Overlapping senses: hearing and touch share circuits in the brain

Traditionally, the human brain is thought to comprise distinct, dedicated areas for processing information from each of our five senses. **Professor Jeffrey M. Yau**, of Baylor College of Medicine in Houston, Texas, is turning this paradigm on its head. His research into how we perceive environmental oscillations – in the form of soundwaves or mechanical vibrations – suggests a complex interplay between hearing and touch, which could be harnessed to treat sensory disorders and may revolutionise the way we think about the brain.

Our brains are constantly bombarded by sensations, and our senses are crucial channels for filtering information to perceive and understand a complex world. Yet from primary school to graduate school we are taught that the sensory onslaught can be broken down into five simple, discrete sensations: sight, hearing, taste, smell, and touch, each of which is supported by unique, dedicated parts of the brain. For instance, visual input is processed in the occipital lobe, and auditory input in the temporal lobe. However, multiple lines of research now hint at a much more complex picture. A more detailed understanding of the perceptual and neural connections between the senses is emerging, and may suggest potentially novel ways to treat sensory impairments caused by ageing, disease or trauma.

GOOD VIBRATIONS

Professor Yau's research focuses on the interactions between two senses: hearing and touch. His starting point is the observation that both hearing and touch involve determining the frequency of the sensations experienced. In hearing, a sound's frequency determines its pitch, and is crucial to the perception of speech and music. In touch, the frequency of vibrations is used to perceive texture and to sense the environment through hand-held tools. Despite these commonalities, we do not have a clear understanding of how the two senses interact during processing of frequency information. It is notable that the range of frequencies detectable by the ear overlaps partially with those sensed by the skin – this overlap may be crucial in allowing these senses to use shared neural circuits in the brain. Because the signals we hear often relate to the signals we feel, Prof Yau believes that the brain may have evolved mechanisms to combine sensory information from both hearing and touch to achieve a more accurate assessment of our environment than possible with either sense alone. His current project, funded by the US National Institutes of Health, uses multiple techniques including behavioural studies, computational modelling, brain imaging, and non-invasive brain stimulation, to explore the complex perceptual and neural interactions between hearing and touch.

Detailed understanding of the connections between the senses may suggest potentially novel ways to treat sensory impairments

FROM SEPARATE TO SUPRAMODAL

Whilst other researchers have focused on how the brain region traditionally associated with sound processing – the auditory cortex – is affected by touch, Prof Yau's recent complementary work also focuses on the impact of sounds upon brain regions traditionally associated with touch, including a region known as the somatosensory cortex.

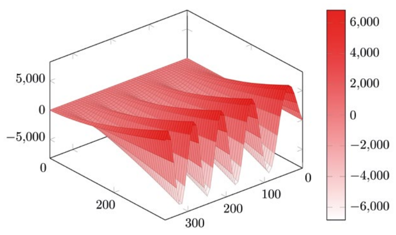
Using functional magnetic resonance imaging (fMRI), a non-invasive imaging method which indirectly measures brain activity by detecting changes in blood flow to different areas, Prof Yau has shown that simply listening to sounds produces patterned activity in the somatosensory cortex as well as the auditory cortex. Furthermore, responses to both sound and touch were distributed across a number of brain regions which he believes may be responsible for integrating the sensory cues received from more than one sense. He calls these regions 'supramodal' – an important new concept in our representation of the workings of the brain. This supramodal paradigm of brain organisation may apply to many types of information we experience through our senses: rather than being initially processed in brain areas that are dedicated to individual senses before being integrated in higher-order parts of the brain, signals from multiple senses may be intertwined from the moment they enter the brain.

Studying perceptual neuroscience

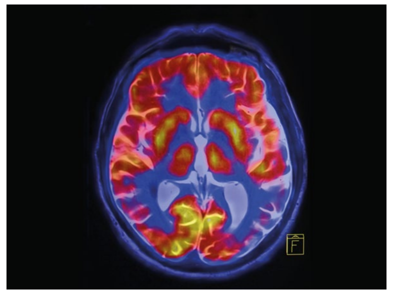
Characterising the perceptual and neural interactions between senses requires a multifaceted approach. Prof Yau's lab uses complementary methods to quantify perception and to understand how the nervous system – what parts of the brain and the computations the brain implements – supports touch and multisensory interactions.

Psychophysics

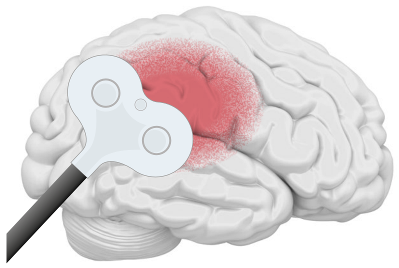
Modelling



Neuroimaging



Brain Stimulation



Senses may be more intertwined than we imagine.

> Signals from multiple senses may be intertwined from the moment they enter the brain

CROSS TALK

The supramodel concept may explain how our senses can influence one another. In a ground-breaking study published back in 2009, Yau and his colleagues showed that exposure to certain sounds can bias our ability to feel vibrations. Specifically, study participants were less able to tell the difference between vibrations of two different frequencies applied to their finger, when they heard sounds at the same time. This occurred because the pitch of a sound received in the ear can actually change the perceived frequency of a vibration felt on the skin. Moreover, a vibration felt on the skin could also bias how a sound was perceived. And this interaction is not confined to frequency; it can apply to intensity too: applying a vibration to the hand can make a sound appear louder. Interestingly, the interactions on intensity perception work only in one direction: hearing a sound does not appear to make vibrations feel more intense. These complex patterns imply that the brain uses different rules when combining touch and sounds depending on whether you are trying to perceive pitch or loudness.

Even more intriguingly, the interactions between sound and touch can endure long after the sensations are experienced: Prof Yau's research shows that prolonged exposure to sounds at certain frequencies alters the perception of vibrations felt by the skin even after the sound has fallen silent. His computational models suggest a mechanism for this effect: the experience of a stimulus (sound or touch) at one frequency 'adapts' the neurons in shared regions of the brain, priming them to respond more efficiently to additional stimuli at similar frequencies, whether these in turn are in the form of sound or touch.

Brain imaging can identify brain regions whose activity may support the perceptual interactions of audition and touch, but fMRI only provides correlational evidence linking the brain to behaviour. Using a non-invasive technique known as 'transcranial magnetic stimulation' (TMS) to stimulate different regions of the brain, Prof Yau has shown that manipulating the somatosensory cortex can impair the sense of hearing. Fascinatingly, the nature of this effect actually depends on the subject's deployment of attention – which sense the subject is 'tuning into' at the time! Yau's work highlights how intimately the functions of hearing and touch are linked, and how much we still have to learn about the workings of the brain. He now plans to compare the predictions of his computational models to data from further human behavioural and psychophysical experiments.

Q&A

Can you explain how functional MRI can be used to estimate and locate areas of brain activity?

fMRI measures changes in how much oxygen is carried in the blood as it circulates around the brain. The assumption is that a region of the brain that is very active "neurally" will require more oxygenated blood given the elevated metabolic demands. This "influx" of oxygenated blood underlies the signal used to indirectly measure brain activity using fMRI.

Do all auditory and tactile stimuli have a frequency element?

All sounds contain frequency information – "soundwaves" consist of oscillatory signals. In contrast, tactile experiences do not all have a frequency component. Only vibrations do (i.e., how quickly something is vibrating against the skin reflects the stimulus frequency). The range of vibrations people can feel ranges from very low 2Hz – 800Hz. We certainly experience and perceive touch that is not vibrating (e.g., the sustained pressure experienced from simply holding a cup).

Do you think other senses may be found to interact in a similar manner to hearing and touch within the brain?

There is ample evidence that other senses also interact. Vision clearly interacts with audition and touch. There is some recent evidence suggesting that touch can interact with taste. The important principle to keep in mind when considering interactions between senses is what information is conveyed by the sensory signals. For instance, both touch and audition convey frequency information, so it is logical for the brain to combine this information. Similarly, we can know what "shape" an object has by seeing it (vision) or by touching it. It turns out that vision and touch interact in shape perception. Basically, if there is something in the world that we can experience through multiple senses, the senses likely interact in processing this information.

Do you think your research might in the future provide help for those with neurological conditions such as sensory processing disorder?

Tentative yes. To the extent that information processing is linked across senses, there may be the potential to leverage one sense in rehabilitating another.

What do you think of the theory that the ear evolved out of the skin to enable more detailed analysis of frequency info?

I think the theory is certainly plausible – the auditory system may have evolved from the more rudimentary mechanosensitive system in the lateral lines of fish as organisms became land dwelling. It is notable that common genes link hearing and touch (Frenzel et al., 2012 PLoS Biol). This fact explains why touch and hearing impairments may co-occur in some clinical populations (e.g., those with Usher syndrome) and why there is a significant correlation between touch sensitivity and auditory sensitivity across the general population.

> There is ample evidence that other senses also interact... vision clearly interacts with audition and touch

Prof Yau is hopeful that his research can pave the way for potential therapies exploiting the cross-talk between our senses. For instance, tactile stimulation may provide a non-invasive, tolerable way to train the brain of cochlear implant patients hearing new sounds for the first time, or could be used to help reduce the debilitating impact of tinnitus. Because the 'supramodal' concept can be expanded to other sensory processes, for example how we perceive motion or objects by vision and touch, it may be of even greater significance in our understanding of how the human brain works.

Detail

RESEARCH OBJECTIVES

Professor Yau's lab investigates the neuroscience of perception, cue integration, and body representation. Some of the lab projects focus on the relationship between hearing and touch – these senses may operate less independently than long thought.

FUNDING

- NIH
- Sloan Foundation
- Dana Foundation

COLLABORATORS

Lexi Crommett (current PhD student; conducted adaptation and modelling experiment); **Dr Alexis Perez-Bellido** (former postdoc; conducted fMRI experiment); **Dr Silvia Convento** (current postdoc; conducted TMS experiment); **Dr Sliman Bensmaia** (collaborator on original behavioural study in 2009).

BIO

Dr Jeffrey Yau received his BS in Psychology from the University of North Carolina at Chapel Hill. He received his PhD in Neuroscience from Johns Hopkins University under Ed Connor and Steven Hsiao and completed a postdoctoral fellowship in the Neurology Department of Johns Hopkins Medical Institutions in the lab of John Desmond. Jeff has been an Assistant Professor in the Neuroscience Department at Baylor College of Medicine since March 2014.

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