

The split-brain: Rooting consciousness in biology

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From bugs to humans, the rate at which we have accumulated information about nervous systems in the last 100 y has been astonishing. Nonetheless, if one always adopted the intellectual style of first learning all there is to know about a topic before studying its new dimensions, future progress would be slow. Unlike many other disciplines, neuroscience does not currently enjoy the luxury of an agreed on set of next questions to be answered. It has been the Wild West, untamed and reinless, and, in many ways, continues to be.

Roger W. Sperry, perhaps the premier brain scientist of the last century, always plunged ahead with the sentiment, “Try it. And don’t read the literature until after you have made your observations. Otherwise you can be blinded by pre-existing dogma.” That is surely a paraphrase of what he said to me a hundred times, and that is how we operated in those delicious carefree and exploring days at Caltech. “Try it.”

The Sperry laboratory was going full tilt with experiments of all kinds on the so-called “split-brain” (1). Cats and monkeys were the main animals, and the results were clear and riveting. Train one side of the brain on

a sensory task, and the other side didn’t know anything about it. The standard preparation was to divide the optic chiasm down the middle, such that information exposed to one eye was only projected to the ipsilateral half brain. Such animals would easily learn a task and would easily be able to perform the task through the originally untrained eye. If in addition to the midline section of the chiasm, the corpus callosum and anterior commissure were sectioned, however, the split-brain phenomenon presented itself. In this condition, the untrained hemisphere remained ignorant of the task learned by the other half brain. It was as if there were two mental systems cohabitating in one head. Riveting as these findings were, they seemed incoherent when considered in the context of human behavior. Could a left hand not know what the right hand is holding? Preposterous.

In 1960, I had the good luck to show up at Caltech on a summer National Science Foundation (NSF) fellowship to study with Sperry. I was drawn to the laboratory by an interest in the issue of neural specificity. One thing led to another, and before I knew it, I was starting graduate school at Caltech the following summer. My first assignment was to prepare a set

of studies for a human patient, W.J., who was being worked up by a neurosurgical resident, Joseph E. Bogen, to sever the corpus callosum for treatment of severe epilepsy.

Looking back at those early days, it is hard to overstate the adventurous nature of our project. Nobody thought the patient would actually provide evidence the mind could be split. Weeks earlier, a case of callosal agenesis, a birth defect where there is a complete or partial absence of the corpus callosum, had come through the laboratory and nothing seemed out of the ordinary. From a larger view, even though one of the world’s greatest neurobiologists was involved, neither Sperry nor certainly I, a green-as-could-be new graduate student, had any significant experience examining patients. To others it might have seemed to be a fool’s game and a waste of time. However, it was not, because at Caltech, the attitude was always, “try it.”

So the adventure went forward. First, unsurprisingly, preoperative testing confirmed that case W.J.’s two hemispheres were normally connected: each hand knew what was in the other, and each visual cortex seamlessly connected to the other. The very thought it could be otherwise was outlandish. As all of the studies were completed, we put the work aside, and went on to other research projects studying nonhuman primate memory systems, cortical pathways involved in eye-hand coordination, and much more. A few months later, our interests changed back to case W.J. The World War II veteran had recovered nicely from his surgery and was ready to be tested again.

The big test came on a bright sunny Pasadena day. W.J. was rolled up to the entrance of the biology building on San Pasquale Avenue. Still recovering from surgery, W.J. used a wheelchair to get around. He still sported his helmet, which he had been wearing to protect himself from possible seizure-associated falls. Was this World



The author displays one of the tachistoscopes he built for the first tests of split-brain subjects.

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War II veteran, who had been knocked out by a blow from the butt of a German rifle after a parachute jump behind enemy lines, going to reveal a deep secret? It did not seem likely. The morning began modestly enough. There was no drum roll as we entered the building. In fact, I was left alone to do the testing. Testing that proved to be mind-boggling. It remains so until this day. Here is how I recently described the moment (2):

M.S.G.: Fixate on the dot.

W.J.: Do you mean the little piece of paper stuck on the screen?

M.S.G.: Yes, that is a dot. ... Look right at it.

W.J.: Okay.

I make sure he is looking straight at the dot and flash him a picture of a simple object, a square, which is placed to the right of the dot for exactly 100 milliseconds. By being placed there, the image is directed to his left half brain, his speaking brain.

M.S.G.: What did you see?

W.J.: A box.

M.S.G.: Good, let's do it again. Fixate the dot.

W.J.: Do you mean the little piece of tape?

M.S.G.: Yes, I do. Now fixate.

Again I flash a picture of another square but this time to the left of his fixated point, and this image is transmitted exclusively to his right brain, a half brain that does not speak (2). Because of the special surgery W.J. had undergone, his right brain, with its connecting fibers to the left hemisphere severed, could no longer communicate with his left brain. This was the telling moment. Heart pounding, mouth dry, I asked,

M.S.G.: What did you see?

W.J.: Nothing.

M.S.G.: Nothing? You saw nothing?

W.J.: Nothing.

My heart races. I begin to sweat. Have I just seen two brains, that is to say, two minds working separately in one head? One could speak, one couldn't. Was that what was happening?

W.J.: Anything else you want me to do?

M.S.G.: Yes, just a minute.

I quickly find some even more simple slides that only project single small circles onto the screen. Each slide projects one circle but in different places on each trial. What would happen if he were just asked to point to anything he saw?

M.S.G.: Bill, just point to what stuff you see.

W.J.: On the screen?

M.S.G.: Yes and use either hand that seems fit.

W.J.: Okay.

M.S.G.: Fixate the dot.

A circle is flashed to the right of fixation, allowing his left brain to see it. His right hand rises from the table and points to where the circle has been on the screen. We do this for a number of trials where the flashed circle appears on one side of the screen or the other. It doesn't matter. When the circle is to the right of fixation, the right hand, controlled by the left hemisphere, points to it. When the circle is to the left of fixation, it is the left hand, controlled by the right hemisphere, that points to it. One hand or the other will point to the correct place on the screen. That means that each hemisphere does see a circle when it is in the opposite visual field, and each, separate from the other, could guide the arm/hand it controlled, to make a response. Only the left hemisphere, however, can talk about it. I can barely contain myself. Oh, the sweetness of discovery.

Thus begins a line of research that, twenty years later, almost to the day, will be awarded the Nobel Prize (3).

The report of that day's findings, as well as many other days' findings, was first reported in a now classic paper published in PNAS in 1962 (4). It was the paper that launched 50 y of intense research on the brain mechanisms that underlie the human conscious experience. All of the subsequent knowledge that has been revealed has been the product of the idea to "just try it," embodied in that paper.

As the finding that a surgeon could seemingly create two minds out of one slowly seeped into our own minds, thinking that consciousness itself could be studied by psychobiologists, as we were all called at the time, gained traction. Additional patients were studied, and although always confirming the original findings, each provided new insights. In addition to the visual system being split, it became clear that the same was true for the somatosensory system, the motor system, and, more stunningly, the

perceptual/cognitive systems of the left and right brain. We worked at a feverish pace. It was like fishing in a stocked pond. Every time we dipped into the unknown, we caught a fish.

As the years rolled by, many talented young scientists trained at Caltech, and other senior investigators visited to study the patients. I moved on to the East Coast and, as luck again would have it, began testing a new series of patients out of Dartmouth Medical School. Knowledge about the kinds of mental processes that could be integrated across the great divide created by the surgery, such as emotional and attentional processes, added to the foundations of how to think about the underlying biology of conscious experience. Overall, the dozens upon dozens of studies revealed the parallel and distributed organization of the human brain even though the patient's sense of psychological unity remained intact.

Were the original findings the product of a perfect storm? Certainly the Caltech culture for discovery, risk, and intellectual adventure was palpable. I happened to live in a storied house that years before housed Howard Temin, Matt Meselson, and Sidney Coleman. Richard Feynman used to show up at our parties, and on one memorable night, Feynman came up to me and said "You can split my brain if you can guarantee I can do physics afterwards." Laughing, I said, "I guarantee it." Quick as a flash, Feynman stuck out both his left and his right hand to shake on the deal! The atmosphere of expectation to do important work during those days of discovery was nothing like I had ever experienced before or since.

Here we are 50 y later with a veritable Who's Who in biology having launched attempts to figure out how to think about the biology of consciousness (see *Inner Workings: Discovering the split mind* on p. 18097). Francis Crick and Gerald Edelman, Wolf Singer, and Jean Pierre Changeux, to name a few, have all contributed and urged on the quest for understanding. I know all of them looked to Sperry and the split-brain work for inspiration. Today, it is still haunting and challenging to ponder the question: what does it mean that one can split the mind?

1 Myers RE, Sperry RW (1958) Interhemispheric communication through the corpus callosum: mnemonic carry-over between the hemispheres. *AMA Arch Neurol Psychiatry* 80(3): 298–303.

2 Gazzaniga MS (2015) *Tales From Both Sides of the Brain (Ecco)* (Harper Collins, New York).

3 The Nobel Prize in Physiology or Medicine 1981. *Nobelprize.org*. Available at www.nobelprize.org/nobel_prizes/medicine/laureates/1981/. Accessed October 14, 2014.

4 Gazzaniga MS, Bogen JE, Sperry RW (1962) Some functional effects of sectioning the cerebral commissures in man. *Proc Natl Acad Sci USA* 48(10):1765–1769.