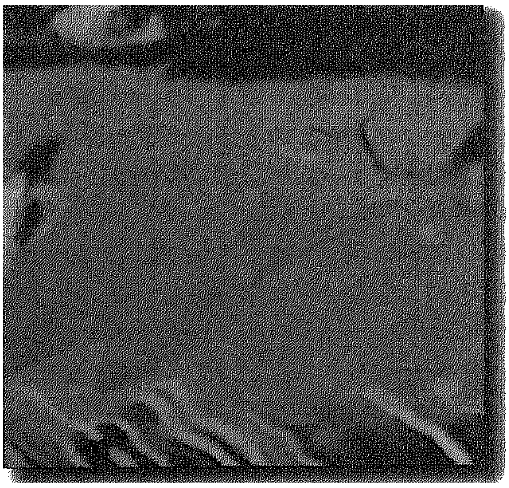

Chapter 4

Sensation and perception

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Introduction

One of the oldest and most difficult questions in science is how we are able to develop an awareness of the world around us from our senses. Topics covered under the title of, 'Sensation and perception' address this very question. *Sensation* encompasses the processes by which our sense organs (e.g. eyes, ears etc.) receive information from our environment, whereas *perception* refers to the processes through which the brain selects, integrates, organises and interprets those sensations. The sorts of questions dealt with by psychologists interested in this area include: 'how does visual information get processed by the brain?', 'how is it that I am able to recognise one face out of many many thousands?', and 'what causes visual illusions to occur?: Within New Zealand there are a number of researchers studying visual perception specifically and their research interests range from understanding the biological

Most introductory psychology textbooks have a chapter on sensation and perception and they usually include detailed diagrams of the eye or ear which show the receptors that pick up environmental stimuli such as light or sound. However this is just the beginning of a fairly miraculous process. We are still left with the difficult question of how the brain interprets the electrical signals that are generated at the receptors. These signals are just a series of electrical impulses, yet somehow they convey detailed information about what is going on in the world around us.

The 'visual system': An example of the complex process of turning sensations into perceptions

The visual system is useful for illustrating the problem of extracting information about the environment. We live in a three-dimensional world yet the eye's optics form a two-dimensional image of this world on the retina (the surface at the back of the eye which contains the light sensitive receptors). When stimulated by light, the retina's rods and cones trigger electrical signals through a process called 'transduction'. These signals travel along the optic nerve to the visual processing areas of the brain. The optic nerve contains many neurons each carrying signals from the rods and cones located in different parts of the retina. Individually, the electrical signals travelling along each nerve fibre in the optic nerve look quite simple. They consist of voltage spikes ('action potentials') that travel along the axon of the neuron. If the rods and cones feeding into the neuron are receiving a lot of stimulation, there are many such spikes, but if the receptors are not being stimulated appropriately, then there are few spikes. However, because the optic nerve is made up of millions of nerve fibres (each one firing at a different rate) the total activity generated in response to light falling on the retina is now incredibly complex. Figure 4.1 illustrates this process.

As well as being part of a two-dimensional surface, nothing actually moves over an individual rod or cone. Yet we perceive moving objects. As an object's image moves on the retina, all that happens at an individual rod or cone is that the light level fluctuates. Each change generates a new barrage of neural activity in the neurons leaving the eye. Now imagine that you are located in the brain and that you are monitoring this electrical activity. Using just the firing rate of the neurons, could you recreate the movement? Could you recreate the three-dimensional scene? These are some of the problems faced by your brain and perceptual system.

To appreciate the difficulty of this task, consider the electrical wiring inside your TV set. If you were able to record the electrical activity travelling along some of these wires, could you determine what is visible on the screen? In fact the perceptual problem is even harder than this. We not only need to know what is on the TV screen, but also about the three-dimensional layout and movement of the objects being presented on the screen. Your brain solves this problem every time you look at something in the world. Based on the activity in the neurons, it generates a percept that appears to you as a three-dimensional world with movement, and with colour and shape too. No depths, movements, colours, or shapes flow along the optic nerve, yet these are what we perceive.

The transformation from light in the world to electrical activity flowing through neurons is a type of code. A simple code for disguising written text is to use certain numbers to stand for certain letters of the alphabet. For example '4 36 218 28' is the code for the word 'brain' using two times the number of the letter as a code for the letter. Most people could break this code in minutes. Decoding the neural activity of the brain is a lot, lot harder – it is an ongoing

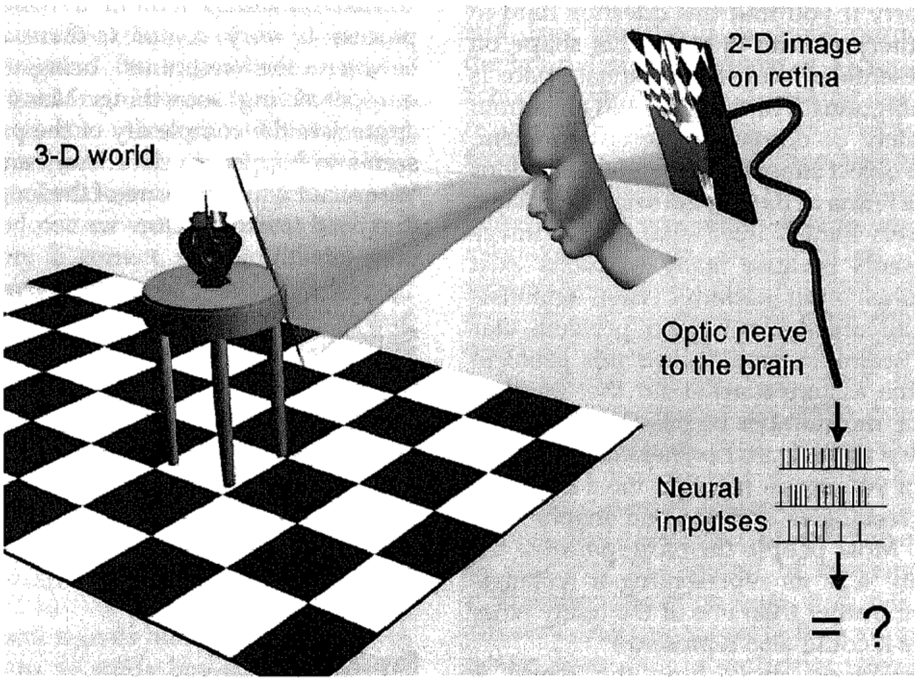

Figure 4.1 Representation of how light in the environment gets converted into neura impulses in the brain

exercise with many philosophers, psychologists, physiologists and neuroscientists involved.

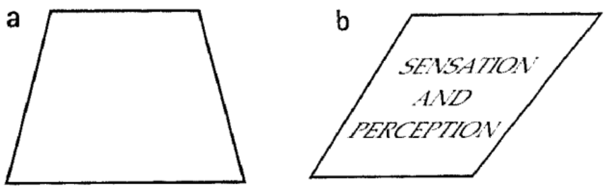

Figure 4.2 Examples of outline figures projected onto the retina of the eye. (a) Ambiguous shape that could represent many different objects in the world (e.g. a trapezoid parallel to the page or a rectangle slanted away from you). (b) Specially designed shape that looks skewed and distorted when viewed straight on but which looks correct when viewed from a special vantage point with one eye only (view from the bottom left part of the page).

For the visual system, the neural code is even harder to break because information is lost in the transformation from the three-dimensional world to the two-dimensional retina. When you look at the outline shape in Figure 4.2a what do you see it as representing? Is it a trapezoid shape parallel to the page or is it a rectangle that is slanted away from you? Don't worry if you find this question hard to answer. The interpretation of what this shape on the page represents in three-dimensional space is completely ambiguous. This image could arise from an infinite variety of objects in the environment. Many different object shapes, sizes and orientations project onto the retina as having the same 2-D shape. This makes it very hard to infer what the 2-D image actually represents because many solutions exist for each stimulus input pattern. Vision scientists refer to this as an 'under-constrained' problem. Our visual system seems to have solved this problem by making some assumptions about the world in order to reduce the number of possible solutions. For example, we assume that corners in the world are made up of 90° angles (i.e. that most things in the world are rectangles and not odd shapes such as pentagons). Most people therefore perceive the shape in Figure 4.2a as representing a rectangle slanted in depth rather than one of the many other possible shapes it could also represent.

These assumptions about how the world is constructed work well 99% of the time because they are based on physical aspects of the world that apply in most situations. But occasionally these assumptions can be wrong; when this happens we misperceive what is actually present in the environment and we experience a perceptual illusion.

Some advertisers have cleverly exploited some of our assumptions about the world to trick us into seeing something that is not there. During televised rugby games, you may have noticed advertising logos painted on the rugby field that nevertheless appear to be standing up vertically. Obviously there is no actual sign standing on the field otherwise the players would have even more large objects to avoid. If you see these logos from the helicopter camera high above the field, they look really strange and stretched out, with no 90° corners (see Figure 4.2b). Yet from a particular pre-placed camera, the logo creates a compelling illusion! The strange shape painted on the ground has been especially designed to project onto your retina an image that looks like a rectangle that is standing up off the ground whenever your brain assumes that things in the world have 90° corners. You can try to replicate this effect by viewing Figure 4.2b with only one eye open from a low angle (near the bottom left of the page).

These illusions remind us that the perceptual process is very complex; there are many steps between the receptors being stimulated and our perceiving something. Many people do not appreciate the complexity of the process because it seems to happen so effortlessly and automatically. We are not usually aware of the long chain of events that need to occur before we see, hear, feel, smell or taste something.

Sensation and perception research in New Zealand

Given the complexity of the senses and the brain, how can we study sensation and perception? In order to answer this question we will look at examples of research being carried out in New Zealand. These illustrate four main approaches to the study of sensation and perception in humans and animals:

Psychophysics

Psychophysics involves a set of techniques for precisely measuring the relationships between physical things in the world (the stimulus) and perception. The basic idea is that we can learn about what is happening in the brain by carefully measuring how an observer responds to a particular level of the stimulus. This approach has a long history (dating back to the 1860s) and it is still used extensively in many laboratories around the world. For example, Robert O'Shea from the Department of Psychology at the University of Otago has used psychophysical methods to study binocular vision.

We have two eyes separated by a small horizontal distance so whenever we look at something, we actually get two slightly different views of the world (Figure 4.1 shows what is happening in only one eye). Our brains have evolved to make use of these small differences (referred to as retinal disparity) and our visual systems convert the two images from each eye into one binocular three-dimensional percept which tells us how far away things are from us. However the fact that each eye is seeing two slightly different things brings up an interesting question: Why don't we see two of everything? This is one of the research questions that O'Shea has examined.

There are at least two possible answers to this question: some people say that although we can use the information from the two eyes to appreciate depth, we see the retinal image of only one eye at a time (suppression theory), whereas others say that we see combined images from both eyes simultaneously (fusion theory). O'Shea used psychophysical methods and recorded how long it took the experimental observers to detect spots presented to one of their eyes (O'Shea, 1987). If suppression theory is correct, sometimes the spot would be delivered to the eye that is not seeing, delaying detection until perception shifted to that eye. If fusion theory is correct, the spot would always be presented to an eye that was seeing, allowing fast detection. This is what O'Shea found, supporting fusion theory. He obtained important insights into what is happening in the binocular part of our visual systems and how the brain deals with the two slightly different images formed on the back of our left and right eyes. Note that he did not have to examine the rod and cone receptors in the retinas or follow the neural signals along the optic nerves of each eye in order to study binocular vision. He could infer a lot about binocular vision just from his psychophysical data. A lot has been learnt (and continues to be learnt) by carefully measuring people's response to particular stimuli and by using psychophysical methods.

Neurophysiology

Another method for studying perception is to try to learn as much as possible about our perceptual systems' receptors and neurons because they clearly shape our perceptions. Such study is undertaken by neuroscientists. One area of neuroscience is neurophysiology, a branch of biology concerned with the functioning of nervous tissue and of the nervous system. In terms of the TV analogy mentioned above, it is the equivalent to following all of the wires in the TV set to see what information they carry and what they do. The brain is much more complex than a TV of course and one of the big challenges in science today is to untangle the huge numbers of neural pathways in the brain and to understand the functioning of its countless components. Despite this complexity, a lot of progress has been made. New tools (e.g. functional magnetic resonance imaging or fMRI) for visualising what is going on in the brain ire helping to make new exciting discoveries each lay. Another useful approach is to use chemicals and drug treatments to probe particular parts of he brain. Jan Lauwereyns of Victoria University's school of Psychology is making use of combined neurophysiological and psychopharmacological techniques to study perception and action.

The discussion of the problem of visual perception above dealt with only one aspect of our interaction with the environment. Once we have seen something, we usually carry out some action (e.g. we reach out and pick up the object or we move towards it). Lauwereyns has been examining how reward mechanisms affect the control of action (Lauwereyns et al., 2002). Some of his own neurophysiological and psychopharmacological research as well as work by others has shown that he brain chemical dopamine plays a major role in earning and processing information about rewards. 3y studying the control of movement in simple spatial-discrimination tasks with rats and by using different drug treatments (which are known to affect certain brain sites in particular ways), Lauwereyns s hoping to gain support for a theory he has developed regarding the role of rewards in the control of action. One important aspect of this type of research is that dopamine is the target of current treatments for conditions such as schizophrenia and Parkinson's disease. The research could provide important insights into pharmacological treatment of these neurological disorders, particularly with respect to problems of motivation and voluntary behaviour.

Computational modelling

Yet another method for studying a complex mechanism such as our perceptual system is to try to build a model of the processes involved. If we could design a system in computer software that responded the same way that the brain does to particular stimuli, then we know that that piece of software must have something in common with the mechanisms being used by the brain. The algorithms and rules used in the software can provide important insights into the neural processes going on in the brain. Unfortunately the brain is far too complex and involves so many different processes that we are still a long way off from being able to recreate all of its abilities in computer software. However computer processing power has improved greatly over the years and there is an increasing number of brain mechanisms that can be simulated using computer models. This is particularly so in the area of vision and there are many researchers working on developing computer vision systems.

Over the years, my own research into visual perception has relied more and more on computers and I have developed models of how humans and primates perceive movement. Motion perception is important to humans and animals alike because we have to move in order to stay out of danger and to find food. When we ourselves move, motion is generated on the retinas of our eyes. This retinal image motion provides us with useful information regarding obstacles in the world and what our bodies are doing. The big question is how the brain extracts this information from just the fluctuating light patterns occurring on the retina.

By using digital images to represent the light patterns on the retina, and custom software that manipulates those images, it is now possible to simulate on a computer the way light is processed at various stages of the visual system. In particular, I have been able to construct computer models of the neurons found in the Middle Temporal (MT) area of the primate brain. MT neurons are specialised for responding to movement and seem to play a key role in our perception of motion. I can test these model MT neurons with the same stimuli used to test MT neurons in monkeys and we are finding that they respond in a very similar fashion (Perrone, 2004). When fully tested and validated, such a computer model becomes a very useful tool for researchers studying the brain because the model can be used to predict what the neurons will do under certain conditions. It means that experiments designed to test these neurons can be carried out in a much more precise and efficient fashion.

Research into sensation and perception often combines aspects from all of these three main methodologies. It is not uncommon today for teams of researchers to use psychophysics, neurophysiology, and computer modelling to answer one particular research question. A complete understanding of the brain and how it works is going to require expertise from a wide variety of disciplines.

Applied areas of research

The study of sensation and perception is not just theoretically interesting; there are many practical applications for the knowledge that is gained from the research. An understanding of how the visual system works can help in the design of the equipment and displays we use in our everyday life. For example, knowledge of how we perceive different colours can be used for designing effective displays that are easy to read and which highlight important information (e.g. aircraft cockpit displays, computer software interfaces and mobile phone displays).

Road safety research is one area in which perceptual and cognitive psychology theory has been put to good use. The Psychology Department at the University of Waikato has one of the most advanced driving simulator systems in New Zealand. It presents realistic computer generated scenes and digital video to drivers sitting in an actual BMW 314i. Drivers steer, accelerate and brake the same way they do on real roads (see Figure 4.3). This simulator has been used for experiments to test people's driving ability and how they react to changes in road design. Samuel Charlton, Robert Isler and I make up the Traffic and Road Safety Research Group (TARS) which conducts research on a wide range of topics including driver training, driver attention, fatigue, decision making, and risk perception.

Concluding comment

There are many fascinating research projects into sensation and perception being conducted in psychology departments all around New Zealand. Each piece of research brings us closer to understanding how physical stimuli in the environment (such as light and sound), get converted into our rich perceptual experience.

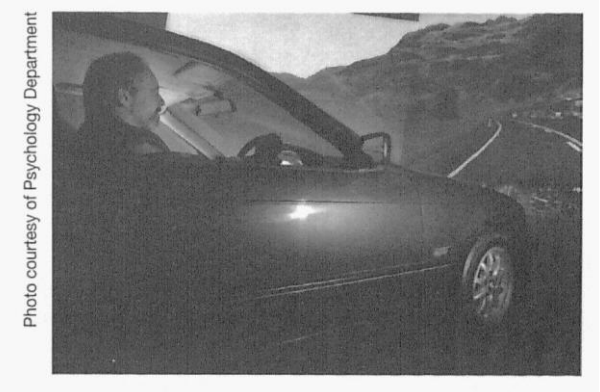

Figure 4.3 Driving simulator in the Psychology Department, The University of Waikato