Published in final edited form as:

Nature. 2002 January 3; 415(6867): 29–31. doi:10.1038/415029a.

Sounds, signals and space maps

Catherine Carr

Catherine Carr is the Department of Biology, University of Maryland, College Park, Maryland 20742-4415, USA. cc117@umail.umd.edu

Abstract

The auditory system transforms information from one frame of reference into another to create a map of space in the brain. The source of a visual signal that guides this transformation in barn owls has now been found.

When a barn owl hears a noise, it can pinpoint where the sound came from because its brain has a mental map of how the noises it hears fit into the space around it. Various auditory cues are used to construct this 'auditory space map', but it must also be guided by visual inputs, because — assuming reasonable eyesight — vision provides more reliable, topographi-cally organized information. But what part of the brain transmits this information to the auditory map, and what form does the information take? On page 73 of this issue Hyde and Knudsen¹ provide an answer. They suggest that a signal from the optic tectum region of the barn owl's brain provides topographic, point-to-point instructions about the correct representation of auditory spatial cues.

For a hungry barn owl, it is vital to be able to use sounds to locate potential prey — hence the importance of the mental map of those sounds in space. This map is found in the midbrain, specifically the optic tectum. But it is initially produced nearby, in the inferior colliculus², using auditory localization cues to tune individual neurons. Such cues include differences in the time it takes for sounds to reach each of the ears, and differences in the level of sounds that arrive at each ear. The map is then relayed to the overlying optic tectum, where it is aligned with a visual map and used to generate orien-tating movements — when the owl focuses its eyes on a mouse, for example.

Most brain maps are 'projection' maps, in which neurons in the retina or skin, say, project to the relevant brain area in such a way that the spatial arrangement of neurons is the same³. In contrast, the auditory space map in the inferior colliculus does not reflect the organization of the auditory nerves, but is actively computed when information from the two ears is combined in the brain (Fig. 1). The translation of auditory cues into a topographic representation of space is clearly a complex transformation, even for a static auditory 'scene'. And the transformation must also be adaptable — able to respond to changes in the environment.

Auditory space maps can be generated without visual input, but their precision and topography depend on visual experience. So, for example, owls raised as if they were blind end up with abnormal, or even partially inverted⁴, auditory maps. And vision does not simply guide map formation. It also wins out when there is a mismatch between visual and auditory cues, as Knudsen and Brainard⁵ showed in a classic experiment in which they raised young owls with prisms mounted in spectacle frames in front of the eyes. The prisms provided erroneous visual signals that caused a perfectly good auditory map to shift.

Because visual experience 'calibrates' the auditory space map, there must be an instructive signal from the visual system. Two years ago, Hyde and Knudsen⁶ and Luksch *et al.*⁷

proposed that the source of this signal is the optic tectum. It seems that neurons in this region project to the auditory space map in the inferior colliculus, in such a way as to connect points in the visual and auditory maps that represent the same part of space. These projections form before the owls hatch. The projecting neurons have some extensions that lead into the superficial tectal layers (which receive input directly from the retina) and some that extend into the deep tectal layers (which receive auditory input from the auditory space map and visual input from the forebrain). From these anatomical data, it seemed likely that the optic tectum could provide the visually based signal that guides the auditory map. But this was not certain.

There are two types of visually based instructive signals that could guide adaptive adjustments of the auditory space map. These are a ‘global value signal’, derived from a visual assessment of how accurately the brain relates auditory and visual stimuli to locate the source of a sound; and a simple spatial template, derived directly or indirectly from a topographic map of visual space⁸. Either signal could account for the effects of the prisms on the auditory space map. But they would have different neural substrates: a global value signal would require a diffuse projection to the auditory space map; and a spatial template would require a point-to-point projection. So the earlier results^{6,7} support the idea of a spatial template.

Hyde and Knudsen¹ now confirm this, in work that not only reveals the source of the instructive signal but also distinguishes between the two types of possible signals. They show that the nervous system indeed uses point-to-point neuronal projections from the tectum as a spatial template to guide the topography of the auditory space map.

First, the authors placed prisms that displaced the visual field on barn owls for six weeks. The owls’ auditory space map gradually shifted to match their displaced visual map. The authors then damaged a small region in the owls’ tectum, and removed the prisms so that the visual (and hence auditory) map could adapt. They found that most of the auditory space map could still change in response to the new visual experience. But the portion of the map that corresponded to the damaged part of the visual map was stuck, and could not adapt. These results show definitively that the optic tectum provides a visual signal to guide the transformation of auditory cues into an auditory space map. Moreover, the signal has a topographic basis. How exactly this signal instructs the auditory map is still unclear, however.

In terms of understanding the fundamentals of learning and neuronal plasticity (the ability to be modified), the real excitement now lies in what can be done with this signal. If researchers can learn how to activate it, then they can begin to unravel the mechanisms by which one set of neurons provides a teaching signal that drives and controls plasticity in another.

References

1. Hyde PS, Knudsen EI. *Nature*. 2002; 415:73–76. [PubMed: 11780119]
2. Knudsen EI, Konishi M. *Science*. 1978; 200:795–797. [PubMed: 644324]
3. Kaas JH, Hackett TA. *J. Comp. Neurol.* 2000; 421:143–145. [PubMed: 10813777]
4. Knudsen EI, Esterly SD, du Lac SJ. *Neurosci.* 1991; 11:1727–1747.
5. Knudsen EI, Brainard MS. *Science*. 1991; 253:85–87. [PubMed: 2063209]
6. Hyde PS, Knudsen EI. *J. Comp. Neurol.* 2000; 421:146–160. [PubMed: 10813778]
7. Luksch H, Gauger B, Wagner HJ. *Neurosci.* 2000; 20:RC70.
8. Rucci M, Tononi G, Edelman GM. *J. Neurosci.* 1997; 17:334–352. [PubMed: 8987759]

NATURE

100 YEARS AGO

Dr. Sven Hedin, the Swedish explorer, who recently arrived at Ladakh from Central Asia, has sent a telegram to King Oscar announcing that he has made an extremely important journey through all Tibet, disguised as a pilgrim, with two followers. On approaching Lhasa they were recognised and captured, but were well treated by order of the Dalai Lama. A second attempt was opposed by 500 Tibetan soldiers. Dr. Hedin's collections were lost, with almost the whole caravan, but his notes were saved.

From observations described by Prof. Geitel in the *Physikalische Zeitschrift*, iii. 4, it appears that atmospheric air is itself capable of inducing radio-activity. When a mass of air remains shut up for a long time in a cellar or a cave, Prof. Geitel finds that its electric conductivity increases to a maximum. There are three hypotheses possible, namely, that the exposed substances were themselves radio-active, that traces of radio-active substances were present in the neighbourhood, or that the air itself is the origin of the radio-activity... Prof. Geitel favours the view that the third is the most likely hypothesis.

Many animals have popular names which have been derived from their cries. Prof. T. D. A. Cockerell writes to suggest that this is also the case with the donkey, the “don” representing the inspiratory and “key” the expiratory sound. Most dictionaries describe the word, which is of comparatively recent origin, as signifying a little dun animal, from dun and the diminutive term — key, but the grounds upon which this derivation is based are not easy to find.

From *Nature* 2 January 1902.

50 YEARS AGO

On September 29, 1951, Dr. Seth B. Nicholson, while examining a plate exposed earlier that night, discovered an object which he thought was a new satellite of Jupiter. No announcement was made until the object had been photographed later on three occasions with the 60-in. telescope at Mount Wilson and also with the 100-in., with which Dr. Nicholson had made the first photograph... The magnitude of the new satellite is 18.3, but this is only a provisional figure; its diameter has been estimated to be about 15 miles — the diameter of satellite X. Dr. Nicholson now ranks with Galileo as the only astronomer who has discovered four of Jupiter's satellites. From *Nature* 5 January 1952.

Figure 1.

Translating auditory cues into a map of 'auditory space' in barn owls. a, Sounds are first transmitted to the brain's central nucleus of the inferior colliculus, where they are grouped by various criteria such as frequency. b, The resulting neural signals are then transmitted into the external nucleus of the inferior colliculus, where they are organized into an arrangement that represents the location of the sounds in space. c, The auditory map is also modified by visual signals (larger arrows), which Hyde and Knudsen¹ now show to be organized topographically and to come from the optic tectum. The resulting auditory map is then transmitted to the optic tectum and aligned with a visual map, producing a multimodal map of space. The values in degrees refer to the space around the animal.