Rhythmic Auditory Entrainment

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Introduction and Terminology

Entrainment, in the chronobiological sense, refers to a dynamic altering of an "internal" periodic process or action generated by an organism in the presence of a periodic stimulus produced by another entity. *Rhythmic auditory entrainment* (RAE) is a specific case of entrainment, in which an acoustic stimulus capable of *beat induction* (during which a stable perceptual pulse emerges from a complex rhythmic surface) causes the internal periodic process to respond by adapting, and potentially *synchronizing*, to the emergent pulse.

The external periodic stimulus used in most RAE paradigms is usually straightforward to describe (although varying in complexity from a metronome to a symphony). The internal periodic process, however, can be translated into numerous outputs; for example: electrical activity generated by populations of neurons in the brain; the influence of the autonomic nervous system over target end organs; and the execution of motor gestures (tapping, clapping, or walking), during which the related concepts of *sensorimotor synchronization* and *rhythmic auditory stimulation* are employed.

Theoretical perspectives

Theoretical accounts of entrainment, developed in the later part of the twentieth century and refined in the twenty-first, are underpinned by (1) psychologically informed theories of musical time (accent, pulse, rhythm, meter), (2) dynamical systems theory, (3) motor control theory, and (4) insights gained from the burgeoning field of neuroscience. Entrainment-based accounts of timing differ from interval-based accounts of timing in how each conceptualizes the internal "clock" used to mark and measure time: an *hourglass* for interval-based timing; an *oscillator* for entrainment-based timing.

The physical properties of oscillators are used to model how internal processes (neural, attentional, physiological) become entrained by external stimuli. Thus, oscillators (1) have a natural, intrinsic periodicity (not unlike to cardiac "pacemaker" cells); (2) are self-sustaining, persisting over time (and in the face of slight perturbations in an external rhythm); (3) exhibit the ability to adapt to systematic changes in an external rhythm via a correction of their phase and period; and (4) resonate at hierarchically nested time scales. Not coincidentally, these properties share a number of common features with music itself: an intrinsic "pulse", flexible adaptation (within limits) to perturbations of that pulse (e.g., expressive timing), and the reinforcement of that pulse at multiple time scales (e.g., eighth note, quarter note, etc.).

Experimental investigations

Experimental approaches seeking a better understanding of the neurological, psychological, and biomechanical underpinnings of RAE have explored a diverse combination of task paradigms, dependent measures, and study populations.

Task paradigms are used to study RAE in a "controlled" environment, and include (1) listening "passively" to simple metronomes or complex music; (2) making judgments about alterations in pitch or timing within an auditory sequence or between a pair of sequences; and (3) performing a motor synchronization-continuation task, in which a listener attempts to maintain a motor sequence after the rhythmic auditory stimulus is removed.

Dependent measures are used to quantify how listeners respond to RAE, and include (1) reaction times; (2) the temporal structure of inter-tap or inter-step intervals; (3) electromyographic (EMG) activity recorded from muscles performing a motor task; (4) cardiorespiratory responses (heart rate, heart rate variability, respiration rate); (5) spectral power within different frequency bands in continuous electroencephalography (EEG); (6) event-related potentials derived from an EEG, associated with specific moments or events in a presented stimulus; (7) blood-oxygen-level-dependent changes measured via functional magnetic resonance imaging (fMRI); and (8) patterns of neural "network activation", quantifying the degree of temporal correlation in fMRI signal among brain regions.

Study populations are used to compare how individuals who share a particular trait or condition respond similarly (to each other) and differently (compared to individuals who do not share that particular trait or condition). Frequently studied distinctions include (1) age (children versus adults), (2) musical expertise (nonmusicians versus musicians), (3) disease status (patients versus controls), and (4) phylogeny (human versus nonhuman primates; vocal-learning versus non-vocal-learning species).

Therapeutic applications

A particularly well-studied effect of RAE on the brain—and its concomitant effect on behavior—can be found among patients with Parkinson's disease (PD). The cardinal symptoms of PD involve disruptions in the coordinated control of movement, stemming from a degeneration of dopamine-secreting cells in the basal ganglia deep within the brain. When presented with an auditory rhythm, however, the task of motor synchronization recruits a different set of neural structures in PD than are used when attempting to self-generate that same coordinated movement. The brain's ability to make use of alternative neural pathways under certain conditions (here, entrainment to a rhythmic auditory cue), resulting in what would otherwise be considered paradoxical behavior, is a hallmark of *neuroplasticity*.

RAE-based motor rehabilitation strategies have also been explored in other patient populations, including Alzheimer's disease, Huntington's disease, multiple sclerosis, and spinal cord injury. A form of motor entrainment (i.e., rhythmic tapping) is also hypothesized to play a role in the facilitative effects of *melodic intonation therapy* on the rehabilitation of language impairments acquired developmentally (e.g., nonverbal children on the autism spectrum) or as the result of brain injury (nonfluent aphasia). While the behavioral changes associated with RAE-based therapeutic activities across these different conditions are likely driven by distinct neural architectures, neuroplasticity remains at the core.

Conclusion

RAE offers a multi-focal lens through which to observe the brains and behaviors of humans (and a few other species) as they dynamically engage with a special kind of auditory environment. Future research will benefit from a rich toolbox of task paradigms and dependent measures to further sharpen this lens, and in so doing, to better understand the when, how, why, and for whom RAE-based therapeutic interventions are effective.

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See also: Attention; Melodic intonation therapy; Oscillatory neural activity; Parkinson's disease; Physiological responses; Rhythm; Synchronization; Tactus and pulse.

Further Readings

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