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The Lateralizer: a tool for students to explore the divided brain

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Motz BA, James KH, Busey TA. The Lateralizer: a tool for students to explore the divided brain. *Adv Physiol Educ* 36: 220–225, 2012; doi:10.1152/advan.00060.2012.—Despite a profusion of popular misinformation about the left brain and right brain, there are functional differences between the left and right cerebral hemispheres in humans. Evidence from split-brain patients, individuals with unilateral brain damage, and neuroimaging studies suggest that each hemisphere may be specialized for certain cognitive processes. One way to easily explore these hemispheric asymmetries is with the divided visual field technique, where visual stimuli are presented on either the left or right side of the visual field and task performance is compared between these two conditions; any behavioral differences between the left and right visual fields may be interpreted as evidence for functional asymmetries between the left and right cerebral hemispheres. We developed a simple software package that implements the divided visual field technique, called the Lateralizer, and introduced this experimental approach as a problem-based learning module in a lower-division research methods course. Second-year undergraduate students used the Lateralizer to experimentally challenge and explore theories of the differences between the left and right cerebral hemispheres. Measured learning outcomes after active exploration with the Lateralizer, including new knowledge of brain anatomy and connectivity, were on par with those observed in an upper-division lecture course. Moreover, the project added to the students' research skill sets and seemed to foster an appreciation of the link between brain anatomy and function.

divided visual field technique; hemispheric asymmetry; brain anatomy

THE POPULAR VIEW of the left and right cerebral hemispheres is powerful and pervasive. Marketers build advertisements that appeal to "both sides of your brain," executive coaches differentiate leadership strategies for "left-brained" and "right-brained" employees, and packaged goods from scented candles to educational baby products claim to selectively appeal to one cerebral hemisphere. Those without any understanding of neuroanatomy will confidently assert that the left hemisphere (LH) is logical, mathematical, linguistic, and analytical, whereas the right hemisphere (RH) is creative, imaginative, and expressive. A medical degree is apparently unnecessary to diagnose oneself as "left brained" or "right brained," reconciling a lack of artistic ability or poor grades in algebra, respectively.

Despite these clichéd misconceptions and neurological fantasies, there are clear functional differences between the left and right cerebral hemispheres in humans. Starting with Paul Broca's first observations of speech impairment associated with LH lesions of the frontal lobe (6), later with Wada's lateralized administration of sodium amobarbital (the Wada test; see Ref. 25) and Sperry and Gazzaniga's pioneering study of callosotomy ("split brain") patients (9), and now with a profusion of functional neuroimaging studies, a wealth of hard evidence has demonstrated that the two hemispheres are not equal. The LH is, for most, the seat of many linguistic abilities, and the RH has advantages with some visuospatial tasks, but these observations are hardly the full story.

What are the real differences between the left and right cerebral hemispheres? This simple question, posed to a beginning undergraduate, presents an accessible entry point to the study of neuroscience (19). Our students are well aware of the pervasive folk psychology dividing the "left brain" and "right brain," and we have observed that many students approach these popular accounts with curiosity and skepticism. Neuroanatomic structures and cortical functions that may otherwise be confusing and abstract can become grounded in an intriguing analysis of the real differences between the two cerebral hemispheres.

Thankfully, hands-on study of human hemispheric differences does not necessarily require patient populations, aggressive surgical procedures, or costly imaging facilities. The divided visual field (DVF) technique is a simple experimental paradigm, used with normal participants, where task performance is compared when stimuli are lateralized to the left visual field (LVF) and right visual field (RVF) (2, 4). This technique capitalizes on the lateralization of the visual system: a visual stimulus that is presented on one visual hemifield will be received and processed first by the contralateral cerebral hemisphere (see Fig. 1). If that cerebral hemisphere has functional advantages for a particular task, we may observe small but reliable improvements in task performance (e.g., faster response time) when the visual information arrives first on that hemisphere. Over the past 50 yr, this DVF technique has been vetted as a reliable test of functional asymmetries between the left and right cerebral hemispheres (3).

To enable active discovery-based exploration of hemispheric functional differences, we developed a Java-based software tool for students to design and conduct DVF experiments, called the Lateralizer (software freely distributed at http://hdl.handle.net/2022/14523; see Fig. 2). This application executes a simple categorization task, with visual stimuli presented briefly on either the left or right side of the screen, and the participant simply assigns each stimulus to one of two categories. Button-press responses (*category A* or *B*) and response times (in ms) are recorded for each individual lateralized stimulus presentation, and these single-trial raw data are provided at the end of the experiment. The Lateralizer is packaged with visual stimuli that allow replication of well-established DVF experiments (see Fig. 3) but can also be customized to present user-supplied image files or text strings, so that students have the opportunity to craft their own original investigations, analyze data, and interpret their results. In its simplest form, if a categorization task requires cognitive mechanisms that are lateralized to one cerebral hemisphere, students should observe faster response times when stimuli are presented on the contralateral visual field.

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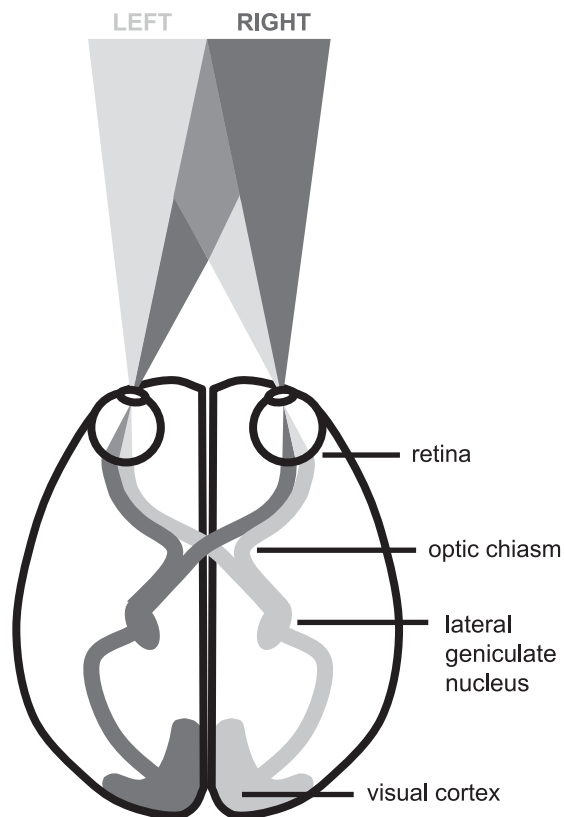
Fig. 1. Visual pathway of the human brain. Information from both visual hemifields enters each eye. At the optic chiasm, any visual information from the right visual field (RVF), as seen by the right eye, is transferred to the left hemisphere (LH), and any information from the left visual field (LVF), as seen by the left eye, is transferred to the right hemisphere (RH). Visual information arrives first in the lateral geniculate nucleus of the thalamus and is then transferred to the primary visual cortex at the posterior of the brain.

Through guided discovery with the Lateralizer, we expected that successful students would make first-hand observations of real functional differences between the left and right cerebral hemispheres and, in doing so, improve their research and writing skill sets. But, moreover, we hoped this exploration would improve students' broader understanding of course material, as has been the case with other active learning tactics (17). The present report outlines our teaching approach, describes student project outcomes, and assesses the impact of these activities on student learning, comparing content knowledge gained between undergraduate students who used the Lateralizer to explore hemispheric asymmetries in a lower-division research methods course with other undergraduates who learned the same topics in an upper-division traditional lecture-based course taught by another instructor.

METHODS

Instructional Context and Organization: Exploring Neuroscience with the Lateralizer

We introduced the Lateralizer during a 3-wk module in a large research methods course, about halfway into the semester. This course is required for undergraduate majors in Indiana University's Department of Psychological and Brain Sciences, with an enrollment of ~240 students/semester, with most students in their second and third year. All students attend a large weekly lecture (50 min), and then in smaller groups (15 students), they attend weekly 2-h laboratory classes that are taught by third-year graduate associate instructors and meet in instructional computer laboratories. In earlier problem-based learning modules, students had practiced basic research skills including, importantly, data analysis and how to write a research report.

For an accompanying reading assignment, Gazzaniga et al.'s textbook chapter on hemispheric specialization (10) was licensed to be included in the course's custom reading packet.

The first week. The objectives of the module's first week were to intrigue students with the topic of hemispheric functional asymmetries, help them understand cerebral structures relevant to the study of hemispheric specialization, and explain and demonstrate the DVF paradigm. In lecture, students were shown online video clips (from YouTube) of representative examples of broken speech accompanying Broca's aphasia and Alan Alda's engaging *Scientific American Frontiers* interview with Gazzaniga and split-brain patient "Joe" (8). The structure of the corpus callosum, the lateralized organization of the visual system, and the DVF technique were then described in detail. The subsequent laboratory section began with a rousing discussion of popular myths of the left brain and right brain, and these led to a demonstration of the Lateralizer, with which students replicated, using themselves as research participants, an established DVF experiment (see Fig. 3).

The second week. During the second week, students were instructed to design their own DVF experiment to test a theory of functional differences between the left and right cerebral hemispheres. The lecture was a broad review of noteworthy experiments that used the DVF technique, presented as examples that would facilitate a unified theoretical account of hemispheric asymmetries and would catalyze the students' ideas for their own DVF investigation. In the laboratory, students reviewed how to organize and analyze raw data, and a large portion of time was reserved for guided independent and collaborative work on their own projects.

The third week. Instruction during the third week provided a theoretical framework for the students to interpret their results. In lecture, the spatial frequency hypothesis was presented as a leading theory of hemispheric differences observed with the DVF technique (11, 15, 21). According to this theory, the RH is more sensitive to low-spatial frequency characteristics (global aspects) of visual information, and the LH is more sensitive to high-frequency characteristics (local aspects) of visual information. Supporting neurophysiological evidence was also described, including observations of larger dendritic arbors in RH pyramidal neurons (presumably facilitating global processing; see Ref. 1) and more densely interconnected macrocolumns in the LH (presumably facilitating a more refined local processing architecture; see Ref. 14). Laboratory sections were dedicated to review of these concepts and peer editing exercises with the students' projects.

Students were assigned to design and conduct their own original DVF experiments on at least eight right-handed volunteers (with a minimum of 40 trials on each visual field), collect and analyze these data, and present their study in a scientific manuscript-style report, complete with a background literature review, a detailed description of the methods, and an interpretation of results. These were due 1 wk after the third week of the unit.

The DVF Technique and the Lateralizer

Participants. Students were responsible for recruiting a minimum of eight right-handed volunteers for their DVF experiments. Often these were friends, classmates, and acquaintances. Such student projects are exempt from Institutional Review Board (IRB) approval under the Common Rule Policy (24), as they were not "designed to develop or contribute to generalizable knowledge" (instead, these are pedagogical exercises). Nevertheless, all students were given instruc-
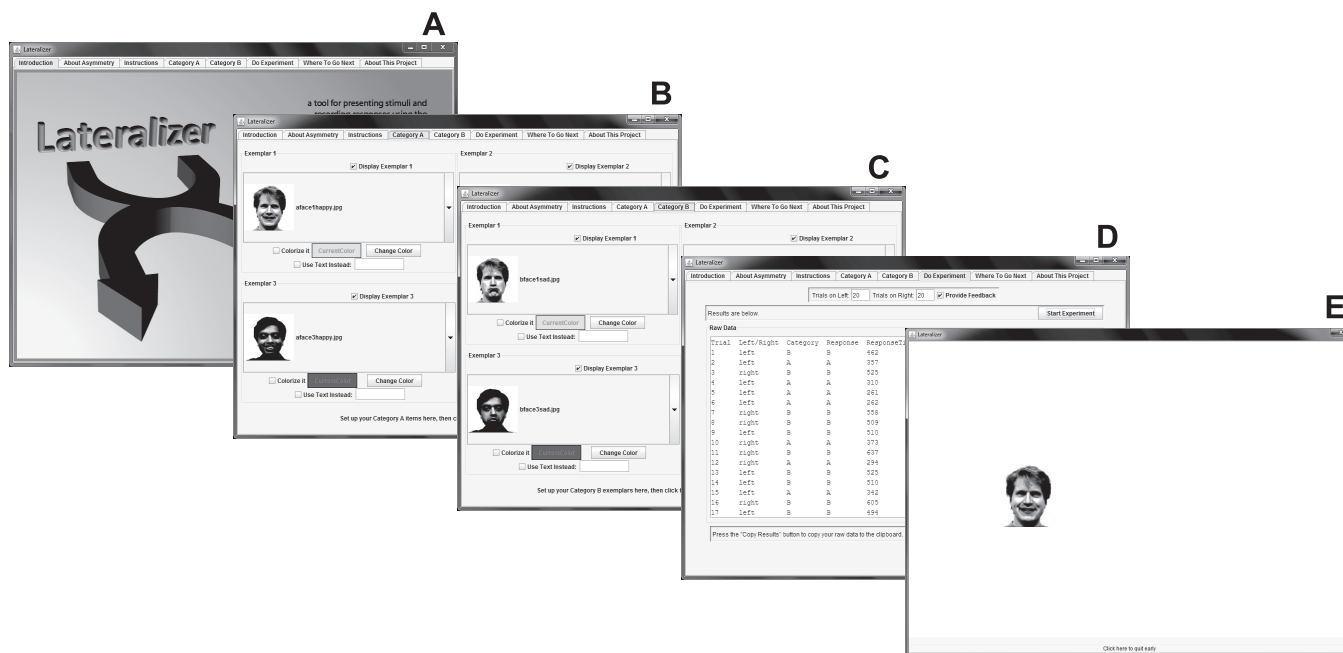
Fig. 2. Screenshots of the Lateralizer. The user navigates through the application by clicking the tabs toward the top of the window. *A*: the main title screen. *B*: the *category A* tab, where the user defines the exemplars for the first category (in this case, photographs of smiling faces). *C*: the *category B* tab, where the user defines the exemplars for the second category (in this case, photographs of frowning faces). *D*: the "Do Experiment" tab, where the user selects the number of trials and where raw data are returned after an experiment. *E*: the presentation window of the experiment, where exemplars are flashed briefly on either side of the screen, and the participant selects whether these belong to *category A* or *category B*.

tion on principles of ethical research and were expected to seek informed consent, offer to debrief participants, maintain their participants' anonymity, keep data confidential, and describe these steps in their reports.

Software. Available at http://hdl.handle.net/2022/14523, the Lateralizer is a simple application that requires no installation and runs on Windows, Mac, and Unix platforms, provided that Java is installed (free download at java.com). Double-clicking the Lateralizer.jar file

Study	Example Stimuli		Categorization Task	Result
	Category A	Category B		
Sergent J. The cerebral balance of power: confrontation or cooperation. *J Exp Psychol Human* 8: 253-272, 1982.	(stimulus)	(stimulus)	Is there an "H"?	LVF/RH advantage
	(stimulus)	(stimulus)	Is there an "H"?	RVF/LH advantage
Kitterle FL, Hellige JB, Christman S. Visual hemispheric asymmetries depend on which spatial frequencies are task relevant. *Brain Cognition* 20: 308-314, 1992.	(stimulus)	(stimulus)	Are the bars wide or narrow?	LVF/RH advantage
	(stimulus)	(stimulus)	Are the bars sharp or fuzzy?	RVF/LH advantage
Hellige JB, Michimata C. Categorization versus distance: Hemispheric differences for processing spatial information. *Mem Cognition* 17: 770-776, 1989.	(stimulus)	(stimulus)	Is the dot near or far from the line?	LVF/RH advantage
	(stimulus)	(stimulus)	Is the dot above or below the line?	RVF/LH advantage

Fig. 3. Classic studies using the divided visual field (DVF) technique. Stimuli for replicating these studies are prepackaged with the Lateralizer.

will execute the application (see Fig. 2 for screenshots), and this file must be in the same directory as a folder called "targets," which contains image stimuli. For original experiments using novel stimuli, new image files (either .jpg or .gif) should be added to this "targets" folder. All image files must be in the "targets" folder when the Lateralizer is initialized; the application should be restarted if new images are added.

Stimuli. The default experiment, when Lateralizer is first initialized, is to execute a categorization task between happy faces (*category A*) and sad faces (*category B*), using black-and-white photographs of four individuals smiling and the same four individuals frowning (inspired by Ref. 7). Any other experiment would similarly require the experimenter to define two distinct categories of visual stimuli, selecting up to four stimuli (called "exemplars") for each category. These stimuli can be either images (deposited in the "targets" folder, as described above) or strings of text, and these are assigned in the *category A* and *category B* tabs of the Lateralizer. While the Lateralizer will automatically shrink image files to fit the presentation window, we recommend that user-supplied image files should be smaller than 200×200 pixels. The experimenter can also change the color of stimuli, either selecting a new font color or creating a monochromatic variation of the selected image.

Procedure. In the "Do Experiment" tab of the Lateralizer, the experimenter defines the number of trials on each visual field (40 trials/visual field were required for student projects) and selects whether the application will provide feedback after each trial (either "correct" or "incorrect"). The Lateralizer will automatically balance the number of *category A* and *category B* presentations for the two visual fields. Each trial begins with a centralized fixation cross, presented for 1,500 ms. The fixation cross then disappears, and a pseudorandomly selected exemplar is flashed for 200 ms, centered either 150 pixels to the left or right of the location of the fixation cross. Stimuli are presented briefly to prevent participants from making eye movements and fixating on the stimuli, which would preclude lateralized visual presentation (4). After the exemplar is presented, the screen becomes white until the user responds, either pressing "G" for *category A* or "H" for *category B* (the "G" and "H" keys are adjacent in the center of common QWERTY keyboards). Students asked their participants to respond with their dominant right hand, providing a response as quickly and as accurately as possible. The time (in ms) between the initial onset of the stimulus and the button press is recorded.

Data analysis. Raw data that are returned at the end of the experiment include incorrect trials and outliers, and data cleansing steps are necessary before any differences between visual fields can be assessed. Response times were excluded from further analysis if the response was incorrect or if the time was faster than 200 ms (unreasonably fast for choice reaction times; see Ref. 23) or slower than 1,500 ms (when higher-order cognitive processes disproportionately skew results). Once incorrect trials and outliers are filtered, a simple comparison is drawn between participants' average response times when stimuli are presented on the LVF and RVF.

Assessment of Learning and Comparison With a Traditional Course

In addition to their research reports using the Lateralizer, student learning outcomes were also assessed using multiple-choice questions about the lateralization of cognitive function, the anatomy of the brain, and the spatial frequency hypothesis. Six multiple-choice questions were presented at the start of lecture on the first week of the unit, before any instruction or readings, providing a "pretest" of baseline knowledge about hemispheric specialization. Students were told that their responses to these questions would not affect their grade in the course but that these same six questions would appear on a quiz at the end of the unit. Two weeks later, at the end of lecture on the third week of the module, a 15-question multiple-choice quiz was administered ("posttest"), including the same 6 questions that were given on the first day of the class. For each student, the difference in scores on these six questions between the pretest and posttest provided an incremental measure of declarative knowledge gained during the first 2 wk of the unit.

For a comparison measure of learning outcomes, the same six-question pretest/posttest was administered to students in a different course, an upper-division course on cognitive neuroscience taught by a different instructor during the same fall 2011 semester. This comparison course also used Gazzaniga et al.'s textbook (10) and included 1 wk of instruction on hemispheric differences; however, rather than exploring hemispheric differences using active discovery, this class used a traditional lecture format. On the first day of their unit on hemispheric differences, students in this course were given the same 6 multiple-choice questions, and these six questions were included in a subsequent 45-question exam 3 wk later. In this way, incremental knowledge gained during active exploration with the DVF technique could be compared with knowledge gained in a traditional course.

Our university's IRB approved this retrospective observation of student projects and our comparison of quiz scores. On the first day of the fall 2011 semester, students in both classes were informed of this analysis and given detailed information sheets describing our study.

RESULTS AND DISCUSSION

Outcomes of Student Projects Using the Lateralizer

There were 233 students enrolled in the research methods course when the Lateralizer was introduced during the fall 2011 semester. Student projects were excluded from analysis if the report was not submitted electronically, if the report was incomplete, if there was evidence of plagiarism, if the method described was unclear, or if the data were not presented or analyzed correctly. For these reasons, 25 students were excluded, and 208 projects remained for the present analysis. Table 1 shows a descriptive summary of these projects.

Many students (44%) investigated the lateralization of visual processing of human faces, frequently with tasks involving the classification of facial expressions ($n = 44$ projects; e.g., happy vs. sad faces) or sex classification ($n = 22$ projects), both of

Table 1. *Descriptive summary of student projects*

Stimuli	Number of Projects	Average Grade, %	Reported Significance of Results		
			Significant expected result, %	Not significant, %	Significant unexpected result, %
Faces	91	86.4	43	55	2
Words	41	84.7	24	68	7
Objects or animals	36	84.5	28	69	3
Hierarchical	27	83.6	41	59	0
Numbers or equations	13	86.6	38	46	15
Total	208	85.4	36	60	4

which were expected to yield LVF/RH advantages. Other tasks involving face processing were expected to yield RVF/LH advantages (23), including classifying the identity of the face ($n = 14$) and distinguishing small features of the face ($n = 11$). Another large proportion of students (20%) developed word classification tasks, including both semantic categories ($n = 14$ projects; e.g., names of mammals vs. names of birds) and syntactic categories ($n = 27$ projects; e.g, nouns vs. verbs). The remainder of projects involved distinguishing between images of different types of objects or animals, hierarchical stimuli (images composed of smaller images), and numbers or simple arithmetic equations.

Across all projects, 40% of students reported a statistically significant difference in response times between LVF/RH and RVF/LH using a two-tailed comparison with an α-level of 0.05; 36% of students reported significant differences that were in line with hypothesized functional asymmetries, whereas 4% reported significant differences that were unexpected. The percentage of projects reporting statistically significant effects did not significantly differ between the five stimulus categories shown in Table 1 [$\chi^2(8, n = 208) = 12.964, P = 0.113$]. We cannot certify the authenticity of the students' results, nor the validity of the methods that students used to obtain these results. We present these values merely to quantify the expected outcomes of student projects using this DVF technique.

It may seem disparaging that the majority of students (60%) did not report significant effects between the LVF and RVF. One prominent reason for the preponderance of null findings is that many student projects attempted to confirm popular but inaccurate myths of the left brain and right brain. For example, most of the projects involving object classification hypothesized that artistic objects (e.g., paint brushes vs. pencils) or artistically depicted objects (e.g., photographs vs. paintings of trees) would have a LVF/RH advantage, nearly all of which were not confirmed. For these students, the project presented an educative opportunity: learning to describe null findings. Importantly, students were not graded on the specific outcome of their DVF experiment, only on their thoughtful interpretation of these results.

Students generally performed well on this project. The average percent score assigned by graduate associate instructors was 85.4%, primarily assessing the quality of the students' comprehension of course material, their experimental methodology, and their empirical reasoning demonstrated in the research report. ANOVA found no significant effects of stimulus category ($P = 0.821$) or significance of reported results ($P = 0.711$) on these project grades, indicating that regardless of the specific task used and regardless of the outcome of their experiment, students had an opportunity to perform at a high level using this experimental paradigm.

Incremental Gains in Declarative Knowledge and Comparison With the Traditional Lecture Course

There were 104 students in the research methods course using the Lateralizer and 69 students in the comparison course (of 233 and 95 enrolled students, respectively) who were present in class for both the pretest and posttest and who marked their names on the pretest (as part of the IRB-approved protocol, students were informed that they would not be penalized if they did not mark their names or did not take the pretest).

Students who used the Lateralizer to actively explore hemispheric differences demonstrated substantial improvements on the six multiple-choice questions between the first and third weeks of the learning activity. For these students, the average score on the pretest was 2.81/6 (46.8%), and the average score on the posttest was 4.97/6 (82.8%), with an incremental improvement of 36%.

Similarly, students in the comparison course showed strong improvement between the pretest and posttest, scoring 3.68/6 (61.3%) and 5.42/6 (90.3%), respectively, with an incremental improvement of 29%.

Performance on both the pretest and posttest was higher for students in the traditional course than for students using the Lateralizer [$F_{(1,171)} = 27.560, P < 0.001$], which may be due to the following: students in the comparison course were more advanced (74% seniors compared with 18% seniors in the course using the Lateralizer); students in the comparison course had higher cumulative grade point averages than students in the course using the Lateralizer (3.241/4, and 3.033/4, respectively); and the comparison course on cognitive neuroscience was an elective, which may have selectively attracted students who were more inclined toward these concepts. For these reasons, students in the traditional course would have be expected to score higher on both the pretest and posttest.

Nevertheless, there was a significant interaction between incremental improvement (difference between the pretest and posttest) and course. Students who were using the Lateralizer made stronger improvements between the pretest and posttest than students in the traditional course [$F_{(1,171)} = 3.948, P = 0.049$ (see Fig. 4)]. However, it is possible that a ceiling effect prevented students in the traditional course from displaying the incremental improvements observed among students in the course using the Lateralizer. In other words, it may be unreasonable to expect students in the traditional course to perform any higher than 90.3% on the posttest, on average. For this reason, we merely assert that incremental learning outcomes during active exploration with the DVF technique in a lower-
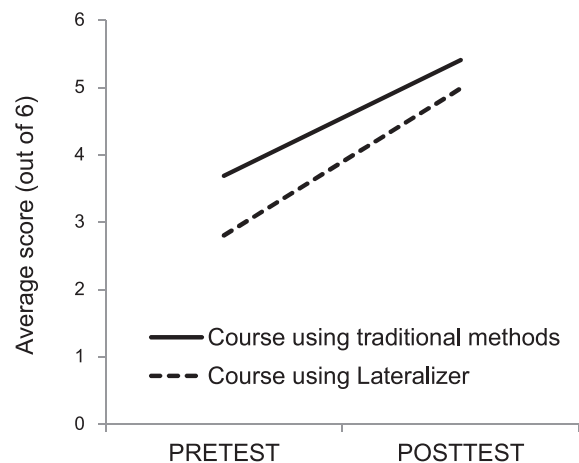

Fig. 4. Scores on the pretest and posttest, split between the course using the Lateralizer (a lower-division research methods course) and the comparison course using traditional teaching methods (an upper-division elective course learning the same concepts).

division course were, at minimum, no less than those observed in a traditional upper-division lecture course.

Conclusions

Through guided discovery-based learning with the DVF technique, students made first-hand observations of complex relationships between brain anatomy and brain function. This activity gave students an opportunity to actively challenge and elaborate on popular myths of the left brain and right brain, added to their research skill sets, and yielded gains in declarative knowledge among lower-division students that were on par with those observed in a traditional upper-division lecture course.

This type of problem-based instruction, focusing on exploration and engagement, has been validated by cognitive scientists and supported by policy makers (17, 18). Particularly in science disciplines, learning activities that encourage inquiry and discovery have been shown to increase engagement and retention in the field, improve learning outcomes, and reduce the achievement gap hampering underrepresented minority students (5, 12, 17). The DVF experiment described in the present report is precisely this type of classroom exercise, providing beginning students an opportunity to explore their own interests and make real discoveries, scaffolded with a relevant and indepth overview of cerebral functional localization and the anatomy of visual pathways in the human brain.

From the research laboratory to the operating room, the localization of brain function is becoming more exacting and more necessary. Modern surgical interventions for epilepsy (20) and brain tumor resections (16) both require brain mapping techniques to avoid or minimize injury to specific cortical sites necessary for language and other cognitive functions. While the DVF technique certainly cannot provide the spatial resolution of other brain mapping technologies, the learning activity nevertheless seems to motivate a more basic appreciation for, and interest in, the relationship between cerebral structure and function.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: B.A.M. and T.A.B. conception and design of research; B.A.M. and K.H.J. performed experiments; B.A.M. analyzed data; B.A.M. and K.H.J. interpreted results of experiments; B.A.M. prepared figures; B.A.M. drafted manuscript; B.A.M., K.H.J., and T.A.B. edited and revised manuscript; B.A.M., K.H.J., and T.A.B. approved final version of manuscript.

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