INTRODUCTION
What makes some foods delicious while others are disgusting? In this lecture John introduces us to the extraordinary complexity of our sense of taste, and how the role of smell is even more significant. He explains how the brain plays the biggest role in our perception of food, setting expectations, and judging whether what we eat satisfies, exceeds, or fails to meet these expectations entirely.

BREAKFAST
Welcome to the second of the Christmas Lectures, 2005, from the Royal Institution in London. The theme of the lectures this year is food, and in this lecture we look at a question that's so big, you might never have thought about it – why do we find some foods disgusting, and others delicious? Does it depend on our senses? Does it depend on our brains, interpreting information from these senses? Does it depend on our individual past experiences? Or does it depend on the culture and society in which we live? To answer these questions we take a trip inside our own bodies.

For example, bacon and eggs is one of my favourite breakfasts; for me, it's yummy. I like the look of it, the smell of it – the taste, of course, but also the feel of it in my mouth, and the sounds. I even enjoy the memory of breakfasts like this from when I was on holiday, when I was young. But when I look at a breakfast of fried cicadas ... well, I just think they're disgusting.

Why is it that I love one, and hate the other? After all, they're both excellent sources of protein. But food is about much more than nutrition. Our cultures and past experiences also help to shape our reactions to different food.
TASTE

To understand why one food is yucky and one food is yummy, let’s start at the beginning of its journey through the body. We experience our food through our senses, so let’s look at our sense of taste, and how it works. To do this we need to find out about the tongue.

Your tongue is made of a mass of muscles that make it move in all sorts of ways – perfect for manipulating and swallowing food. But to taste the food you use special taste cells found in taste buds buried in the skin of the tongue.

Your tongue surface is a grainy texture and is covered in red bumps. The bumps are called papillae and that’s where your taste buds are hiding. If you magnify a papilla it looks a bit like a microscopic mushroom.

When your food is mashed up by your teeth and squelched around with saliva, some of it trickles down between the ‘stalks’ of these mushroom-like papillae. And the taste buds are hidden at the bottom of the stalk!

Each taste bud is a bundle of dozens of taste cells, and each of those has tiny hairs sticking out which mix with the mashed-up food. The hairs are minute. They are a hundredth of the thickness of a hair on your head.

And it’s on the hairs of the taste cells that the chemistry that causes us to taste things actually happens.

Molecules from the food mix with receptors on the taste cell hairs. The right sort of molecules from our food triggers receptors on the hairs, and these send a signal all the way back to your brain. Finally, you taste your food.

Those receptors are phenomenally sensitive. A bucket of water tastes salty if there’s as little as one teaspoon of salt in it. You could try it at home – see how little salt you need to add to a jug of water before you can just taste it.

The whole apparatus – the tongue, the papillae, the taste buds, the cells, the hairs, and the receptors – make up an incredibly elaborate system. But what’s even stranger is that it’s there to detect very few basic tastes.

FIVE TASTES

We all learn about four different types of taste. We’ve already mentioned salt. Then there’s sweet, which is the taste of things like sugar; sour, which is one of the tastes of citrus fruit like lemons; and bitter, which is the main taste of coffee. There are a lot of myths about taste. You might have learned that, for example, you taste sweet things on the tip of your tongue.
That's not exactly true, because your taste cells are all mixed up all over your tongue. And there's another myth, too – there aren't just four basic tastes, there are five. Think about Wotsits and mushrooms, and what they taste of. Wotsits taste sort of cheesy, but not really like cheese. And mushrooms taste earthy. But neither of those taste sweet, sour, bitter, or salty. It's a fifth taste, and it's called ‘umami.’ The word comes from a Japanese word meaning ‘delicious flavour,’ but in English we'd more likely translate it as ‘meaty’ or ‘savoury’ or even ‘yummy’. But none of those are quite right, so we'll call it ‘umami’.

**THE IMPORTANCE OF TASTE**

To uncover why we need to taste at all we need to look for clues in what we use our foods for. If you're an early human scrabbling around looking for suitable foods, you need to know what's good to eat, and what isn't. Things taste sweet because they contain sugars, which we use for energy. So being able to taste sweet things helps us find energy. We also need salt – our brains and nerves depend on it. Umami is sometimes described as the taste of proteins, of things like meat, and we need proteins for growth and repair. But what about tastes we don't like? We don't usually like sour things, and that's also been an advantage for us as we've evolved, because sour-tasting foods have often gone bad. And we don't like bitter things. This helps us avoid eating plants that taste unbearably bitter, for example, belladonna and henbane, that are extremely poisonous. Most poisons taste bitter, so our dislike of bitter tastes was a crucial help to our ancestors when they were working out what to eat, and what to avoid.

**SUPER-TASTERS AND NON-TASTERS**

The fact that there are sensible evolutionary reasons why we all like certain tastes and don't like others doesn't mean that we all taste food in exactly the same way. In fact there are some variations in how the tongue works from person to person. When we test a group of people to see if they can taste a chemical called 6-n-propylthiouracil, or ‘PROP’, some of the group will detect a bitter taste and others will not be able to taste it at all. For a few people the chemical will taste very bitter indeed. We can call ‘non-tasters’ the people who don't taste this chemical, and those who detected a much stronger
bitter taste are called ‘super-tasters’. Roughly one in four people are super-tasters.
Using a dye we can stain the tongue so that it looks blue everywhere except for on the papillae – those lumps that hide your taste buds. The dye makes it easier to see where the papillae are.
When we do this we can see that super-tasters have more papillae, and therefore more taste buds, than normal tasters. Super-tasters probably experience foods more vividly – a bit like being in a psychedelic world of taste.
Super-tasters would be better than most of us at spotting faint traces of poisons, which might have been useful to our ancestors. But they also tend to be fussier eaters, rejecting as too bitter things the rest of us eat quite happily.
It's likely that being a super-taster is useful enough to have survived millions of years of evolution – but not so useful that we'd all benefit from it. What this does reveal though is that although there are only five different categories of taste, we're not all experiencing exactly the same thing. So that might be the beginning of an explanation of why we don't all like the same foods.
The tongue, though, is only the beginning of the story. We still have to travel further to understand why some foods are yucky and others yummy.

SMELL

Taste is obviously an extraordinary process, and there's some variation in how we taste. But it can't be the whole story, because we know that food is a much richer experience than just five tastes.
If the tongue is such a blunt instrument, there must be something else involved. And in fact, the nose plays a much more sophisticated rôle in our appreciation of food.
Just as there are myths about the tongue, so there are myths about the nose. Most people imagine that you smell your food by sniffing it, drawing the aromas into your nose. But you experience the most intense smells when your food is already in your mouth and you breathe out.
Breathing out blows all the aromas, the chemicals that your nose detects, across cells found inside the top of your nose, in an area called the olfactory epithelium.
These cells work in a similar sort of way to your taste buds, but rather than just five basic types, there are about 350 types of receptor.
Each of the 350 receptors is involved in detecting many different aromas. Combinations of many different molecules cause different aromas, and each of those molecules can trigger several different receptors.

Because of that combination upon combination, we can distinguish not 350 different smells, but 10,000.

Until recently, it wasn't understood how your brain works out what's going on in your nose. But last year two American scientists were awarded the Nobel Prize for their work on exactly this problem.

Here are some of the experiments that they tried:

**FRUIT FLY TANK**

Drosophila are tiny flies that feed on fruit. Astonishingly, their antennae smell in the same sort of way as our noses do. Humans and fruit flies had a common ancestor that lived 500 million years ago, and our sense of smell hasn't changed since then.

By studying these flies, the scientists were able to find the areas of the brain that process the information from the nose. And it turns out that those brain areas – they're called glomeruli – mirror the types of receptor. There's a glomerulus for each type of receptor – all 350 of them. When a receptor is triggered, so is a glomerulus.

It seems that smell is so important, and so ancient, it's wired directly into the brain. Your brain learns to recognise about 10,000 different combinations of receptor activity, and hence about 10,000 different smells.

It's an astonishing feat of chemical analysis, and your brain does it enormously quickly, without you even noticing the effort.

**AROMA PROFILE MACHINE**

This delicate aroma profile machine tries to do the same thing. A volunteer breathes into the machine and it analyses the same chemicals that are being analysed by the volunteer's nose.

The machine produces a graph tracing, which shows a peak on the graph each time the volunteer breathes out. The peak is produced by a specific chemical called isoprene. This is a natural product of your body, and you exhale it quite normally. So we can use that to spot when the volunteer is breathing out.

When we give the volunteer a raspberry to chew, we see extra peaks on the tracing. These are the chemical signatures of the raspberry.
Each peak represents a different chemical component that the machine is detecting – and that the volunteer’s nose is detecting.

The machine is separating out the chemical components of the raspberry aroma using a technique called mass spectrometry – each peak on the trace represents a chemical of a different weight. The volunteer’s brain can piece together a picture of what’s going on in her nose, by recognising these combinations as ‘raspberry.’

But the aroma profile machine allows us to work out what each of those chemicals is – what chemical each trace on the screen represents. And then with that information, we can build our own raspberry smell.

**ARTIFICIAL RASPBERRY SCENT**

To make the artificial raspberry smell we can mix up the chemicals that the aroma profile machine identified when the volunteer smelled raspberries:

The first chemical is called propionic acid. It smells a bit like vinegar – not very nice – and it certainly doesn’t smell of raspberries.

A second one is ionone. This one is rather nice – perhaps a bit like wild flowers – but not exactly raspberries either.

A third chemical in the mixture is ethyl acetate – which smells of glue – or pear drops if you’re feeling generous.

None of these chemicals smells of raspberries. None of them even smells pleasant. But if we mix them together and then thin the mixture down with some sugar solution we can make what the aroma profile machine tells us should be similar to the smell of raspberries. It’s fairly close, despite being a very simple combination of chemicals that each smells nothing like raspberry. But that combination of aromas is close to what your brain thinks of as ‘raspberry’.

A real raspberry has a much more subtle smell however. And that’s because its aroma contains another 300 chemicals! So the chemists have a long way to go yet, and nothing smells quite like a real raspberry.

**FLAVOUR = TASTE + SMELL**

We’ve seen that the chemistry of smell is enormously complex, and that it’s crucial to identifying flavours. But how does it work in relation to that other main sense – taste?

It’s a partnership, a combination. To see what this means you can try a simple experiment at home for yourself. Try peeling a...
banana. Then hold your nose very tightly with one hand so you have to breathe through your mouth while you bite and chew, but don’t swallow, the banana.

You should find you don't taste much banana until you let go of your nose! The nose is an important part of the equation in your perception of flavour – you could taste banana, but until your nose joined in, it wasn't really banana.

Taste and smell go together to make the experience of food what it is. But what is doing the combining? What brings smell and taste together to help us work out whether we like a food or not?

The answer to this is, of course, your brain. This is the most vital organ when it comes to food and our enjoyment of it.

**THE BRAIN – FMRI**

Gradually, scientists are unpicking the secrets of what happens in your brain, and how it interprets the information it receives from your senses.

FMRI scanning machines show an image of the brain with bright areas that indicate where the brain is busy processing information. When a person tastes sugar solution, there is no smell, just a sweet taste. A scan of their brain has a tiny bright area in the part of the brain that is involved in processing the information – an area called the frontal operculum/insular area.

When a person smells, but doesn't taste, strawberries, a different area of their brain scan glows brightly, showing that the information is being processed in a different area of their brain. So what happens if we give the person strawberry smell, and sweet taste?

This time the area of the brain that's involved is a new one – one we didn't see light up with the separate scans for either taste or smell.

This new part of the brain – the left anterior orbitofrontal cortex – is drawing together the information about taste and smell. It's one of the areas where your brain perceives flavour.

**PSYCHOLOGY – INTRODUCTION**

We've now understood that our sensory experience is brought together by our brains. But we still haven't explained why some foods are yucky, and others yummy. We need to take a further step, and explore how our brains set expectations about what we're going to eat – and what happens when those expectations aren't met.
PSYCHOLOGY – CRUNCHY / SOGGY

Different senses contribute to our experience of food, but our brains don't just receive and interpret information, they actively shape our experience of food. For example: if you eat yoghurt while listening to loud crunchy noises like crisps you will find that the yoghurt seems to taste weird. Your brain doesn't expect yoghurt to sound crunchy, so it gets confused. Maybe we're not ready for crunchy yoghurt yet! What's amazing about your brain is that when you were born, you didn't know that yoghurt is supposed to be smooth and creamy. That's something your brain has learned. Your brain builds up your own personal roadmap of flavour, and that process starts very early in life.

We now know, for example, that babies fed on powdered milk formula tend to have more conservative tastes than those raised on breast-milk, because breast milk gives the babies experience of a greater range of flavours. Since we've all had different experiences, our brains have different responses to food. Which is why we all have different ideas about what's yummy, and what's yucky.

PSYCHOLOGY – LEARNED RESPONSE – YUCKY FOODS

But of course that's not the whole story. We don't just learn things individually. Our brains' expectations are shaped by the society and culture in which we live. Hence, because we've all had different experiences, we all have different expectations. And some of those expectations are shaped by the culture in which we've grown up.

Take, for example, crispy-fried bamboo worms. They're very popular in Thailand. Or durian. This is a perfectly common fruit in places like Singapore and Malaysia, and it tastes sweet and rather pleasant but we keep it in a sealed container because it smells of rotten meat!

What's intriguing is that our attitudes aren't set in stone; we can change our minds about what we think is disgusting. In Mrs. Rundle's cookery book from 1806, 200 years ago, there's a recipe for the best way to serve the head of a hare so that dinner party guests can most easily help themselves ... to its ears and brains. To us, today, it sounds disgusting – but Mrs. Rundle was British. So our tastes, as a country, have changed. In fact we know they have – our tastes change all the time. For example: sushi – this is raw mackerel on rice – it's very simple,
but Mrs. Rundle would have thought it utterly disgusting. Opinions about food are changing all the time, and today, you can get sushi on many high streets in Britain. Cultural expectations are incredibly strong. That's why some of us think durian or bamboo worms are disgusting, but others think they're delicious.

The reason why we can change our minds about something that we feel so strongly about is probably to do with the time when we were hunter-gatherers, and at the mercy of geography and climate. Then, we needed to be able to seek out and explore new tastes. If we'd stuck to just the nuts we were used to, or the seeds we'd always eaten, we might have died out. It was in our favour to be curious.

**NOVEL FLAVOURS**

So we can change our perceptions of foods, and indeed we do it all the time, gradually, as a society. But how quickly can we change our expectations?

Ashley Watts, the head chef of the Fat Duck restaurant, can make a novel food – you probably like ice cream, but what about bacon and egg ice cream? I've never tasted it myself, and I think the idea sounds pretty disgusting.

Ashley makes the eggs into smooth sweet custard. Then soaks the bacon in the custard overnight. This flavours the custard with bacon. He then fills blown eggshells with the custard. The filled eggshells are then frozen by stirring them round in liquid nitrogen. This freezes the mixture so quickly it locks in the aromas that would otherwise evaporate, so you get more of the wonderful smells when you eat it.

This is very important to our perception of the flavour. Quick-freezing also means the ice crystals in the ice cream don't have time to grow, which gives you a silky-smooth texture. And you know, it's absolute delicious. It shouldn't work, but it does!