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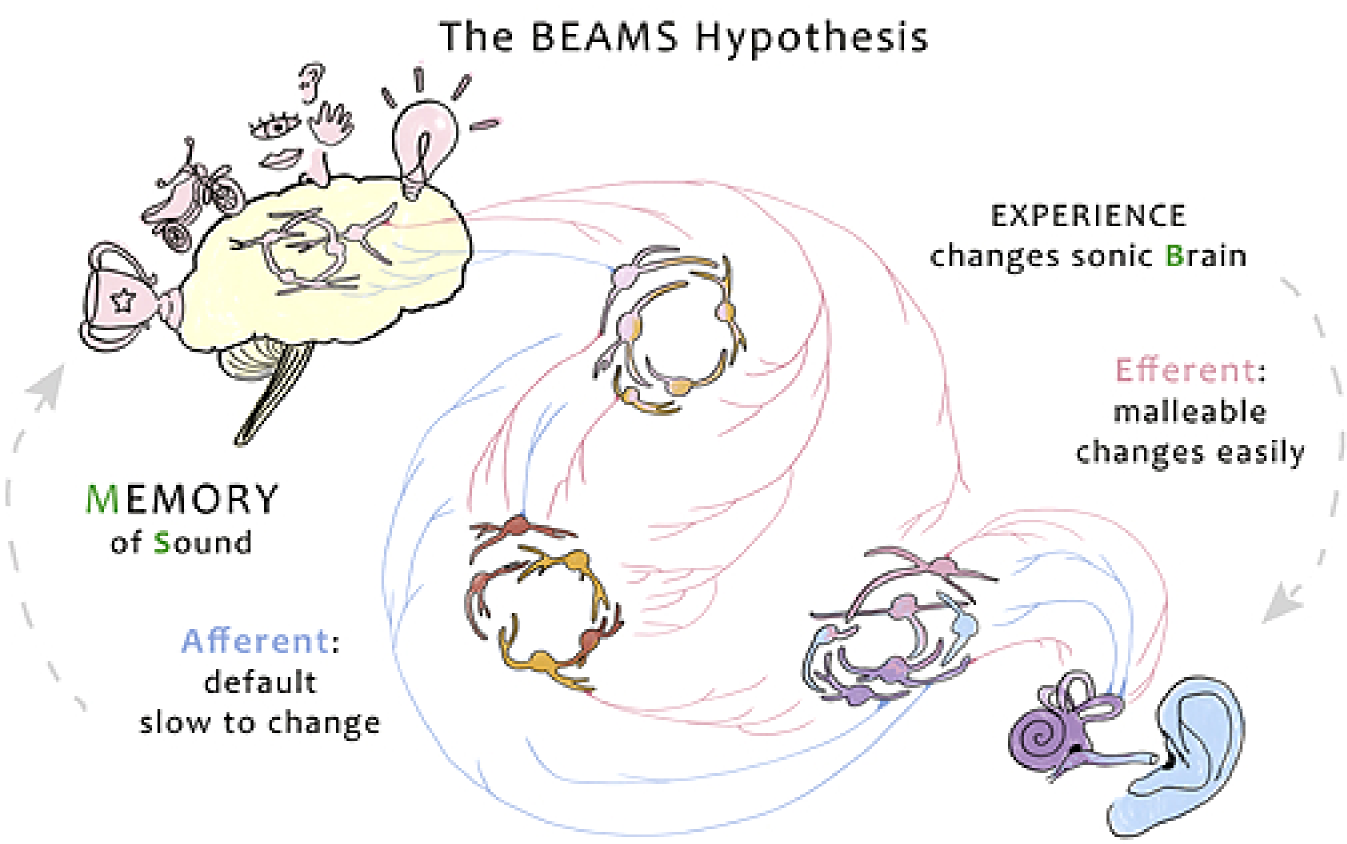

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Memory for sound: The BEAMS Hypothesis [Perspective][☆,☆☆]

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For a musician, keen tuning to the pitch and timbre of one's instrument is important. For a bilingual, the distinctive pitch, phonetic repertoire, and cadence of one's two languages are important. For an auto mechanic, the sounds coming from an engine in distress are important. The listening brain must respond optimally to the sounds a listener cares deeply about. The sounds of music, language, or pistons become prioritized over time—to become processed automatically, rapidly, and preferentially *by an ear-to-brain system tuned to a default state, informed by efferent-modulated brain-to-ear plasticity*. In other words, the brain shapes how the ear hears.

We used to think hearing occurred hierarchically, from ear to brain, and that all the real work, such as forming memories, got done in the cortex. Now we can think differently. Neural response properties are flexible right down to the hair cells of the cochlea. It is no accident that there are three times more outer (efferent) than inner (afferent) hair cells. The outer hair cells listen to what the brain has to say and inform the ear accordingly. Alterations occur first in more flexible central structures, with the "message" of increased stimulus importance delivered, over time…from non-primary auditory cortex to primary cortex (Atiani, et al., 2014) and beyond, through an extensive efferent infrastructure. Indeed, if the efferent system is disrupted, reorganization in more peripheral structures is abolished (Bajo, et al., 2010).

Not every part of the auditory system demonstrates plasticity with the same ease. It takes relatively little training to change neural activity in auditory cortex. The auditory cortex changes moment to moment to accomplish the task at hand. Other parts of the hearing brain are more resistant to change. It would be chaos if auditory neurons systemwide changed constantly. Stability is as important as plasticity. The more rigid the structure—usually the more peripheral—the more permanent the change. If I change my phone's ring tone, I need the importance of that new melody to manifest itself right away or I will miss some calls. But it is probably not particularly advantageous for my eighth nerve to permanently alter its response properties to the ring-tone version of the opening bass guitar riff of "My Sharona" because I may change my ring tone on a whim. Some memories for sound, like those of language, are more important than others.

Afferent change with learning

The brain-to-ear system sculpts the ear-to-brain system. With repeated experience a new default state is reached; a *newly altered cascade of afferent neural activity is launched* to a given sound. This default auditory infrastructure provides a runway onto which incoming sounds land, a mechanism for us to best "hear" what is most important—like the sounds of pistons or music or a second language. This infrastructure then houses the basis of predictive coding models of auditory processing (Carbajal and Malmierca, 2018). The afferent auditory pathway is slowly, progressively, and fundamentally altered in accordance with one's life experience with sound up to that moment, much as the earth's geography is slowly altered over time by plate tectonics, weathering, and erosion. Generally speaking, the more peripheral the structure,

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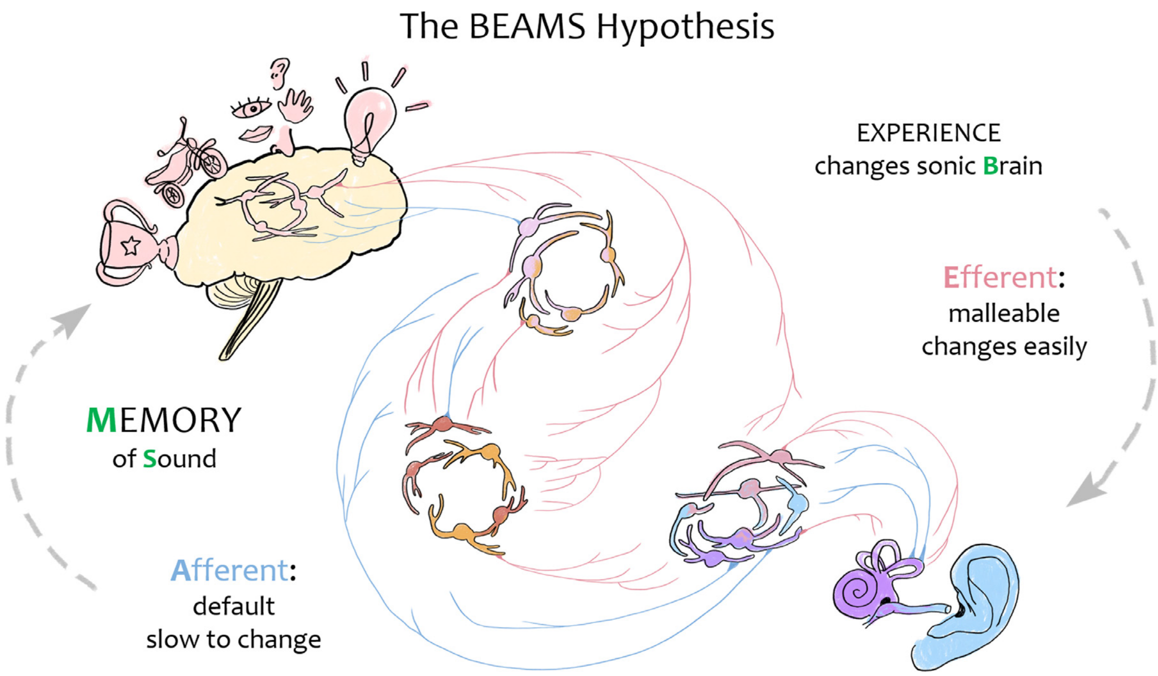

Fig. The BEAMS hypothesis. The dynamic auditory Brain, via Efferent influence, attains a new default Afferent state that represents Memory for Sound. The neural interaction embodied by the BEAMS framework supports the *binding* of how we move, think, feel, and connect all our senses. Illustrated in partnership with Katie Shelly.

the more motivation, attention, and time it takes to alter default response properties.

Memory

Central structures require less experience to exhibit representational plasticity, housing our short-term memory. The more peripheral structures, which change only after long-standing learning and experience, likely store our most deeply ingrained long-term memories for sound. In this view, each part of our auditory brain retains traces of our sonic history. The BEAMS framework describes the auditory Brain, via Efferent influence, attaining a new default Afferent state that represents the Memory of Sound (see fig.). Said another way, robust memory for sound exists in response properties of afferent auditory pathway neurons.

The process of sound-to-meaning learning begetting an alteration in afferent sensory processing exists along a continuum. It is neither discrete, binary, nor inflexible. It is a seamless process, not a concatenation of discrete steps. Instead of thinking of efferent and afferent as extremes, we can think of them as distinct but not ultimately separate, a process, a fabric.

How we think about sound, how we feel about sound, the movements that accompany sound, and what our other senses are telling us, play key roles in shaping our auditory infrastructure (Kraus and White-Schwoch, 2015; Kraus, 2021). Experience with sound leaves a legacy on this massively interconnected auditory system. Each of us—through experience with the sounds that matter most to us—forges a unique sound processing foundation that formats our own sonic world. Our memories then, implicit and explicit, weave together who we are, our consciousness.

Author statement

Nina Kraus is the sole author of this manuscript.

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