

# The psychophysical approach to measuring perceptions

Gabriel Baud-Bovy

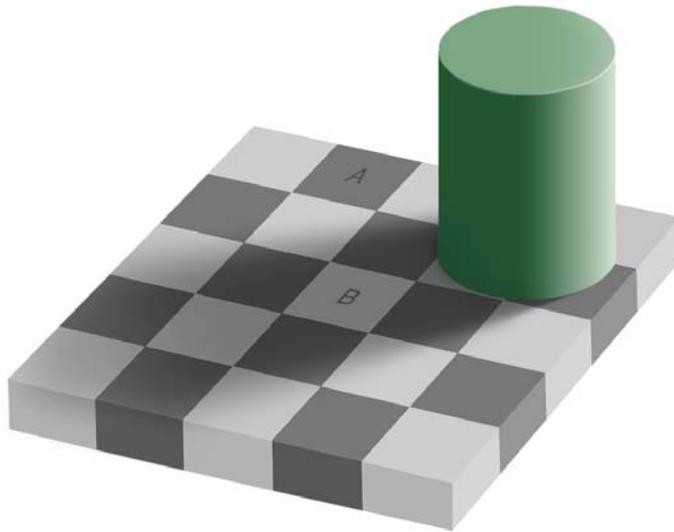
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## References

- Gescheider (2001) Psychophysics – The Fundamentals, third edition. Lawrence Erlbaum Associates.
- Macmillan NA, Creelman CD (2005) Detection Theory: A User's Guide, 2nd edition. Lawrence Erlbaum Associates.

- Psychophysics: “an **exact science** of the fundamental relations of dependency between body and mind” (Fechner, 1860, see Gulliksen in Togerson, 1958, p. v)
- A set of theories about the relationship between physical and mental phenomena and, in particular, about how our sensory systems function.

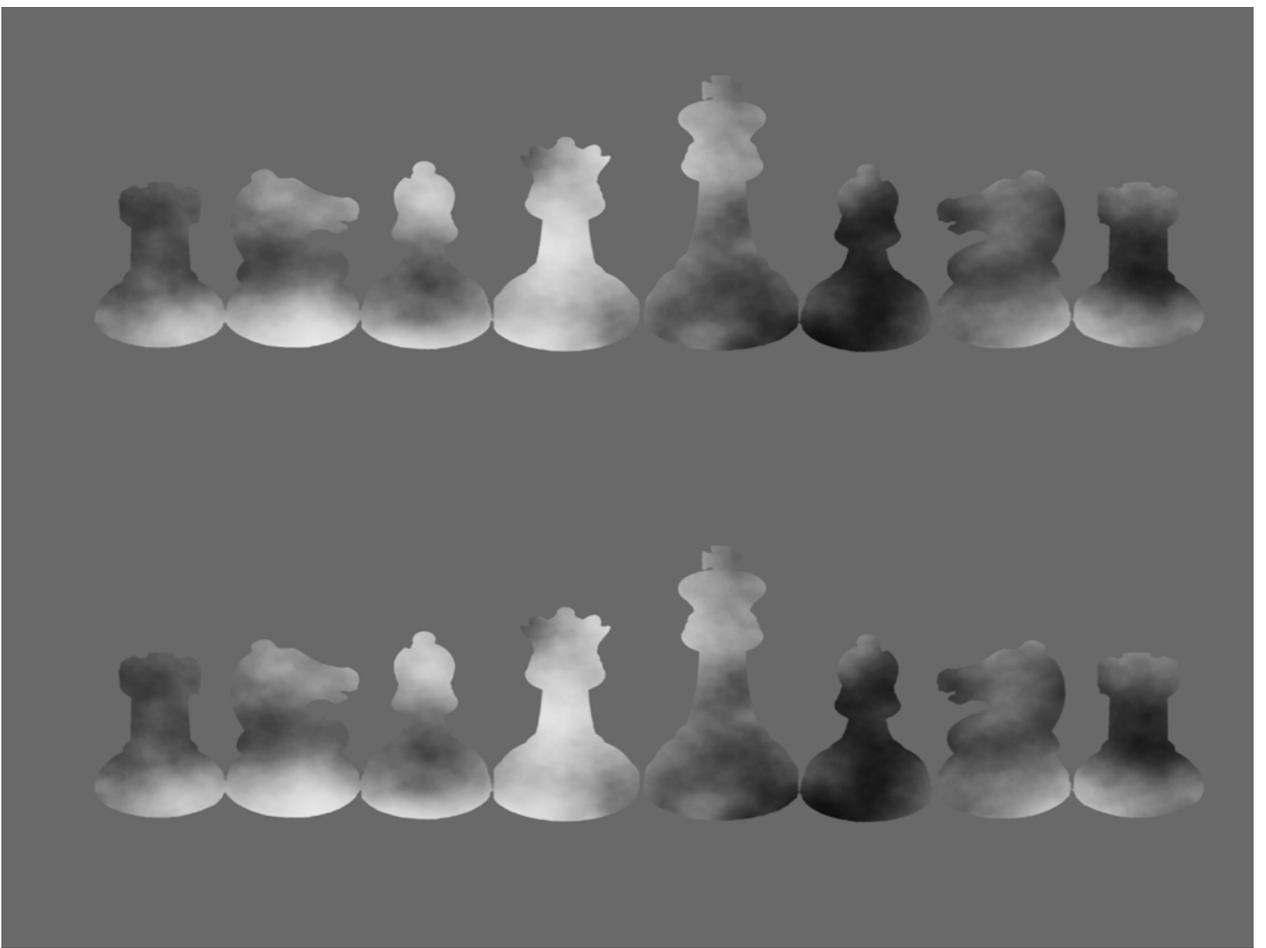
- Perception is the process by which we acquire information about the environment through our sensory systems
- For centuries thinkers have recognized the importance of understanding sensation.
- Perception is one of the main fields of application of psychophysical methods and has helped to address many issues such as:
  1. *Is perception veridical?*
  2. *How precise / accurate is perception?*
  3. *Can different sensory modalities interact?*
  4. *Can perceptual mechanisms be modified?*

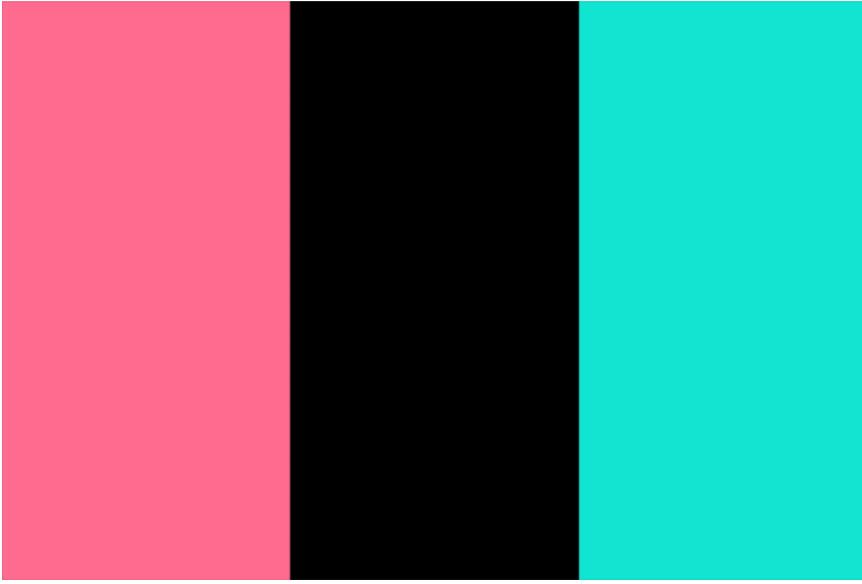


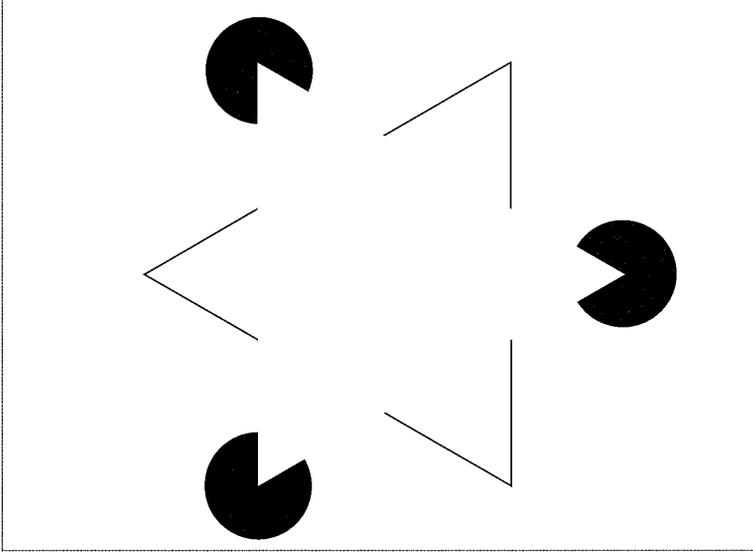
**Physical dimensions  $\neq$  perceptual dimensions**

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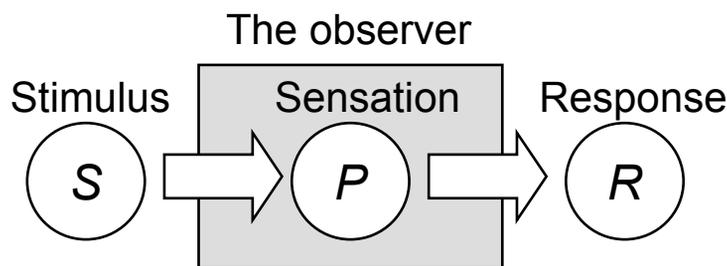




- Psychophysics define a set of methods to measure sensory thresholds:
  - **Absolute threshold:** What is the smallest stimulus intensity that can be perceived?
  - **Difference threshold:** What is the smallest difference between two stimuli that can be perceived?

and, more generally, to measure sensations or perceptions:

- **Psychophysical or psychological scaling methods:** How intense / beautiful / likable is this or that object / thing ?



- Sensation  $P$  is not directly observable and must be inferred from the stimulus-response  $S$ - $R$  relationship. This is the fundamental problem of psychophysics and psychology in general.
- To address this issue, psychophysical methods attempt
  1. to elicit specific sensations by controlling precisely the stimulus
  2. to keep the link between sensation and response as simple (transparent) as possible by asking very simple questions.



Gustav T. Fechner

- Gustave T. Fechner, a trained physicist, coined the word “psychophysics”.
- In 1860, he published “Elements of Psychophysics”.
- The first volume “Outer Psychophysics”, deals with the relationship between a stimulus and sensation. It describes methods and theory for the measurement of sensation (including the famous Weber-Fechner Law).
- The second volume “Inner Psychophysics” deals with the relationship between neural and mental events, a largely inactuated program until the recent development of imaging technique in neurosciences (=> Neurophenomenology).

- At the methodological level, the problems of psychophysics constitutes some of the most fundamental problems of psychology
- Mental phenomena are sensations, ideas or emotions. By definition, mental phenomena are cannot be observed by a third person; how could they be studies scientifically?
- According to Fechner, physical and mental measurements must be based on the same principles and his methods provided a way of doing it.

“As an exact science psychophysics, like physics, must rest on experience and the mathematic connection of those empirical facts that demand a measure of what is experienced or, when such a mesure is not available, a search for it” (Fechner, [1860], 1966, p. 38)

- Prior to Psychophysics, the approach to psychological problems consisted primarily in philosophical speculations.
- Consensus between psychologists/philosophers were elusive on many issues (e.g., controversies about existence of imageless thought, the structure of emotion or feeling, etc.)
- Arguments based on first-person accounts (introspection) could not settle controversies in an objective manner, i.e. by doing an experiment as they would in other sciences

- Widespread skepticism about the scientific viability of introspection, especially the concern that the introspective act interferes with or destroys the mental state or process that is its target.

“But as for observing in the same way *intellectual* phenomena at the time of their actual presence, that is a manifest impossibility. The thinker cannot divide himself into two, of whom one reasons whilst the other observes him reason. The organ observed and the organ observing being, in this case, identical, how could observation take place? This pretended psychological method is then radically null and void.” (Comte 1830, using the translation of James 1890/1981, 188)



Wundt in the Laboratory at Leipzig

- In 1879, Wundt founded the first experimental laboratory aimed at studying psychological phenomena.
- In fact, Wundt's research did *not* rely upon discursive descriptions of mental contents. Most of his experiments involved no more than indicating the moment when a certain sensation entered consciousness, or saying whether a musical tone seemed higher or lower than the one presented just before.
- Moreover, Wundt was a very careful experimentalist reportedly did not credit the introspective reports of people with fewer than 50,000 trials of practice in observing their conscious experience (Boring 1953). We will talk again of the importance of training when discussing response biases in psychophysical experiments.

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- Structuralist approach in Psychology (Wundt, 1897; Titchener, 1908) had the objective to analyze the adult mind in terms of the simplest definable components and then to find the way in which these components fit together in complex forms.
- The main method was introspection and its proponents assumed that all levels of processing were available to introspective observation.
- Proponents of the introspective method were aware of its problem such as the difficulty for an observer not to focus on aspects of conscious experience that are consistent with preconceived notions. However, they assumed that it is possible with a proper training to focus only the low-level elements of the conscious experience independently from higher-order inferences (e.g., possible to focus on the two-dimensional components of visual and ignore the third dimension).

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- Several schools of thought grew up in the beginning of the 20<sup>th</sup> century as a reaction to structuralism:
- **Gestalt:** Gestalt theory originated in Europe as a reaction against the associationist and structural schools' atomistic orientation (an approach which fragmented experience into distinct and unrelated elements). "The whole is more than the parts".
- **Behaviorism:** Behaviorists in United-States rejected both the concepts of "mental states" as a valid explanatory concept in Psychology and the introspection method as a valid method of investigation. The goal of behaviorism was to explain "behavior" by identifying the relationships between stimuli and responses.

- Demise of Gestalt was related to its inability to formulate its "laws" in a formal manner.
- Demise of behaviorism is due mostly to its refusal to acknowledge the importance of the internal (possibly innate) structure of the organism and the development of new theories about how information (representations) might be processed (e.g., Logic, Cybernetics, Information Theory, Theory of Computability).
- In the 60ies, Cognitive Psychology became the dominant paradigms in Psychology.
- In recent years, the development of imaging techniques (fMRI, TMS, EEG, ...) and computer science (artificial intelligence) has lead to the development of the field of Cognitive Science or Cognitive Neuroscience, which approach mental phenomena and its neuronal correlates from a multiple disciplines.

- Psychophysics marked the transition of psychology from a philosophical (introspective method) to a scientific discipline (experimental method).
- Psychophysical methods continue to be extremely useful to study perception.
- Psychophysical methods have been extended to many different mental phenomena besides measuring sensations.
- In particular, in the 50-60ies, Signal Detection Theory provided a new theoretical framework in which to interpret the results of psychophysical experiments

- **Sensory psychophysics**

Specification of sensory capacities

=> Information useful for engineers (for example, it has been used in the production of television sets, etc.)

- **Analytical psychophysics**

Testing of hypotheses about underlying biological mechanisms that determine sensory capacity

- **Non-Sensory psychophysics**

- **Principle of nomination:** identical neural events give rise to identical psychological events.
- When stimuli A and B produce the same neural response, they will yield the same sensory experience. The reflexive form of the principle states that when A and B produce the same sensory experience, they produce the same neural response.
- This principle with the psychophysical procedures constitutes a powerful tool for discovering the neural events that determine sensory experience. It is possible to bridge the gap between psychophysical and biological facts.
- Since sensations are based on identical physiological reactions, a physiological hypothesis can be tested by a psychological procedure.

## Psychophysical linking hypothesis

- *Class A:* two stimuli of the same type are adjusted to produce identical sensations (i.e. matching experiment) i.e. adjust the intensity of two lights in order to have the same final percept.
- *Class B:* any observation that cannot be expressed as the identity or non-identity of two sensations (with two stimuli different for some dimensions) (i.e. say when a green and a blue square appear of equal brightness)-> here you can't apply the principle of nomination

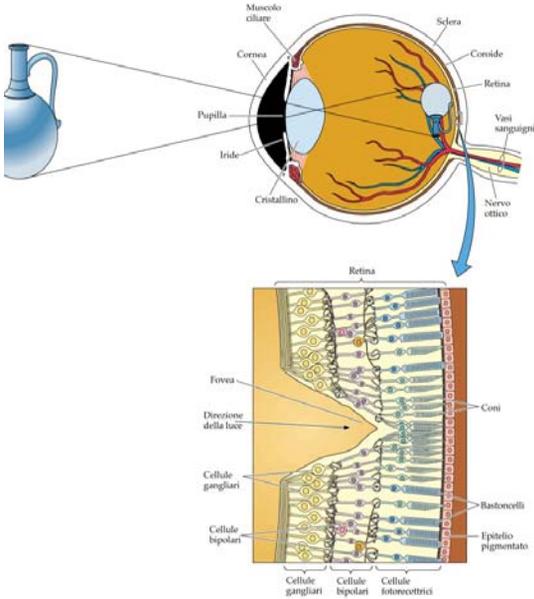
### Class A Observation

Stimulus A → Neural Response X → Sensation Y  
 Stimulus B → Neural Response X → Sensation Y

### Class B Observation

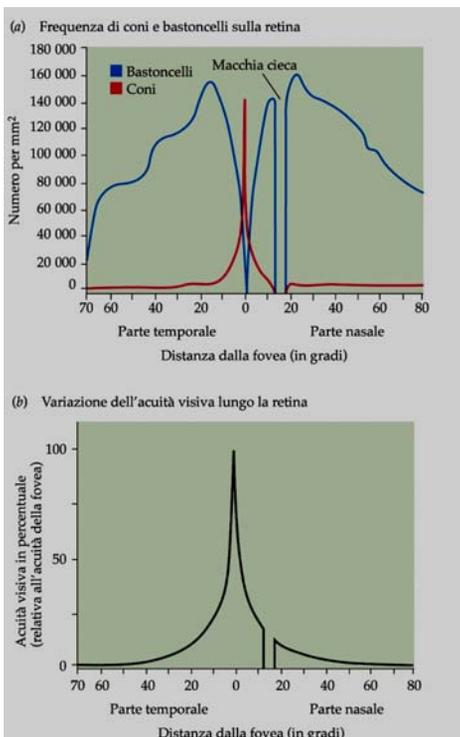
Stimulus A → Neural Response X → Sensation Y  
 Stimulus P → Neural Response Q → Sensation R

- Class A assumes that identical sensations are based on identical physiological events and there are many evidences that sustain this assumption by comparing psychophysical and neural threshold functions.

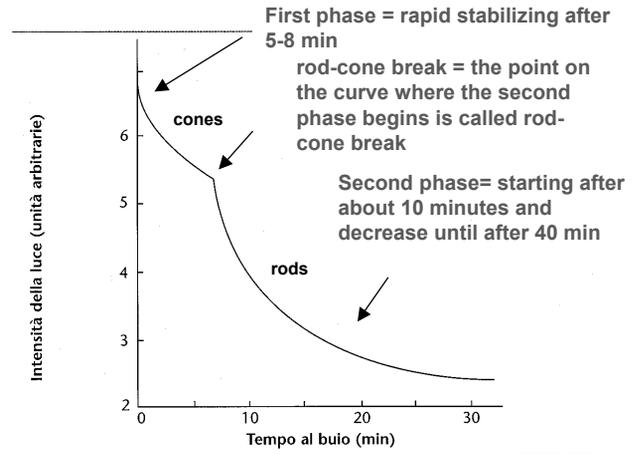
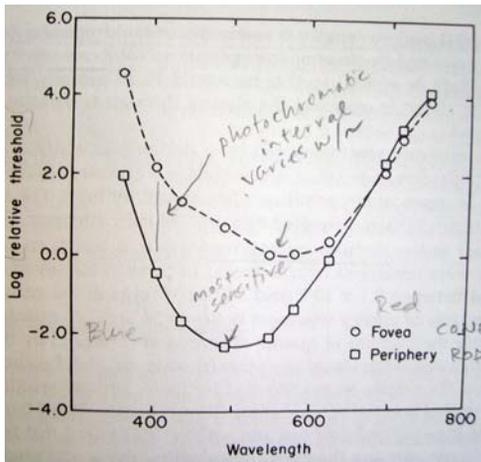


Rods	Cones
Achromatic	Tri-cromatic ( <b>color vision</b> )
High sensitivity ( <b>dark vision</b> )	Low sensitivity
High convergence	Low convergence
Low acuity	<b>High acuity</b>
Peripheral (15°)	<b>Central (Fovea)</b>
100 millions	6 millions
Slow answer	Fast answer
Not selective for light direction	Selective for light direction

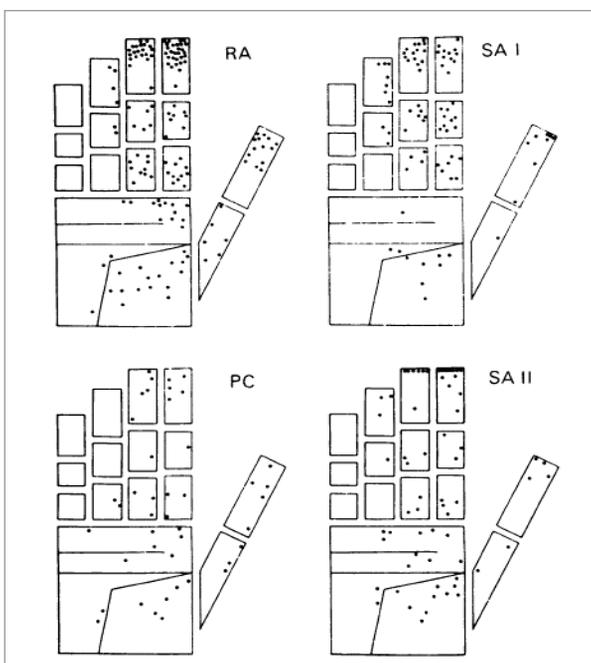
- Numerous psychophysical observations have been linked to physiological properties of the visual system and the presence of two kinds of photo-receptors.



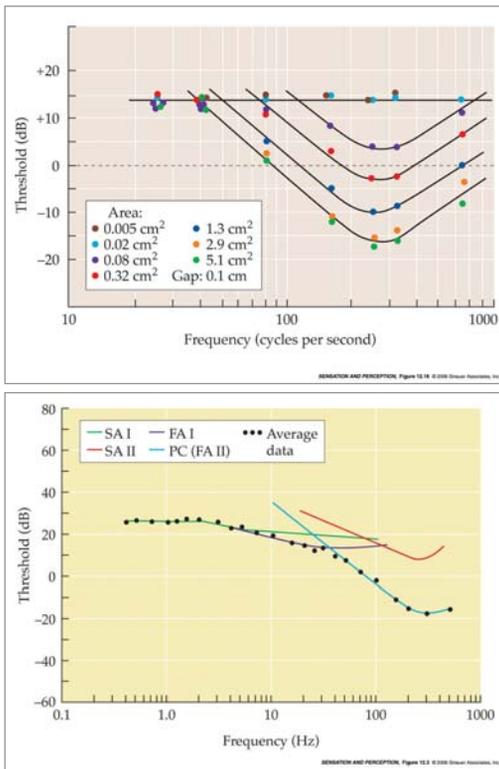
- Example of relationship between psychophysical (visual acuity) and physiological measure (density of cones).



- Absolute threshold change also for different stimulus eccentricity (fovea-periphery)
  - The periphery of the retina is most sensitive to light with a wavelength of approximately 500 nm and the fovea when the stimulus wavelength is about 560 nm.
  - Operation of rods needs much less energy than operation of cones
- Biphasic curve dark adaptation



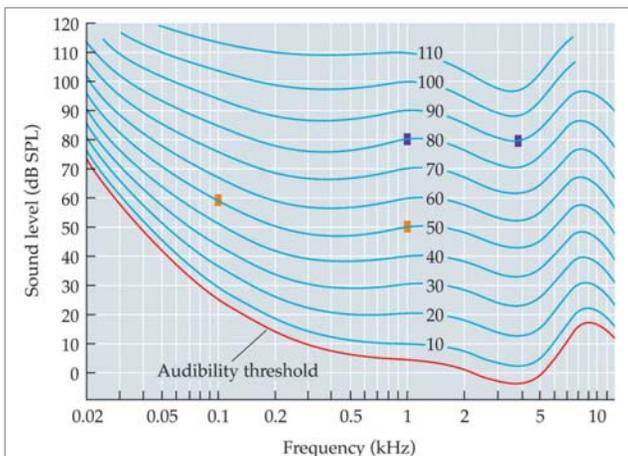
- One way of measuring tactile sensitivity is to determine the smallest amplitude of vibration of the skin that can be detected by an observer.
- Vibrotactile thresholds depend on stimulus factors as the locus of stimulation



- Tactile thresholds for different stimulation areas. When the stimulus was bigger than 0.02 cm<sup>2</sup>, the function has a U shape with the minimum around 250 Hz. Absolute tactile threshold depends on size of contact, frequency of vibration, position of skin stimulated.

- By measuring vibrotactile thresholds, Verrillo found that the skin contains at least two receptor systems for detection of mechanical disturbances.

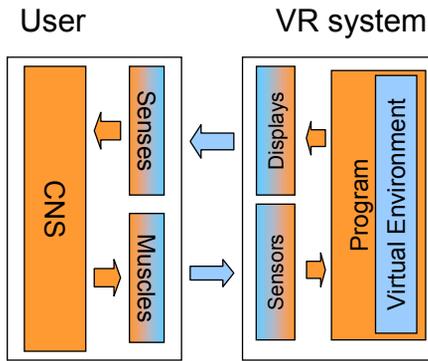
- One way to measure auditory sensitivity to determine the lowest intensity at which a sound may be heard and it is frequency dependent



- Young people can hear sound when its frequency of vibration is between 20 and 20,000 Hz but the auditory system is most sensitive to vibration between 2000 and 4000 Hz.

- It is generally agreed that sensations can differ on at least four basic dimensions:
  1. **Intensity**
  2. **Quality**
    - between modality (hearing, seeing)
    - within modality (e.g., loudness and pitch in hearing, color and luminance in vision)
  3. **Extension**
    - size, position, separation
  4. **Duration**

- Stimuli are intrinsically **multidimensional**.
  - For example, a mechanical **vibration** is defined by an **amplitude** and **frequency**.
  - This vibration must be transmitted by some physical device which is made of some material with specific properties (**temperature**, **color**, **friction**, etc.)
  - The contact happens over some **area** of a specific **body part** where the vibrating object is pushed with some **force** during some **time** interval.
- Only one or two dimensions are typically manipulated in a psychophysical experiment but all these factors can influence sensations



Haptic Workstation, EPFL, Switzerland

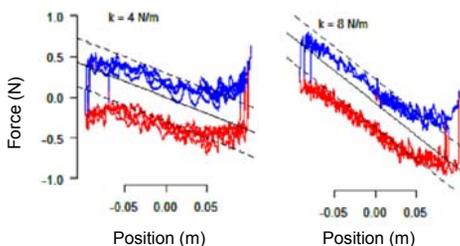
- Psychophysical experiments provide useful information for designing virtual reality systems. However, sensory thresholds might have been measured in conditions that differ too much from the VR setup to be useful.
- Psychophysical experiments realized with the VR setup can be useful to test specific aspects of the system (e.g. if an asynchrony between haptic and visual feedback is perceptible, if the subjects perceive well the distance or the weight of virtual objects, etc.)
- In principle, VR systems offer a flexible and powerful way to realize psychophysical experiments but it is important to be aware that the stimulus actually produced by a VR system can differ significantly from the desired one (**transparency issue**)
- To use VR system, it is important to measure the actual behavior of the system.

## Haptic device transparency

The actual behaviour of an haptic interface does not necessarily correspond to the desired one defined in the virtual environment.

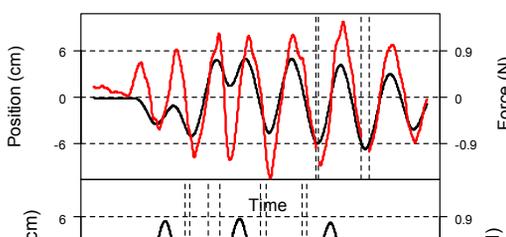


- Setup. Omega device (Force Dimension)
  - apparent mass between 250 and 450 g
  - static friction of 0.25 N.
  - inadequate specifications for psychophysical experiments



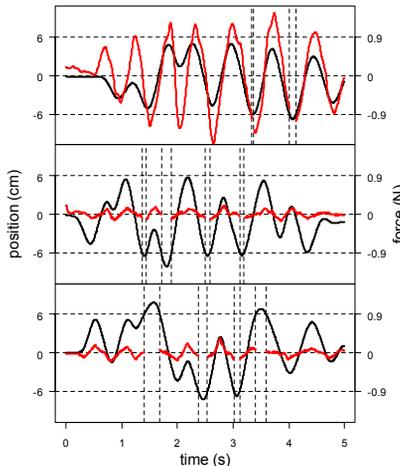
- Simulation of a weak spring

Interaction force during slow to-and-fro movements (color codes the movement direction)



- Simulation of "free movement"

Force during "free motion" can reach 1 N (100 g)!



- In our experiments, the problem could be in part resolved by mounting a **force sensor** between the device and the user to measure the interaction force
- The measured force ( $f_s$ ) was used to implement **force feedback control law**

$$f_m = f_d + K(f_s - f_d) + f_c(\dot{x})$$

- As a result, RMS error between actual and desired force was  $< 0.015$  N (1.5 g)
- We analyzed the force error during “free movements” ( $f_d=0$ )

$$f_s - f_d = \beta_0 + \beta_x x + \beta_c |\dot{x}| + \beta_v \dot{x} + \beta_a \ddot{x} + \varepsilon$$

- Apparent inertia ( $\beta_a$ ) was reduced to about 30 gr and it was the largest residual contribution.

- Psychophysical methods can also be applied in different contexts such as linguistics, memory, learning, social behavior, and esthetics. In these contexts, an observer might be asked to judge things like the likability of a person or of an image, to indicate whether a word was included in a previously presented list, etc.
- **Psychometrics:** “any branch of psychology concerned with psychological measurements” (G. Miller’s laboratory, <http://wordnet.princeton.edu>).

- **Stimulus-centered approach** or **Judgment approach**. Variation in the reactions of the subjects to the stimuli is attributed to differences in the stimuli.
  - ➡ – Psychophysical approach
- **Subject-centered approach**. Variations in the reactions of subjects to the stimuli is attributed to individual differences in the subjects.
  - ➡ – Psychometric approach
- **Response approach**. Variability in the reactions to stimuli is ascribed to both variations in the subjects and in the stimuli.
  - ➡ – Modern psychometrics and psychophysics (e.g., Rasch models, mixed models)

Ref: Torgerson, p. 45-46

## Quantitative psychology

