Neural Plasticity (PSY 335)

Steven St. John ❄ Spring, 2006 💻 Office: PSY 122 ☎ Phone: 7676

Overview

This course was motivated by findings that indicate that the brain is a self-organizing structure that is constantly altering its own structure throughout life. Psychobiology courses often stress the role of our brains and nervous systems in causing our behavior, without a full appreciation of how our behavior and environment feed back and affect the structural organization of our brains. Without question, neural plasticity is one of the hottest areas of psychological and neuroscientific research; most of the readings in the course are drawn from the past five years.

The first part of the course will focus on development of the brain, because plasticity in some sense can be viewed as the operation of developmental events in adulthood. The second part of the course will focus on plasticity within and between sensorimotor systems. Finally, we will examine the role of plasticity in overcoming brain damage.

Evaluation

Midterm Paper (30%). Due: Thursday, March 9. Write a 6-8 page paper on any one research article from the papers covered thus far. A "research article" means a non-review article; it must be an empirical report. The paper requires 3 components: a summary of the main article, a critique of the main article, and a follow-up research proposal. (If the format looks familiar it is modeled after the Psychology Junior Qualifying Exam.) Details to follow.

Brief Review Article (30%). Due: Tuesday, April 4. There are far too many topics to cover in this course in 13 weeks! For this assignment, I'd like you to imagine we had another week, and that you've been assigned to add a new topic to the syllabus. For example, I would have liked a session of the downside of plasticity (for example, phantom limb pain) or rehabilitation strategies (e.g., constraint-induced movement therapy), but there wasn't time. Other examples would include going deeper in visual or other sensory development, exploring the role of sleep in plasticity, discussing molecular underpinnings of plasticity, reviewing the contribution of neuroethological models to plasticity research (*Aplysia*, barn owl), etc. Choose one of these (or your own) uncovered or minimally covered topics and plan a one or two session reading list (i.e., 4-8 papers). Review these papers for me in an 8-12 page short review modeled after the Trends In Neurosciences or Current Opinion In Neurobiology style reviews.

Final Paper – Grant Proposal (30%). Due: Tuesday, April 25. Write a miniature grant proposal to study some aspect of development or plasticity. You may use the same topic as either of your first two papers if you choose. A grant proposal has 3 sections: Specific Aims, Background and Significance, and Research Design and Methods. You will propose 3-4 related experiments that follow from some literature that you will review. This paper will probably be 12-20 pages. Details to follow.

Participation (10%). Speak!

Timeline

The following syllabus divides the course into the major topics (left column) and the topics for each day. Readings, denoted by , are keyed to the Reading list at the end of the syllabus. Articles available on the internet are linked to the course web page: http://academic.reed.edu/psychology/courses/stjohn/psy335/. Others are found on library e-reserves.

Review Topics	T 1/24	**Synapses.** You may wish to refresh neural signaling chapters in your Psychobiology text. We will review the basics of synaptic transmission.
	R 1/26	**LTP.** Readings: A review of one form of synaptic plasticity: long-term potentiation. [1-4]
Dynamic Brains	T 1/31	**Brains Grow Like Muscles.** Readings: Experiments in the 1950s and 1960s changed the view of the brain as static and unchanging. [5-10].
Neural Development	R 2/2	**Induction, Patterning, Apoptosis, and Pathfinding.** Some basic principles of neural development. [11-14].
	T 2/7	**Neuron-Target Interactions.** Communication between neuron and target are critical during development and regeneration. [15-18].
	R 2/9	**Developmental Malleability of Cortex.** Is the cortical map specified in our genes, completely by input, or a combination? [19-22].
	T 2/14	**Experiential Effects on Visual Development.** Experience affects the development of the visual system. [23-27].
	R 2/16	**Experiential Effects on Sensory Development.** The shaping of connections by input is ubiquitous in development. [28-32].
Adult Plasticity	T 2/21	**Phrenology again?** The idea that brain areas might grow larger in response to specific aptitudes seems like an old-fashioned idea. [33-35].
	R 2/23	**Micro-phrenology.** Several papers have shown regional reorganization following specific experience. [36-38].
	T 2/28	**Rapidity and Transience of Plasticity.** Plastic changes can be quite dynamic. [39-42].

R 3/2 **Neuromodulators and Plasticity.** Cholinergic and dopaminergic input may be required for some forms of plasticity.

[43-46].

Cross-Modality

T 3/7 **Abilities of the Blind.** Do people deprived of sight truly show an enhancement of other sensory systems?

[47-52]

R 3/9 **Late vs. Early Blind: Are They Different?** Are plastic changes only evident when blindness occurs in childhood? Are Cohen & Kujala agreeing or disagreeing?

[53-57].

T 3/21 **Synesthesia.** The neuropsychological phenomenon of having multiple percepts for sensory stimuli could provide insight into how plasticity works.

[58-61].

R 3/23 **Is Cortex General-Purpose?** Some developmental cross-wiring work, which may relate to both synesthesia and cross-modal plasticity, suggests that cortex obeys its inputs.

[62;63].

T 3/28 **Sensory Interaction.** Can synesthesia and plasticity be explained via normally-existing cross-modal connections?

[64-68]

Neurogenesis

R 3/30 **New Neurons in Hippocampus.** Evidence has existed since 1965, but only in the last 7-8 years have investigators began evaluating the importance of neurogenesis in the adult nervous system.

[69-72].

T 4/4 **Neurogenesis and Learning.** Evidence is beginning to suggest that new neurons may be critical in learning or even in mood.

[73-76].

R 4/6 **Neurogenesis and Brain Damage.** Can new neurons replace those lost due to brain damage?

[77-80].

Neural Damage

T 4/11 **Response of Cortex To Injury.** Damage to the cortex or to structures that send the cortex data can initiate plastic changes in cortex itself.

[81-84].

R 4/13 **Medical Interventions for CNS Injury.** Because of the failure of the mammalian CNS to regenerate after injury, a number of strategies are being tried in order to promote recovery.

[85-88].

Neural Prosthetics

T 4/18 **Brain-Machine Interfaces.** The effectiveness of brain-machine interfaces are undoubtedly aided by plastic processes.

[89-94].

R 4/20 **Prosthetics Redux.** We will watch a video and do course evaluations (if available).

[95;96].

The New Paradigm?

T 4/25 **Plasticity as an organizing theory of brain function.** In a recent review, Pascual-Leone suggests that plasticity should not be treated as a special topic in neuroscience, but rather should be the way we think about all brain processes.

[97;98].

R 4/27 **Class does not meet.**

Readings

1. Malenka RC, Nicoll RA: **Long-term potentiation--a decade of progress?** *Science* 1999, **285:**1870-1874.

2. Toni N, Buchs PA, Nikonenko I, Bron CR, Muller D: **LTP promotes formation of multiple spine synapses between a single axon terminal and a dendrite**. *Nature* 1999, **402:**421-425.

3. Liao D, Zhang X, O'Brien R, Ehlers MD, Huganir RL: **Regulation of morphological postsynaptic silent synapses in developing hippocampal neurons**. *Nat.Neurosci.* 1999, **2:**37-43.

4. Aramakis VB, Metherate R: **Nicotine selectively enhances NMDA receptor-mediated synaptic transmission during postnatal development in sensory neocortex**. *J.Neurosci.* 1998, **18:**8485-8495.

5. Rosenzweig MR: **Environmental complexity, cerebral change, and behavior**. *American Psychologist* 1966, **21:**321-332.

6. Rosenzweig MR, Bennett EL: **Cerebral changes in rats exposed individually to an enriched environment**. *J.Comp.Physiol.Psychol.* 1972, **80:**304-313.

7. Diamond MC, Krech D, Rosenzweig MR: **The effects of an enriched environment on the histology of the rat cerebral cortex**. *Journal of Comparative Neurology* 1964, **123:**111-120.

8. Diamond MC, Law F, Rhodes H, Lindner B, Rosenzweig MR, Krech D, Bennett EL: **Increases in cortical depth and glia numbers in rats subjected to enriched environment**. *Journal of Comparative Neurology* 1966, **128:**117-126.

9. Greenough WT, Volkmar FR: **Pattern of dendritic branching in occipital cortex of rats reared in complex environments**. *Exp.Neurol.* 1973, **40:**491-504.

10. Kolb B, Forgie M, Gibb R, Gorny G, Rowntree S: **Age, experience and the changing brain**. *Neurosci.Biobehav.Rev.* 1998, **22:**143-159.

11. Artavanis-Tsakonas S, Rand MD, Lake RJ: **Notch signaling: cell fate control and signal integration in development**. *Science* 1999, **284:**770-776.

12. Raff M: **Cell suicide for beginners**. *Nature* 1998, **396:**119-122.

13. Tessier-Lavigne M, Goodman CS: **The molecular biology of axon guidance**. *Science* 1996, **274:**1123-1133.

14. Chiang C, Litingtung Y, Lee E, Young KE, Corden JL, Westphal H, Beachy PA: **Cyclopia and defective axial patterning in mice lacking Sonic hedgehog gene function**. *Nature* 1996, **383:**407-413.

15. Schotzinger RJ, Landis SC: **Cholinergic phenotype developed by noradrenergic sympathetic neurons after innervation of a novel cholinergic target in vivo**. *Nature* 1988, **335:**637-639.

16. Buller AJ, Eccles JC, Eccles RM: **Interactions between motoneurones and muscles in respect of teh characteristic speeds of their responses**. *J.Physiol.* 1960, **150:**417-439.

17. Ninomiya Y: **Reinnervation of cross-regenerated gustatory nerve fibers into amiloride-sensitive and amiloride-insensitive taste receptor cells**. *Proc.Nat.Acad.Sci.USA* 1998, **95:**5347-50.

18. Smith DV, Som J, Boughter JD, Jr., St.John SJ, Yu C, Christy RC: **Cellular expression of alpha-gustducin and the A blood group antigen in rat fungiform taste buds cross-reinnervated by the IXth nerve**. *Journal of Comparative Neurology* 1999, **409:**118-130.

19. Lopez-Bendito G, Molnar Z: **Thalamocortical development: how are we going to get there?** *Nat.Rev.Neurosci.* 2003, **4:**276-289.

20. Sur M, Leamey CA: **Development and plasticity of cortical areas and networks**. *Nat.Rev.Neurosci.* 2001, **2:**251-262.

21. Schlaggar BL, O'Leary DD: **Potential of visual cortex to develop an array of functional units unique to somatosensory cortex**. *Science* 1991, **252:**1556-1560.

22. Huffman KJ, Molnar Z, Van Dellen A, Kahn DM, Blakemore C, Krubitzer L: **Formation of cortical fields on a reduced cortical sheet**. *J Neurosci.* 1999, **19:**9939-9952.

23. Hubel DH, Wiesel TN: **Binocular interaction in striate cortex of kittens reared with artificial squint**. *J.Neurophysiol.* 1965, **28:**1041-1059.

24. Blakemore C, Cooper GF: **Development of the brain depends on the visual environment**. *Nature* 1970, **228:**477-478.

25. Pettigrew JD, Freeman RD: **Visual experience without lines: effect on developing cortical neurons**. *Science* 1973, **182:**599-601.

26. Spear PD, Tong L, McCall MA, Pasternak T: **Developmentally induced loss of direction-selective neurons in the cat's lateral suprasylvian visual cortex**. *Developmental Brain Research* 1985, **20:**281-285.

27. Crair MC, Gillespie DC, Stryker MP: **The role of visual experience in the development of columns in cat visual cortex**. *Science* 1998, **279:**566-570.

28. Zhang LI, Bao S, Merzenich MM: **Persistent and specific influences of early acoustic environments on primary auditory cortex**. *Nat.Neurosci.* 2001, **4:**1123-1130.

29. Nakahara H, Zhang LI, Merzenich MM: **Specialization of primary auditory cortex processing by sound exposure in the "critical period"**. *Proc.Natl.Acad.Sci U.S.A* 2004, **101:**7170-7174.

30. Lendvai B, Stern EA, Chen B, Svoboda K: **Experience-dependent plasticity of dendritic spines in the developing rat barrel cortex in vivo**. *Nature* 2000, **404:**876-881.

31. Ronca AE, Alberts JR: **Effects of prenatal spaceflight on vestibular responses in neonatal rats**. *J Appl.Physiol* 2000, **89:**2318-2324.

32. Zou DJ, Feinstein P, Rivers AL, Mathews GA, Kim A, Greer CA, Mombaerts P, Firestein S: **Postnatal refinement of peripheral olfactory projections**. *Science* 2004, **304:**1976-1979.

33. Maguire EA, Gadian DG, Johnsrude IS, Good CD, Ashburner J, Frackowiak RS, Frith CD: **Navigation-related structural change in the hippocampi of taxi drivers**. *Proc.Nat.Acad.Sci.USA* 2000, **97:**4398-4403.

34. Gaser C, Schlaug G: **Brain structures differ between musicians and non-musicians**. *J Neurosci.* 2003, **23:**9240-9245.

35. Hutchinson S, Lee LH, Gaab N, Schlaug G: **Cerebellar volume of musicians**. *Cereb.Cortex* 2003, **13:**943-949.

36. Recanzone GH, Jenkins WM, Hradek GT, Merzenich MM: **Progressive improvement in discriminative abilities in adult owl monkeys performing a tactile frequency discrimination task**. *J.Neurophysiol.* 1992, **67:**1015-1030.

37. Recanzone GH, Merzenich MM, Jenkins WM, Grajski KA, Dinse HR: **Topographic reorganization of the hand representation in cortical area 3b owl monkeys trained in a frequency-discrimination task**. *J.Neurophysiol.* 1992, **67:**1031-1056.

38. Recanzone GH, Merzenich MM, Jenkins WM: **Frequency discrimination training engaging a restricted skin surface results in an emergence of a cutaneous response zone in cortical area 3a**. *J.Neurophysiol.* 1992, **67:**1057-1070.

39. Pascual-Leone A, Wassermann EM, Sadato N, Hallett M: **The role of reading activity on the modulation of motor cortical outputs to the reading hand in Braille readers**. *Ann.Neurol.* 1995, **38:**910-915.

40. Classen J, Liepert J, Wise SP, Hallett M, Cohen LG: **Rapid plasticity of human cortical movement representation induced by practice**. *J Neurophysiol.* 1998, **79:**1117-1123.

41. Butefisch CM, Davis BC, Wise SP, Sawaki L, Kopylev L, Classen J, Cohen LG: **Mechanisms of use-dependent plasticity in the human motor cortex**. *Proc.Nat.Acad.Sci.USA* 2000, **97:**3661-3665.

42. Sawaki L, Boroojerdi B, Kaelin-Lang A, Burstein AH, Butefisch CM, Kopylev L, Davis B, Cohen LG: **Cholinergic influences on use-dependent plasticity**. *J.Neurophysiol.* 2002, **87:**166-171.

43. Conner JM, Culberson A, Packowski C, Chiba AA, Tuszynski MH: **Lesions of the Basal forebrain cholinergic system impair task acquisition and abolish cortical plasticity associated with motor skill learning**. *Neuron* 2003, **38:**819-829.

44. Bao S, Chan VT, Merzenich MM: **Cortical remodelling induced by activity of ventral tegmental dopamine neurons**. *Nature* 2001, **412:**79-83.

45. Kilgard MP, Merzenich MM: **Cortical map reorganization enabled by nucleus basalis activity**. *Science* 1998, **279:**1714-1718.

46. Sachdev RN, Lu SM, Wiley RG, Ebner FF: **Role of the basal forebrain cholinergic projection in somatosensory cortical plasticity**. *J.Neurophysiol.* 1998, **79:**3216-3228.

47. Van Boven RW, Hamilton RH, Kauffman T, Keenan JP, Pascual-Leone A: **Tactile spatial resolution in blind braille readers**. *Neurology* 2000, **54:**2230-2236.

48. Stevens AA, Weaver K: **Auditory perceptual consolidation in early-onset blindness**. *Neuropsychologia* 2005, **43:**1901-1910.

49. Amedi A, Raz N, Pianka P, Malach R, Zohary E: **Early 'visual' cortex activation correlates with superior verbal memory performance in the blind**. *Nat.Neurosci.* 2003, **6:**758-766.

50. Sadato N, Pascual-Leone A, Grafman J, Ibanez V, Deiber MP, Dold G, Hallett M: **Activation of the primary visual cortex by Braille reading in blind subjects**. *Nature* 1996, **380:**526-528.

51. Cohen LG, Celnik P, Pascual-Leone A, Corwell B, Falz L, Dambrosia J, Honda M, Sadato N, Gerloff C, Catala MD, Hallett M: **Functional relevance of cross-modal plasticity in blind humans**. *Nature* 1997, **389:**180-183.

52. Hamilton R, Keenan JP, Catala M, Pascual-Leone A: **Alexia for Braille following bilateral occipital stroke in an early blind woman**. *Neuroreport* 2000, **11:**237-240.

53. Kujala T, Alho K, Naatanen R: **Cross-modal reorganization of human cortical functions**. *Trends Neurosci* 2000, **23:**115-120.

54. Kujala T, Alho K, Huotilainen M, Ilmoniemi RJ, Lehtokoski A, Leinonen A, Rinne T, Salonen O, Sinkkonen J, Standertskjold-Nordenstam CG, Naatanen R: **Electrophysiological evidence for cross-modal plasticity in humans with early- and late-onset blindness**. *Psychophysiology* 1997, **34:**213-216.

55. Cohen LG, Weeks RA, Sadato N, Celnik P, Ishii K, Hallett M: **Period of susceptibility for cross-modal plasticity in the blind**. *Ann.Neurol.* 1999, **45:**451-460.

56. Buchel C, Price C, Frackowiak RS, Friston K: **Different activation patterns in the visual cortex of late and congenitally blind subjects**. *Brain* 1998, **121 (Pt 3):**409-419.

57. Burton H, Snyder AZ, Conturo TE, Akbudak E, Ollinger JM, Raichle ME: **Adaptive changes in early and late blind: a fMRI study of Braille reading**. *J.Neurophysiol.* 2002, **87:**589-607.

58. Grossenbacher PG, Lovelace CT: **Mechanisms of synesthesia: cognitive and physiological constraints**. *Trends Cogn Sci.* 2001, **5:**36-41.

59. Ramachandran VS, Hubbard EM: **Psychophysical investigations into the neural basis of synaesthesia**. *Proc.R.Soc.Lond B Biol.Sci.* 2001, **268:**979-983.

60. Aleman A, Rutten GJ, Sitskoorn MM, Dautzenberg G, Ramsey NF: **Activation of striate cortex in the absence of visual stimulation: an fMRI study of synesthesia**. *Neuroreport* 2001, **12:**2827-2830.

61. Nunn JA, Gregory LJ, Brammer M, Williams SC, Parslow DM, Morgan MJ, Morris RG, Bullmore ET, Baron-Cohen S, Gray JA: **Functional magnetic resonance imaging of synesthesia: activation of V4/V8 by spoken words**. *Nat.Neurosci.* 2002, **5:**371-375.

62. Sharma J, Angelucci A, Sur M: **Induction of visual orientation modules in auditory cortex**. *Nature* 2000, **404:**841-847.

63. von Melchner L, Pallas SL, Sur M: **Visual behaviour mediated by retinal projections directed to the auditory pathway**. *Nature* 2000, **404:**871-876.

64. Gutfreund Y, Zheng W, Knudsen EI: **Gated visual input to the central auditory system**. *Science* 2002, **297:**1556-1559.

65. Kauffman T, Theoret H, Pascual-Leone A: **Braille character discrimination in blindfolded human subjects**. *Neuroreport* 2002, **13:**571-574.

66. Schroeder CE, Foxe J: **Multisensory contributions to low-level, 'unisensory' processing**. *Curr.Opin.Neurobiol.* 2005, **15:**454-458.

67. Shimojo S, Shams L: **Sensory modalities are not separate modalities: plasticity and interactions**. *Curr.Opin.Neurobiol.* 2001, **11:**505-509.

68. Zangaladze A, Epstein CM, Grafton ST, Sathian K: **Involvement of visual cortex in tactile discrimination of orientation**. *Nature* 1999, **401:**587-590.

69. Eriksson PS, Perfilieva E, Bjork-Eriksson T, Alborn AM, Nordborg C, Peterson DA, Gage FH: **Neurogenesis in the adult human hippocampus**. *Nat.Med.* 1998, **4:**1313-1317.

70. van Praag H, Schinder AF, Christie BR, Toni N, Palmer TD, Gage FH: **Functional neurogenesis in the adult hippocampus**. *Nature* 2002, **415:**1030-1034.

71. Gould E, Beylin A, Tanapat P, Reeves A, Shors TJ: **Learning enhances adult neurogenesis in the hippocampal formation**. *Nat.Neurosci.* 1999, **2:**260-265.

72. Leuner B, Mendolia-Loffredo S, Kozorovitskiy Y, Samburg D, Gould E, Shors TJ: **Learning enhances the survival of new neurons beyond the time when the hippocampus is required for memory**. *J Neurosci.* 2004, **24:**7477-7481.

73. Doetsch F, Hen R: **Young and excitable: the function of new neurons in the adult mammalian brain**. *Curr.Opin.Neurobiol.* 2005, **15:**121-128.

74. Macklis JD: **New memories from new neurons**. *Nature* 2001, **410:**314-5, 317.

75. Shors TJ, Miesegaes G, Beylin A, Zhao M, Rydel T, Gould E: **Neurogenesis in the adult is involved in the formation of trace memories**. *Nature* 2001, **410:**372-376.

76. Santarelli L, Saxe M, Gross C, Surget A, Battaglia F, Dulawa S, Weisstaub N, Lee J, Duman R, Arancio O, Belzung C, Hen R: **Requirement of hippocampal neurogenesis for the behavioral effects of antidepressants**. *Science* 2003, **301:**805-809.

77. Kokaia Z, Lindvall O: **Neurogenesis after ischaemic brain insults**. *Curr.Opin.Neurobiol.* 2003, **13:**127-132.

78. Magavi SS, Leavitt BR, Macklis JD: **Induction of neurogenesis in the neocortex of adult mice**. *Nature* 2000, **405:**951-955.

79. Nakatomi H, Kuriu T, Okabe S, Yamamoto S, Hatano O, Kawahara N, Tamura A, Kirino T, Nakafuku M: **Regeneration of hippocampal pyramidal neurons after ischemic brain injury by recruitment of endogenous neural progenitors**. *Cell* 2002, **110:**429-441.

80. Arvidsson A, Collin T, Kirik D, Kokaia Z, Lindvall O: **Neuronal replacement from endogenous precursors in the adult brain after stroke**. *Nat.Med.* 2002, **8:**963-970.

81. Wall JT: **Variable organization in cortical maps of the skin as an indication of the lifelong adaptive capacities of circuits in the mammalian brain**. *Trends Neurosci* 1988, **11:**549-57.

82. Wall JT, Felleman DJ, Kaas JH: **Recovery of normal topography in the somatosensory cortex of monkeys after nerve crush and regeneration**. *Science* 1983, **221:**771-3.

83. Wall JT, Cusick CG: **Cutaneous responsiveness in primary somatosensory (S-I) hindpaw cortex before and after partial hindpaw deafferentation in adult rats**. *J.Neurosci.* 1984, **4:**1499-515.

84. Xerri C, Merzenich MM, Peterson BE, Jenkins W: **Plasticity of primary somatosensory cortex paralleling sensorimotor skill recovery from stroke in adult monkeys**. *J.Neurophysiol.* 1998, **79:**2119-2148.

85. Schwab ME: **Repairing the injured spinal cord**. *Science* 2002, **295:**1029-1031.

86. Shin JJ, Fricker-Gates RA, Perez FA, Leavitt BR, Zurakowski D, Macklis JD: **Transplanted neuroblasts differentiate appropriately into projection neurons with correct neurotransmitter and receptor phenotype in neocortex undergoing targeted projection neuron degeneration**. *J Neurosci.* 2000, **20:**7404-7416.

87. Fong AJ, Cai LL, Otoshi CK, Reinkensmeyer DJ, Burdick JW, Roy RR, Edgerton VR: **Spinal cord-transected mice learn to step in response to quipazine treatment and robotic training**. *J Neurosci.* 2005, **25:**11738-11747.

88. Campos L, Meng Z, Hu G, Chiu DT, Ambron RT, Martin JH: **Engineering novel spinal circuits to promote recovery after spinal injury**. *J Neurosci.* 2004, **24:**2090-2101.

89. Rauschecker JP, Shannon RV: **Sending sound to the brain**. *Science* 2002, **295:**1025-1029.

90. Klinke R, Kral A, Heid S, Tillein J, Hartmann R: **Recruitment of the auditory cortex in congenitally deaf cats by long-term cochlear electrostimulation**. *Science* 1999, **285:**1729-1733.

91. Giraud AL, Price CJ, Graham JM, Truy E, Frackowiak RS: **Cross-modal plasticity underpins language recovery after cochlear implantation**. *Neuron* 2001, **30:**657-663.

92. Rita P, Kercel W: **Sensory substitution and the human-machine interface**. *Trends Cogn Sci* 2003, **7:**541-546.

93. Ptito M, Moesgaard SM, Gjedde A, Kupers R: **Cross-modal plasticity revealed by electrotactile stimulation of the tongue in the congenitally blind**. *Brain* 2005, **128:**606-614.

94. White BW, Saunders FA, Scadden L, Rita P, Collins CC: **Seeing with the skin**. *Perception & Psychophysics* 1970, **7:**23-27.

95. Nicolelis MA: **Actions from thoughts**. *Nature* 2001, **409:**403-407.

96. Craelius W: **The bionic man: restoring mobility**. *Science* 2002, **295:**1018-1021.

97. Pascual-Leone A, Amedi A, Fregni F, Merabet LB: **The plastic human brain cortex**. *Annu.Rev.Neurosci.* 2005, **28:**377-401.

98. Burton H: **Visual cortex activity in early and late blind people**. *J Neurosci.* 2003, **23:**4005-4011.