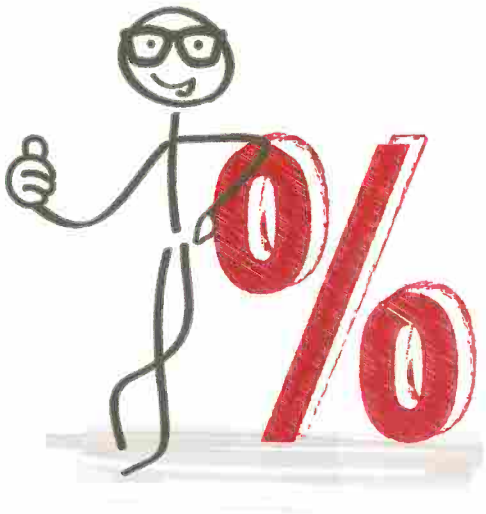
Percentages and scales



Bill Indge continues his advice on calculations

In *Upgrade* in the November 2014 issue of Biological Sciences Review we looked at some of the mathematical topics that underpin AS biology. An underlying message emerged: simple mathematical tools are extremely useful to a biologist and there is no need to be apprehensive when it comes to using them. In this *Upgrade*, we will follow the mathematical theme a little further and look at two more topics — percentages and scales.

Harlequins

I live in an old farmhouse. As the weather warms up each spring, ladybirds start to become active and crawl across the windows. They are harlequin ladybirds. This species first arrived in the UK in 2003 after being introduced intentionally into North America and continental Europe for the biological control of aphids and other plant-sucking insect pests (see Biological Sciences Review, Vol. 23, No. 3, pp. 10–15). As it gets colder towards evening, these insects retreat towards the corner of a window frame, clustering there until the following day (see Figure 1).

Harlequin ladybirds are extremely variable in both colour and pattern. The background colour of the wing-cases (elytra) may be orange, red, or black. If it is orange or red, there can be anything from 0 to 21 black spots. These spots

Figure 1 A cluster of harlequin ladybirds showing the variation in colour and pattern

Figure 2 Mating harlequin ladybirds. Notice that, although they are the same species, the female (in front) has patterns very different from those of the male

may be light or heavy, discrete or fused together. With black or melanic forms, there may be two or four red or orange patches.

In front of the elytra is the pronotum, which covers the ladybird's thorax. This is white or cream and shows a range of black markings. These colour forms all belong to the same species — they are simply genetic variants, and will readily mate with each other on a patch of nettles or the leaves of a lime or a sycamore tree, for example (see Figure 2).

Percentages

Earlier this year, I investigated variation in harlequin ladybirds in a little more detail. I wondered whether there were differences in the colour patterns of the elytra of harlequin ladybirds in different places that I visited. I allocated the ladybirds that I saw in a particular area to one of five categories:

- melanic: background colour of elytra black
- heavy spotted: at first sight the ladybird appeared dark in colour
- medium spotted: intermediate between heavy spotted and light spotted
- light spotted: needed to look carefully to see spots on the elytra
- spotless: no spots visible on orange or red elytra

You might criticise my method by saying that it is subjective, but I needed an approach that I could use whenever I encountered a harlequin ladybird. In addition, I found that I was able to achieve a high degree of consistency when I tested myself on the same ladybirds on different occasions.

Table 1 shows the results I obtained at three different sites in June 2014.

Data such as those in Table 1 are not easy to interpret because you are looking at different total numbers of ladybirds each time. Look at the first column — the number of melanic ladybirds. The figures for Suffolk stand out as being much higher than the other two, but the total number of ladybirds involved was also much higher — 147 as opposed to 65 and 51. In situations such as this, percentages

Table 1 Variation in the colour pattern of harlequin ladybirds. Data given as numbers of ladybirds

	Number of ladybirds in each category					
Site	Melanic	Heavy spotted	Medium spotted	Light spotted	Spotless	Total
Worcestershire, UK	12	17	20	13	3	65
Suffolk, UK	25	44	50	23	5	147
Hannover, Germany	6	3	22	13	7	51

Table 2 Variation in the colour pattern of harlequin ladybirds. Data given as percentages

	Percentage of ladybirds in each category				
Site	Melanic	Heavy spotted	Medium spotted	Light spotted	Spotless
Worcestershire, UK	18.5	26.2	30.8	20.0	4.6
Suffolk, UK	17.0	29.9	34.0	25.6	3.4
Hannover, Germany	11.8	5.9	43.1	25.5	13.7

are extremely useful. By converting the data to a proportion of 100 we take out variation in the total. The calculation itself is straightforward. In this case, 25 out of a total of 147 ladybirds were melanic, so we multiply this fraction by 100%:

$$\frac{25}{147} \times 100\%$$

which gives us 17.0%.

Table 2 shows the same data as in Table 1 but this time converted to percentages.

The advantage of expressing the data this way should be immediately apparent. The figures can be compared and you can see, for example, that there is a low proportion of melanic and a high proportion of spotless harlequin ladybirds in the Hannover sample. Introducing the concept of 'per' into the units that you use allows a comparison to be made. Percentages allow data to be compared where numbers in samples differ, as in this case. Per gram allows a comparison where mass differs, per metre^2 where area differs, and so on.

Be careful

Before we leave the topic of percentages, however, a few words of caution. Calculating percentages does not make data 'more scientific' or more reliable. Percentages are only as useful as the data from which they are derived. Let's return to harlequin ladybirds and consider the percentage of all ladybirds seen on a patch of nettles that were harlequins. A figure of 67% might look impressive but it could have been calculated from two harlequins out of a total sample of three ladybirds. You cannot draw valid conclusions from raw data as limited as these and you cannot draw valid conclusions from percentages based on such data. Generally, the larger the sample size, the more reliable the data and the problem with percentages is that they ignore sample size.

There is also one thing that you simply cannot do with percentages: you cannot average them. Look at the figures for spotless ladybirds in the last column of Table 1. If you combine all three sets of data, the overall percentage of spotless ladybirds is:

$$\frac{3 + 5 + 7}{65 + 147 + 51} \times 100\% = 5.7\%$$

Now, suppose we calculated an 'average value' by dividing the sum of the three percentages in Table 2 by 3. This gives us a different figure, 7.2%, a figure that is meaningless because it fails to take into account differences in sample size. So, don't average percentages.

Size matters

One of the concerns expressed by biologists about the introduction of harlequin ladybirds is that they will compete with some of Britain's native ladybirds for aphids. Such competition might well lead to a decrease in numbers of these native species.

There is a large bank of nettles on the other side of the lane that runs past my house and, earlier this year, there were lots of aphids on the stems and under the leaves of these plants. There were also several different species of ladybird present. The most common of these were the native 7-spot and the introduced harlequin. It struck me that as they were both feeding on aphids, if they were the same size as each other then they probably would be competing. If they were significantly different in size, then they might be feeding on different sized prey and competition may be less important. Obviously, if I wanted to pursue this idea, I needed to measure some ladybirds and I did not want to kill them. I soon found that accurately measuring the length of a moving ladybird is not easy.

The approach I finally adopted was to catch a small sample of ladybirds and store them in the fridge overnight, because cool temperatures slow them down. I then carefully transferred each insect onto a sheet of 1 mm graph paper and photographed it before releasing it. It was then a matter of looking at the image on the computer screen and applying a mathematical tool — scaling — to obtain a measurement of the ladybird's actual length.

Figure 3 shows one of my photographs. There were two steps in the process by which I obtained the actual size. First, I needed to know the magnification of the photograph. Then, armed with this information, I could determine the length of the ladybird from the length of its image. The only principle that you need to understand is that when an object is magnified, the resulting image will look larger than the real thing. In other words, magnification is the length of the image compared with the length of the object. We can write this as a simple formula:

$$\text{magnification} = \frac{\text{length of image}}{\text{length of object}}$$

The ladybird was photographed on a 1 mm grid, so the real distance between points A and B, the length of the object, is 10 mm. If we place a ruler along the line, we can measure the length of the image. This is 70 mm.

As magnification = length of image/length of object, it will be 70/10 or 7.0.

We now know the magnification and, by placing a ruler on the photograph, we can measure the length of the image of the ladybird. Dividing this by the magnification we will get the actual length of the insect, in this case 6.8 mm.

Figure 3 Photograph of a harlequin ladybird on a 1 mm graph paper grid

Table 3 The prefixes and symbols that are added to units. Those that are in the green boxes are the ones with which you should be familiar

Getting larger ↑ / ↓ Getting smaller

Prefix	Symbol	Prefix	Symbol
10^{12} tera	T	10^{-3} milli	m
10^{9} giga	G	10^{-6} micro	μ
10^{6} mega	M	10^{-9} nano	n
10^{3} kilo	k	10^{-12} pico	p

Be careful

As an A-level biologist you will use scaling frequently, although it is more likely that this will be in the context of cells rather than ladybirds. When I was an examiner, I never ceased to be amazed at the number of candidates who produced incorrect answers to questions based on scaling. Errors usually fell into one of two main categories: mistakes made with units, and errors made from not understanding the basic principles.

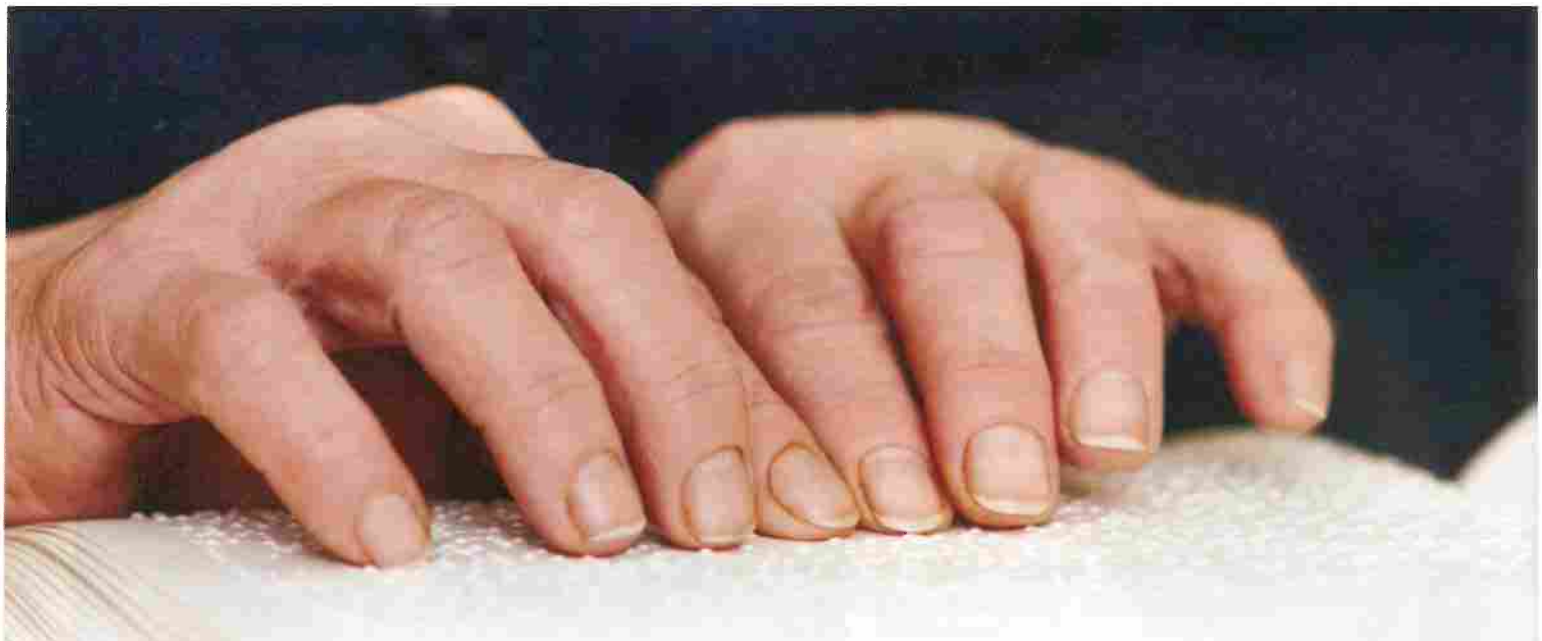
The SI unit of length is a metre (see pp. 2–6, this issue), but this is not always convenient to use. The mean body length of a harlequin ladybird, for example, is 0.008 m and the mean diameter of a human red blood cell is 0.000007 m. It doesn't make much sense using metres for the length of a ladybird or for the diameter of a red blood cell. We get round this problem by adding a prefix to the front of the base unit. Some of the more important prefixes are given in Table 3.

It is only the two prefixes in the green boxes in Table 3 that you are likely to use when it comes to scaling. If you use these units you are talking about a thousand times — a millimetre is a thousand times larger than a micrometre or, if you prefer, a micrometre is a thousand times smaller than a millimetre — and your calculations will only involve multiplying or dividing by this number. The prefix centi (10^{-2}) is a commonly used and perfectly acceptable prefix. Its use, however, often leads to error when scaling objects seen under a microscope because some students struggle to convert centimetres to micrometres. So, when answering questions that involve the use of magnification and size:

- get everything into the same units as soon as possible
- stick to millimetres and micrometres

There we are then. I won't pretend that mathematical techniques are necessarily exciting to a biologist, but they are extremely useful and certainly nothing to be apprehensive about.

Bill Indge has had many years' experience as a senior examiner in A-level biology. He is a member of the Biological Sciences Review editorial board and the author of a number of books, including the *Biology A–Z Handbook*. Visit **www.hoddereducation.co.uk** for more information and to see Bill's other publications.



How are you feeling?

Touch signals and touch receptors

Catherine McCrohan

Neuroscientist Catherine McCrohan describes some of the different types of touch receptors that are located in the skin, how touch signals are conveyed in the nervous system, and some of the ways we use this information

Key words

Touch
Mechanoreceptor
Pacinian corpuscle
Transduction
Ion channel

Some people live without sight, or hearing, or a sense of smell. But can you imagine a world without touch? Our sense of touch allows us to collect information about objects with which we come into contact. This process involves conversion of mechanical signals into the electrical signals that are used by our nervous system.

Touch may include light through to heavy pressure. It tells us about the weight and texture of an object — whether smooth or rough — and whether the object is moving — for example, vibrating. We use all this information to guide a multitude of activities, including the skilled movements of a violinist or surgeon.

Closely associated with the sense of touch are sensations relating to pain and temperature, which are also detected through our skin but do not require mechanical deformation of the skin. Our ability to perceive mechanical changes depends on the fact that our skin is flexible and will deform when it comes into contact with an object. Specialised nerve receptor cells called mechanoreceptors, located beneath the surface of the skin, pick up changes in the amount of bending or stretching of the skin.

Skin receptors

Our skin has many functions, including protecting the underlying tissues from damage and water loss. The skin consists of an outer layer — the epidermis — and an inner layer — the dermis. The dermis contains millions of mechanoreceptors, often named after the scientist who first described them (see Figure 1). Each receptor consists of the ending of a **nerve fibre**, which originates from a nerve cell (neurone) located in the central nervous system. Many of these endings are associated with specialised structures that allow them to respond preferentially to different types of touch stimuli.

For example, Meissner's corpuscles are found near the skin surface under ridges of skin such as those on our fingertips. Each Meissner's corpuscle responds to light touch over a small area of skin only a few millimetres across. This area of skin is called the **receptive field** of the receptor. These mechanoreceptors respond best to brief touch stimuli, such as a light pin prick. They also respond to rough textures, movement of an object or slow vibrations. Merkel's discs, on the other hand, respond to long-lasting touch. These are found in the skin, at the boundary between the dermis and epidermis

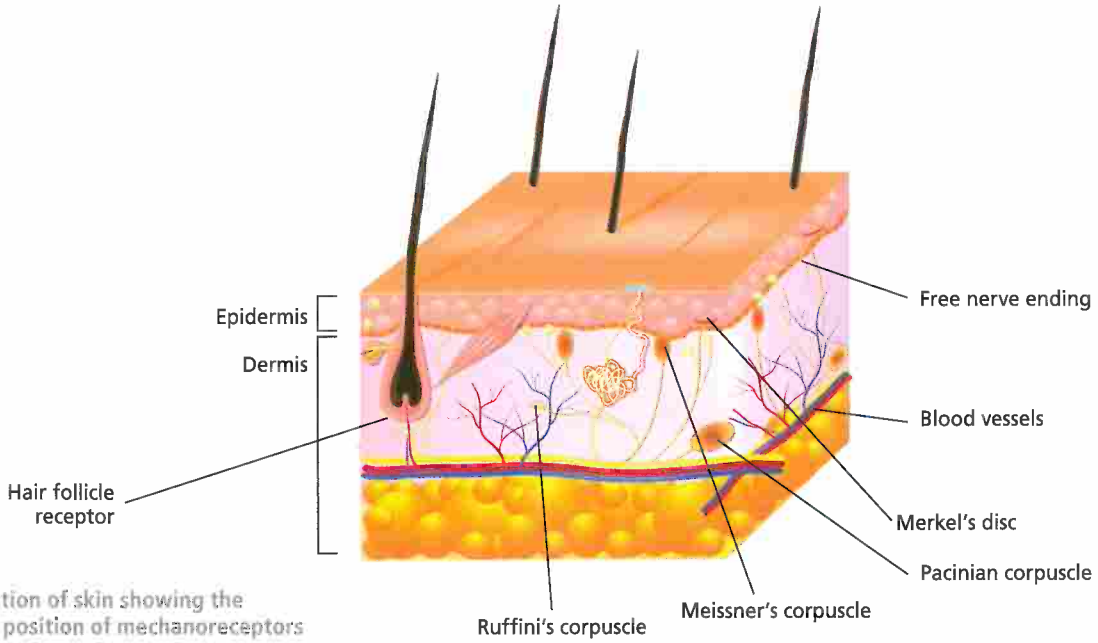


Figure 1 Section of skin showing the structure and position of mechanoreceptors

(see Figure 1), and they record information about the amount of steady pressure applied to the skin and hence the weight of an object.

Receptors on hair follicles respond to movement of the hair, as would occur during a light caress. By combining information from different types of mechanoreceptor, the brain is able to identify objects simply by touch.

Different parts of your body have different sensitivity to touch and also vary hugely in a two-point discrimination test. This test is a measure of the ability to tell apart two stimuli applied close together on the skin. Your fingertips can distinguish two points more than about 2.5 mm apart. On your back, the two points must be more than 35 mm apart before you can identify them as two separate stimuli. The reasons for this difference include the fact that the skin on the fingers has a much higher density of touch receptors than other parts of the body. In addition, more of the receptors have a small receptive field. Less overlap of receptive fields of adjacent receptors means better two-point discrimination.

Terms explained

Generator potential A change in the membrane potential in response to a sensory stimulus.

Haptic technology Technology that uses the sense of touch.

Mechanosensitive ion channels Ion channels that open in response to mechanical deformation of the cell membrane.

Membrane potential The difference in electrical potential (voltage) between the inside and outside of a cell.

Nerve fibre Fine extension of a nerve cell, used for transmitting electrical signals.

Receptive field Region in which a stimulus will lead to a response in a sensory neurone.

Transduction A process by which one type of stimulus (energy) is converted into another.


The skilled movements of a violinist are guided by touch receptors

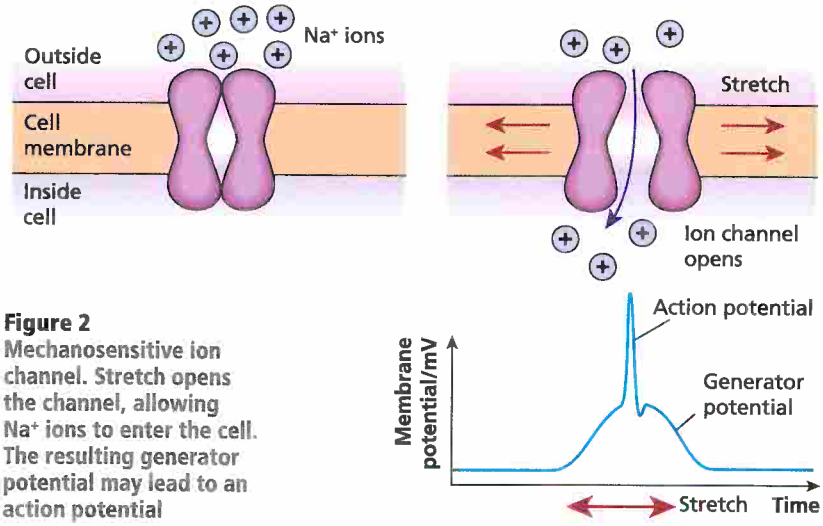


Figure 2 Mechanosensitive ion channel. Stretch opens the channel, allowing Na^+ ions to enter the cell. The resulting generator potential may lead to an action potential

Converting mechanical energy into electrical energy

One of the main ways by which the nervous system transmits information is in the form of electrical signals (action potentials). These electrical impulses travel long distances along nerves, and information is conveyed by the number, frequency and pattern of the electrical impulses. The challenge for all our senses, whether smell, vision, hearing or touch, is to turn one form of energy into electrical signals that can be interpreted by the brain. This process is called **transduction**.

In the case of touch, mechanical energy exerted on the skin is converted into an electrical signal in the nerve ending of the mechanoreceptor. How does this work? Embedded in the cell membrane of the nerve ending are specialised proteins called **mechanosensitive ion channels** (see Figure 2). When the membrane is stretched or distorted, the ion channels open. This allows positively charged ions such as sodium ions to move across the membrane. Sodium ions enter the cell from the outside where they are more concentrated, leading to a change in the electrical charge — **membrane potential** — across the membrane. The inside of the cell becomes more positively charged. This change in membrane potential is called the **generator potential** and, if it is large enough, it triggers an action potential. Action potentials are then transmitted along the nerve fibre to the central nervous system. When the stimulus is removed, the membrane protein reverts to its original shape and the ion channel closes. The ion channel protein can be thought of as a transducer, converting mechanical stretch into an electrical signal.

Box 1 Studying the responses of a Pacinian corpuscle

When scientists started to study Pacinian corpuscles, over 50 years ago, they suspected that it was the onion-like capsule around the nerve ending that made it selective for vibrations. They carried out a simple, but extremely fiddly, experiment to test this.

An individual corpuscle was isolated by dissection and placed in a bath of saline solution. Electrodes were positioned to record the electrical response of the nerve ending and a tiny mechanical probe was positioned against the side of the corpuscle. This probe could be moved in a controlled way to exert pressure on the receptor. The generator potential induced in the nerve cell was measured. Next, the experimenters peeled away the 'onion' layers using fine dissection instruments, to see if this would alter the response. It did. When the layers were removed, the nerve ending responded continuously to steady pressure (see Figure 1.1). This finding confirmed that it is the layered structure surrounding the nerve ending that makes the corpuscle respond only briefly to sustained pressure, making it selective for vibrating stimuli.

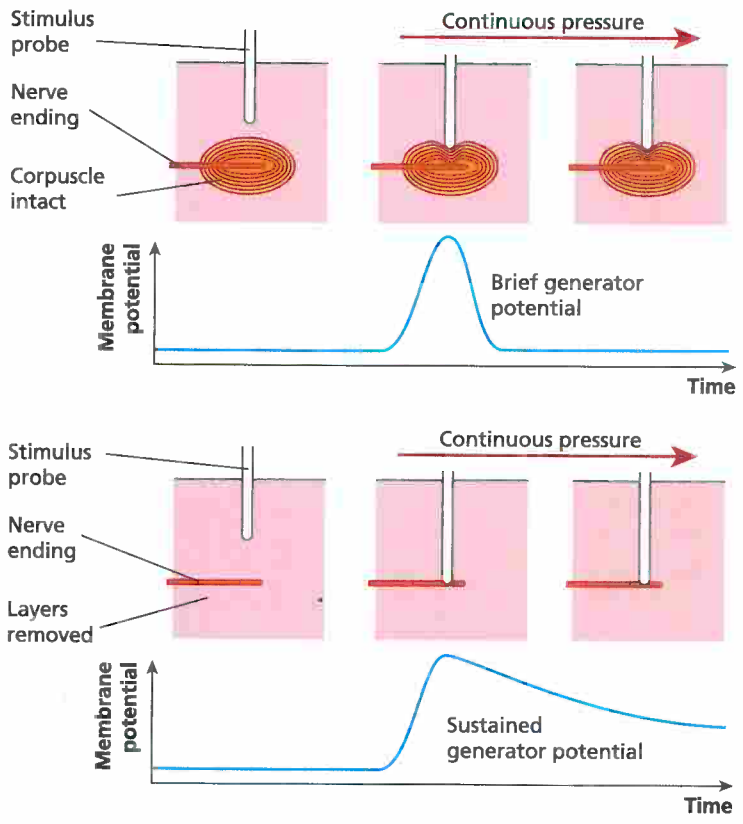


Figure 1.1 Peeling away the layers of a Pacinian corpuscle changes its response to continuous pressure

Good vibrations: the Pacinian corpuscle

The Pacinian corpuscle is the best understood of all the mechanoreceptors, probably because it is the largest and therefore the easiest to study. It is about 2 mm long, and when cut in sections and viewed under a microscope, it looks a bit like an onion (see Figure 3). The nerve ending is surrounded by layers of connective tissue, separated by a viscous fluid. Pacinian corpuscles are found deep in the dermis and are especially sensitive to vibrations.

In contrast to the Meissner's corpuscles they have a large receptive field. Each Pacinian corpuscle responds to stimuli over an area of skin that may be several centimetres across. When stimulated with continuous pressure, the receptor responds at first but then stops responding very quickly — a process called adaptation. However, when it is stimulated with a vibrating stimulus, it responds repeatedly. This makes the corpuscle highly selective for high frequency vibrations as opposed to steady pressure. It is the layers of tissue around the nerve ending that make it respond in this way. The fluid between the layers absorbs the mechanical energy by allowing the layers to slip past each other. As a consequence, only the onset of the stimulus gets through to distort the nerve cell membrane and induce a generator potential (see Box 1).

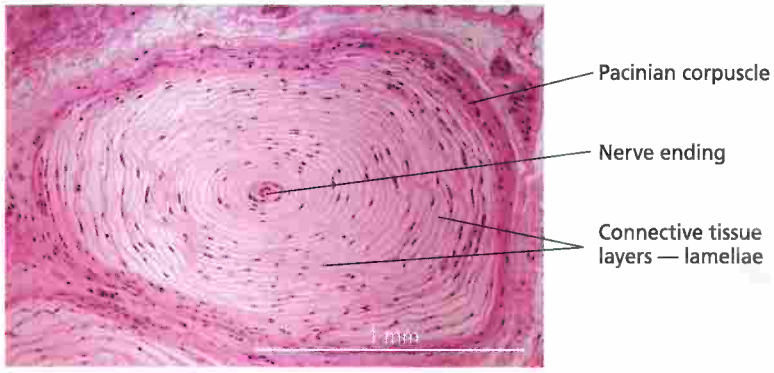
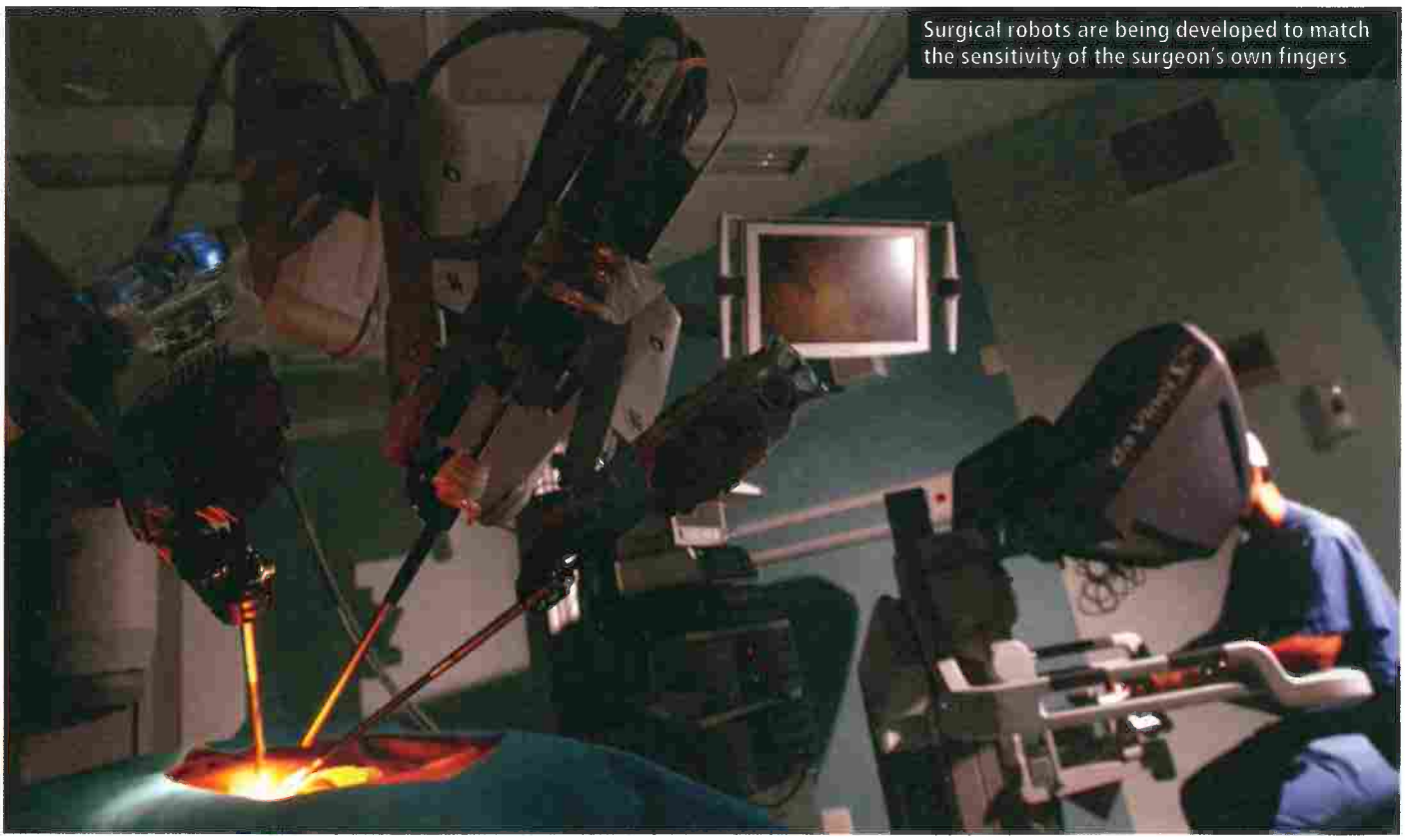


Figure 3 Onion-like appearance of a Pacinian corpuscle

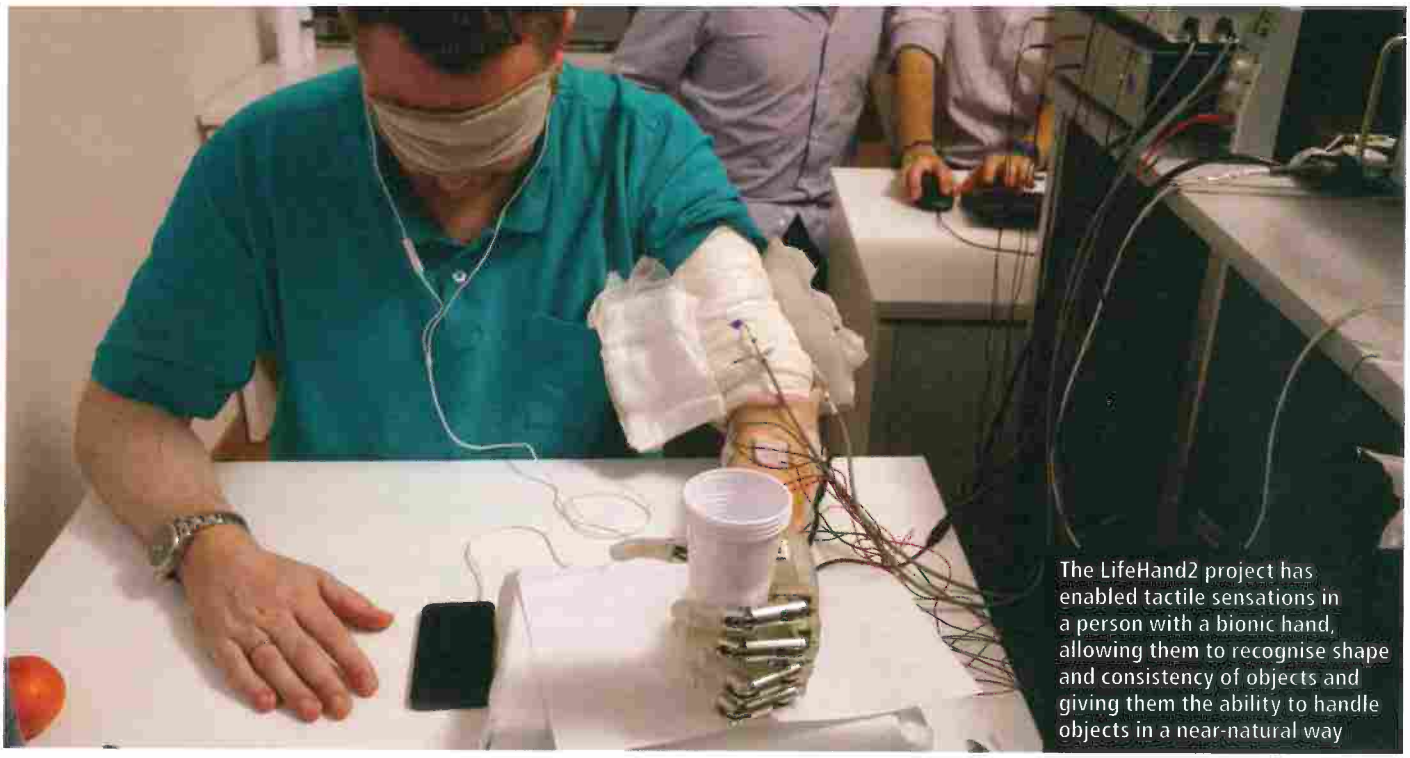
Exploiting our understanding of touch

Our sense of touch is being exploited in the field of **haptic technology**. Carefully controlled mechanical stimuli can be applied to a person's skin to give the sensation of an object — a 'virtual object'. This approach helps scientists to understand what it is about an object that we are most sensitive to, and also to develop systems that can reproduce the function of our own mechanoreceptors. Their findings provide the basis for new biomedical devices.

Robotic surgery is one area in which haptic technology is being applied. Robotic devices are increasingly used to perform the most delicate manipulations during an operation, providing better outcomes for patients. The surgeon has control using his own hands to guide the surgical tools, via a computer console, or even remotely from another location. Recovery times for the patient are often faster because the miniaturised capabilities of the



Surgical robots are being developed to match the sensitivity of the surgeon's own fingers



The LifeHand2 project has enabled tactile sensations in a person with a bionic hand, allowing them to recognise shape and consistency of objects and giving them the ability to handle objects in a near-natural way

robotic tools mean small incisions, low blood loss, and low associated damage and pain.

Robots can be used in a wide range of procedures, including heart, abdominal and brain surgery. During these procedures, it important that the robot — and the surgeon — receives information about the forces and mechanical resistance between the tool and the tissue being manipulated. That way the pressure exerted by the tool itself can be adjusted appropriately. This is where haptic technology comes in. Devices are being developed that use extremely sensitive force sensors at the working end of each surgical tool, providing rapid tactile feedback to the computer interface and user. In this way, the fine sensitivity provided previously by the surgeon's own touch receptors in their fingers can be reproduced.

Another way in which our understanding of the sense of touch is being exploited is in improving the function of prosthetic limbs. Neuroscientists at the University of Chicago recently reported progress in research to make an artificial hand that has a realistic sense of touch. In their prototype, sensors in the fingers send signals to electrodes implanted in the brain, which are then interpreted by the wearer to provide information about the weight and texture of an object and how firmly it is being gripped. If successful, this will allow people with artificial limbs to do much more than they can at present, as their prosthesis will better mimic the capabilities of a normal limb.

We will probably never completely replicate our exquisite sense of touch. But the more we understand about how different receptors are tuned to respond to specific types of stimuli, and how the nerves transmit touch signals, the better placed we are to use this knowledge in a huge range of technologies.

Things to do

- Try out the two-point discrimination test on different parts of the body of a blindfolded volunteer. You will need two fine (but blunt) probes and a ruler or measuring callipers. Try finger, palm, back of hand, forearm, back, leg, foot. Then look up the term 'sensory homunculus' and relate this to your findings.

Catherine McCrohan is professor of comparative neurobiology at the University of Manchester. Her research involves studies on sensory coding and sensory-guided behaviour in simple organisms such as the fruit fly.

Key points

- Our sense of touch uses mechanoreceptors located beneath the skin surface.
- Mechanical deformation of the skin leads to an electrical response in nerve fibres associated with the mechanoreceptors.
- Transduction of mechanical energy to electrical energy is via ion channels in the nerve cell membrane, which respond to stretch.
- The specialised sensitivity of the Pacinian corpuscle to vibration is due to the presence of layers of tissue surrounding the nerve ending.
- We can exploit our knowledge about touch in the fields of robotic surgery and prosthetics.

Further reading

How a man with a robotic hand can feel degrees of pressure: **http://tinyurl.com/o9ugoel**

How robotic surgery works: **http://tinyurl.com/p6szmh8**