Fundamentals of Psychophysics

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Visual neuroscience

• How do we see the world?
• The brain is a complex system with many different levels
• So we need approaches with different scales of analysis
  • Physiology, e.g. recording from individual neurons
  • Neuroimaging, e.g. fMRI scans to see the brain regions activated
  • Psychophysics: the system as a whole, e.g. reading, seeing colours
Today

• An overview of psychophysics
• Key methodological approaches
  • Stimulus, task, method, and outcomes
• Some general aspects of visual function
  • Discrimination: Weber’s Law
  • Appearance: Stevens’ Power Law
Psychophysics

- Originates from Fechner (1860)
- Investigates the relationship between physical stimuli and psychological quantities (‘psyche’)
  - We can’t measure the mind directly, so we measure behaviour
  - Requires **linking hypotheses** between subjective and objective phenomena
  - Requires precise control over physical stimuli and testing procedures
  - If you know the properties of a stimulus, and how a person responds to that stimulus, you can infer the underlying perceptual operations of the brain
From behaviour to function

• How can we infer neural processes from behaviour?
The stimulus

Luminance patch
e.g. Andrew Stockman’s lectures

Oriented Gabor
e.g. my lecture on ‘Spatial Vision’

Moving Gabor
e.g. Keith May’s lectures

Depth stimuli
e.g. Stewart Shipp’s lectures

Letters
e.g. Gary Rubin’s lectures

Faces
e.g. my lecture on ‘Objects & Faces’
From behaviour to function

- How can we infer neural processes from behaviour?

Stimulus
- Luminance patch
- Gabor etc.

Task
- detection
- discrimination

Method

Outcome
- performance
- appearance
- Reaction times
- Percent correct
- Thresholds
Thresholds

• A major concern of psychophysics: thresholds
  • The lowest stimulus quantity that can be reliably seen
  • e.g. for size, brightness/luminance, motion, etc.
• Thresholds measure sensitivity, which can be related to the tuning of a neural detector (our linking hypothesis)
• Two types of thresholds:
  • Absolute / detection thresholds
  • Difference / discrimination thresholds
Detection thresholds

• Definition: The minimum intensity at which a stimulus is “just detectable”

  e.g. brightness

  The lowest brightness value you can see

  e.g. motion

  The slowest speed that you can see
Discrimination thresholds

- The smallest *difference* in intensity that is just detectable
- Requires comparison between two or more stimuli, or between one stimulus quantity and a standard/reference

*E.g.* brightness

The lowest difference in brightness that you can see

*E.g.* orientation

The smallest orientation offset from vertical that you can see
From behaviour to function

• How can we infer neural processes from behaviour?

Stimulus
- Luminance patch
- Gabor etc.

Task
- detection
- discrimination

Method

Outcome
- performance
- appearance

Reaction times
- Percent correct
- Thresholds
Task

• Let’s select detection thresholds for a luminance patch
  • Why do this? e.g. Hecht, Haig & Chase (1937)
  • Measured detection thresholds after different durations in the dark
• How do you ask the question?
  • Yes/no methods
    • e.g for detection: “Can you see it?” Yes / no

![Graph showing log threshold vs time in dark](image)
Method / sampling procedure

• On the range of intensity values, where do you select the ones to show the observer?

• Method of Limits
  • Intensity gradually increased/decreased until response changes
Method of limits

• Errors of habituation
  • Giving the same response continually and don’t change

• Errors of anticipation
  • Know the threshold is coming and change response too soon
Method of limits

- Minimise these errors by approaching in both directions ($\infty$ to 0, and 0 to $\infty$)
- Threshold is then the average of these measurements
  - performance measure: average setting = brightness threshold
Method of adjustment

- As with the method of limits, but the observer adjusts the stimulus levels themselves until their report changes from visible to invisible or vice versa.
Issues with adjustment/limits

- **Advantage of method:**
  - Rapid estimation of threshold

- **Disadvantage:**
  - Errors of habituation and anticipation
  - Although these errors can be partly overcome with different directions of measurement, there is an alternative
Method of Constant Stimuli

- Intensities presented in a random order, with repeats
  - Removes issues of anticipation/habituation
Method of Constant Stimuli

• But where is the threshold?
  • Performance varies from 0 to 100%
• Can fit a ‘psychometric curve’
  • Cumulative form of a Gaussian function

![Graph showing percentage 'yes' responses against brightness (cd/m²)]
Method of Constant Stimuli

- At what point do we call the threshold?
  - It should be above 0% (never seen) and below 100% (always seen)
  - The midpoint (50%) is the most sensitive point of the curve - fastest rate of change so can easily see e.g. individual differences or experimental manipulations
Method of Constant Stimuli

• Advantages:
  • Avoids issues of habituation/anticipation

• Disadvantages:
  • Slower estimation of threshold
  • Need to test a predetermined range of intensity values

• Good practice:
  • Pilot testing with Method of Limits/Adjustment
  • Use this to select parameters for Method of Constant Stimuli
From behaviour to function

• How can we infer neural processes from behaviour?

**Stimulus**
- Luminance patch
- Gabor etc.

**Method**
- Limits
- Adjustment
- Constant stimuli

**Task**
- detection
- discrimination

**Outcome**
- performance
- appearance

**Limits**
- Adjustment
- Constant stimuli

**Thresholds**
- Reaction times
- Percent correct

- yes/no
  - e.g. “can you see it?”
  - e.g. “are they different?”

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• Yes/no procedures confound the threshold with the observer’s subjective criterion
  • Consider the effect of increased sensitivity vs. decreased sensitivity
Threshold vs. criterion

• Now consider the effect of criterion differences
  • Someone eager to indicate “yes” (a liberal criterion) vs. someone reluctant to do so (conservative criterion)
• Impossible to distinguish from changes in sensitivity
Forced-choice measures

• Yes/no measures rely on a subjective criterion
• Forced-choice measures can minimise this influence
  • Force the observer to choose between 2 or more responses on each trial
  • Compare these judgements against an objective standard
  • e.g. two-alternative forced choice (2AFC)

Was the patch to the left or right?

Was the motion to the left or right?
Forced-choice MCS

What happens with the psychometric function?

- e.g. the detection task for luminance/brightness
- With a 2AFC design the guess rate is 50%
- The midpoint (threshold) is now taken as 75% correct
Changing the chance level

- You can also increase the dynamic range
  - e.g. 4AFC for motion: chance is now 1/4 (25%), threshold is 62.5%
- $x$AFC gives chance performance at $100/x$
Forced-choice issues

• Advantages
  • Avoids issues of subjective criterion
  • Can use to test perception in animals / pre-verbal children

• Disadvantages
  • Not always possible to create ‘objective’ scoring

from Carandini & Churchland (2013)
From behaviour to function

- How can we infer something about function from behaviour?

**Stimulus**
- Luminance patch
- Gabor etc.

**Task**
- detection
- forced choice
- yes/no
- discrimination
- yes/no
- forced choice

**Method**
- Limits
- Adjustment
- Constant stimuli

**Outcome**
- performance
- Reaction times
- Percent correct
- Thresholds
- PSEs

- appearance
Appearance vs. Performance

- An objective Method of Constant Stimuli approach also lets us determine stimulus appearance (vs. performance)
- Clearest if we change task to orientation discrimination
  - 2AFC discrimination task
  - “Is the Gabor oriented clockwise or counterclockwise of vertical?”
Appearance vs. Performance

• We could plot this as percent correct as before.
• But if we plot it as percent CCW responses instead then we can separate out the threshold from the midpoint.
Appearance vs. Performance

- Midpoint of the curve now crosses chance:
  - 50% likelihood of saying CW or CCW
  - This is the Point of Subjective Equality with the reference (vertical)
Appearance vs. Performance

- How do we measure the threshold now?
  - Take the difference in orientation required to get to 75% CCW
  - A rotation of ~3 degrees is required to judge a CCW rotation
From behaviour to function

- Two more approaches to measure stimulus appearance

**Stimulus**
- Luminance patch
  - Gabor
  - etc.

**Task**
- detection
  - yes/no
  - forced choice
- discrimination
  - yes/no
  - forced choice

**Method**
- Limits
- Adjustment
- Constant stimuli

**Outcome**
- performance
- appearance
  - Reaction times
  - Percent correct
  - Thresholds
  - PSEs
  - Matching
  - Scaling
Appearance: matching

- A simple way to measure the perceived equivalence of two stimuli: ask observers to match their appearance
  
  - e.g. with two patches of colour: match the appearance of a narrowband yellow reference with a test patch made via superimposition of red & green lights
  
  - Allows the measurement of metamers - stimuli that are physically dissimilar but perceptually identical
Appearance: scaling

• A method to measure the perceived difference between two stimuli
  • Formalised by Stanley Smith Stevens
  • Show a reference stimulus and assign a value (e.g. “10”)
  • Then show a test stimulus at a different intensity
  • Observer must then assign a number to the test that is proportional to the reference
    • e.g. if the test appears twice as bright it is reported as 20
  • And so on…
From behaviour to function

**Stimulus**
- Luminance patch
- Gabor etc.

**Method**
- Limits
- Adjustment
- Constant stimuli

**Task**
- Detection
- Discrimination

**Outcome**
- Performance
- Appearance

**Limits**
- Thresholds
- Percent correct

**Adjustment**
- Reaction times
- Matching

**Constant stimuli**
- PSEs
- Scaling
Quantifying perception

• Can we predict how well people can distinguish between two stimulus quantities?

• This was a major concern of both Fechner (1860) and Ernst Weber (1834)

• When we measure difference thresholds, we do so at a particular reference point

• What happens when we change this reference point?

• Does stimulus intensity alter discrimination thresholds?
Weber’s Law: brightness

- Thresholds for brightness discrimination increase as the reference brightness increases.

![Graph showing Weber's Law for brightness discrimination.](image)

- Table showing reference and test brightness levels for different threshold values.
Weber’s Law

• The just noticeable difference (JND; i.e. the discrimination threshold) between two stimuli is proportional to the magnitude of the stimuli

\[ k = \frac{\Delta l}{l} \]

• where \( \Delta l \) is the JND and \( l \) is the reference intensity

• \( k \) (Weber’s constant) signifies that the value of \( \Delta l \) is a constant proportion of \( l \)
Weber’s Law: brightness

- $k$ is $4/50 = 8/100 = 16/200$
  - i.e. 0.08 for brightness
- Thresholds for brightness discrimination are a constant proportion of the reference
  - e.g. with a reference value of 150 cd/m$^2$, we can predict a threshold of $150 \times 0.08 = 12$
Weber’s Law: everything

- Weber measured thresholds with many stimuli and found a similar relationship, albeit with different $k$ values
  - Brightness $k = 0.08$
  - Line length $k = 0.03$
  - Weight $k = 0.02$
  - Loudness $k = 0.05$
- Although thresholds rise in absolute values of intensity, they remain constant in terms of relative intensity
But does it hold?

- Subsequent measurements show Weber’s Law can break down
- Particularly at very low reference intensities
  - e.g. brightness (Barlow, 1957)
- Deviation may reflect the dominance of noise at low stimulus intensities
- Nonetheless, the law does apply to a wide range of stimulus values
Fechner’s interpretation

• Fechner argued JNDs were the unit of our internal responses (his linking hypothesis), so:
  • Two stimuli that are just noticeably different are separated by one unit of internal response
  • A stimulus with an intensity equal to 3 JNDs should be seen as 3 times more intense than a stimulus equal to one JND
• Links appearance with performance and predicts a linear relationship
  • Does this hold when we measure it?
Stevens’ Power Law

- Fechner predicted a linear relationship between intensity (in JNDs) and perceived magnitude.
- Stevens (1962) used Scaling to measure this for a range of stimuli.
  - Some dimensions are linear, e.g. line length.
  - But doubling brightness does not double perceived brightness: response compression.
  - For electric shocks the opposite is seen: response expansion.
Stevens’ Power Law

- Power functions described by the form $P = KS^n$
  - $P$ = perceived magnitude, $S$ = stimulus intensity, with exponent $n$ and constant $K$
  - $n$ determines the slope of the function
- So Fechner was wrong here
- Many perceptual dimensions rise non-linearly with intensity
- But these patterns can all be described by a power function
  - A single principle can vastly change our experience in each domain
Weber, Fechner, Stevens

• Weber’s Law: the discriminability of two stimulus values is a linear proportion of their intensity
• Fechner argued that this could be extended to understand stimulus appearance
• But Stevens’ Power Law shows our experience of intensity follows a power function that can expand or compress the ends of the intensity range
Psychophysics provides tools to investigate the relationship between physical stimuli and psychological quantities.
Summary

• With linking hypotheses we then make inferences about the underlying mechanisms

• These simple techniques can tell you things like:
  • Discriminability increases linearly with the reference intensity (Weber’s Law)
  • Perceived intensity increases with a power function (Stevens’ Law)

• In future lectures you’ll go into more detail about specific visual dimensions

• Reading for this lecture: Chapter 1 of Sensation & Perception by either Goldstein or Wolfe et al (or both)