Remodeling the Brain With Behavioral Experience
After Stroke

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Background and Purpose—Behavioral experience can drive brain plasticity, but we lack sufficient knowledge to optimize its therapeutic use after stroke.

Methods—We outline recent findings from rodent models of cortical stroke of how experiences interact with postinjury events to influence synaptic connectivity and functional outcome. We focus on upper extremity function.

Results—After unilateral cortical infarcts, behavioral experiences shape neuronal structure and activity in both hemispheres. Experiences that matter include interventions such as skill training and constraint-like therapy as well as unguided behaviors such as learned nonuse and behavioral compensation. Lateralized behaviors have bihemispheric influences. Ischemic injury can alter the sensitivity of remaining neocortical neurons to behavioral change and this can have positive and negative functional effects.

Conclusions—Because experience is ongoing in stroke survivors, a better understanding of its interaction with brain reorganization is needed so that it can be manipulated to improve function and prevent its worsening. (Stroke. 2009; 40[part 2]:000-000.)

Key Words: learned nonuse ■ motor cortex ■ motor rehabilitation ■ synaptic plasticity

Behavioral experience can drive dendrites to grow and regress, synapses to change in efficacy, vasculature and glia to be modified, and, sometimes, neurons to be added or lost.1 It is at work continuously and across the lifespan. It is safe to assume that it will be a factor in stroke recovery. However, what pragmatic use can we make of this? Currently, experience, in the form of physical therapy and rehabilitation, is the major tool available for treatment in the chronic poststroke period, but we lack the knowledge required to optimize its use alone or in combination with other treatments. Animal research is beginning to reveal how behavioral experience interacts with degenerative and regenerative cascades after stroke onset. This research suggests that the nature and timing of behavioral experiences can have a major influence on brain reorganization with good, bad, and mixed consequences for functional outcome.

Shaping Postinjury Experience
Brain damage can impair and enhance experience-dependent plasticity depending on the region and time window after the injury.1,2 We have found that, in rats with unilateral ischemic sensorimotor cortical lesions, the contralesional motor cortex, in concert with transcallosal degenerative changes, becomes more sensitive to behavioral experiences of the ipsilesional “unaffected” forelimb (Figure).3 After these lesions, rats spontaneously begin to rely more on the unaffected forelimb and this drives the growth of synapses and dendrites in the contralesional cortex. More synapses also have ultrastructural characteristics of enhanced efficacy.1 These effects occur more robustly than those resulting from similar asymmetrical forelimb experience in intact animals. Thus, this is an example of injury-induced enhancement of experience-dependent plasticity.

The facilitation of plasticity in the contralesional cortex may enhance an animal’s ability to learn compensatory ways of using the unaffected forelimb. Consistent with this, even in the presence of significant impairments in the “unaffected” limb, some types of skill acquisition with this limb are enhanced, an effect that is lesion size- and time-sensitive.3,4 However, there is a cost for the impaired limb. When rats were trained to use the unaffected limb for skilled reaching in the weeks after injury, it reduced neuronal activation (as assayed by FosB/ΔFosB expression) in the remaining peri-infarct motor cortex, a region that is important for recovery of the impaired limb.5 This was linked with slowed recovery of skilled motor function in the impaired limb and an exacerbation of its disuse.3,5 Thus, experience with the unaffected limb has bihemispheric neuronal effects that can simultaneously enhance function in the unaffected limb and worsen function in the impaired limb.

Humans with cerebral stroke have altered interhemispheric excitability and abnormal influences of the intact hemisphere...
over the stroke-affected hemisphere. Our animal research suggests that experience-dependent plasticity could contribute to unbalanced interhemispheric activity. Attempts to improve impaired limb function, for example using constraint-induced movement therapy, may have to overcome some neuronal changes driven by experience with the unaffected limb. Like with humans, anesthetization of the unaffected limb in rats transiently improves function in the impaired limb. Unfortunately, it can sometimes be detrimental to restrict use of the unaffected limb too intensely early after a stroke. Thus, we need to learn how to safely shape early behavioral experience to prevent it from driving brain plasticity in a suboptimal direction for bilateral function.

**Enhancing Neurorehabilitation**

Behavioral improvements, neuronal structural plasticity, and brain functional changes can be driven by targeted poststroke behavioral rehabilitative therapies in humans and animal models as reviewed previously. For example, targeted training of the impaired upper extremity in motor skills enhances motor map reorganization near cortical infarcts and improves motor function. A limitation of motor rehabilitative training is that it can take much time and effort to greatly improve function and, even then, it may be far from sufficient to normalize it. It might be enhanced by its combination with therapies that facilitate its neuroplastic effects. An approach that we and others have investigated is combining motor training with motor cortical stimulation (CS). In rats and monkeys with motor cortical ischemic lesions, daily training in skilled reaching results in greater functional improvements when administered concurrently with CS. The CS was delivered epidurally or subdurally in the peri-infarct cortex at levels subthreshold to that needed to evoke movements. CS might

![Figure. Behavioral interventions change the course of neural reorganization after sensorimotor cortical infarcts.](image-url)
help to activate remaining motor cortical neurons so that they
can participate in the synaptic plasticity underlying motor
relearning. Consistent with this possibility, CS with motor
training increases dendrites and synapses (Figure D),
and potentiates motor cortical-evoked
potentials. Currently, it is unclear whether the benefits of
epidural CS can be reproduced in human stroke survivors.
However, a broader implication of these animal studies is that
facilitation of training-induced plasticity may greatly improve
functional outcome after cortical ischemia.

Conclusion
Experience is a potent factor in brain restoration and reorga-
nization that can both improve and impair function. A more
detailed knowledge of experience–injury interactions is
needed to tailor manipulations of experience for time, inju-
ries, and individual characteristics in a manner that optimizes
restorative brain plasticity and functional outcome.

Acknowledgments
We thank Drs. S. Cramer and R.J. Nudo for their review of
the manuscript.

Sources of Funding
The research overviewed here was supported by the National
Institute of Neurological Disorders and Stroke grants RO1
NS056839 and U54 NS048126.

Disclosures
None.

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Stroke, published online December 8, 2008;
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2008 American Heart Association, Inc. All rights reserved.
Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/early/2008/12/08/STROKEAHA.108.533653.citation

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