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AMAZING PAPERS IN NEUROSCIENCE
Exploring Neuroplasticity in the Classroom: Teaching Cortical Reorganization in the Visual System with a Stroke Patient Study

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Neuroscience education often dedicates a substantial amount of time to the study of neuroplasticity and cortical reorganization. Research articles that demonstrate neuroplasticity and cortical reorganization in human patients provide opportunities for neuroscience education. Dilks et al., in a 2007 article published in the *Journal of Neuroscience* provided evidence for cortical reorganization within the human primary visual cortex by utilizing both behavioral and fMRI data. The study examined stroke patient B.L. who was cortically blind in the upper left visual field. In the presence of visual stimuli from the lower left visual field, cortical reorganization allowed for the activation of areas of V1 that would not normally respond to this visual information. Therefore, B.L. perceived visual stimuli presented in the lower left visual field to be vertically elongated into the upper left visual field (Dilks et al., 2007). This paper is an ideal platform for teaching an undergraduate neuroscience audience about neuroplasticity within the human brain. The article allows students to combine knowledge of both the visual system and neuroplasticity and provides a visual representation of cortical reorganization that helps facilitate understanding of principles of neuroscience.

Key words: neuroplasticity; cortical reorganization; primary visual cortex (V1); stroke damage; visual distortion

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Neuroplasticity and cortical reorganization is a fundamental topic in undergraduate neuroscience education (Meil, 2007). Neuroplasticity is the ability to form and reorganize new synaptic connections, particularly in response to injury or throughout the process of learning (Fuchs and Flügge, 2014). Neuroplasticity was once believed to exist only in childhood for the purposes of neural development, but it is now widely understood that the brain can exhibit “plastic” behaviors through adulthood (Bennett et al., 1964; Rakic, 2002). Literature often discussed within an undergraduate classroom setting typically revolves around plasticity within the primary somatosensory cortex (S1) in the monkey following deafferentation of certain cortical areas. In this example, deafferented somatosensory regions take on the function of surrounding cortical areas. This results in the deafferented area responding to somatosensory stimuli that would normally only be directed to the surrounding cortical areas (Merzenich et al., 1983; Manger et al., 1996). Teaching of cortical reorganization also often addresses phantom limb perception, a phenomenon in which areas of S1 that previously responded to a missing limb now respond to sensory stimuli from another part of the body, which is located in close somatotopic proximity to the deafferented region (Aglioti et al., 1994; Ramachandran, 2000; Meng et al., 2005).

Neuroplasticity has also been extensively examined in the human adult visual system and forms the foundation of our knowledge of activity-dependent plasticity (Darian-Smith and Gilbert, 1994; Baker et al., 2005). In fact, undergraduate neuroscience students are often taught early on about the pioneering work of Hubel and Wiesel, which uncovered principles of information processing in visual cortex and activity-dependent plasticity in the visual system (Hubel and Wiesel, 1959). Despite the abundance of evidence to suggest the existence of cortical reorganization in the visual system, there is often surprisingly little emphasis placed on neuroplasticity within the human visual system in the classroom. It would benefit students and educators alike to examine some of this evidence, as it provides valuable insight into an interesting and informative topic. Most research focuses on developmental plasticity in the visual system; that is, plasticity that occurs as a result of the malleable synaptic connections that exist in childhood. For example, there is typically a lower incidence of abnormal visual functions in children who sustained some type of damage to the primary visual cortex, as compared to adults who suffered the same injuries (Guzzetta et al., 2010). This suggests that children have a preexisting mechanism of cortical reorganization present in the visual system that is not evident in adults. However, a 2007 paper published by Dilks and colleagues in the *Journal of Neuroscience* demonstrates evidence for neuroplasticity and cortical reorganization within the visual system of an adult, well beyond early developmental years.

Dilks et al. (2007) provides educators with a platform for teaching principles of neural plasticity in the human visual system and demonstrates evidence for the existence of neuroplasticity through adulthood. Dilks et al. (2007) provides compelling evidence for cortical remapping within the human visual cortex after deafferentation of a section of the primary visual cortex. Here I examine the benefits of presenting Dilks et al. (2007) in an undergraduate classroom. I begin by outlining the methods and findings of the study, then examine the value for teaching and discuss ways of presenting this paper in a classroom.

OVERVIEW

Dilks et al. (2007) presents a series of behavioral and fMRI experiments conducted on a single patient, 'B.L.' Stroke damage to the lower right optic radiations ensured that almost no information from his upper left visual field reached V1, even though the corresponding region was still functioning. Predictably, patient B.L. was cortically blind in the upper left visual field. What makes B.L.'s case so fascinating is the fact that visual information presented in his lower left visual field appeared elongated into his upper left visual field. If a square was presented close to the scotoma in B.L.'s lower left visual field, he reported seeing an elongated rectangle that stretched into the blind portion of his upper left visual field. These findings suggest cortical reorganization of the primary visual cortex occurred in response to deafferentation of the lower right V1.

In the first behavioral experiment, B.L. was asked to fixate on a specific point on a screen. Rectangles of varying lengths were then presented in the lower left visual field (LVF) and lower right visual field (RVF). B.L. then had to name whether the left or right was taller or if they were of equal length. The results indicated that B.L. did in fact have a visual distortion that elongated figures upwards from his lower LVF into his upper LVF. It also confirmed that it was only a vertical distortion, and no horizontal distortion was present. B.L. judged rectangles in the lower LVF to be longer than they actually were, and the right rectangle had to be two centimeters taller than the left rectangle for B.L. to perceive them as equal in height.

The next behavioral tasks required B.L. to estimate the height of a rectangle and discriminate the space between two horizontal lines, both presented in either the lower LVF or lower RVF. These tests revealed that B.L. overestimated the height of a rectangle in lower LVF, and that his cortical reorganization was not particular to only properties of shape, two lines in the lower LVF. This shows that verticalelongation occurred due to cortical reorganization, and that this reorganization is not specific to a particular property of visual stimuli. This suggests the reorganization occurred in V1.

To demonstrate that B.L.'s overestimation of vertical size was consistent across modalities, a grip aperture sensor was used while B.L. used visual feedback to reach and "grasp" visual stimuli (i.e., rectangles). B.L. inaccurately overestimated the height of rectangles presented in the LVF while he grasped, showing that the distortion was reflective of both ventral and dorsal stream information and occurred in V1 prior to the divergence of visual information into either ventral or dorsal information streams. His overestimation of rectangle height in the grasping task was equivalent to the overestimation of rectangle height in the previous vision-only tasks (about two centimeters). When the visual stimulus presented in the lower LVF was a square, he would always perceive it as a vertically elongated rectangle, and he always overestimated the space between.

During retinotopic mapping of B.L.'s primary visual cortex using fMRI, his upper and lower left V1 responded normally to data presented in the lower and upper right visual field respectively. This was consistent with activation of V1 in control participants. As was expected, there was no activation of lower right V1 when visual stimuli were presented in the cortically blind upper left visual field region. However, fMRI data showed activation of deafferented lower right V1 when visual stimuli were presented in the lower left visual field. This shows functional evidence for cortical reorganization within B.L.'s primary visual field.

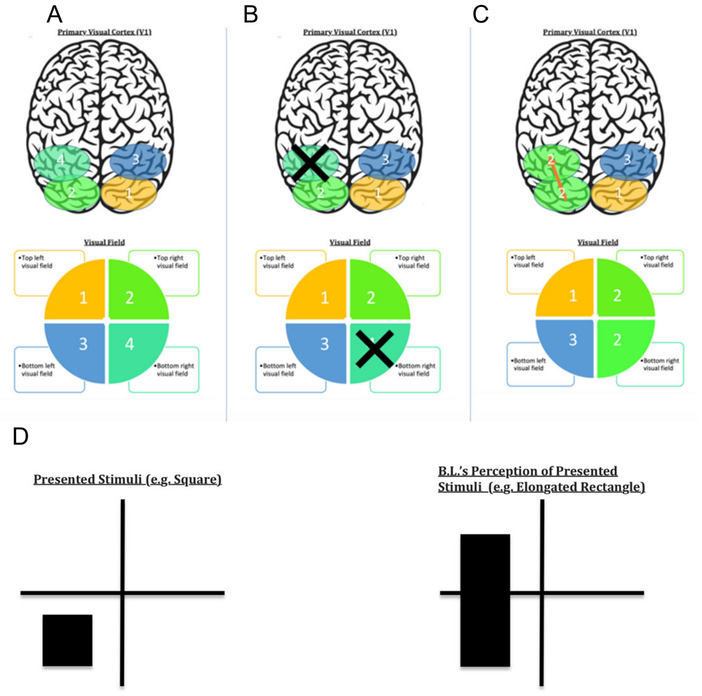

Figure 1. Diagram of visual distortion in the visual system of the patient 'B. L.' studied in Dilks et al. (2007) *A)* Representation of how stimuli from each quadrant of the visual field activates opposite regions in the Primary Visual Cortex (V1) in a neurotypical human brain. *B)* Visual of patient B.L.'s visual field and V1. Due to a stroke in the lower right Optic Radiations, patient B.L. receives no visual information to lower right V1. He is cortically blind in upper left visual field. *C)* Representation of cortical reorganization in patient B.L. Lower right V1 now responds to stimuli from lower left visual field. Areas that would have responded to upper left visual field now respond to lower left visual field. *D)* Representation of how patient B.L. perceives stimuli presented in the lower left visual field. Because lower right V1 is now activated while lower left visual field stimuli are presented, B.L. perceives a vertical elongation of stimuli in lower left visual field.

AUDIENCE

This paper is well suited for upper level (i.e., 3rd and 4th year) undergraduate courses where students already have a grasp of core concepts in neuroscience. One way to present this paper would be to allow the students to pretend that they were the clinical researchers conducting these experiments. When presented with this patient, what experiments would *they* do? What would they look for, and how would they go about testing their hypotheses? After proposing each behavioral task and fMRI experiment conducted in the paper, the students could discuss what they believe the findings would show and why. Deducing the findings of each experiment would allow students to gain a deeper understanding of how to go from a clinical observation to hypothesis testing. Figure 1 of this review provides a useful representation to help students visualize what occurs in V1 and the visual field for B.L. and control participants.

The lecturer could go on to emphasize the experiments that showed B.L. inaccurately perceived the distance between line segments in the lower left visual field. The instructor can explain why it is necessary to test for this and why it provides even greater evidence for cortical reorganization within V1. In anticipation of questions from students, the instructor can explain that differentiation between properties of visual stimuli (i.e., shape, color, spacing, direction, orientation) occurs in downstream pathways after stimuli pass through V1 (Milner and Goodale, 1995). This approach would allow students to deepen their understanding of the roles that different brain regions play in visual perception.

The results of the blindfolded touch-discrimination task (indicating that B.L.'s distortion is selective to visual information and does not affect other modalities) could be taught in tandem with the grip aperture task in which B.L.'s visually guided reaching was affected by cortical reorganization of V1. While the grip aperture test also crosses modalities, it is looking at the effect of cortical reorganization on visually guided grasping, which exists independently of the somatosensory system (Jeannerod, 1988). The instructor can discuss how one current theory of visual cognition is the Two-Streams hypothesis in which 'vision-for-perception' and 'vision-for-action' occur in ventral and dorsal information streams (respectively) in the human brain. Vision-for-perception in the ventral stream is involved in the recognition of objects, places, and faces whereas vision-for-action in the dorsal stream involves the use of visual stimuli to interact with the environment mechanically (Goodale and Milner, 1992; Milner and Goodale, 1995; Westwood and Goodale, 2011). With this knowledge, students can infer that if the cortical reorganization seen in V1 of patient B.L. does in fact occur in V1, it is before the split between the dorsal and ventral streams. Therefore, the distortion should not be specific to either vision-for-perception or vision-for-action systems.

Asking students to think as though they were clinical researchers studying patient B.L. provides attractive options for assessment. For example, a test question could disclose the symptoms B.L. experiences and ask students to analyze what is happening inside his primary visual cortex. Another option would be to reveal functional information about the reorganization itself; in this case, students would have to determine what patient B.L.'s symptoms would look like and deduce how he would perceive the world around him.

Before teaching this paper, it would be helpful for students to have a basic understanding of fMRI and information processing in the vertebrate visual system. A review of fMRI by Heeger and Ress (2002) contains excellent introductions to fMRI approaches. The Visual Brain in Action, by Milner and Goodale (1995) can be used to introduce students to basic anatomy and function of the vertebrate visual system.

VALUE FOR TEACHING

Dilks et al. (2007) is a great example of how you can obtain significant data with an n = 1. Many experiments discussed within a classroom setting have large sample sizes that control for many variables in an ideal world. However, this experiment exposes undergraduates to the benefits of reviewing case studies and literature where limited sample sizes do not necessarily limit the legitimacy of the evidence found. This is also an opportunity to discuss the limitations of the paper. Because there is only one subject, it is impossible to assume that the reorganization seen in B.L.'s primary visual cortex would occur in every human brain. Overall, the paper provides a means to understand the opportunities and limitations of human neuroscience research.

This paper is ideal to use in an undergraduate neuroscience classroom because it combines behavioral assays with fMRI data. Students can see what is happening functionally within the brain after an injury and how that injury and subsequent reorganization influences perception and behavior. For example, students can deduce that visual stimuli presented in the lower left visual field activated the deafferented lower right V1. Then students can then see the results of damage in this region and compare to control subjects. This comparison can help students understand the connections between perception and function in specific brain regions.

This paper provides both functional and behavioral data in support of cortical reorganization of V1. Students can gain practice interpreting the fMRI results (e.g., Heeger and Ress, 2002) as well as examining how this reorganization leads to a perceptional visual distortion and how the two are related. After learning about the effects of B.L.'s stroke on his visual system, one can physically conceptualize what this may look like. Similarly, while it may be difficult to imagine the reorganization of the somatosensory system or a phantom limb, one can clearly see how cortical reorganization has affected patient B.L. by envisioning how he must perceive the world around him. The fact that this study found compelling evidence for neuroplasticity in the human adult visual cortex (as opposed to an animal model) provides students with a means of understanding the human brain as an ever-changing, adaptable machine.

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