Introduction to Perception Research
Speaker: Lothar Spillmann **September 22, 2009**

Dear Faculty and Students:

I want you to see vision research and visual psychophysics in perspective. Vision is the most important sense for us, 40% of the cerebral cortex is dedicated to vision, but it is only one sense among others. You will understand this immediately, when you ask yourselves: What are the most important things in life? Money? Cars? A Rolex watch? No! The most important functions are: navigation, foraging, mating. If you cannot go somewhere on your own, if you cannot find food, if you cannot find a mate, you are in trouble. You (and your genes) will not survive.

Senses

To be able to survive you need your senses. Senses will tell you much (but not all) about your environment. Let us begin with the so-called "far" senses that rely on distant stimuli. You need not come close to them in order to notice and evaluate an object under consideration.

For example, the eyes tell you where to go, what kind of food to look for, and how to find a mate. But the visual signal is often assisted by your ears. You can hear danger (predators, enemies), before you see it. Both of these senses are supported by your nose. You can smell food, even if it is invisible. You can smell a fire without seeing or hearing it. These three senses complement each other. If one fails, the other one may take over. A blind person makes better use of his hearing.

Often, these senses work synergistically, but they may also work antagonistically. A partner may look attractive, but if his voice does not appeal to you, his looks don't help him very much. And if his scent is not agreeable with you (bad breath, smelly feet), he has little chance of becoming your mate. The same is true for food that may look enticing, but smells terrible (stinky), then – as a rule - you won't eat it. On the other hand, you may not care about looks that much, but value the sound of a nice voice (profundo basso) or the fragrance of the skin (natural body odors), and happily accept a compromise, because auditory and olfactory signals are more important to you than visual impressions. This shows that there is a hierarchy of senses; the non-visual ones are more robust, when it comes to choosing.

In addition to the "far" senses", a number of "near" senses shape our experience. They come into play, when the stimulus is close to us. For example, in order to taste food, you use your tongue. In order to find out about firmness or softness of an object, you use touch. To examine whether a given surface is smooth or rough, you slide your hand over it and the sense of vibration will tell you. Similarly, in order to feel the heat or cold of a surface, you must be in direct contact or very near. While these experiences are pleasant, unpleasant or neutral, a most important biological function of the skin is the mediation of pain. Pain almost always is unpleasant, it signals immediate danger, so that you want to stay away from it. A painful experience (from a hot plate or an electric fence), results in a one-trial learning. Once you have been burnt, you never approach that stimulus again. Can you imagine what it is like to be born without the sense of pain? See: James J. Cox et al.: An SCN9A channelopathy causes congenital inability to experience pain. Nature 444, p. 894

These and other senses are phylogenetically older and more robust than the more advanced "higher" senses. They help animals that rely on tactile, thermal, chemical and electrical information to navigate, forage and find a mate. Such animals have survived on earth much longer than mankind. See how little it takes to cope with the environment? You don't need eyes, ears or noses. Under certain conditions, the lowly creatures with their vastly reduced sensory inventory can do as well and even better than us. If this does not make you humble. The following table summarizes of what I just said.

Sense Organ	Modality	Sense	Receptor(s)
"Far" senses			
Eyes	vision	visual	cones, rods
Ears	hearing	auditory	hair cells in the cochlea
Nose	smell	olfactory	chemoreceptors
"Near" senses			
Tongue	taste	gustatory	taste buds
Skin	touch	cutaneous	mechanoreceptors (Meissner)
	stretch & vibration		corpuscles of Ruffini
	pressure		corpuscles of Pacini
	temperature		thermoreceptors
		chemical	
		electrical	side organs
	pain	nociceptive	nociceptors
Muscles	weight	proprioceptive	muscle spindles
Labyrinth	balance	vestibular	hair cells, semicircular canals

Although each of these senses may be treated in isolation (for example: vision), the various senses often complement each other, by providing information on different stimulus attributes. Being predominantly visual animals, we do not even notice that the various kinds of information come from different sensory organs. For example, an apple may look green, round, large, fruity, sweet or sour, juicy, and heavy. But the eyes do not mediate the smell, taste and weight of the apple. This information relies on multimodal input (and memory) in a hypothetical *Sensorium commune*. Indeed, neurophysiologists, especially for visual and vestibular inputs, have found multimodal neurons, that respond to stimuli of more than one sensory modality. Cross-modal interaction is quickly becoming a "hot" research topic. Take, for example, the perceived loss of taste when you damage your olfactory bulb (smell) in an accident.

This brings us to one more, very important sense, the vestibular sense. Whenever we stand or walk, we need to know about the position of our body relative to gravity. The labyrinth in the inner ear with its semicircular canals and hair cells will tell us. It provides balance without which we would stumble or fall, for example on a shaky train. People suffering from vestibular malfunction (Meniere's disease) experience vertigo and other problems. The same holds when you drink too much alcohol. A tight rope artist needs very exquisite balance to compensate for any sway.

I would not want to finish telling you about senses without mentioning that in nature most sensory experiences result in motor action by reflexes (fast and safe) or cognitive decisions (variable, but slow). This is called the sensori-motor *Gestaltkreis* in German. Our senses did not evolve to admire a painting in a museum (although this may be highly enjoyable), but to throw a spear and impale a fish (or other animal) when we see it. We don't need aesthetics for survival. Again, sensori-motor research has become a vibrant field of research. It requires that you know both, the receptor and the effector organs.

<u>Visual perception</u>

Now we have arrived at a better understanding of the larger context of vision and can dedicate ourselves to the description of visual attributes. What do we see when we look around? Most people see fairly little; they cannot even describe an object properly. On the other hand, artists see more than the average observer because they are trained to use their eyes. The table below lists the major attributes of visual objects: Brightness, color, size, orientation, depth and motion. (For the time being, we will ignore the so-called material properties such as evenness, smoothness, roughness, shininess, gloss, matte appearance, etc.)

All of the above attributes are mediated by the visual sense hence they are subjective. They reflect the visual properties of an object, but they are not the object itself (naïve realism). And they are relative. When you place an object in a different surround, its brightness or color may change (simultaneous contrast). Similarly, when you change the illumination from bright to dark, the color blue may change its relative brightness and look brighter than green (Purkinje shift). Thus, the perceived properties of an object or its appearance are not absolute. They depend on many factors, including the adaptation of the eye.

<u>Perceptual and stimulus attributes</u>

The goal of psychophysics is to correlate these subjective percepts to their objective or physical counterparts. These are the attributes of the stimulus that can be measured with appropriate instruments or devices. In order these are: luminance (for brightness), wavelength (for color), visual angle (for perceived size), angular inclination (for orientation), lateral disparity (for the small difference between the two retinal images resulting in stereo depth) and speed or velocity (for perceived motion). Each has its own unit. These attributes are not the object either, but properties of the object that give rise to (or elicit) subjective percepts when processed through the eyes and visual system. A stimulus is not red, but looks red; it has no color (only a wavelength). Make sure that you keep the subjective and objective terms apart. Few people do it when they talk about vision (example: red, green or blue photoreceptors).

Properties of percept	Stimulus attributes	Unit
(Psycho-	Physics)	
Brightness	Luminance	cd/m2
Color	Wavelength	nm
Size	Visual angle	deg/arcmin
Orientation	Inclination	deg
Shape	Configuration	height x width
Depth	Lateral disparity	arcmin
Motion	Speed	m/s

Psychophysics

The study of the relationship between percept and stimulus is called *psychophysics* (Fechner, 1870), more precisely outer psychophysics, because it connects the beginning of the stimulus cascade (light rays impinging on the retina) with the end (conscious sensations or perceptions in the brain). The intervening stages that convert light to photochemical processes, electrical currents, spikes or action potentials were not known at the time and were considered a Black Box. Nowadays, we know more about the entire signal transduction chain and therefore can also study inner psychophysics. Thus, we can correlate neurophysiological events in the visual pathway with visual phenomena. (Check select chapters of Spillmann & Werner, 1990: Visual Perception – The Neurophysiological Foundations)

Subjective and objective world

At this point I should say that what we see is not representative of the world, only of parts of it. All of our visual experiences depend on the properties of the senses and the nervous system. Those properties define and limit how much of the stimulus information is encoded, decoded and ultimately becomes conscious. Bees can see ultraviolet, which we cannot; goldfish can see infrared, which we cannot; rabbits can see what is behind them without turning their heads, which we cannot. There are countless examples in the animal kingdom showing us that our visual functions are less than those of some animals, although they serve us well under natural conditions. They suffice to get around obstacles (navigate), find food (forage) and choose partners for reproduction (mating). Yet, what we take for granted as our world probably is only a small window of it.

The physicist with his highly developed instruments can demonstrate electromagnetic radiation that we can never see or hear (whales and bats utilize those signals in sonar and echolocation). We use phototropic sunglasses that turn dark when illuminated by UV-light, which would otherwise damage our retinae. We use the cell-phone, but need a technical transducer to make the voices audible, as our ears cannot do it. These examples demonstrate that there is more out there in the world than our senses tell us. This has been known for long to philosophers who thought about the world, for example, Immanuel Kant, who stated that we could not possibly recognize the *thing per se*.

Relating the percept to the stimulus

The task of psychophysics is to relate stimulus and percept to one another. The first step typically is to collect, describe and name phenomena. An example in the realm of color is the list: red, green, purple, yellow, blue (and many other colors that you see).

This is called a *nominal scale*, because at this stage there are only names. In order to properly describe something, you must stay away from any biases and expectations. This is important when a biologist discovers a new plant or animal or when a psychologist discovers a new phenomenon. The next step is to put things in order, such as the sequence: Red, yellow-red, yellow, yellow-green, green, blue-green, blue, purple. Now the colors have been arranged according to their similarity (or hue). This is called an *ordinal scale* and it reflects the Linnean system in biology, where plants are arranged according to their similarity in structure and presumed relation during evolution. This is called taxonomy. But there is still something missing to qualify for truly scientific status. This is achieved by assigning colors to the wavelengths of the stimuli by which they are elicited: red (630 nm), yellow (575 nm), green (505 nm), blue (470 nm). This is called an *interval scale*, because it can be mapped on a linear vector by the distance between the individual hues within the visible spectrum (450-700 nm). You can apply the same strategy to other visual properties and associated stimulus parameters as well, such as size.

Thresholds

How do we quantify perceptual attributes along a given continuum? This is typically done by comparing stimuli in terms of multiples of their threshold. There are two kinds of threshold. A threshold can be defined by the minimum amount of information required to detect a stimulus, say a star in the night sky. This is called the *absolute threshold*. Or it can be defined by the minimum amount of information required to discriminate a signal against noise (such as a dark or bright spot on a gray surface). In this case we are dealing with a decrement or increment relative to a background. This is called the *differential threshold*.

There are different procedures for establishing a threshold. The simplest and fastest is the *method of adjustment*. Here subjects turn a knob back and forth until they just see or do not see the brightness associated with a given light stimulus. This method is highly subjective, but serves to obtain an estimate of the threshold quickly. A better procedure is the *method of limits*. Here, the stimulus variable (intensity) is gradually increased or decreased by the experimenter until the subjects responds by saying "seen" or "not seen". This is called ascending and descending threshold measurement and typically produces an intermediate range where the two thresholds overlap. The "true" threshold is in the middle (geometric mean). This method is frequently used, but not generally accepted by reviewers who prefer the third technique: the *method of constant stimuli*. Here, the stimulus continuum is subdivided into a number of equal steps (say 10) roughly around the presumed threshold value and presented 10 times each in random order. Now the subject has no advance information and therefore, the procedure is considered objective. When the results are plotted for the response criterion "seen" as a function of the independent variable, one obtains what is called a psychometric function. The threshold is derived from the 50% (or sometimes 75%) response frequency.

In order to reduce the number of stimulus presentations and shorten the time needed, one nowadays uses an *adaptive staircase procedure* where redundant stimuli that produce the same response over and over again (usually at the beginning and end of the stimulus continuum) are eliminated.

Threshold measurements have led to two important quantitative relationships: First, *Weber's Law* which states that the ratio between the increment (decrement) size and the background intensity I is constant: $\Delta I / I = c$. Thus, if you need 2 incremental steps to discern a light spot on a background of 10 units, you need 20 such steps on a background of 100 units and 200 steps on an even brighter background of 1000 units. Another well-known relationship describes brightness as proportional to a constant times the log of the intensity: $B = a \times \log I$. This is called *Fechner's Law*. Stevens modified this law by applying an exponent: B = a x I exponent. This is called the *Power Law* where the exponent varies dependent on the task.

<u>Other techniques</u>

What do you do when threshold measurements are impractical, such as with quantifying qualitative judgments? Here one uses *magnitude estimation* or rating. The experimenter specifies an upper anchor and a lower anchor for reference, say 100 for the strongest and 1 for the weakest percept. The task of the subject is to assign to each stimulus an estimated value between these two references. This procedure yields a straight line of given slope and has considerable variability. However, a regression line can easily be fitted. Those of you who are interested in this topic may want to read the very clear and elegantly written chapter by Ehrenstein & Ehrenstein (included under supplemental material). The article also discusses *signal detection* (d prime), which I will not go into. (A speaker at the 2009 Conference of the Psychological Society of Taiwan in Taipei gave a very clear introduction to this topic.)