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CROSSED TEMPERATURE DISCRIMINATION FOLLOWING SECTION OF FOREBRAIN NEOÇORTICAL COMMISSURES[1]

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The degree of ipsilateral somatosensory representation in the cerebral cortex remains somewhat uncertain. Although regions of the head and neck appear to be bilaterally represented through the 5th nerve (Mountcastle and Rose, 1959), the primary somesthetic projection of the body below the neck ascends via the contralateral spinothalamic and medial lemniscal tracts. However, there exists physiological, anatomical, and behavioral evidence that an ipsilateral system is also present for regions of the body below the neck.

Ipsilateral evoked responses have been obtained by several investigators in phalangers, rabbits, cats, and monkeys (Adey and Kerr, 1954; Adey, Carter and Porter, 1954; Amassian, 1954; Patton, Towe and Kennedy, 1962; Shealey, Tyner and Taslitz, 1966). Furthermore, studies in the hemispherectomized cat or monkey indicate that there is at least some small sensitivity to tactile stimuli in the ipsilateral hemisphere (Bogen and Campbell, 1962; White, Schreiner, Hughes, Mac Carty and Grindley, 1959). Some researchers have even reported a complete absence of aphasia or agnosia for somesthetic stimuli whose input was via the left or non-dominant side of the body in human patients lacking a corpus callosum (Akelaitis, 1944; Solursh, Margulies, Ashem and Stasiak, 1965). Since the ability to recognize and verbally identify a stimulus presented to the left side of the body depends on the stimulus information reaching language centers, such a finding indicates either an ipsilateral projection or the presence of speech in the minor hemisphere.

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Other investigators, in contrast to the above findings, have found severe somesthetic deficits in the recognition of ipsilateral stimuli. Geschwind (1965) has found complete tactile aphasia in a patient with a lesion in the midportion of his corpus callosum. Gazzaniga, Bogen and Sperry (1963) report that cross-localization of touch, temperature discrimination requiring cross-communication between the hemispheres, and speech recognition of left-side body position were all lacking in a commissurotomized man. Gazzaniga (1965) saw these same deficits following commissurotomy in another patient. Absence of interhemisperic transfer of a tactile learning task was found by Russell and Reitan (1955) in a patient who had agenesis of the corpus callosum. Recently Lee-Teng and Sperry (1966) reported that split-brain monkeys were unable to cross-match somesthetic stimuli according to size.

With respect to temperature discrimination, as pointed out (Gazzaniga, Bogen, and Sperry, 1963; Gazzaniga, 1965), commissurotomized patients have been completely deficient in cross-matching or cross-comparison for regions of the body below the neck. This finding is rather surprising in view of the fact that patients can verbally identify a painful sensation on the left side of the body (Gazzaniga, 1965). It might be expected that pain and temperature sensibility would be present or not together since both pain and temperature fibers share similar central pathways, one of which is an uncrossed, short-chained pathway which ascends via Lissauer's fasciculus.

The present study presents the results of a more intensive investigation of the lateralization and cross-integration of temperature discrimination in two commissurotomy patients at 3½ and at 2 years after surgery.

Case Material and Procedure

Subjects

Two subjects were studied who had previously shown the general symptoms of hemispheric disconnection. Both had undergone cerebral commissurotomy for control of advanced epilepsy. The surgery has been quite successful to date in controlling the seizures, and both people lead essentially normal lives. These are the same two select patients from whom most of the evidence has been obtained to date regarding the symptoms of forebrain commissurotomy (Gazzaniga, Bogen, and Sperry, 1963; Sperry and Gazzaniga, 1967; Sperry, 1968).

One of the patients, N.G., is a 32-year-old housewife (Bogen, Fisher and Vogel, 1965). The full-scale WAIS was administered to her by the first author in May 1967. Her verbal I.Q. was 87 and performance I.Q. was 69, full-scale, 78. The 18 point difference between her verbal and her performance scores suggests minor hemisphere damage. This is also suggested in the particular difficulty she had with the block design subtest both with her right or left hand or with both hands together. Tests administered to her in June 1967 by Milner (1967) showed normal sensitivity for two-point discriminations on both the left and right sides of N.G.'s body.

The second patient, L.B., was a 17-year-old schoolboy at the time of testing. His I.Q. is in the bright-normal range. He was kept out of schoool for most of a year and lost one grade because of his surgery, but he is now back in public school and is doing satisfactorily. He appears bright, has a fine rapport with the authors, and seems to enjoy the testing situation. L.B. was also tested by Milner in June 1967 for cutaneous sensitivity and was found to be normal (Milner, 1967).

Apparatus

Temperature stimulation was applied with two temperature applicators (Ts) made of brass tubing 1 cm in diameter and 25 cm long, sealed at one end and insulated by foam rubber tubing 3 mm thick except for 5 mm at the sealed end. The applicators were filled with water of the proper temperature and were corked with a rubber stopper holding a thermometer that indicated the temperature of the applicators (see Figure 1). During intertrial intervals the applicators were kept in thermos bottles containing water of the desired temperature in order to keep the temperature of the Ts constant.

In some of the tests a finger-tracing readout was used in which N.G. was required to trace and identify the letters "S" and "O" and select the "S" if the temperatures of the two Ts she had felt were the same and the letter "O" if the temperatures were opposite. The letters were formed of 2 mm soldiering wire shaped into "O" and "S." The letters were 2 inches high and 1 inch wide and glued onto a piece of plexiglas 8 × 5 inches. Because these two letters each have identical mirror images, the plexiglas could be presented to the subject with either letter on the right or left.

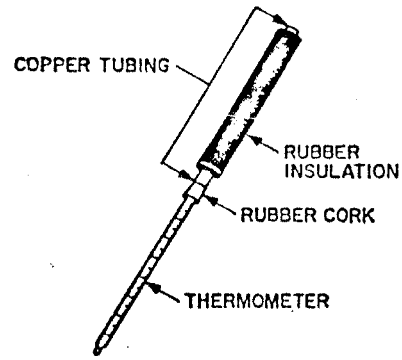

Fig. 1 — ***Temperature*** *stimulus.*

Some of the tests were carried out with the subject's hand behind a masonite shield. A space 6 inches high was left at the bottom through which the subject's hand could be placed. A black fringe hung over the space to prevent the subject from seeing his hands under the shield.

General procedure

Most of the intensive testing was done with N.G. A limited series of tests were given to L.B., following those with N.G. L.B.'s results were clear-cut and confirmed the findings with N.G.

Three types of tests were administered to N.G. consisting of a temperature comparison on the left side of her body utilizing a verbal read-out, an intrahemispheric and interhemispheric comparison procedure requiring a finger-tracing readout, and finally intra- and interhemispheric comparisons with a head-movement readout, i.e., an affirmative up-down head shake indicating that two temperatures were the same, or a negative sideways head shake indicating that they were different. Only the latter procedure was used with L.B.

The sequence of hot-cold presentations was random in all types of tests, and in the cross-comparisons the side of the body touched first was random. The cold stimulus ranged from 20 to 25 °C and the hot stimulus from 35 to 40 °C.

Observations

In the initial series of tests the Ts were applied to the left side of the body on the foot, calf, back, upper arm, and hand of N.G. and she was asked to state verbally which was warmer. It was assumed that any verbal report would come from the major hemisphere and would indicate temperature discrimination in the ipsilateral hemisphere.

One of the Ts was placed on a particular area of N.G.'s body and allowed to remain there for 1 second. It was removed, and the other T was placed on the same area and allowed to remain for 1 second. N.G. was then asked, "Which was hotter, one or two?," "one" or "two" referring to first and second stimulus. N.G. was lying down, either on her back or prone, with a towel draped at neck level to eliminate visual cues. Twenty trials were given for each area of the body. It had earlier been determined in preliminary trials that N.G. could perform these discriminations accurately when the right side of her body was tested. The results are presented in Table I.

TABLE I

Number of Correct Trials Out of 20 for Verbal Readout Tests

Area	Correct of 20	chi^2
Foot	15	4.05*
Calf	15	4.05*
Back	14	2.40
Upper arm	19	14.45*
Hand	15	4.05*

* $p < .05$

As can be seen from Table I, N.G. was able to give a correct verbal response at a level significantly better than chance for all areas of the body tested except the back. At this point it became uncertain whether the minor hemisphere might not be able to trigger the simple responses involved here, especially after the prompting by the examiner.

Accordingly another testing procedure was tried in which N.G. was instructed that either a hot or cold temperature applicator would be placed on her hand, removed, and then followed by the same applicator or the other one on first the same hand and in later series on the other hand. The solid raised wire letters "O" and "S" were then presented to her left or right hand, and she was instructed to select the "S" if the two temperatures she had felt were the same and the "O" il the two temperatures she had felt were the opposite. Preliminary trials were given with both her hands with the shield removed until it appeared she understood the procedure. During preliminary testing it was established that N.G. could discriminate with both right and left hands the "O" and the "S." It was also established during pretesting that she could not cross-match the "O" or the "S" either from left to right hands or from right to left. This was in line with previous results concerning the transfer on trunk and extremities of shape information between the hemispheres. On each trial a temperature applicator was placed on N.G.'s left or right hand and allowed to remain for 1 second. It was then removed, and either the same temperature applicator or the other one was applied for 1 second. N.G. was then given the letters and allowed to select either the "O" or the "S" to indicate her answer. All testing was done with N.G.'s hand behind the shield as described in the apparatus section, so that no visual cues were available either during application of the stimuli or during readout. Eighty trials were given, forty unilateral comparisons in which the two stimuli were both applied to the same hand, twenty to the right hand and twenty to the left, and in which readout came via the same hand to which the stimuli had been applied, and forty crossed comparisons in which the two stimuli were applied to different hands. Twenty of these latter trials required a readout through the right hand and twenty a readout through the left hand. The placement of the temperature applicators on her right or left hand first for the crossed comparisons was randomized as was the sequence of hot or cold. The results of these comparisons are shown in Table II.

TABLE II

Unilateral and Crossed Comparisons Using Readout by Manual Stereognosis

	Hand controlling readout			
	Left hand		Right hand	
Type of trial	Correct of 20	chi²	Correct of 20	chi²
Unilateral	9	.05	18	11.25**
Crossed	8	.45	16	6.05*

* $p < .025$
** $p < .005$

Although comparisons, both unilateral and crossed, could be carried out using the right hand for readout, responses with the left hand remained at chance level for either type of comparison. Whether the minor hemisphere was incapable of performing under these conditions or had failed to grasp the procedure remained unclear.

A final series of tests on N.G.'s temperature discrimination involved a much simpler form of response, namely a nodding or shaking of the head for "yes" or "no" in answer to the question whether the two stimuli were the same or not the same. As above, the two stimuli were applied for both unilateral and crossed comparison from bilateral symmetrical areas. Four hundred comparison trials were carried out on ten areas of the body including head, neck, chest, upper arm, lower arm, hand, belly, thigh, calf and foot. The exact regions tested are shown in Figure 2. The particular area of the body tested on any given trial was randomized, but the randomization was restricted to the extent that each area of the body received 10 left-side unilateral trials, 10 right-side unilateral trials,

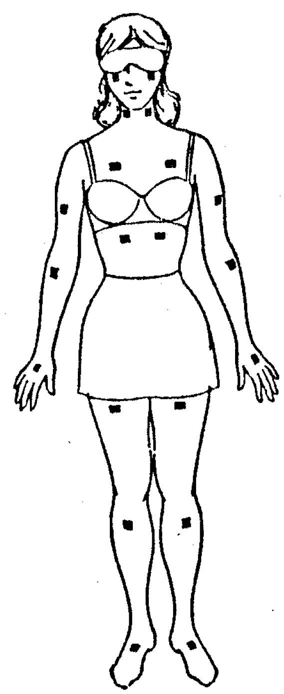

Fig. 2 — *Exact regions tested for temperature discrimination.*

and 20 crossed trials. The presentation of the stimuli was randomized as to hot and cold, and on the cross-comparison trials as to which side of the body received the stimulus first. The nature of the trial, whether unilateral or crossed, was randomized throughout the 400 trials. These trials were conducted over a period of 5 days, 80 trials being given a day during a one-hour period with 5-minute breaks being given after every 20 trials. During all trials N.G. was lying on her back on a couch with her eyes covered. The results of these comparisons are given in Table III. As can be seen the unilateral comparisons on the right side of the body resulted in almost perfect scores. Except for the face and calf, no more than 1 out of 10 errors was made. In each of the 4 general regions of the body as grouped in Table III, discrimination ability was far above chance. Although scores were less accurate on the left side than on the right (difference in left and right scores, excluding head and neck: chi^2 = = 17.22, $p < .005$), 3 of the 4 general body regions on the left side also resulted in above chance scores. For stimuli presented to the arm region on the left side, however, scores were at chance level. In the crossed comparison tests, scores were above chance for all body areas except for the upper arm and the leg. When the data were pooled from individual areas, 3 of the 4 general regions resulted in

TABLE III

Results of Comparison Using Head-Movement Readout

Area	Left side		Crossed			Right side	
	Correct of 10	chi^2	Correct of 20	chi^2	chi^2	Correct of 10	chi^2
Face	10	8.45**	19	14.45**	27.23**	8	11.25**
Neck	7		18	11.25**		10	
Chest	8	8.45**	15	4.05*	21.03**	9	14.45**
Belly	9		20	18.05**		10	
Upper arm	6		12	.45		10	
Lower arm	5	.03	17	8.45**	14.01**	10	24.30**
Hand	4		16	6.05*		10	
Thigh	7		13	1.25		10	
Calf	7	4.03*	11	.05	2.81	8	17.63**
Foot	7		13	1.25		9	

* $p < .05$
** $p < .005$

scores far above chance. Scores obtained from the legs, however, remained at chance.

L.B. was given a total of 80 comparisons of the same nature as the last series of trials described for N.G. above. Only his hands and feet were tested. He was sitting up during all testing with his hands behind the screen and his feet underneath a draped table. L.B. scored 100% correct on all 80 trials: left foot 10, right foot 10, left hand 10, right hand 10, crossed between right and left on feet 20, and crossed between right and left on hands 20.

Discussion

The fact that N.G. could accurately describe verbally stimuli presented to the left side of her body can be interpreted either by presuming that temperature information was reaching her ipsilateral dominant hemisphere, or that there is minor hemisphere speech. However, unpublished data by the authors make the latter interpretation highly improbable. Except under very specialized circumstances N.G. is totally unable to describe objects by shape when they are placed in her left hand. This inability to give verbal descriptions of such objects is not the result of an inability to identify objects with the left hand, since N. G. can be shown a picture of an object and can select it by touch with her left hand, or she can feel an object with her left hand and can identify the same object visually. In view of this almost total verbal deficiency with respect to shape objects in her left hand, the idea of minor hemisphere speech seems untenable. That the left hemisphere has information available with respect to temperature stimuli coming into the left side of the body seems to be the most reasonable assumption.

In the cross-comparison tests using a finger-tracing readout, the inability of the left hand to perform the readout was at first puzzling. It seemed that perhaps information from the left side was reaching the dominant hemisphere, but that information from the right side was not reaching the minor hemisphere. However, the ipsilateral comparisons revealed that even when the stimulus input was directly to the minor hemisphere, the left hand was incapable of giving an accurate readout. Pretesting had shown that the left hand was perfectly capable of discriminating the "S" from the "O", and N.G. could also trace the appropriate letter when she was instructed to do so when the tester said "same" or "opposite." Since the verbal readout test had already shown that the left hand was capable of temperature discriminations, and in view of the fact that the minor hemisphere was apparently capable of relating "S" to "same" and "O" to "opposite," the reasons for the deficiency in left-hand finger-tracing readouts are not obvious. However, the use of alphabetic letters involves aspects of language and symbolic usage, and it was thought, perhaps, that it was this involvement which may have accounted for the minor hemisphere failure.

The final series of tests therefore used a head-movement readout which can be controlled by either hemisphere, and which avoids the problem of language usage. In the cross-comparison tests all areas of the body except for the leg region and upper arm yielded scores well above chance. It is apparent that for most areas of the body stimulus input from both sides of the body gets into the same hemisphere where it is processed and read out. Whether such input gets into both the left and right hemispheres cannot be determined from this test, nor can it be determined which hemisphere controlled the readout. However, since the scores for ipsilateral comparisons on the left were far less accurate than those on the right, and since this difference is highly significant ($p < .005$), it seems probable that the readout for the cross-comparison trials was being controlled by the major hemisphere. It also even seems quite reasonable that ipsilateral trials on the left side may have been read out by the major hemisphere. This seems to be particularly likely in view of the findings with the finger-tracing procedure in which the minor hemisphere was not able to readout at all. There is little reason to expect such low accuracy scores on the left side if the readout had been via the same hemisphere as the stimulus input. High error scores might be expected if ipsilateral pathways are transmitting the information, or if the information is transferred via the midbrain. The known ipsilateral pathway consists of short multisynaptic connections and whether information reaches the ipsilateral hemisphere by way of an ipsilateral pathway or by way of the midbrain, more synapses are involved in reaching the hemisphere on the same side as stimulus input than in reaching the contralateral hemisphere. In terms of information theory, the pathway may simply be more noisy.

However, if this is the case, that is, if the major hemisphere controls the readout for all comparisons, whether a head movement or a finger tracing is used, we are still left with the problem as to why the minor hemisphere is incapable of mediating a response. It is possible that the integration required for making a comparison and coming up with a concept such as "same" or "different" based on that comparison is beyond the capabilities of the minor hemispere. Further research is now being conducted in an effort to ascertain the reasons for minor hemisphere deficiency on this problem.

In any case, these studies with N.G. establish with little doubt that temperature information reaches the ipsilateral hemisphere, definitely from the left side of the body to the left hemisphere, and possibly, although this could not be definitely determined, from the right side of the body to the right hemisphere.

The results with L.B. showed him to be 100% accurate on all trials — cross-comparisons as well as left and right intrahemispheric comparisons for both the foot and hand. These findings with L.B. confirm that temperature information is available to the ipsilateral hemisphere. His high accuracy score may reflect the pure commissurotomy case better than the scores of N.G. L.B. suffered very little trauma from the surgery. He was able to talk almost as soon as he recovered from the surgical anesthesia and even repeated a classical tongue twister within 24 hours after surgery. On the other hand N.G. was mute for some time following surgery. She displayed labile emotional reactions for up to two weeks following the operation, her mood swinging from her normal happy personality into depression abruptly. X-rays showed a small calcification in the right hemisphere. As stated previously, her I.Q. difference on the performance and verbal scales, as well as her extreme difficulty with the block design subtest, indicate minor hemisphere damage. The relatively high error scores of N.G. on the left side intrahemispheric tests, as well as on the cross-comparison, may reflect minor hemisphere damage which is not present in L.B.

The earlier findings of Gazzaniga, Bogen and Sperry (1963) and Gazzaniga (1965) that temperature is only represented bilaterally in the head and neck region may result from the fact that, when these patients were tested, available ipsilateral pathways had not become functional. Therapists working with neurological patients have found much improvement over time and as a result of training techniques. It is possible that the intensive testing done with N.G. and L.B. since the time of the earlier studies has had a trophic effect on previously nonfunctional pathways.

Summary

Two neurological patients who had undergone total forebrain commissurotomies for the control of epilepsy were examined for the ability to make crossed temperature comparisons. Warm or cool temperature stimuli were presented to homologous regions on opposite sides of the body, and the patients were required to indicate whether the two stimuli were of the same or different temperatures. Results indicated that the left hemisphere has access to temperature information from the left side of the body. It could not be determined whether the right hemisphere also has access to ipsilateral temperature information. We concluded from these findings that the left somesthetic ipsilateral pathway can convey sufficient temperature information to allow for accurate comparisons.

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