Lecture 1: Information Processing and Signal Detection

Lecture 01 part 02

Basics of Psychophysics

Relevance

Jo, I., Park, Y., Kim, H. and Bae, J., 2019. Evaluation of a Wearable Hand Kinesthetic Feedback System for Virtual Reality: Psychophysical and User Experience Evaluation. *IEEE Transactions on Human-Machine Systems*, *49*(5), pp.430-439.

Groeger, D., Feick, M., Withana, A. and Steimle, J., 2019, October. Tactlets: Adding tactile feedback to 3D objects using custom printed controls. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (pp. 923-936).

Jones, L.A. and Tan, H.Z., 2012. Application of psychophysical techniques to haptic research. *IEEE transactions on haptics*, *6*(3), pp.268-284.

Alzayat, A., Hancock, M. and Nacenta, M., 2014, April. Quantitative measurement of virtual vs. physical object embodiment through kinesthetic figural after effects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2903-2912).

Boem, A., Enzaki, Y., Yano, H. and Iwata, H., 2019, March. Human Perception of a Haptic Shape-changing Interface with Variable Rigidity and Size. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (pp. 858-859). IEEE.

Piumsomboon, T., Lee, G.A., Ens, B., Thomas, B.H. and Billinghurst, M., 2018. Superman vs giant: A study on spatial perception for a multi-scale mixed reality flying telepresence interface. *IEEE transactions on visualization and computer graphics*, *24*(11), pp.2974-2982.

Learning Objectives

To develop an understanding of basic psychophysical principles

To understand the different ways in which experimenters can measure the effect of a stimulus and the percept it generates.

To understand the key differences and similarities between different types of psychophysical approaches to measurement.

To develop an appreciation of how basic psychophysical principles have been applied to interface design and evaluation.

Learning Outcomes

To understand what is meant by measuring perceptual effects using psychophysics.

To be able to describe the key measures and methods used in perceptual experiments.

To be able to describe how the value of threshold can be obtained and the key characteristics of the psychometric function.

Psychophysics to Measure Perception

Psychophysics is the study of the relationship between changes in the physical properties of a stimulus (*physics*) and the perceptual (*psycho*) response to these stimuli.

For instance in a typical perception study with participants responding to stimuli:

The main idea is that by changing external parameters of a stimulus (e.g., a visual, auditory, touch, olfactory, taste stimulus) we can measure the corresponding measure of a behavioral parameter such as accuracy, reaction time, sensory thresholds). This information can then be used to infer an aspect of the internal *percept* of a participant.

An advantage is that the measure is also quantitative (objective scale of measurement).

Psychophysics to Measure Perception

There are a number of ways in which a participant's response to a stimulus can be recorded.

In response to a stimulus, a person could provide the following information (measure):

<u>Overall Description</u>; e.g., describe what is happening.
<u>Recognise</u> and categorise the stimulus; e.g., is it blue or red? Is it a low-pitch or high-pitch sound?
<u>Detect</u> an aspect of the stimulus. E.g., is it present or not?
<u>Difference</u>: Detect a difference between stimuli.
<u>Describe</u> an aspect of the stimuli. e.g., is it bigger or brighter?
<u>Search</u> for a specific stimulus characteristic amongst other stimuli. e.g., search for the blue letter k amongst all the purple letters k.

Overall Description Measure

The overall description measure is not used so much now.

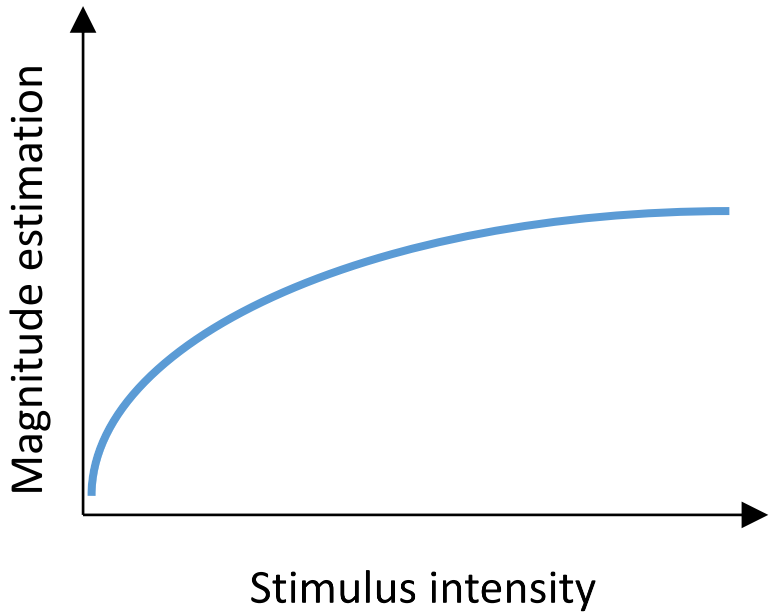
This measure was often used in the past, when an experimenter would record an individuals' general sensation to stimuli.

For instance this could mean recording how an individual reported different aspects of the same stimulus- such as far away it is, and what particular colour…

But it is not quantitative.

Other methods that can provide a more quantitative relationship between the stimulus and perception are favoured- these experiments are easier to replicate and to compare results across individuals.

Example of a Descriptive Measure: Magnitude Estimation in Vision



E.g. visual stimulus experiment

Experimenter presents a "standard" stimulus e.g., a light of moderate intensity and gives it a value of e.g. 10.

Lights of different intensities are presented and the observer is requested to assign a number to the brightness with respect to the standard stimulus. E.g., if the light appears twice as bright as the standard, the observer rates it as 20, If the light appears half as bright as the standard, the observer rates it as 5.

If multiple observer responses are plotted we may achieve the plot on the left: doubling the intensity does not necessarily double the perceived brightness (response compression)

Recognition Measure

If collecting recognition measures we could take the following steps:

A stimulus is presented.

The task of the participant is to recognise, and thereby categorise the stimulus.

E.g., Present a sound stimulus

Participant task: To say whether it is a high-pitch or low-pitch sound

E.g., Present an image of a blurred fruit

Participant task: To say if it resembles an apple or an orange

Detection and Difference Measures

Common measure that is used in perception experiments is that of the "Threshold" for detection of a stimulus or Threshold for detecting the difference between stimuli.

Reminder:
Detect an aspect of the stimulus. This involves judging whether it is present or not.
Difference between stimuli: This involves judging whether there is a difference between stimuli.

Threshold: This is the smallest amount of a stimulus energy necessary to detect a stimulus or detect a difference between stimuli.

Can measure Thresholds for detecting whether a stimulus is present or not.
Can measure Thresholds for detection whether there is a difference between stimuli.

Example of measuring threshold for detecting a stimulus

[We will cover this in more detail later, but this is presented early to introduce the concept]

Generally in methods for estimating <u>absolute threshold</u>, trials are presented to the participant in which the stimulus is either not present or the stimulus is present at e.g., loudness (auditory), brightness (visual), strength of fragrance (olfactory), strength of skin contact (touch)…

Example of measuring threshold for detecting a stimulus

[We will cover this in more detail later, but this is presented early to introduce the concept]

Generally in methods for estimating absolute threshold, trials are presented to the participant in which the stimulus is either not present or the stimulus is present at e.g., loudness (auditory), brightness (visual), strength of fragrance (olfactory), strength of skin contact (touch)…

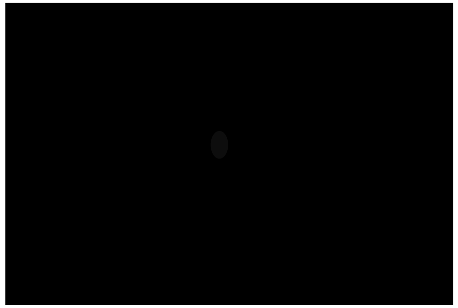
For instance using a light stimulus at different intensities:

More trials and with repeat presentations →

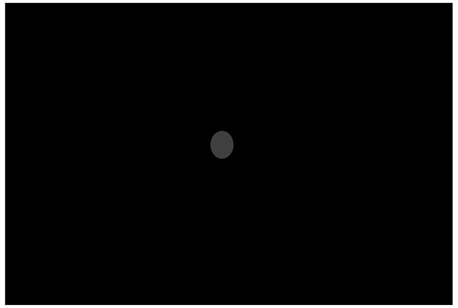
A trial refers to each observation window

Question: Can you see the light spot?

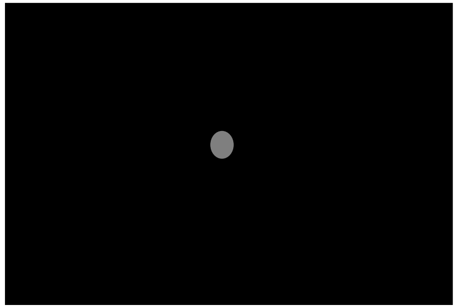
Trial 01



Trial 02



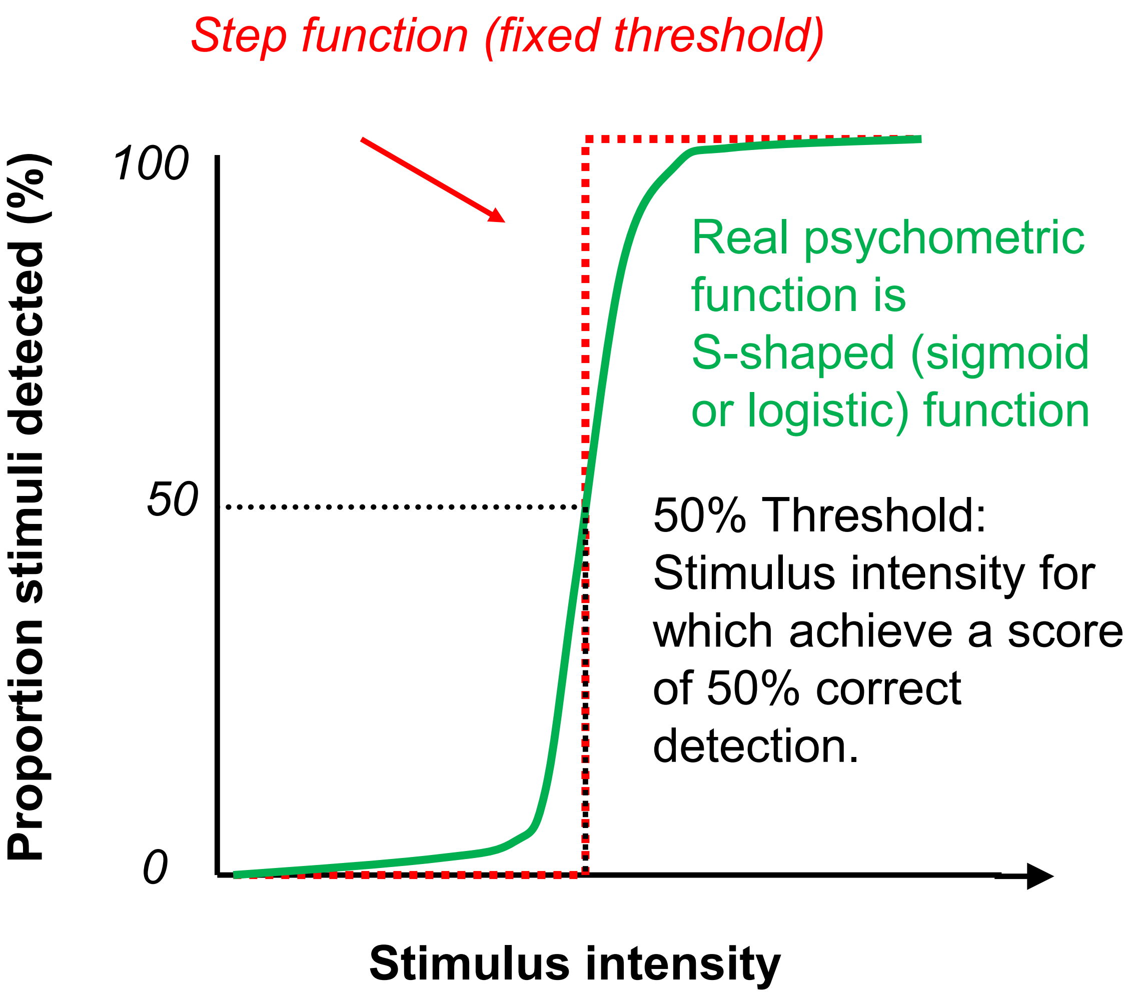
Trial 03



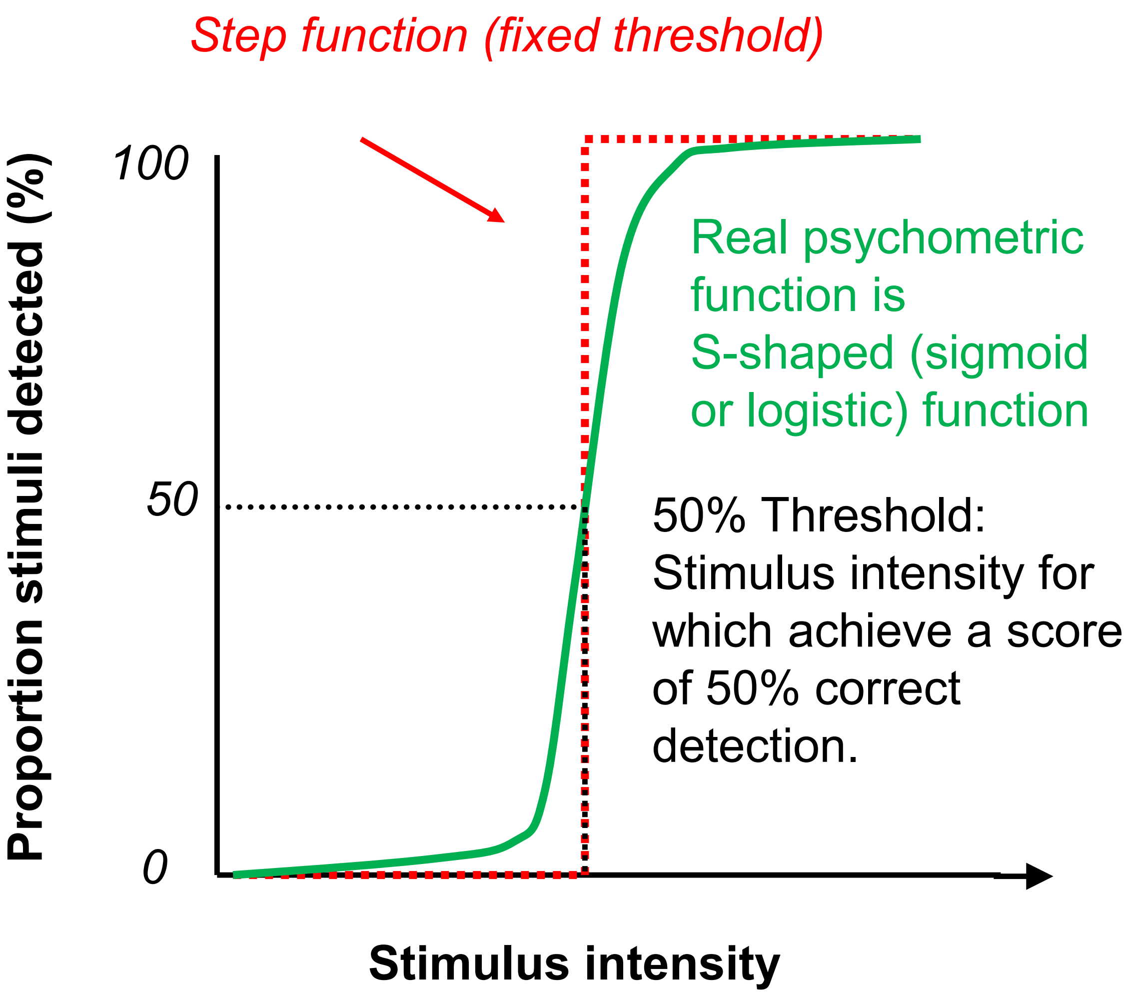
Observer may respond as:

"No" "Yes" "Yes"

How do we plot the threshold values?



How do we plot the threshold values?



Psychometric function: plot of proportion of stimuli detected or discriminated vs. stimulus intensity.

May have expected a step function- i.e.,

Participant(s) scoring 100% for detecting higher stimulus intensities and then at some point cannot see the stimulus and immediate shift to always scoring 0% for detecting the stimulus -> step function.

The actual (real) psychometric function is not a step function, it is sigmoidal/logistic in shape.

The actual psychometric function not a step function because of **noise** (we will return to this concept later).

Absolute Threshold

The most common way in which to obtain a measure of detection or difference is that of Absolute Threshold.

Measuring Absolute Thresholds

This is the smallest amount of a stimulus energy necessary to detect a stimulus.
E.g., the smallest amount of light energy that enables a person to just detect it's presence.
Or the quietest sound that can be heard.

Variations of the methods used for estimating threshold are used clinically for eye-sight tests and hearing tests.

Absolute Thresholds:
Present **one** stimulus at a time.
The stimulus is very weak
Possible responses can be: "Yes, I can sense it" or "No, I don't sense it".

Difference Threshold

Measuring Difference Thresholds

Difference Threshold:
Present **two** stimuli at a time:
Present a standard stimulus which is fixed, easily detectable
Present a comparison which is either more or less intense than the standard
Possible responses can be:
e.g., “Comparison is brighter (or comparison is dimmer)”
e.g., “Comparison is louder (or Comparison is quieter)”

Example of The Difference Threshold

Instead of asking observers/participants to indicate whether they detect a stimulus, they are requested to indicate whether they detect a difference between 2 stimuli.

E.G
An observer lifts tray 1 with a weight of 100g, and a tray 2 with a weight of 101g
And makes a judgement as to whether the weight of tray 1 and tray 2 are the same or different.
The observer judges them to be the same in this case.

The observer then lifts tray 1 with a weight of 100g, and a tray 2 with a weight of 102g
And makes a judgement as to whether the weight of tray 1 and tray 2 are the same or different.
The observer now judges them to be different.

In this case the "difference limen" is 2g

Three Main Ways of Measuring Thresholds

There are 3 main methods used to determine the threshold:
Method of limits, Method of adjustment, Method of constant stimuli.

All 3 can be used to measure absolute threshold, 2 of which can be used to measure the difference threshold. For 1 of the methods the participant can adjust the stimuli.

	Absolute Threshold	Difference Threshold	Who adjusts the stimuli presented
Method of Constant Stimuli	✓	✓	Experimenter
Method of Limits	✓	✓	Experimenter
Method of Adjustment	✓	Not used	Participant

There are also adaptive (staircase) techniques which can be applied to the basic method of limits and to the method of constant stimuli.

The Method of Adjustment

The observer/participant adjusts the stimulus intensity continuously until the observer can just about detect the stimulus.

This can be repeated multiple times and threshold can be estimated by taking an average of the estimate.

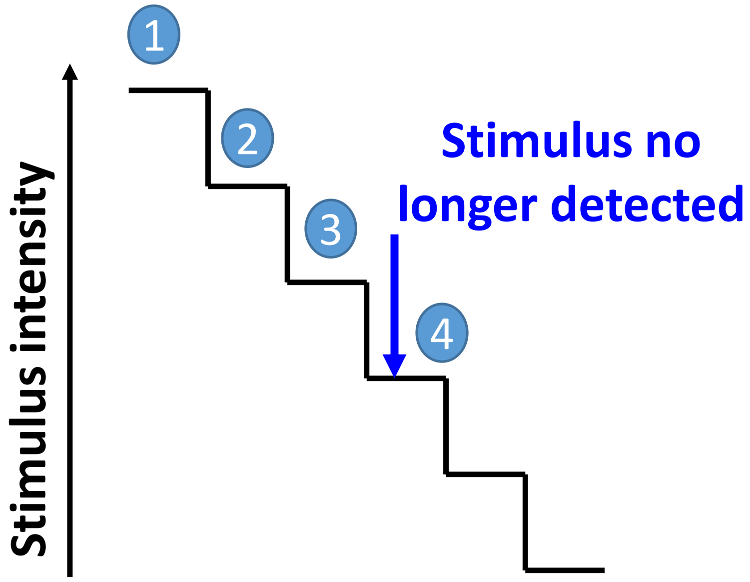
Note that the observer is not required to say yes or no as each stimulus is presented.

Method of Limits to Establish threshold

Example: To find the threshold for a sound stimulus. Participant/observer wears headphones and is presented with sounds to listen to. On each trial a sound is presented and the participant has to say “yes” if they heard a sound

Method of Limits to Establish threshold

Example: To find the threshold for a sound stimulus

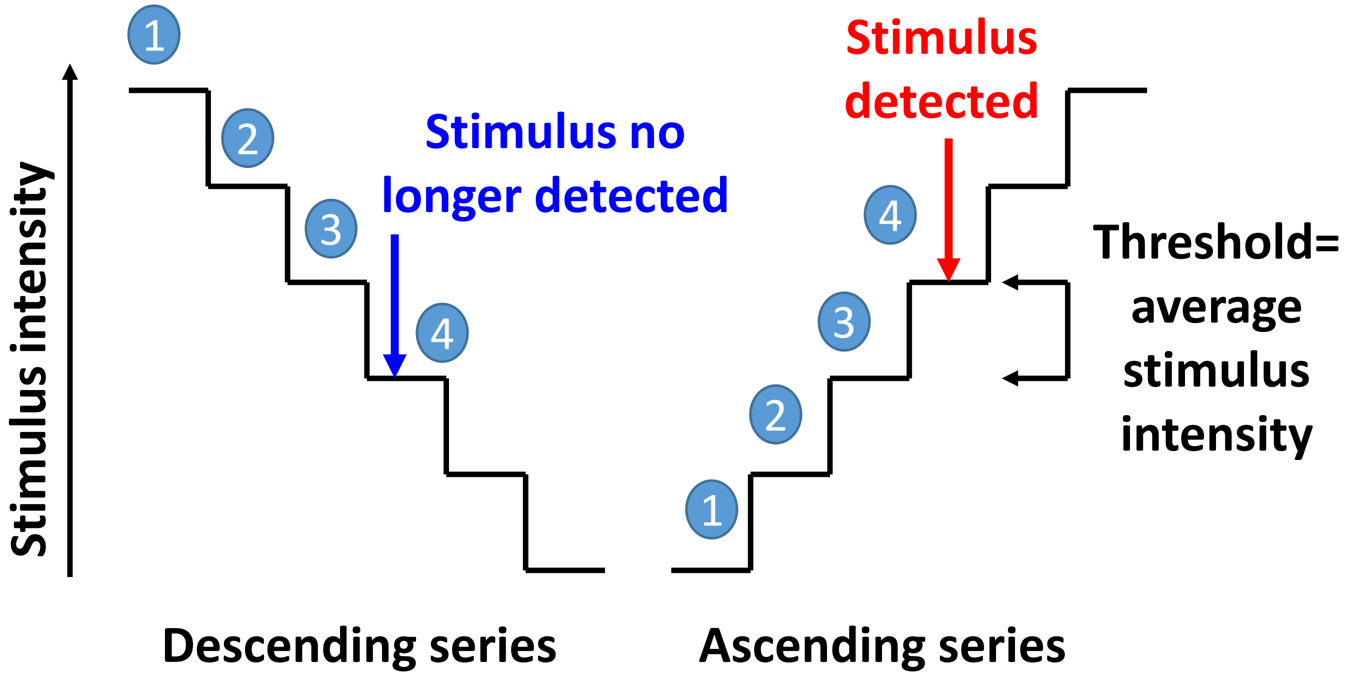


Descending series

The observer reports "yes" until they cannot hear the sound stimulus

Method of Limits to Establish threshold

Example: To find the threshold for a sound stimulus

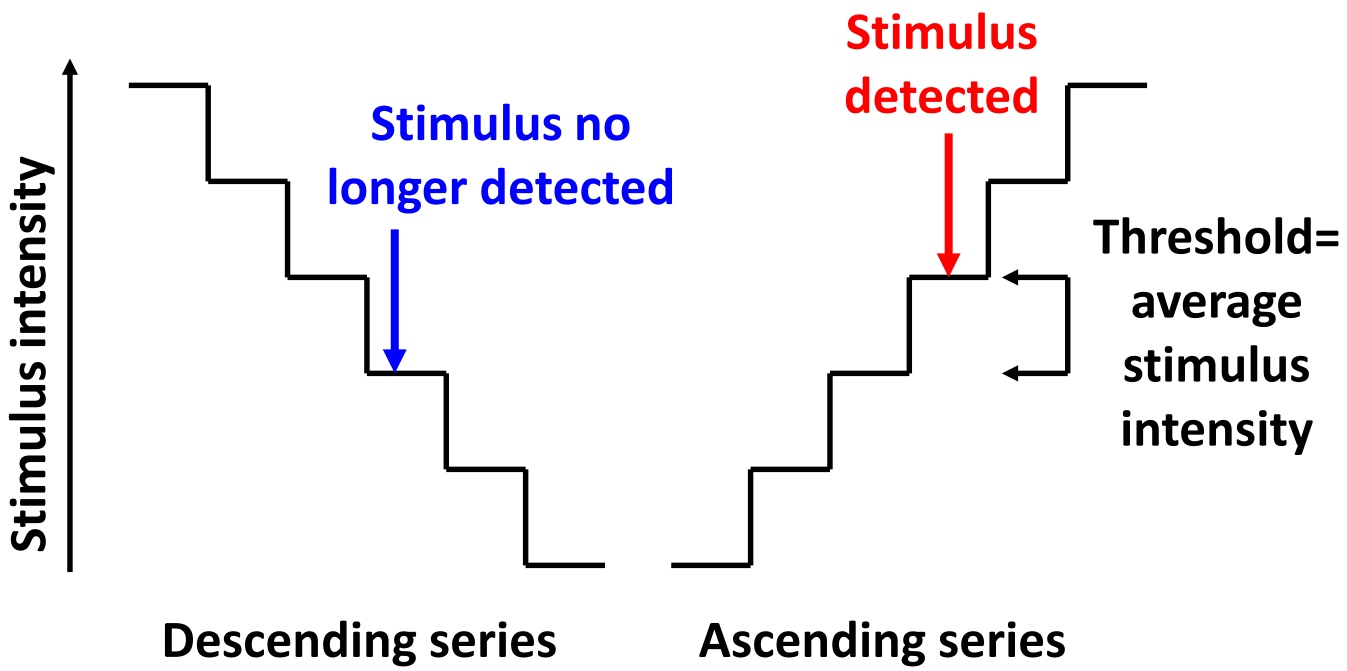


The observer reports "yes" until they cannot hear the sound stimulus

The observer reports "no" until they can hear the sound stimulus

Method of Limits to Establish threshold

Example: To find the threshold for a sound stimulus



The observer reports "yes" until they cannot hear the sound stimulus

The observer reports "no" until they can hear the sound stimulus

The experimenter presents on each trial (on each presentation) the stimuli in ascending order (i.e., The sound stimulus becomes louder).

and the experimenter presents the stimuli in descending order (i.e., the sound stimulus becomes quieter).

Ascending and descending series are done in alternation.

The change point from yes to no and no to yes is called the crossover point.

The threshold can be estimated by calculating the average of all of the crossover points.

Method of Limits: Advantages and Disadvantages

In experiments, the ascending and descending methods are used alternately and the thresholds are averaged.

Relatively easy instructions to understand.

Possible disadvantages:

Observer may become accustomed to reporting that they perceive a stimulus and may continue reporting the same way beyond threshold (error of habituation).

Observer may anticipate that the stimulus is about to become detectable or undetectable and may make a premature judgment (error of expectation).

Method of Constant Stimuli to Establish Threshold

Instead of the stimuli being presented in ascending or descending order, in the **method of constant stimuli** the levels of a certain property of the stimulus are not related from one trial to the next, but presented **randomly**.

This prevents the observer from being able to predict the level of the next stimulus, and therefore reduces errors of habituation and expectation.

The observer/participant again reports whether he or she is able to detect the stimulus.

Method of Constant Stimuli to Establish Threshold

For example for a visual detection experiment:

Experiment: Stimuli with a fixed range of intensity levels are presented in a detection task in random order(or fixed range of differences for a discrimination task).

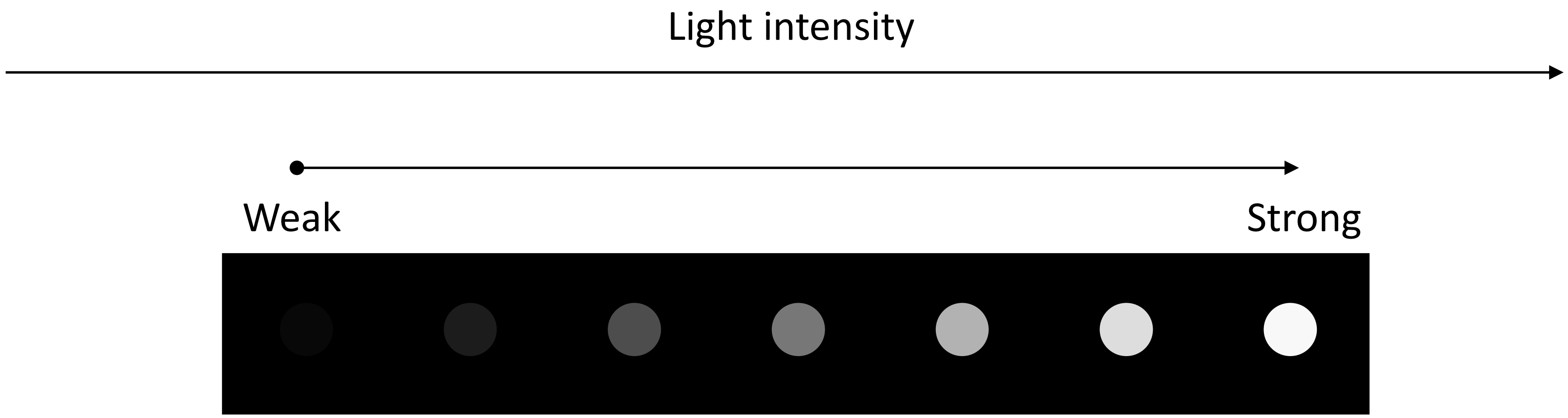
Participant responses: Participant's report whether the stimulus is absent or present (for a detection task) or same/different or weaker/stronger than the standard stimulus for a difference task).

Data: Participant's reports are plotted against stimulus intensity.

Data fitting: Usually a psychometric function is then fit (by nonlinear function fitting or logistic regression) to the psychometric data.

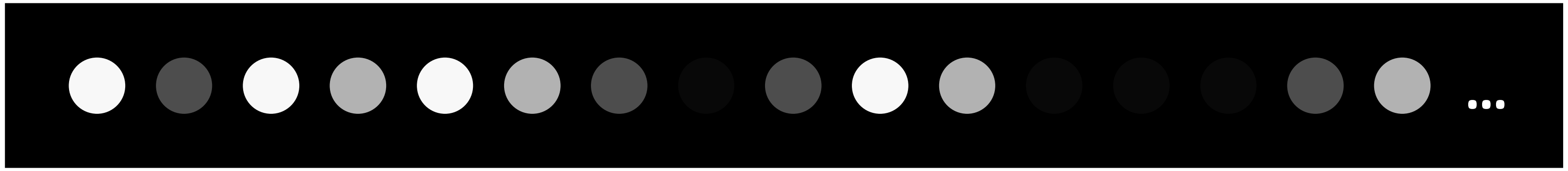
Threshold Estimation: Threshold is midway between chance level performance e.g. 50% and 100% detection.

Example of Method of Constant Stimuli



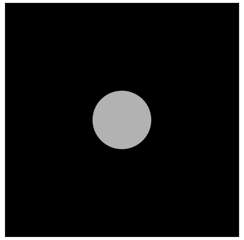
1. Select a range of light intensities from strong to weak
2. Pick some points uniformly in this intensity range; this will be the constant stimulus set

Example of Method of Constant Stimuli



3. Prepare a set of stimuli that can be presented in random order

Example of Method of Constant Stimuli



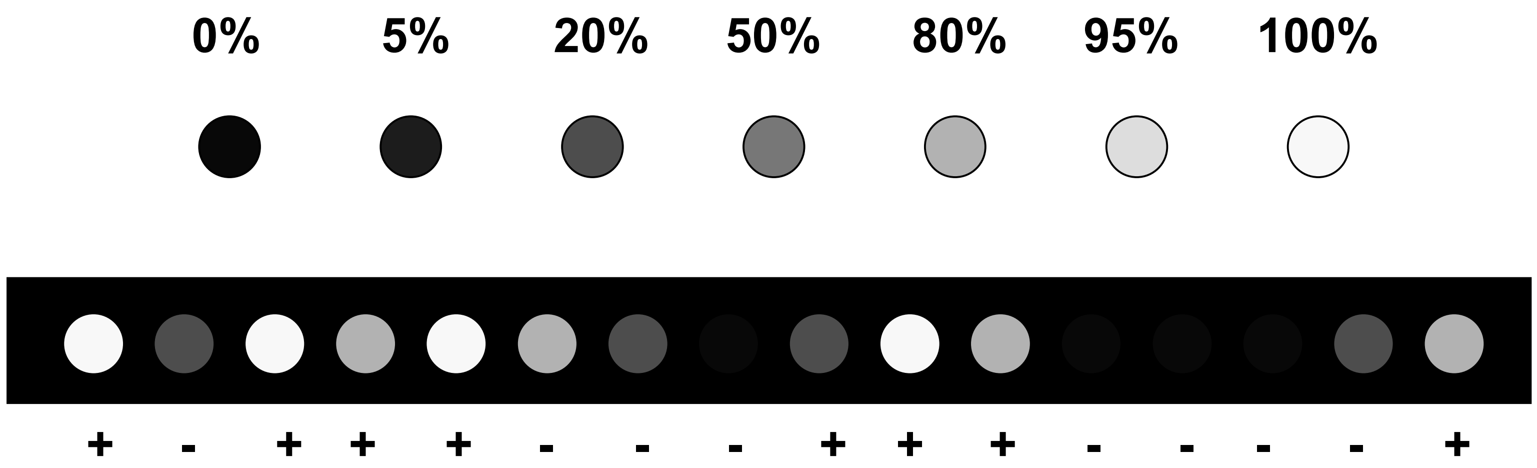
Visible?

YES NO

4. Each stimulus of the set is presented one at a time and the task of the observer is to say if it is visible or not.

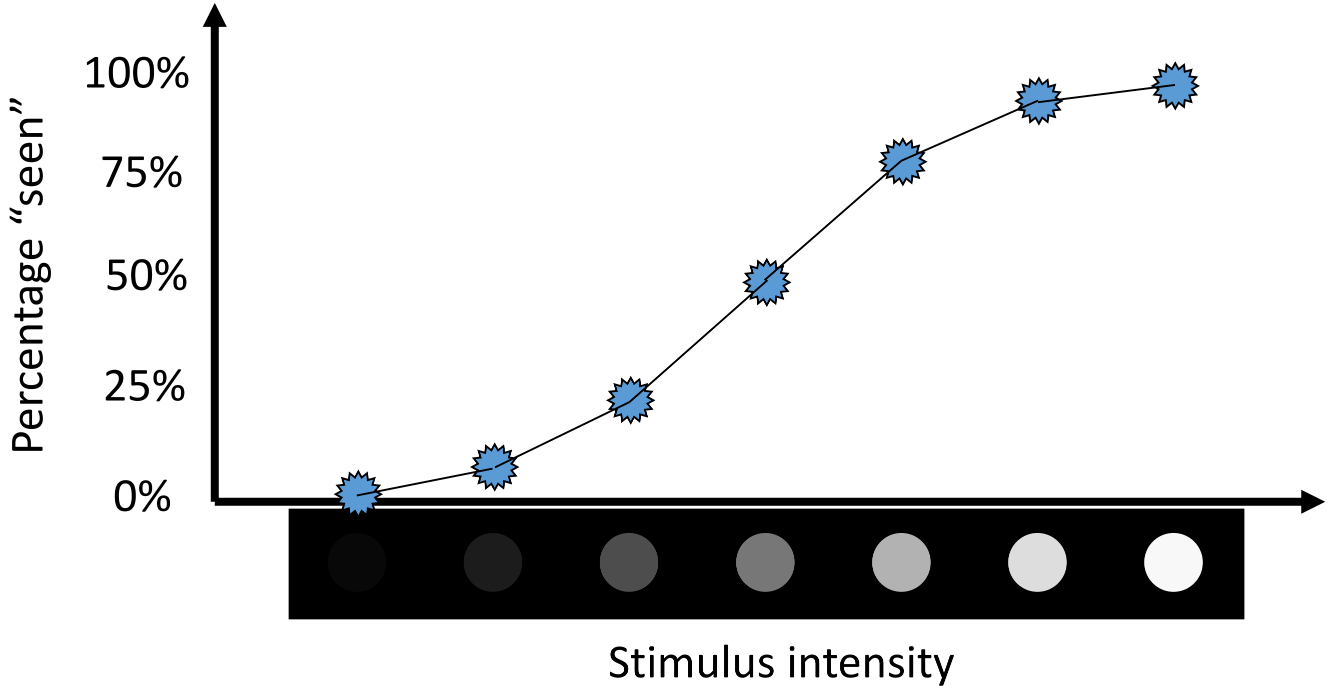
Each stimulus is presented multiple times (20-25) in random order

Example of Method of Constant Stimuli



5. Calculate the proportion of “yes” and “no” responses at each light level

Example of Method of Constant Stimuli



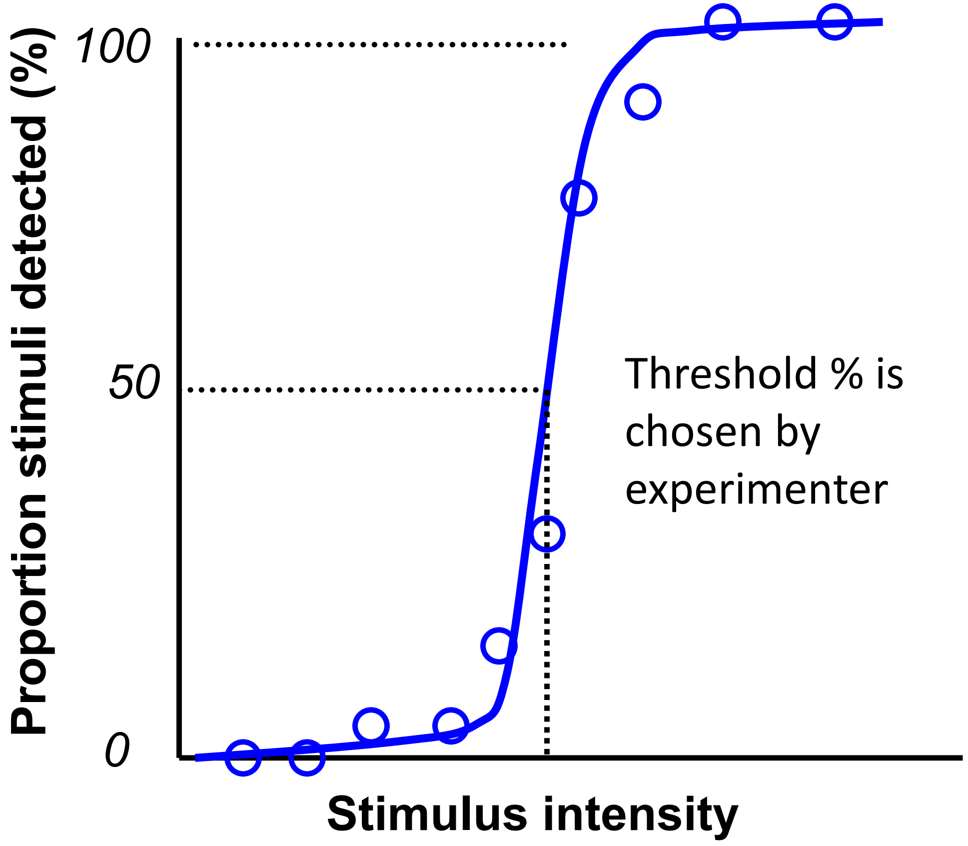
Stimuli with a fixed range of intensity levels are presented in random order

Observers report stimulus absent/present

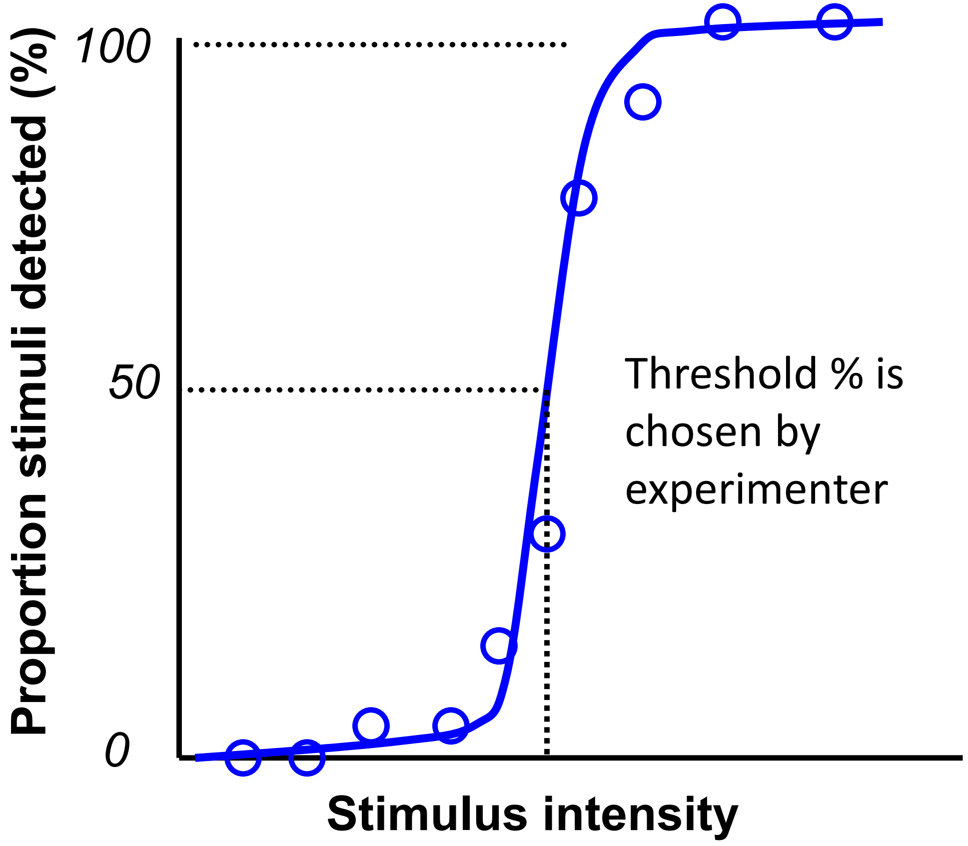
Observers' reports are plotted against stimulus intensity / to give a *psychometric function*

6. Plot the percentages against stimulus intensity
   → **Psychometric Function**

Threshold and the Psychometric Function



Threshold and the Psychometric Function

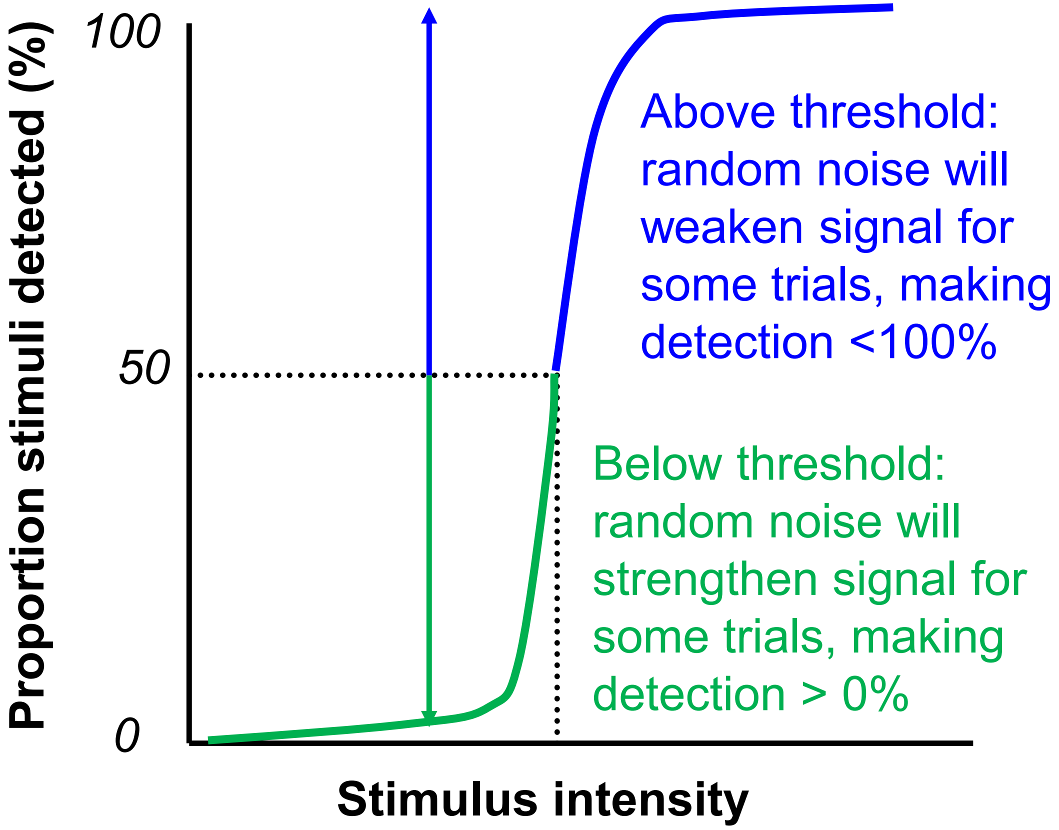


Usually a psychometric function is then fit (by nonlinear function fitting or logistic regression) to psychometric data

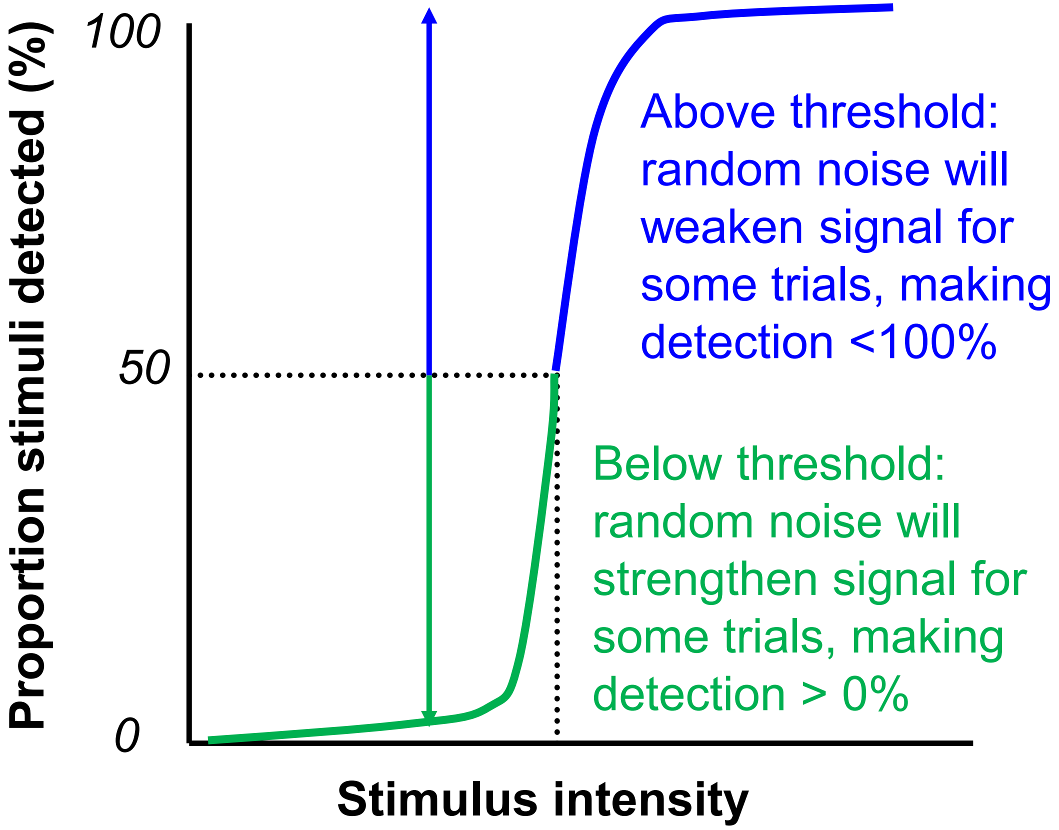
Threshold is midway between chance level performance (bottom of psychometric function, e.g. 50% and 100% detection. Threshold level is chosen by the experimenter.

Note- This is not a step-function. Absolute threshold varies somewhat from trial to trial (due to constant fluctuations in sensitivity) and obtain a sigmoid shape.

The Effect of Noise on Psychometric Functions



The Effect of Noise on Psychometric Functions



Threshold % is chosen by experimenter

The detection (or discrimination) of stimulus is always subject to noise. Noise can be due to:

Neural activity

Stimulus (physical)

Attention

On any trial, noise will randomly increase or decrease the perceived signal intensity.

Participant perceives *signal+ noise* (cannot tell the difference).

This changes step function to a sigmoid (logistic) function which is what is obtained.

Adaptive Staircase Techniques Can Be Applied to Some of These Methods

The adaptive staircase technique can be applied to the method of limits and to the method of constant stimuli.

Adaptive staircase refers to the way in which, a chosen parameter of the stimulus in the stimulus series presented to the participant, can reverse direction depending on the participant's decision.

This way the experimenter is able to "zero in" on the threshold.

Adaptive Staircase Techniques Can Be Applied to Method of Limits

Example of adaptive staircase method for an auditory stimulus task using the method of limits:

In this method, the sound starts out audible and gets quieter on each trial after each of the participant's responses, until the participant does not report hearing it.

At that point, the sound is made louder on each trial, until the participant reports hearing it, at which point it is made quieter in steps again.

Adaptive Staircase Techniques Can Be Applied to Method of Constant Stimuli

Similar to constant stimuli, but range of stimulus intensity levels to use are changed over course of experiment (not fixed)

Allows more time to be spent measuring responses near threshold, good for fitting psychometric functions (samples responses over entire psychometric function curve)

Example of an Adaptive Staircase

E.g., for sound stimuli

	Sound level presented	1. Participant response With decreasing (by 10dB) stimulus level
Higher level sound	60 dB	Yes
	50 dB	Yes
Medium level sound	40 dB	Yes
	30 dB	Yes
	25 dB	
	20 dB	**No**
Very quiet sound	15 dB	
	10 dB	

Example of an Adaptive Staircase

E.g., for sound stimuli

	Sound level presented	1. Participant response With decreasing (by 10dB) stimulus level	2. Participant response With increasing (by 5dB) stimulus level
Higher level sound	60 dB	Yes	
	50 dB	Yes	
Medium level sound	40 dB	Yes	
	30 dB	Yes	
	25 dB		**Yes**
	20 dB	**No**	
Very quiet sound	15 dB		
	10 dB		

Example of an Adaptive Staircase

E.g., for sound stimuli

	Sound level presented	1. Participant response With decreasing (by 10dB) stimulus level	2. Participant response With increasing (by 5dB) stimulus level	3. Participant response With decreasing (by 10dB) stimulus level
Higher level sound	60 dB	Yes		
	50 dB	Yes		
Medium level sound	40 dB	Yes		
	30 dB	Yes		
	25 dB		**<u>Yes</u>**	
	20 dB	**<u>No</u>**		
Very quiet sound	15 dB			**<u>No</u>**
	10 dB			

Example of an Adaptive Staircase

E.g., for sound stimuli

	Sound level presented	1. Participant response With decreasing (by 10dB) stimulus level	2. Participant response With increasing (by 5dB) stimulus level	3. Participant response With decreasing (by 10dB) stimulus level	4. Participant response With increasing (by 5dB) stimulus level
Higher level sound	60 dB	Yes			
	50 dB	Yes			
Medium level sound	40 dB	Yes			
	30 dB	Yes			
	25 dB		**Yes**		**Yes**
	20 dB	**No**			No
Very quiet sound	15 dB			**No**	
	10 dB				

Example of an Adaptive Staircase

E.g., for sound stimuli

	Sound level presented	1. Participant response With decreasing (by 10dB) stimulus level	2. Participant response With increasing (by 5dB) stimulus level	3. Participant response With decreasing (by 10dB) stimulus level	4. Participant response With increasing (by 5dB) stimulus level
Higher level sound	60 dB	Yes			
	50 dB	Yes			
Medium level sound	40 dB	Yes			
	30 dB	Yes			
	25 dB		**Yes**		**Yes**
	20 dB	**No**			No
Very quiet sound	15 dB			**No**	
	10 dB				

In this case the rule is 10dB steps decreasing until reach a "no" response and then increasing in 5 dB steps until reach a "yes" response (a 10-down, 5-up rule). The threshold is taken as the stimulus value that achieved a "yes" response on two ascending steps (25dB)

An Example Application (see slide 3 for more examples)

Groeger, D., Feick, M., Withana, A. and Steimle, J., 2019, October. Tactlets: Adding tactile feedback to 3D objects using custom printed controls. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (pp. 923-936).

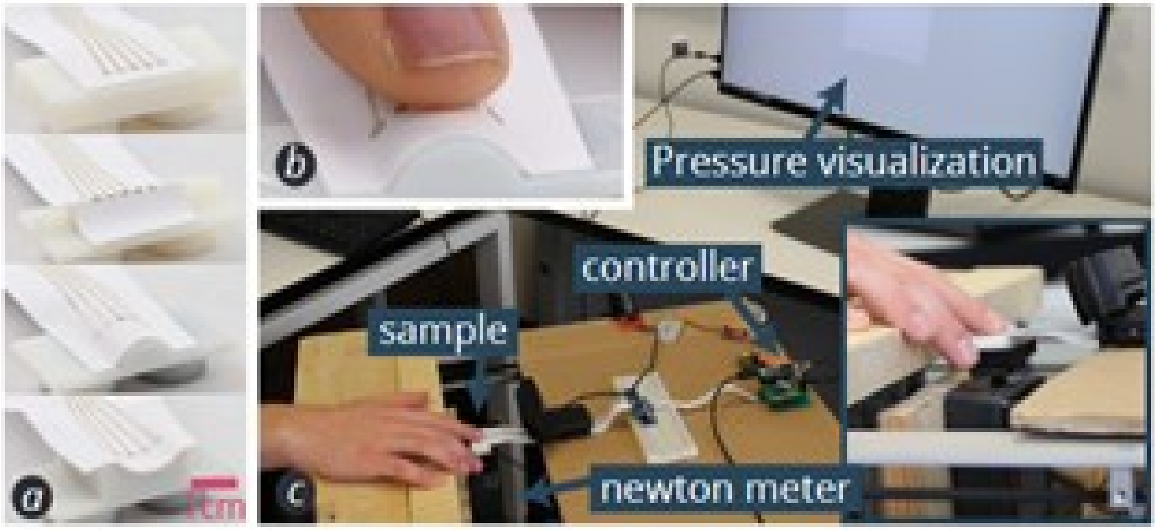


Figure 11. Study overview: (a) planar, convex and concave geometries used; (b) finger on convex curved geometry, and (c) study setup.

Looked at a novel fabrication approach for printing customised high-resolution controls for tactile input and output on 3D objects – these controls are called tactlets. A tactlet is a custom-printed arrangement of tactile pixels that sense touch input and deliver electro-tactile output.

Question: Could participants consistently perceive electro-tactile stimulation on four different tactlet configurations (geometries): planar, concave, convex and edge.

An Example Application (see slide 3 for more examples)

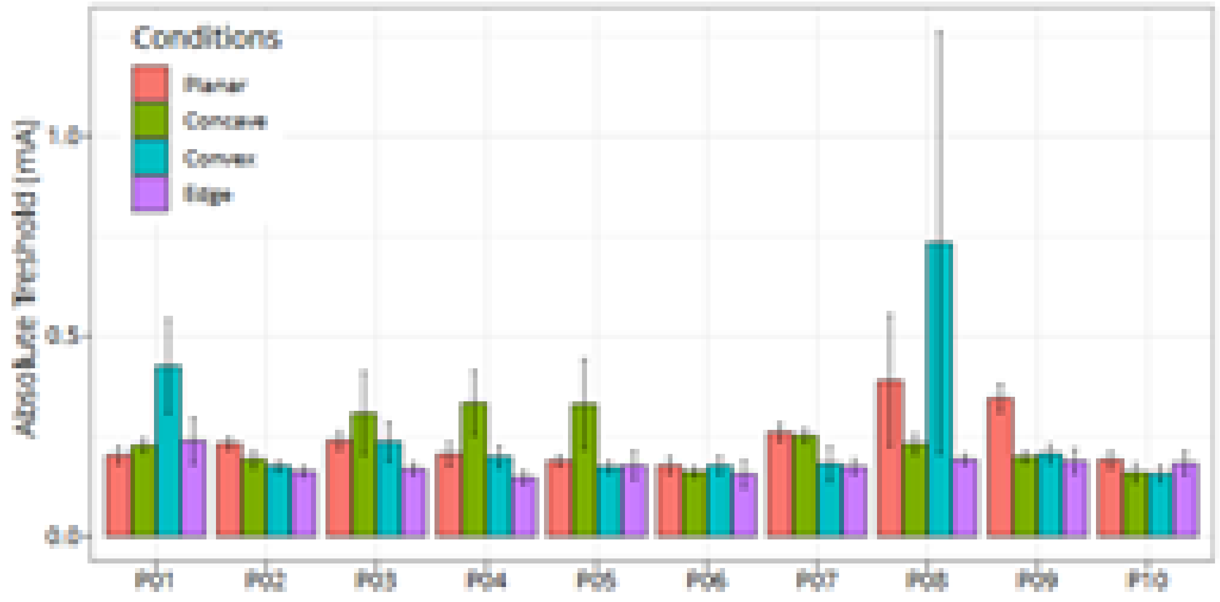


Figure 12. Study results: Absolute threshold of the stimulation intensity (mA) for each curvature condition for each subject.

15 participants.
3D printed the four geometries.

Used the method of limits with a double-staircase method (to minimize errors of habituation and expectation)
Intensity was varied on each presentation step.

Measured absolute thresholds.

Questions to Consider (10 mins)

Regarding the Groeger, D., Feick, M., Withana, A. and Steimle, J., 2019, study:

Q1: In which way could habituation and expectation have affected their results ?

Q2: In which ways could the study design have been improved?

(We can discuss this in the Question and Answer Sessions)

Overall Summary

A description of psychophysics.

An overview of some basic perceptual measures.

A focus on detection and difference measures.

The main methods used for measuring threshold (e.g. methods of constant stimuli, method of limits and method of adjustment); similarities and differences.

The adaptive staircase method can also be used for threshold measures .

The threshold data can be plotted as a psychometric function with key characteristics.

Resources

Essential:

Sensation and Perception 8th edition (book) page 3 to 20.

Groeger, D., Feick, M., Withana, A. and Steimle, J., 2019, October. Tactlets: Adding tactile feedback to 3D objects using custom printed controls. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (pp. 923-936).

Jo, I., Park, Y., Kim, H. and Bae, J., 2019. Evaluation of a Wearable Hand Kinesthetic Feedback System for Virtual Reality: Psychophysical and User Experience Evaluation. *IEEE Transactions on Human-Machine Systems*, *49*(5), pp.430-439.

Supplementary:

Alzayat, A., Hancock, M. and Nacenta, M., 2014, April. Quantitative measurement of virtual vs. physical object embodiment through kinesthetic figural after effects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2903-2912).

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Piumsomboon, T., Lee, G.A., Ens, B., Thomas, B.H. and Billinghurst, M., 2018. Superman vs giant: A study on spatial perception for a multi-scale mixed reality flying telepresence interface. *IEEE transactions on visualization and computer graphics*, *24*(11), pp.2974-2982.