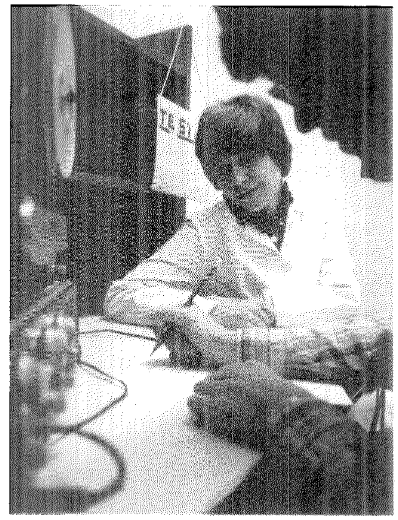
Research in Progress



Psychobiologist Polly Henninger administers a new dichotic listening test that she developed to examine hemispheric action in the brain to senior Tad White.

Quadraphonic Brain

THE HUMAN BRAIN, which has doubled in size at least once in its evolutionary history, could be said to have undergone a comparable transformation in the 1960s and 1970s, with the discovery by Caltech's Roger Sperry, Board of Trustees Professor of Psychobiology, Emeritus, and 1981 Nobel laureate, that each hemisphere has its own distinctive capacities and functions. Working with split-brain patients whose corpus callosi — the dense network of fibers linking the two halves of the brain — had been severed, Sperry was able to demonstrate that the right hemisphere is predominant for spatial-holistic thought, pattern recognition, and music, while the left hemisphere is specialized for verbal, numerical, and analytical tasks.

Now Polly Henninger, 1982-1984 research fellow in psychobiology and currently a visiting associate at Caltech and assistant professor at Pitzer College in Claremont, has uncovered evidence that could again double the brain's attributes. Her findings, based on two years of experimental work with normal and split-brain subjects, suggest that each hemisphere may itself house a hemisphere — a secondary center that to an as-yet undetermined degree mimics the role and functions of the opposite half of the brain.

This notion is based on data that surfaced during Henninger's research into suppression — a phenomenon exploited by auditory tests that examine lateralization, or the hemispheric division of labor. In hearing, input to one ear is carried by the primary contralateral pathways to the opposite hemisphere for processing and to the hemisphere on the same side as the receiving ear by the secondary ipsilateral pathways. The dichotic technique makes use of the fact that when both ears simultaneously hear competing stimuli, the input entering the brain from the ipsilateral pathways is inhibited, or suppressed, by the input to the stronger, more numerous contralateral pathways.

Verbal dichotic tests of the type Henninger is currently using illustrate how this process works. Test subjects hear a different word, syllable, or number in each ear and are asked to report it. Since verbal material is more effectively processed by the left hemisphere, which governs the right side of the body, subjects usually show a right-ear advantage, meaning that they hear and report more correct right-ear (contralateral) than left- ear (ipsilateral) input. In normal subjects, ear differences are small. But in split-brain subjects, where communication between the two hemispheres has been cut off, almost all reported input is from the right ear, reflecting suppression of the ipsilateral pathways.

Henninger's dichotic study focuses on the unanswered question of the relative influence of cognitive as opposed to perceptual demands on left-hemisphere processing (more difficult task versus more intense stimulus). In tests she has developed, the cognitive element is task-loading; the perceptual factor variation in volume. Subjects listen to a dichotic digits tape in which the one-syllable digits 1 through 12 (less 7 and 11) are presented to both ears as practice trials. Then, in the actual tests, different digits are presented simultaneously to each ear, either with the volume equal in both ears or raised or lowered five decibels in one ear. In both the practice and actual trials, subjects write what they hear.

The test was initially administered to one of the split-brain subjects, with results that raised a completely new issue. With the volume up in the left ear (to offset the right-ear advantage), the subject first wrote down left-ear digits but shifted to writing only right-ear digits after the task load increased from three digits to four. Three additional split-brain subjects were tested, with similar results. Even with the higher volume, such verbal fluency on the part of an isolated right hemisphere was so unlike dichotic results generally obtained from splits that Henninger questioned whether there had been any right hemisphere involvement at all. Was it possible that the shift had not occurred between hemispheres but rather within the single left hemisphere, from the ipsilateral to the contralateral pathways?

To explore this possibility, the test was given to a subject who at the age of seven had undergone a hemispherectomy that removed his entire right hemisphere. Input to both ears was processed in his left hemisphere. Nevertheless, like the split-brain subjects, he successfully reported more left- than right-ear digits at lower levels of task difficulty before shifting dramatically and almost entirely to right-ear reporting at the higher levels. How could two mindless pathways induce a cognitive shift as the task got harder? And where had the initial "right hemisphere" advantage come from?

Henninger showed these data, and the results of an earlier music test she had given the hemispherectomy subject, to Sperry, who came up with an interesting interpretation. He suggested that just as the contralateral pathways led to the left hemisphere, the ipsilateral pathways led to a secondary center within the left brain that constituted a "pseudo" right hemisphere.

In investigating this theory,

Henninger's first step was to determine whether the left-to-right-ear cognitive shift observed in the clinical subjects was unique to non-intact brains or occurred also in subjects with intact brains. To examine this, she administered dichotic tests to 41 normal subjects. Computer analysis and tabulation of the raw data was performed by Tad White, a math major and SURF (Summer Undergraduate Research Fellowship) student working on the project.

According to the data, 46 subjects and nearly 46,000 digits agree — cognitive factors outweigh perceptual ones in inducing ipsilateral suppression in the left hemisphere. Normal subjects showed a significant increase in the relative right-ear advantage as the task became harder, although their threshold of difficulty, not surprisingly, was considerably higher than either the splits' or the hemispherectomy subject's.

On the basis of these findings, Henninger concludes that the engagement of the left hemisphere in verbal dichotic listening depends on the extent to which cognitive tasks use left-brain resources. The test is currently being given to a new round of subjects to further substantiate this hypothesis. She is also developing a new listening test to examine whether this model holds true for functions associated with the right hemisphere.

To examine the hypothesis of a secondary center and its possible features, Henninger turned again to the hemispherectomy subject. With the volume up in the left ear, he was asked to report left-ear digits only. During the practice trials (numbers 1 through 12, less 7 and 11, presented to both ears), instead of writing 8 after 6, he wrote 7, suggesting, says Henninger, that he was unable to focus on the (ipsilateral) input and was guessing at the meaning of sounds he could hear but not interpret. He then reported 8, 9, and 10 for 9, 10, and 12, leading her to believe he was recalling from earlier testings that the practice trials were sequential. On the first dichotic pair that presented different digits to each ear, he reported a single right-ear digit, further evidence that he could not focus on the ipsilateral input. For the rest of the level-one trials, he wrote down digits to both ears, indicating that despite his aim to report only left-ear data, he could not suppress contralateral input to the right ear.

When the test was repeated, the subject identified the practice digits correctly, and reported left-ear digits only at the "ones" level but shifted to the right-ear digits as the task load increased. This test clearly showed his lack of voluntary control over the shifts.

In another testing, whose results Henninger considers particularly significant, the subject was asked to report only right-ear digits, with the volume raised in the left ear. During the practice trials in which the same numbers are presented to both ears, he said "I can't. They're all coming in this (pointing to his left) ear."

On the first dichotic trial, he still didn't distinguish the right-ear digit (10), but reported a left-ear 9 for a 5 (a common error) — behavioral evidence that he was accurately able to identify the sound's location. On the second trial, however, he said, "Oh, now it's coming in this (right) ear," and reported the right-ear digits for the remaining trials.

Henninger's analysis is that initially the higher volume in the left ear shifted him to the ipsilateral pathways and secondary center, but as soon as he perceived competing numbers, he could distinguish different locations in space, and his intent to report only right-ear digits engaged the contralateral center. The fact that his awareness of the input's locale shifted along with his switch from left- to right-ear input points to the existence of two distinct centers within his lone hemisphere, oriented toward opposite sides of space. Furthermore, the proposed ipsilateral center appears clearly oriented to the left side, normally the domain of the right hemisphere.

Finally, in monaural testing of the left ear, on the practice trials, the subject accurately reported digits 1 through 10, skipping 7. On the final trial, however, he wrote a second 10, then changed it to 11, apparently recalling that there were not two 10's in a row. Later, during the first four dichotic pairs he reported a digit order that was similar but not identical to the actual test ("1,3,2,3" for "10,2,3,2"), then shifted to left-ear digits and finished the rest of the test without difficulty, correctly identifying left-ear digits.

Henninger's conjecture is that initially the subject could not locate the center for the incoming left-ear digits, and was instead in the major hemisphere's area of long-term memory and recalling data from earlier tests. However, once he realized these digits were not what he was hearing, and that the information he needed was unavailable, he shifted to the subsidiary center, where the ipsilateral input from the left ear could be easily identified.

The subject's ability to identify ipsilateral input when the contralateral was out of the picture suggests that the secondary center is as capable as the primary center of processing the full sequence of numbers. The difference appears only when they are in competition. Henninger surmises that both centers are tied in to the cerebral equivalent of a mainframe processor, which performs the actual cognitive activity. However, the contralateral center has preferred access, and the subsidiary ipsilateral center cannot get online while this unit is monopolized by the primary center.

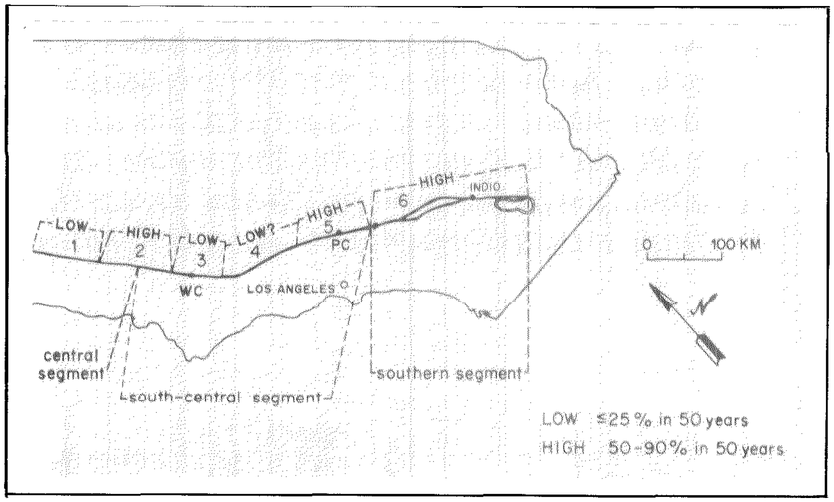
Henninger's thesis, of course, raises enough questions to keep any central processor tied up for quite a while. She is currently working on a new series of tests designed to help distinguish between secondary center functions and those that can only be performed by the more powerful contralateral hemisphere. Another area to be explored is whether the subsidiary hemisphere is capable of complex cognitive functions, and whether these are functions commonly associated with the opposite primary hemisphere.

There is also the intriguing question of whether secondary center activity is unique to clinical subjects or is a widespread phenomenon. In normal subjects, Henninger speculates, the secondary center(s) may function as a rarely used backup system. On the other hand, she says, the evidence also supports the possibility that intrahemispheric activity is a standard feature of the normal brain that up to now has been exclusively interpreted as inter-hemispheric behavior. What does seem certain is that if new research reinforces and extends Henninger's findings, current theories of lateralization could themselves be in for a major shift. □ — *Heidi Aspaturian, Publications*

Quake Forecast

AFTER SEVEN YEARS of excavation and geological analysis of the San Andreas fault, Kerry Sieh, associate professor of geology, has developed a clear enough picture of that complex structure to attempt forecasts of which portions are likely to rupture next and which are not. He has recently revealed new data and given a comprehensive overview of the potential for fault movement from central California to the Mexican border.

Sieh's forecasts of the future of the San Andreas are based largely on studies of sediments and landforms that record the prehistoric behavior of the fault (*E&S*, April 1981). Radiocarbon dating of these disruptive features has proven critical in dating the ancient earthquakes that resulted from these dislocations.



The map above (with California lying on its side) shows potentials for earthquakes along the San Andreas fault over the next 50 years.

A superquake the entire length of the San Andreas probably can be ruled out, said Sieh, because the central reach of the fault creeps annually at a rate equal to the movement of the fault segments to the north and south. This creeping segment of the fault (marked 1 on the map) effectively isolates the northern reaches of the fault near San Francisco — which last broke in 1906 — from the southern parts, much of which last broke in 1857.

The short segment of the fault (2 on the map) centered on Cholame, however, is likely to produce magnitude 6 to 7½ earthquakes before the turn of the century. "This segment has historically been a zone of transition between the fully creeping and fully locked portions of the fault," said Sieh. "Based on its previous behavior, this segment is a prime candidate for generating a large earthquake in the near future." Fortunately, the region transversed by this volatile segment of the fault is only very lightly populated.

Another far more dangerous segment is the southernmost 300 kilometers of the fault. The probability of a large earthquake within the next 50 years along this stretch (5 and 6 on the map) is between 50 and 90 percent, Sieh estimated. The effects of such an earthquake, which might range between magnitude 7½ and 8½, would be quite severe in Los Angeles, San Bernardino, Palm Springs, Indio, and nearby communities.

Sieh's new excavations across the fault at Pallett Creek (PC on the map), near Palmdale, have revealed evidence that large earthquakes occur about every 145 years on the average, the latest being 127 years ago in 1857. This is a refinement of data collected and reported several years ago. These earthquakes have typically occurred after 3 to 4½ meters of strain have been stored in rocks adjacent to the fault. This is about the amount that appears to have accumulated there since 1857.

Sieh bases his conclusions that portions of the San Andreas can be ruled out as near-term large earthquake sites on his studies of the offset of Wallace Creek (WC), a stream channel crossing the fault in the region east of San Luis Obispo, about halfway between San Francisco and Los Angeles. Over the past 13,500 years, the channel has been offset by about 475 meters, yielding an average slip rate of about 35 millimeters per year. Other measurements show that within the past 3,700 years, about 130 meters of slip has taken place per year (mm/yr) for this time period as well.

"Small channels in this area indicate that when the fault slips there it slips suddenly," Sieh said, "with shifts of about 10 to 13 meters." For example, the latest great earthquake in southern California, in 1857, was associated with about 10 meters of offset near Wallace Creek. Sudden shifts of such size would be spaced 240 to 450 years apart. "At the rate we believe strain to be accumulating, it will be at least a century before the area around Wallace Creek is likely to rupture again," he said.

Sieh's warning that the San Andreas fault is not the only important player in the seismic future of California stems from studies of the movement of the San Andreas compared to the overall relative movement of the Pacific and North American plates. Over the past several millenia, the San Andreas fault has moved at a rate of only 35 mm/yr, which represents only about 60 percent of the total relative movement of the two plates. Other large faults, in particular the San Gregorio-Hosgri, must make up the 200 mm/yr deficiency. This fault parallels the coast offshore from Point Reyes, north of San Francisco, to Point Conception, west of Santa Barbara.

Sieh and his students are now engaged in studies along the southern reaches of the fault, near Indio, where the fault has not broken during the entire two centuries of recorded history and where considerable strain is thus believed to be stored. His research is sponsored by the U.S. Geological Survey.□ — *Dennis Meredith, News Bureau*