

## EDITORIAL

## Inducing Brain Growth by Pure Thought: Can Learning and Practice Change the Structure of the Cortex?

In this issue of the *American Journal of Neuroradiology* (AJNR), the cortical gray matter attenuation in the inferior frontal and parietal regions of mathematicians is found to be increased compared with that of control subjects (Aydin et al). Cortical attenuation also correlates with time spent as an academician, suggesting that this is experience-dependent structural plasticity. The surprising discovery that the brain can actually change its shape within weeks in response to certain mental and physical stimuli differs from the traditional concept that brain morphology must remain unchanged, except as a result of neurologic disorders. Although it was previously known that plasticity leads to functional changes and new connections at the microscopic level, it was not until recently that stimuli-induced macroscopic changes in the brain were observed. A new and powerful technique, voxel-based morphometry, has now made it possible to evaluate changes in brain morphology in vivo and to correlate these changes with experience-related effects and brain function.

Historically, considerable attention has been given to the effect of knowledge and intelligence on brain size and shape, but all of these efforts have been completely unsuccessful. In the 19th century, multiple attempts to map personality attributes by observing bumps on the head (phrenology) were thoroughly discredited. It is only now that researchers have finally demonstrated that certain parts of the brain are function-specific and may grow with learning. Indeed, the expression "la bosse des maths" could now refer to the "bump for mathematics" described in this paper (Aydin et al).

The recent studies using voxel-based morphometry indicate that persons with particular skills developed for years have a thicker cortex. Specific anatomic alterations of the human brain have been observed in functional brain regions in response to various tasks involving music, navigation, language, and activity. In mathematicians, the increased cortical attenuation observed may be a result of their greater skills, but it may also be a cause. The correlation of cortical-attenuation difference with time spent as an academician suggests that this difference is an experience-dependent type of structural plasticity. This form of plasticity generally reflects learning and practice but is not necessarily the type that changes the makeup of the cortex. If the mechanisms producing learning-induced cerebral alterations produce macroscopic changes, what are the corresponding changes at the microscopic level? Moreover, if there are changes at the microscopic level, will they be manifested at the macroscopic level?

In terms of macroscopic changes, previous anatomic studies have reported increased attenuation of synapses, glial cells, and capillaries in the motor cortex. Biochemical studies have also shown that neurotrophic factors can play an essential role in affecting neuronal development. Nerve growth factor and brain-derived neurotrophic factor affect both neuronal survival and activity-related plasticity. Neurogenesis with in-

creased neurons derived from basic stem cells has been documented in the hippocampus. In a study by Maguire et al,<sup>1</sup> increased cortical gray matter was demonstrated in the right posterior hippocampus of London taxi drivers compared with control subjects, and this correlated with time spent as a taxi driver. These changes were thought to be secondary to increased memory storage with internal changes in the hippocampus. However, the additional spatial information associated with increased posterior hippocampal volume was also thought possibly to affect adversely new spatial information in the anterior hippocampus. It has thus been theorized that too much plasticity may not always be good.<sup>2</sup> In a study involving medical students studying for their medical examination, the gray matter in the posterior and lateral parietal cortices was found to be significantly increased.<sup>3</sup> Similarly, changes have been observed in the Broca area and Heschl gyrus of musicians compared with nonmusicians. These results were thought to be use-dependent adaptation caused by musical training.

In terms of microscopic changes, mechanisms such as modulation of synaptic transmission may also lead to brain plasticity. Establishment of new synaptic contacts has been described as a possible neural mechanism mediating long-term cortical reorganization.<sup>4,5</sup> On the other hand, unmasking of existing but latent corticocortical connections could underlie the shorter term reorganization observed after deafferentation.<sup>6</sup> Reduced local inhibition and changes in synaptic efficacy may mediate connectional unmasking, with reduced gamma-aminobutyric acid (GABA)ergic function, possibly contributing to short-term cortical plasticity induced by deafferentation.<sup>6</sup> Although GABAergic-pathway modulation is rapid and short-term, it would not be expected to cause significant learning-related morphologic changes.

Other imaging techniques have also been used to further investigate learning-induced cerebral changes. In a previous issue of the AJNR,<sup>7</sup> MR spectroscopy was used to evaluate cerebral metabolite changes in musicians. *N*-acetylaspartate (NAA) concentration in the left planum temporale of musicians was found to be increased compared with that in nonmusicians, and this increase correlated with the total duration of musical training. Although these changes may possibly be attributed to increased neuronal attenuation, increased NAA may also result from the increased size of neurons, alterations in synaptic attenuation, and changes in concentration of the other smaller metabolites under the NAA peak. In patients with impaired mathematic ability due to Gerstman syndrome or acalculia, spectroscopy demonstrated a focal decrease in NAA in the left posterior temporoparietal region,<sup>8</sup> indicating an alteration of neuronal attenuation or size. A decrease in creatine suggested impaired regional cellular energetics of the neurons or a decrease in glial cells. Diffusion-tensor imaging has also been used to evaluate brain changes resulting from learning tasks. In studies evaluating the effect of practicing piano on the brain,<sup>9</sup> a correlation was found between practicing and increased fiber tract organization. MR blood volume maps were also used to examine the effect of exercise on the brain. In a recent *Proceedings of the National Academy of Science U S A* publication,<sup>10</sup> exercise-induced neurogenesis was described and found to target the dentate gyrus, a subregion that is important for memory and implicated in cognitive aging.

The exciting recent discovery that the brain can alter its shape and size during a period of weeks in response to the acquisition of new skills has led to valuable new insights on the structural response of the brain to learning and practice. New “functional” brain mapping techniques can now allow us to further evaluate morphologic brain changes in response to learning, development, disease, and recovery following injury. Future advances in imaging should also lead to a better understanding and use of the mechanisms underlying structural plasticity.

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