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Sound Case for Enrichment. Focus on “Environmental Enrichment Improves Response Strength, Threshold, Selectivity, and Latency of Auditory Cortex Neurons”

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“Use it or lose it.” It is common wisdom that a healthy body and mind require physical and mental exercise. Numerous studies suggest that “exercising” an animal’s nervous system by housing it in an environment “enriched” with additional sensory and motor cues has beneficial effects on a wide range of morphological, molecular and physiologic features of the brain. Enriched environments, usually targeting sensorimotor modalities, have been shown to improve cognitive function (Kobayashi et al. 2002; Rosenzweig and Bennett 1996) and to facilitate recovery from injury or stroke (Johansson 2000). Engineer and coworkers (this issue, p. 73–82) have now added a new dimension to the typical enrichment scenarios. They exposed animals to an enriched aural environment consisting of an intricate and varied blend of artificial and natural sounds. Consequently they were able to investigate the impact of a truly multi-modal, “generalized” enriched environment on auditory cortex neurons in young and mature rats.

In a typical enriched housing experiment, animals, usually rats, live in what the experimenter believes must be an animal paradise. In contrast to the standard housing, where the cages contain just litter material, an enriched environment is filled with tunnels, pipes, toys, and building material. Enrichment is believed to present animals with increased sensory, motor, and cognitive demands and to reinforce a variety of behaviors including learning, social interactions, physical activity, and exploration. The close association between the challenges produced by an enriched environment and sensorimotor performance stimulated a number of studies that centered on the investigation of sensorimotor cortex. For example, cortical receptive fields of primary somatosensory neurons narrowed and cortical maps enlarged and became more orderly (Coq and Xerri 1998). Strikingly, this form of cortical remodeling extends well into old age. Housing aged animals under enriched environmental conditions delayed and ameliorated age-related deterioration of somatosensory cortex (Coq and Xerri 2001; Godde et al. 2002). Beneficial effects were also reported for adult visual cortex, where environmental enrichment resulted in sharper orientation tuning (Beaulieu and Cynader 1990). But until now, enriched environments were essentially silent. Because of this, it made no sense to record from auditory neurons in enriched animals, and little was known about a possible impact of acoustic enrichments on auditory cortical processing.

By recording evoked potentials from awake rats and extracellular action potentials from anesthetized rats, Engineer and coworkers (2004) demonstrated a remarkable capability of auditory cortical neurons to adapt to the new sound-enriched environment. They found that response strength of auditory cortical neurons increased dramatically, mostly through recruitment of more neurons. Also neurons became more sensitive to quiet sounds and developed higher selectivity for sound frequency.

How can these changes be explained? During the last several years, it has been clearly demonstrated that major factors driving cortical plasticity are use and training. Auditory practice and training produce parallel changes in perception and receptive fields and maps of auditory cortex, and these effects occur selectively in the frequency range relevant for the training task (Recanzone et al. 1993). In contrast, the remodeling of auditory cortex induced by the auditory enrichment provided by Engineer and coworkers (2004) lacked this frequency specificity and occurred across the entire frequency map in auditory cortex. Conceivably, while their acoustic environment contained a large number of relevant sounds linked to specific types of behavior, it also contained a sound mixture mimicking natural acoustic scenes.

In addition to use and training, the statistics of input signals are powerful driving forces for cortical remodeling. Many studies have demonstrated that cortical reorganization and parallel changes in perception can be evoked by variation of input statistics alone without invoking task training, or cognitive factors such as attention or reinforcement, provided the statistics are sufficiently altered (cf. Dinse and Böhmer 2002; Dinse et al. 2003). It is therefore conceivable that the acoustic enrichment induces plastic changes of auditory cortical processing due to the profound changes in the input statistics of the acoustic material.

Engineer and coworkers (2004) also explored the time required to induce and to recover from the acoustic enrichment effects. By exposing rats sequentially to a standard or to an enriched environment, Engineer and coworkers (2004) were able to track the time course of cortical changes and found that the timescale was unexpectedly rapid. Environment-induced changes occurred in <2 wk, supporting the notion that rapid remodeling of cortical processing is ongoing throughout life. Although auditory cortex processing improves from enriched housing within 2 wk, these beneficial effects are lost within a week after return to standard housing. On a more general level, their finding indicate that the acquired gain of cortical processing cannot be frozen and preserved beyond the driving periods but must be renewed on a very short time scale all over again.

While there are many papers examining the impact of enriched housing, there are few conventions about how best to do so. While many studies use quite large cages allowing for the construction of complex three-dimensional environments, others use conventional two-dimensional cages “enriched” with

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toys and tunnels. Conceivably, the amount of enrichment provided differs significantly, and this lack of standards makes comparisons across studies difficult. One can imagine that research on the influence of enriched environments will benefit from the introduction of clearly defined criterions, and such regulations should include sounds as used by Engineer and coworkers to establish a real generalized enriched housing.

A couple of years ago, a major dogma in neurosciences was overturned: previously, neurogenesis was assumed to occur almost exclusively during development, now neurogenesis is known to be possible not only in adult but even in aged brains (Kempermann et al., 1997 1998). Intriguingly, in these studies exercise and housing under enriched environmental conditions were particularly effective in driving neurogenesis. Accordingly, the dramatic increase in the efficacy of auditory processing demonstrated by Engineer and coworkers (2004) might provide an attractive starting point for further study of the relationship between structural changes and emerging cortical processing advantages. In addition, changes in auditory processing evoked by brief periods of living in acoustically enriched environments must almost certainly have an impact on auditory perception, which would be very interesting to validate. In that sense, the experiments by Engineer and coworkers may trigger new experiments on environment-induced plasticity, both in the direction of underlying pharmacological or structural mechanisms, and in the direction of emerging properties of altered perception.

REFERENCES

Beaulieu C and Cynader M. Effect of the richness of the environment on neurons in cat visual cortex. I. Receptive field properties. *Brain Res Dev Brain Res* 53: 71–81, 1990.

Coq JO and Xerri C. Environmental enrichment alters organizational features of the forepaw representation in the primary somatosensory cortex of adult rats. *Exp Brain Res* 121: 191–204, 1998.

Coq JO and Xerri C. Sensorimotor experience modulates age-dependent alterations of the forepaw representation in the rat primary somatosensory cortex. *Neuroscience* 104: 705–715, 2001.

Dinse HR, and Böhmer G. Plastic-adaptive properties of cortical areas. In: *Cortical Areas: Unity and Diversity: Conceptual Advances in Brain Research,* edited by Schüz A and Miller R. London: Taylor and Francis, 2002, p. 311-348.

Dinse HR, Ragert P, Pleger B, Schwenkreis P, and Tegenthoff M. Pharmacological modulation of perceptual learning and associated cortical reorganization. *Science* 301: 91–94, 2003.

Engineer ND, Percaccio CR, Pandya PK, Moucha R, Rathbun DL, and Kilgard MP. Environmental enrichment improves response strength, threshold, selectivity, and latency of auditory cortex neurons. *J Neurophysiol* 92: 73–82, 2004.

Godde B, Berkefeld T, David-Jürgens M, and Dinse HR. Age-related changes in primary somatosensory cortex of rats: evidence for parallel degenerative and plastic-adaptive processes. *Neurosci Biobehav Rev* 26: 743–752, 2002.

Johansson BB. Brain plasticity and stroke rehabilitation. The Willis lecture. *Stroke* 31: 223–230, 2000.

Kempermann G, Kuhn HG, and Gage FH. More hippocampal neurons in adult mice living in an enriched environment. *Nature* 386: 493–495, 1997.

Kempermann G, Kuhn HG, and Gage FH. Experience-induced neurogenesis in the senescent dentate gyrus. *J Neurosci* 18: 3206–3212, 1998.

Kobayashi S, Ohashi Y, and Ando S. Effects of enriched environments with different durations and starting times on learning capacity during aging in rats assessed by a refined procedure of the Hebb-Williams maze task. *J Neurosci Res* 70: 340–346, 2002.

Recanzone GH, Schreiner CE, and Merzenich MM. Plasticity in the frequency representation of primary auditory cortex following discrimination training in adult owl monkeys. *J Neurosci* 13: 87–103, 1993.

Rosenzweig MR and Bennett EL. Psychobiology of plasticity: effects of training and experience on brain and behavior. *Behav Brain Res* 78: 57–65, 1996.