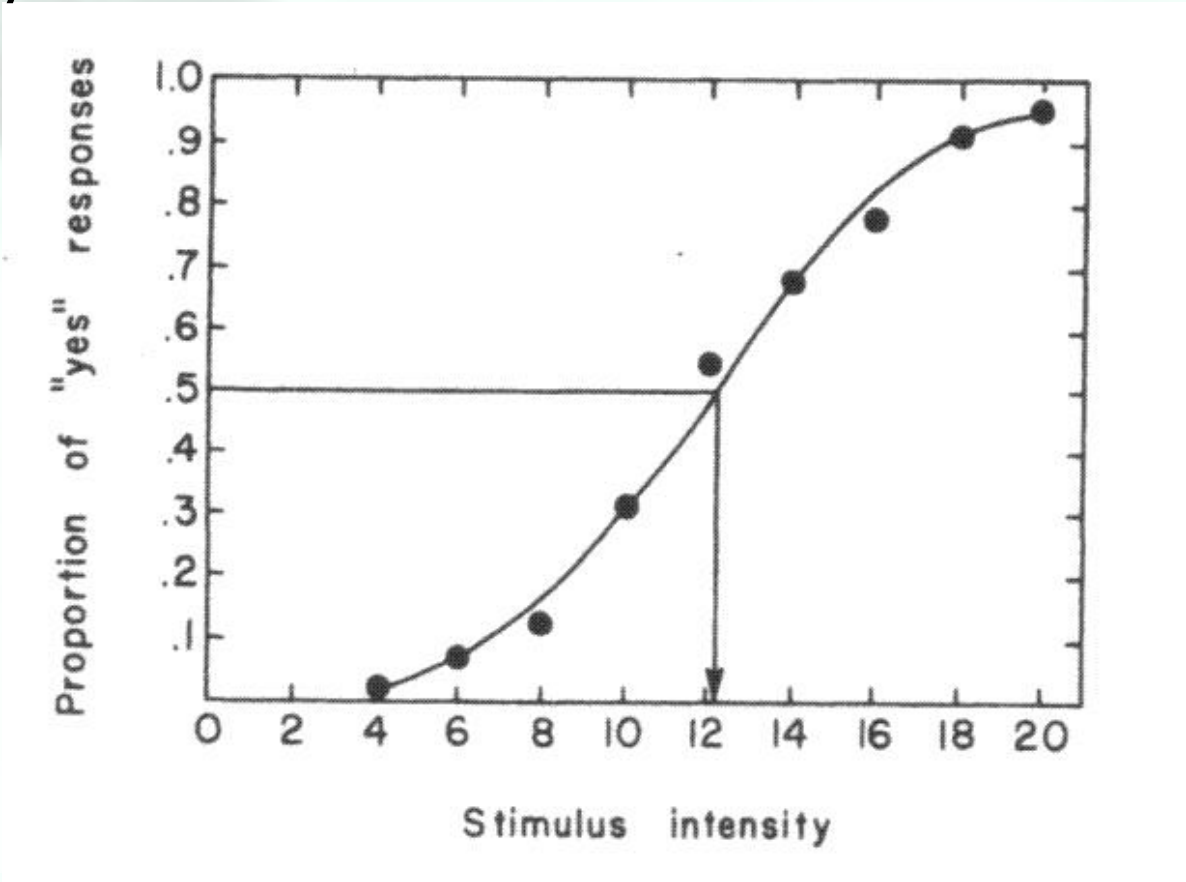
- Adaptive Methods
  - PEST: Parameter Estimation by Sequential Testing
  - Maximum-Likelihood Procedures
  - Staircase Procedures

Method of Constant Stimuli

- Stimuli
  - A set of stimulus intensities (5-9) that are evenly spaced
- Procedures
  - A stimulus randomly selected from the stimulus intensity set is presented to a subject
  - The subject is asked to answer
    - Whether the stimulus was detected (for AL), or
    - Whether the test stimulus was greater than the reference stimulus (for DL)
  - Each stimulus level should be repeated in a large number of trials (e.g., 100)

Data Analysis

- Record the proportions of "yes" and plot them against the stimulus intensity
- Fit a psychometric function to the recorded data



Magnitude Estimation

- The most widely used method for psychophysical ratio scaling

- Magnitude estimation with modulus
  - The subject is presented with a standard stimulus and told that the sensation it produces has a certain numerical value (modulus), e.g., 10.
  - On subsequent trials, other stimuli are presented, and the subject assigns numbers to his sensations relative to the value of the modulus.
  - The observer is instructed to make his judgment reflect how many times greater one sensation is than another (the ratio between the two sensations).

Magnitude Estimation (cont).

- Magnitude estimation without modulus
  - No standard modulus is defined by the experimenter.
  - A subject can define his own modulus in the first trial and use it as a modulus in the subsequent trials.
- Magnitude estimation without modulus is used more frequently.
- In no modulus design, the data of different subjects are combined using the geometric mean.

$$\text{Geometric Mean} = \log^{-1}\left(\frac{\sum \log X}{N}\right)$$

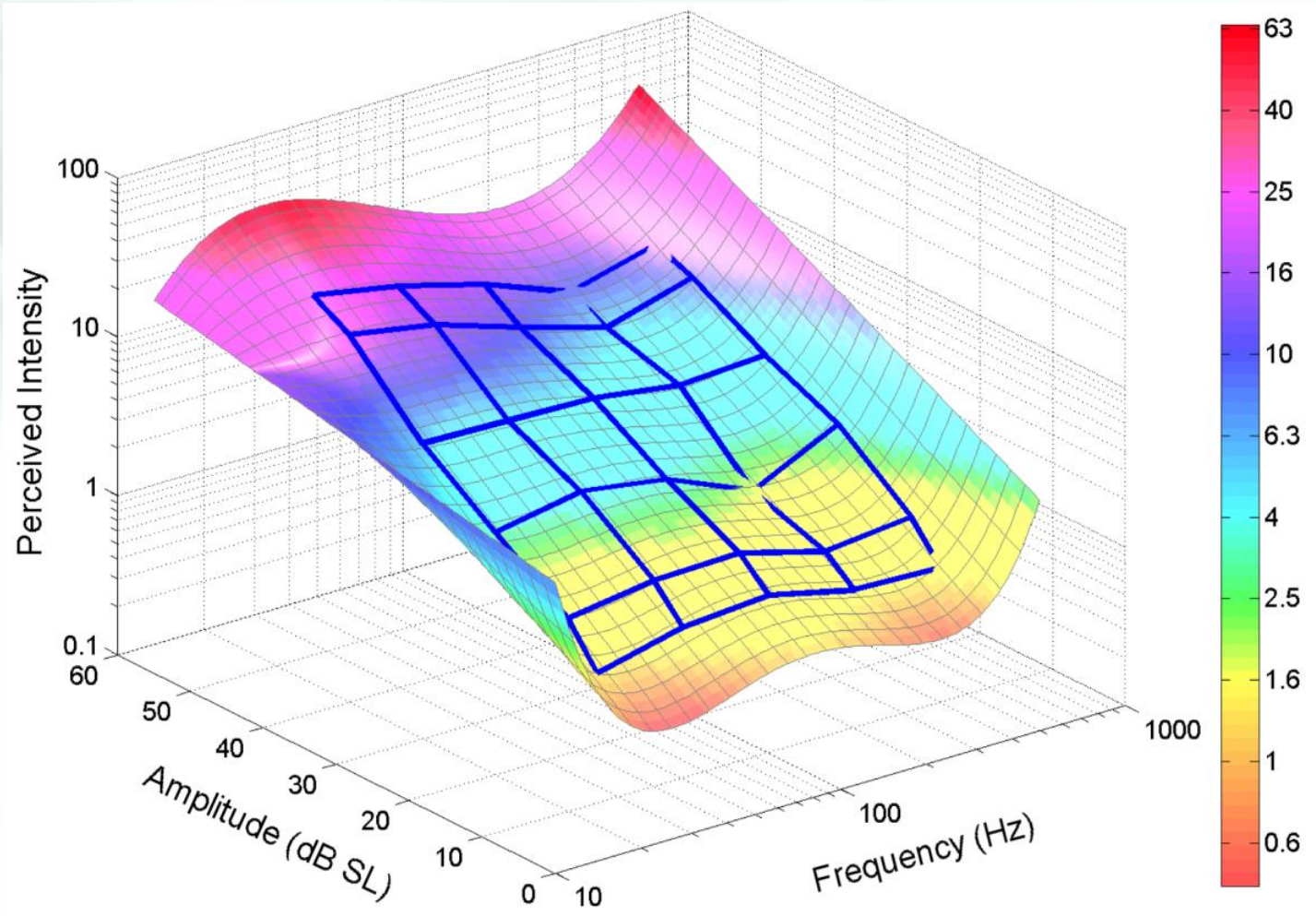
Absolute Magnitude Estimation

- There have been ample evidences that we use an absolute scale for sensory magnitudes, which may have been fixed at an early age.
- If a standard stimulus arbitrarily assigned by the experimenter is different from that which the subject would assign in absolute scaling, the use of the standard stimulus seems to bias the resulting psychophysical scale.
- At present, the method of absolute magnitude estimation is recommended due to the potential biasing effects of a standard stimulus.

Subject Instructions in Absolute Magnitude Estimation

- In this experiment, we would like to find out how intense various stimuli appear to you. For this purpose, I am going to present a series of stimuli to you once at a time. Your task will be to assign a number to every stimulus in such a way that your impression of how large the number is matches your impression of how intense the stimulus is. We all have impressions of how large various numbers are, and impression of how intense various stimuli are. I would like you to assign a number to each stimulus so that your impression of the size of the number matches your impression of the intensity of the stimulus.
- You may use any positive numbers that appear appropriate to you – whole numbers, decimals, or fractions. Do not worry about running out of numbers – there will always be a smaller number than the smallest you use and a larger on than the largest you use. Do not worry about numbers you assigned to preceding stimuli. Do you have any questions?

Perceived Magnitude – Mobile Device



Advanced Topic – Detection Theory

- More modern approach
- Based on the signal detection theory in communication
- Provides means to separate decision process (e.g., response bias) from perception process

- Models a human as a noisy communication channel
- Uses metrics of sensitivity index (d') and response bias (c)
- Also leads to the amount of information transfer as a context-free performance measure of communication

TASK PERFORMANCE

Task Performance

- More application oriented
- Given a task, its performance is evaluated using several metrics
  - Task success rate
    - Accuracy
    - Error rate
    - Time on task
  - Task completion time
  - Efficiency
  - Learnability
- Widely used
- The values of performance metrics depend on the task context significantly.

SUBJECTIVE EVALUATION

Subjective Evaluation

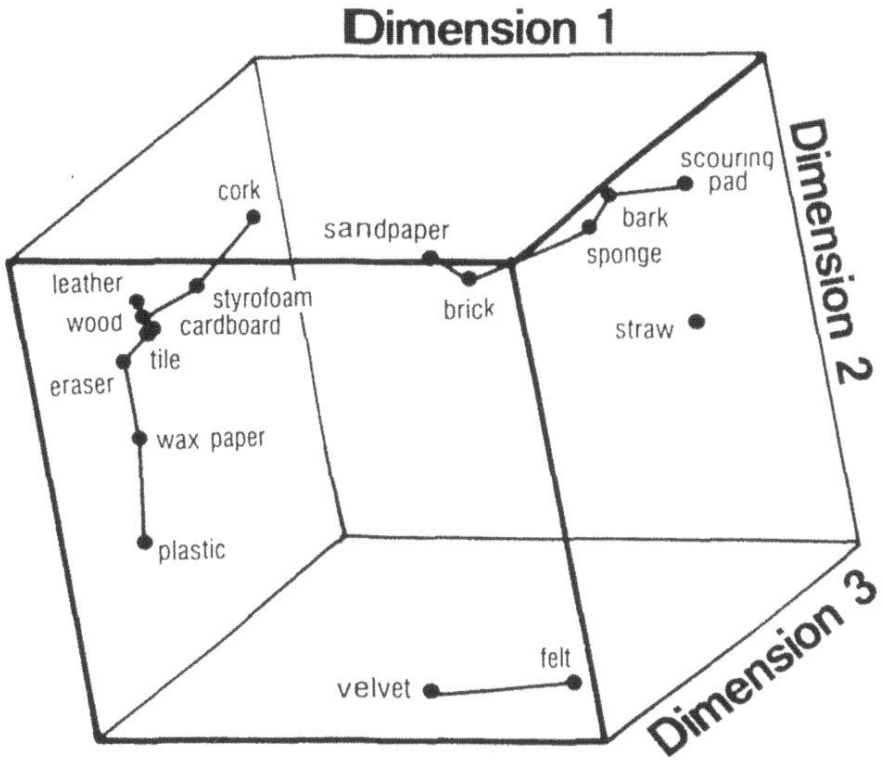
- Asks the participant to rate a certain metric in numbers within a range
- Examples
  - Fun, Easiness to use, Difficulty to learn …
- Often used as an accompanying evaluation in addition to quantitative assessments

ADVANCED TOPICS

Perceptual Space

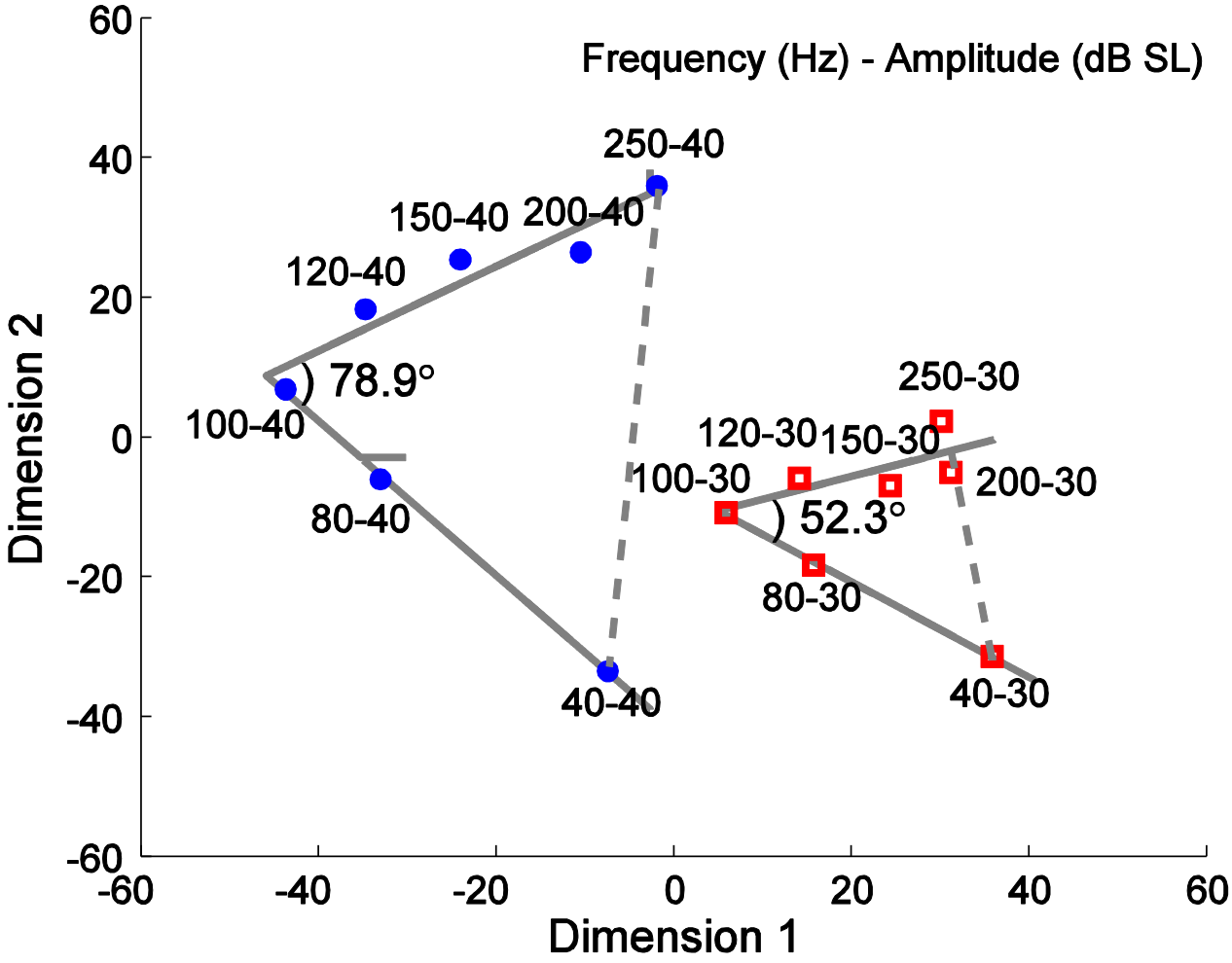
- An abstract space where a percept is represented by a point
- Example: Color space
- Perceptual dimensions: Meaningful axes that span a perceptual space
- Steps to obtain a perceptual space
  - Dissimilarity rating
  - Multi-dimensional scaling (MDS)
  - Adjective rating and regression

Perceptual Space – Haptic Texture

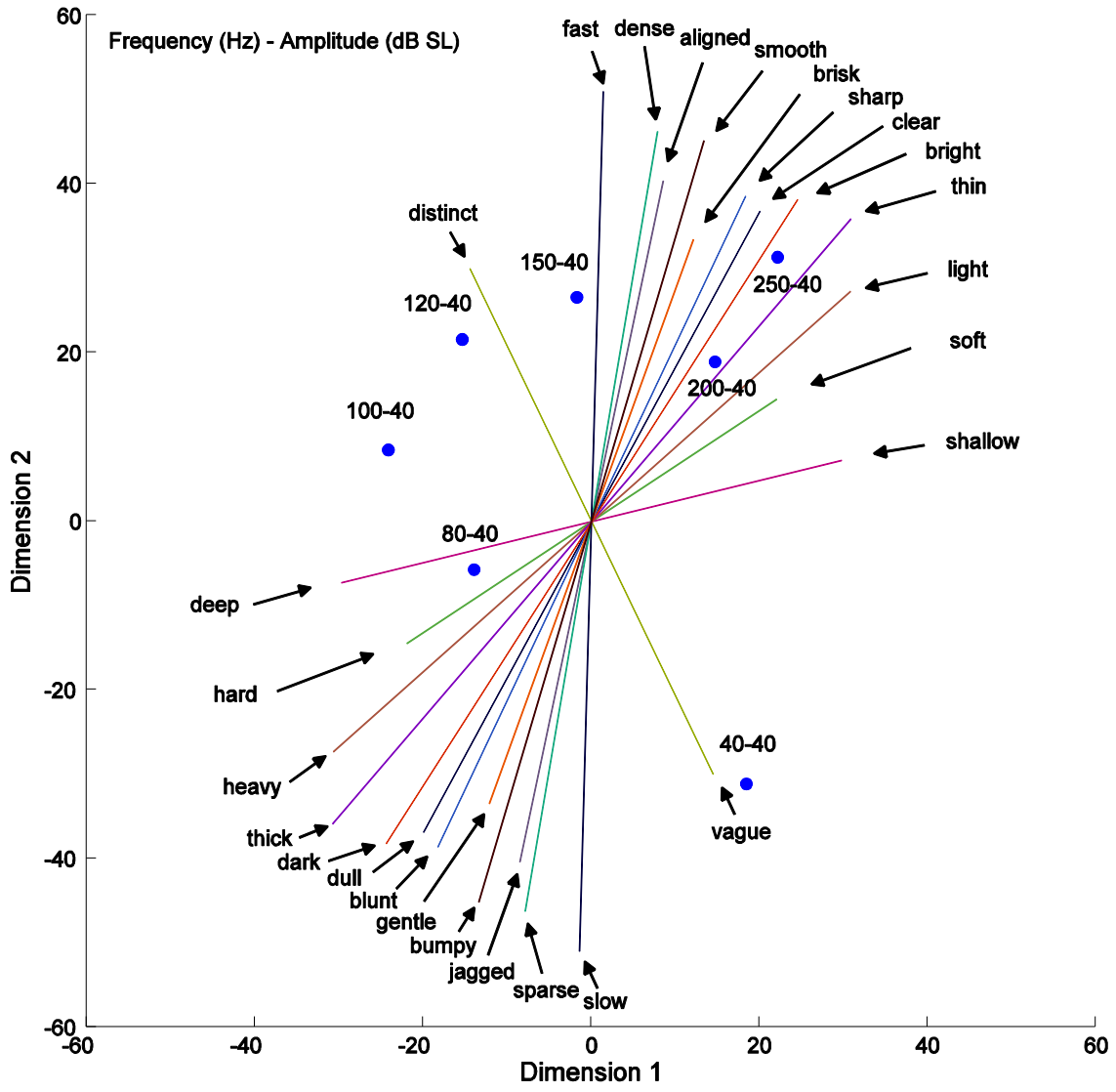


Perceptual Dimensions: Soft-Hard, Smooth-Rough, Slippery-Sticky

Perceptual Space – Mobile Device Vibration



Perceptual Space and Adjective Rating – Mobile Device Vibration



Mental Workload

- NASA TLX (Task Load Index)
  - A multidimensional scale consisting of 6 dimensions
  - Mental demand (MD): Related to perceptual activity such as thinking, deciding, calculating, remembering, looking, and searching
  - Physical demand (PD): Related to physical activity such as pushing, pulling, turning, controlling, and activating
  - Temporal demand (TD): Related to time pressure
  - Performance (OP; Own Performance): Related to personal goal accomplishment
  - Effort (EF): Related to energy expenditure in accomplishing the level of performance
  - Frustration (FR): Related to the feelings of insecurity, discouragement, irritation, stress, and annoyance

Affection

- Cognitive Valence Theory
  - Theoretical framework that describes and explains the process of intimacy exchange within a dyad relationship
  - Uses subjective or biometric measurements

REFERENCES

References

- G. A. Gescheider, "Psychophysics: The Fundamentals," 3rd ed., Lawrence Erlbaum Associates, 1997.
  - Much more detailed topics can be found about psychophysics.
- T. D. Wickens, “Elementary Signal Detection Theory,” Oxford University Press, 2002
  - Signal detection theory