Auditory illusions illustrate sound source localization

Professor William Yost, and colleagues at Arizona State University, are investigating how the brain processes auditory stimuli to accurately locate a sound. Building on work that started in the early 1940s but has seen little in the way of progress until now, the research group are pioneering novel methods to probe this complex area of neural computation.

In the everyday world listeners and sound sources move, which presents a challenge for localising sound sources. The subtle differences in sound received at each ear, known as auditory spatial cues, are used for locating sound sources. However, these cues change based on the movement of either the sound source and/or the listener. This means, when listeners move, the auditory spatial cues would indicate that the sound source moved, even if it was stationary. In the everyday world, however, this is not the case: a stationary sound source is not perceived as moving when a listener moves. Professor Yost’s research is focussed on understanding how the auditory system determines that a stationary sound source does not move when listener movement causes the auditory spatial cues to change.

In 1940, Hans Wallach described an auditory illusion which could be created by rotating the listener and the sound source in the same plane. If the sound source is rotated at twice the speed of the individual’s head, the sound is perceived as stationary originating from the opposite position from which it started. This correlates with another feature known as front-back confusions, where a sound located behind an observer can appear to emanate from in front, and vice versa when the head remains stationary.

A FORGOTTEN MYSTERY

Much of Wallach’s research was largely forgotten with the outbreak of war in Europe, and his experiments only recently reproduced, but modern researchers in sound source localization (such as Prof Yost) are coming to understand the importance of the observations he made. Wallach reasoned that, “Two sets of sensory data enter into the perceptual process of localization, (1) the changing binaural cues and (2) the data representing the changing position of the head.”

Prof Yost has picked up where Wallach left off, having already identified these features independently before discovering Wallach’s earlier work. He believes, based on research in vision, that, “sound source localization requires the interaction of two sets of cues, one based on auditory spatial cues and another that indicates the position of the head (or body, or perhaps the eyes). Both sets of cues are required for the brain to determine the location of sound sources in the everyday world.”

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To test this hypothesis the team are using two interacting approaches. The first involves experiments examining the role of auditory spatial cues and their interaction with head-position cues when listeners and/or sound sources move. The second is concerned with cues used to determine the position of the head (or body, or eyes) when listeners and/or sound sources move. This facility is shedding light on a much under-researched topic.

**A VERY MODERN APPROACH**

This research is important for understanding the basic concepts of how we perceive and process dynamic auditory cues, though this relatively new premise has proven difficult to tease out in practice. It is clear that complex neuronal computation is at work to process the various cues, so discoveries in this field have the potential to impact on other areas of neural computation. The relevance of the work has also expanded as virtual reality (VR) has developed. The requirement of VR developers and programmers to produce virtual auditory scenes to accompany the visual elements (within the strict computational constraints imposed by available technology) is a unique driver to this field of research.

"The vast majority of what is known about sound source localization comes from studies in which the listener and the sound source were stationary," says Prof Yost, "I decided that a study of sound source localization when listeners and sound sources move might be a valuable research undertaking."

**DETECTIVE TOOLS**

With generous funding from Arizona State University, a specialised facility was constructed to empirically investigate these phenomena, believing to the first of its kind in the world. A chair which enables listeners to be immobilised and precisely rotated, sits within an array of loudspeakers in an echo-reduced room so that sounds can be presented from multiple sources or themselves rotate about the subject.

Alongside new psychophysical procedures, which have been developed to study sound source localization when listeners and sound sources can be manipulated independently, this facility is shedding light on a much under-researched topic.

We assume and hope others, who do health care research, will follow up on our work - Prof William Yost

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**Auditory Systems**

**REMOTE LOCALIZATION OF AUDITORY SOURCES USING IMPLANTED ELECTRODES**

Hans Wallach published three papers in a row in the late 1930s and they have been usually cited in terms of the role head motion might play in reducing front-back sound source localization confusions. While the papers require some effort to understand, they are full of incredible insights regarding sound source localization. It just took a while to discover those insights.

What are the main challenges in investigating neural computation of auditory cues?

There are several: First, the differences between the sounds arriving at two ears that are partially responsible for sound source localization can be incredibly small, e.g., a few microseconds. Second, reflections from surfaces (e.g., the ground or walls) near a listener can adversely affect the ability to localize a sound source, so ideally you want to reduce those reflections as much as possible.

Most of the time, multiple systems provide simultaneous information about head position. It takes a lab like ours to be able to study one potential head-position cue at a time.

**What has the funding from Oculus VR impacted your research?**

The Oculus VR funding compliments our NIH funding in providing sufficient resources to run the lab. Our interaction with first-hand VR opens up new possible applications of what we are doing, those beyond dealing with issues of sensory impairments which is of interest to the NIH.

**How does movement of listener and sound source enable you to probe neural computation?**

First, as sound has no dimensions of space and there are no auditory spatial receptors source localization can be presented from multiple sources moving in different directions. This research is important for understanding the processing of auditory spatial cues. This work is uncovering a new understanding of the basic systems underlying sound source localization, vitally important to those who work to restore hearing impairments. Prof Yost is aware of the potential applications of this research, saying, “we assume and hope others, who do health care research, will follow up on our work.” But the real driver for him is the thrill of discovery, investigating a mystery which stretches back into the last century and beyond, to the core of our perception of the world around us.