Neuropsychologia, 1963, Vol. 1, pp. 209 to 215. Pergamon Press Ltd. Printed in England

LATERALITY EFFECTS IN SOMESTHESIS FOLLOWING CEREBRAL COMMISSUROTOMY IN MAN*

M. S. GAZZANIGA, J. E. BOGEN,† and R. W. SPERRY

California Institute of Technology, Division of Biology, Pasadena, California

(*Received* 28 *February* 1963)

Abstract—A variety of basic somatosensory tests carried out on a patient with surgical section of the cerebral commissures revealed a marked separation of somesthetic effects from right and left extremities and from right and left sides of the trunk. Predominantly contralateral projection of somesthesis was evident; the presence of any ipsilateral representation at all four regions below the neck remained questionable. Bilateral projection was indicated in results from the face and the top and back of the head with equal representation on both sides. Comparatively little functional impairment was the rule when the sensory and motor output involved the same hemisphere, but severe impairment and complete incapacity were evident when right–left cross integration was required. These and similar results in the present case suggest that in the absence of cerebral damage during infancy, transcallosal interaction is of critical importance for utilization of ipsilateral somesthetic data particularly when the left extremities participate in activities involving the symbolic functions of the dominant hemisphere.

INTRODUCTION

THERE remains considerable uncertainty regarding the nature of somatosensory representation in the cerebral cortex of primates and other mammals, particularly with respect to the presence and significance of ipsilateral components. There is basic agreement to the extent that cerebral projection of the various somatic afferent systems is mostly contralateral for all regions of the body excepting the head and neck which are bilaterally represented through the ascending pathways of nerve V [1, 2].

Evidence regarding the presence and extent of ipsilateral representation for the trunk and limbs, however, is less consistent. Survival of at least crude sensitivity to stimuli after hemispherectomy on the affected side in the cat and monkey suggests the presence of significant ipsilateral representation [3, 4]. Survival of somatosensory function is apt to be particularly good following hemispherectomies for infantile hemiplegia, suggesting that potential ipsilateral pathways may tend to lie dormant or undeveloped in the normal brain [5, 6]. Studies of men with cortical bullet wounds have suggested a much more diffuse and bilateral representation for the left hand than for the right [7]. The presence of some ipsilateral projection is supported also from both anatomical and electrophysiological studies particularly with reference to the spinothalamic system now believed to contain some touch and pressure components [1]. Evoked cortical potentials are mainly contralateral [4] but recently have also been found to be ipsilateral as well [8–14]. Two separate potentials appearing in sequence in the ipsilateral cortex of the cat were observed by PATTON *et al.* in response to peripheral stimulation [14]. The later of the two survived the

* Aided by the National Institutes of Health, U.S. Public Health Service, Grants No. M3372 and No. 2086, and the Frank P. Hixon Fund.

† Loma Linda University School of Medicine, Department of Neurosurgery, Los Angeles, California.

combined transection of the rostral portion of the corpus callosum, anterior and posterior commissures, and massa intermedia, plus ablation of the surrounding cortex to eliminate intracortical relays. In evoked potential studies in normal human subjects, some authors have found [15] three main types of waveforms, while others have found five [16]. Among these the two earlier responses are solely contralateral, but the later ones are bilateral. The extent to which the ipsilateral components are transmitted through the callosum remains unclear.

Further evidence bearing on these and related questions has been obtained recently from somatosensory testing in a human subject with complete section of the corpus callosum, anterior and hippocampal commissures [17]. The following is a more detailed account of somatosensory tests that relate to the laterality of cortical representation and the cross integration of somesthetic information from one to the other side of the body. In general the results demonstrate the importance of the corpus callosum for such cross integration and the lack, in this case, of appreciable ipsilateral effects except from the head and neck.

CASE HISTORY AND PROCEDURE

The patient, a male war veteran 48 years old, had been having intractable grand mal convulsions for 10 years subsequent to a war injury. Despite some brain damage as well as the repeated seizures, the patient remained above average in intelligence. Subsequent to the surgical disconnection of the hemispheres he has remained essentially convulsion-free except for a few minor unilateral attacks. Additional details regarding the patient's history and the results of other tests have been reported elsewhere [17, 18].

Prior to surgery no abnormalities in somesthetics were detected in standard neurological examinations excepting a mild hyperesthesia on the left side. It was also shown in pre-operative testing that the patient could write legibly with either hand, and when blindfolded, could tell time with either hand by feeling the positions of the hands on an open-face clock 6″ in diameter. Also with a blindfold he could describe or name correctly various objects such as coins and block letters held in either hand and with either hand could write the name of an object held in the opposite hand. Occasional errors were recorded in the discrimination between similar-sized coins with the left hand, e.g., between a dime and a penny. The following is based on postoperative tests conducted in the laboratory and in the patient's home in weekly 2–3 hr sessions during the 6th to 40th weeks following surgery.

Observations

Localization of light touch. With vision eliminated by a blindfold the subject was required to localize by pointing with his finger the spot on the skin at which a brief, light, tactile stimulus was applied by the experimenter with a pencil point or a small, wooden, toothpick-size stylus mounted at the end of a meter-long aluminium handle. In most of the tests the patient was instructed to use either the right hand or the left hand as designated by the experimenter. In other tests free use of either hand was allowed and in others verbal reports of the stimulus locus were obtained.

It was consistently evident throughout the tests that the patient was able to find all points of stimulation if both the stimulus and the response were kept to the same side of the body. For example, if the patient was responding with the left hand, all points of stimulation on his left foot, leg, trunk arm, hand, and face were found with reasonable accuracy. He could locate very accurately with the left thumb points of stimulation among the left fingers and did so by responding immediately and also with a 5, 10, or 20 second delay imposed.

If free use of the hands was in order the patient generally used the left hand for any point on the left half of the body and the right hand for any point on the right side, except in the facial region where either hand was used with seemingly equal facility. Correct verbal description of the locus of stimulation was obtained only for points on the right extremities, right-half trunk and the head. All regions of the head and face were correctly cross-localized with either hand and also reported accurately in verbal response tests.

However, with the left hand the patient was totally inept in attempts to localize points on the right foot, leg, arm, hand, and the right half of the trunk. In many cases, when the right leg or hand was stimulated, the patient failed to make any response at all with the left hand.

In the early cross-localization testing there seemed to be gradients as to the degree of error, decreasing somewhat toward more proximal and axial regions. With further testing, however, the erratic ability to locate proximal points on the right side with the left hand and vice versa was shown to be attributable in large part to failure to confine the stimulation completely to one side. In particular the patient was discovered to be using incidental auditory and other uncontrolled cues present in the examination. When these were better controlled, the responses involving the axial region became grossly inaccurate like those for the extremities.

When the right hand was being used in response to tactile stimulation, the same sort of picture emerged with some interesting variations. Occasionally a stimulus on the left side would elicit an automatic response with the left hand contrary to the prevailing test procedure, while the right side failed to respond and apparently remained naïve to the whole event. After such a left-handed response was completed and the patient was asked why he had not responded with the right hand, he often claimed that he had not been touched that time. It was as if a strong shift of attention to one hemisphere had tended to extinguish perceptual awareness in the other.

Light taps were also applied doubly, i.e. at two separated points simultaneously on opposite sides of the body, occasionally at corresponding symmetrical points, but more often at non-symmetrical points. The same laterality effects prevailed as in the foregoing. All manual and verbal responses were correct in all combinations for points on the face and head. Below the neck double manual responses were carried out accurately with each hand responding to the homolateral stimulus. However, when a subsequent verbal description of the two stimulus points was asked for, those on the left side could not be reported. This was true in spite of the fact that the subject had correctly found the point of stimulation with his left hand.

In a second testing situation the patient was tapped at points on his body one to four times on a randomized schedule. The patient, seated at a table, responded by tapping the corresponding number of times with his fingers on the palm of his hand. These tests revealed the same sort of lateralization picture. The patient, that is, was able to give the correct number of taps only when the stimulus and response were kept to the same side of the body or within the cranial areas where cross-localization was possible. However, if the left hand, or foot, was touched when the right hand was being used in response, or vice versa, the score was never above chance.

All tests to both the left and the right side tended to yield a score somewhat below 100 per cent. More mistakes occurred when the body was tapped three or four times than once or twice. With the possibility in mind that the errors might be attributed largely to an uncontrolled fluctuation of attention between the two hemispheres, corollaries of this

test were carried out with the aim of potentiating the fluctuation of attention away from the working hemisphere. For example, in the course of tests in which the subject was responding with the left hand to taps on the left side, he was asked to give a simultaneous verbal report of the number of times he was tapped along with customary left hand responses. Under these conditions both the manual and the verbal responses dropped to chance.

Temperature discrimination. In testing thermal sensibility it was observed that those areas on the left side of his body which were not cross-localized by the right hand were also incapable of initiating a correct verbal response as to which one of two randomly presented stimuli were hotter or colder. For example, if the subject was touched on the left hand with a warm and a cool stimulus in series, he responded verbally at a chance level as to whether the first or the second stimulus was warmer or cooler. However, if a warm or a cool glass was first presented to him and he was then required to fetch a glass with a similar temperature from two others, he was able to perform at a high level. When this comparison was attempted intermanually the response again fell to chance. Those areas on the head and face which seem to be bilaterally represented as a result of the tactile test were also adept in thermal discrimination involving either verbal or hand responses on either side.

Pain sensibility. When the patient was stimulated by either a scratch or pin prick over various body regions, no greater ability to cross-locate the stimulus was observed. Indeed, the same sort of mapping found for touch and temperature seemed to hold also for nociceptive stimuli. It may be noteworthy that since the operation the patient has described most stimuli presented to the left side of his body as giving him a non-specific shock. The exact nature of the subjective sensation involved remains unclear.

It is of interest to note that the patient reported having scalded his left hand with hot water on at least two separate occasions while shaving. However, these incidents took place in the early months after surgery and, according to his wife, his hand showed no reflexive action. When a very hot aluminium drinking glass was presented along with a cool one in the present tests, the subject always withdrew his hand reflexively from the hot glass even though he described it as being the cool glass half of the time.

Position sense. The same lateralization scheme emerged also in tests of joint and position sense. In these tests the several joints, such as the wrist, elbow, shoulder, knee and ankle were placed by the experimenter in a given position and the subject, wearing a blindfold, was required to state verbally the position in which the relevant distal portion of the limb was pointing. This presented no problem for the right hand and foot but the subject was totally unable to describe joint position in the left wrist, fingers, and toes. Sense of position at the left shoulder was preserved while that for the left elbow was inconsistent. Position was correctly reported without difficulty for all joints of the right arm and also for the left knee and ankle. When the end of a pencil was held in one hand and positioned by the experimenter at different angles and positions, the subject was unable to reach accurately for the other end of the pencil with the opposite hand.

As noted above, position of the subject's left arm at the shoulder was generally reported correctly, the arm being lifted and held out straight from the body at different angles. However, when the right arm was held out simultaneously with the left thereby equalizing and obscuring the secondary mechanical tensions across the spinal column, ability to describe the position of the left arm dropped to chance.

DISCUSSION

The subject's ability to localize with accuracy, both verbally and with either hand, cutaneous stimulation on either side of the face, and top and back of the head, suggests a strong ipsilateral representation of sensation for these cranial areas in both hemispheres, equal to or almost as efficient as the contralateral representation. This is in line with the above-cited anatomical and electrical evidence of bilateral projection in the trigeminal system. Cross-localization from the back of the head in the present case suggests that the cortical projection for C2 also is bilateral following the plan of cranial nerve V rather than that of the lower cervical segments.

Below the neck the results were quite different in that responses to somatosensory input were appropriate only when the main cortical motor control was in the hemisphere contralateral to the stimulation. Verbal reports for stimulation confined to the left side were grossly inaccurate and often absent depending on the testing procedure. The absence of any accuracy across the midline suggests that somatosensory information from each half of the body below the neck is projected in this patient only to the contralateral hemisphere, and further, that the sensations involved are not accessible in any direct way to the ipsilateral hemisphere. The possibility that weak, latent ipsilateral effects might be revealed by other methods cannot be ruled out, but no evidence for such appeared in the tests as applied.

It should be pointed out that the inability to cross-localize with the left and right hands may involve somewhat different cerebral mechanisms. When the stimulus is administered to the right side the patient is capable of verbally describing and thereby remembering its location, while this is not true for stimuli presented to the left side. Therefore, when a response is desired with the left hand to right-sided stimuli, inability to carry out this activity is not due to a non-realization as to the location of the stimulus, but rather to a left-sided apraxia which consistently appears in this case when the left dominant hemisphere is attempting to govern the movements of the left extremities. It is possible that the minor hemisphere could have a more primitive non-verbalised memory of where stimuli fall on the left side and yet similarly be unable to bring the right hand into action.

That the subject was able to report position of the left limbs by using kinesthetic and postural cues arising from mechanical effects across the spinal column especially during gross or rapid movements of the limbs has interest for studies dealing with intermanual transfer of learning. Intermanual transfer in this subject of the learning of a stylus maze of the same sort used in earlier studies of callosum-sectioned patients [19] seems attributable in part at least to the nature and size of the maze and the consequent shoulder movement and trunk adjustments involved in its performance. Tactile discriminations limited to palpation of objects with the fingers showed no intermanual transfer. Some of the intermanual transfers reported in monkeys [20] involved the use of proprioceptive cues that might have had secondary mechanical effects at the shoulder.

The neural pathways by which somesthetic information from the left side is made available for processing in the major or language hemisphere would appear to involve mainly the corpus callosum rather than direct ipsilateral projection systems according to the present data. In this regard it would also seem likely that the extra cortical representation for the left hand in the left hemisphere found in other human studies [7] is mediated through the corpus callosum since all areas below the neck in the present case are sharply lateralized.

It appears that for areas of the body below the neck any somesthetic information arriving in the surgically disconnected cortex via ipsilateral pathways is inadequate to direct a voluntary motor response. Also, the qualitative difference between the separate functions of the left and right hemisphere in man becomes most impressive in this case. The only task tested so far in which the minor hemisphere appears to perform better than the major hemisphere is in the drawing of a Necker cube and related simple spatial sketches. To what extent the mental retardation in the minor hemisphere is a result of possible greater brain damage on this side, or is more apparent than real owing to the lack of language, remains to be determined.

REFERENCES

1. MOUNTCASTLE, V. B. and ROSE, J. E. *Handbook of Physiol.*, Sec. 1, Vol. 1, 387, 1959.
2. TORVIK, A. *Am. J. Anat.* **100**, 1, 1957.
3. BOGEN, J. E. and CAMPBELL, B. *Science* **135**, 309, 1962.
4. WHITE, R. J., SCHREINER, L. H., HUGHES, R. A., MACCARTY, C. S. and GRINDLAY, J. H. *Neurology* **9**, 149, 1959.
5. FRENCH, L. A. and JOHNSON, DAVID. R. *Neurology* **5**, 390, 1955.
6. GARDNER, W. JAMES., KARNOSH, L. J., MCCLURE, J. R., CHRISTOPHER, C. and GARDNER, Ann K. *Brain*, **78**, 487, 1955.
7. SEMMES, JOSEPHINE, WEINSTEIN, S., GHENT, LILA and TEUBER, H. L. Harvard University Press, **1960**.
8. ADEY, W. R. and KERR, P. B. *J. Comp. Neurol.* **100**, 597, 1954.
9. ADEY, W. R., CARTER, I. D. and PORTER, R. *J. Neurophysiol.* **17**, 167, 1954.
10. AMASSAIN, V. E. *J. Neurophysiol.* **17**, 39, 1954.
11. BREMER, F. and TERZULO, C. *Journal de Psysiologie* **47**, 105, 1955.
12. BROOKS, U. B., RUDOMIN, P. and SLAYMAN, C. L. *J. Neurophysiol.* **24**, 286, 1961.
13. NAKAHAMA, H. *J. Neurophysiol.* **21**, 611, 1958.
14. PATTON, H. D., TOWE, A. L. and KENNEDY, T. T. *J. Neurophysiol.* **25**, 501, 1962.
15. UTTAL, W. R. and COOK, LOUELLA. I.B.M. Research Reports, Shaker Heights, New York, 1960.
16. GOFF, W. R., ROSNER, B. S. and ALLISON, T. *Electroenceph. Clin. Neurophysiol.* **14**, 697, 1962.
17. GAZZANIGA, M. S., BOGEN, J. E. and SPERRY, R. W. *Proc. Nat. Acad. Sci.* **48**, 1765, 1962.
18. BOGEN, J. E. and VOGEL, P. J. *Bull. Los Angeles Neurol. Soc.* **27**, 169, 1962.
19. SMITH, K. U. *Science* **114**, 117, 1951.
20. GLICKSTEIN, M. and SPERRY, R. W. *J. Comp. Physiol. and Psychol.* **53**, 322, 1960.

SUPPLEMENTARY REFERENCES

MALIS, L. I., PRIBHAM, K. H. and KRUEGER, L. *J. Neurophysiol.* **16**, 161, (1953).
WOOLSEY, C. N. *Fed. Proc.* **6**, 437, (1947).

Résumé—Une série de tests somato-sensitifs a été appliquée chez un sujet ayant subi une section chirurgicale des commissures cérébrales. Ces examens révèlent une nette différence des effets somesthésiques entre les extrémités droite et gauche et entre les côtés droit et gauche du tronc. De façon prédominante la projection controlatérale de la somesthésie apparaît avec évidence. L'existence d'une représentation ipsilatérale pour les régions situées en dessous du cou reste douteuse. La projection bilatérale ressortait des résultats obtenus au niveau de la face et du sommet et de l'arrière de la tête avec représentation égale des deux côtés. Par comparaison, il y avait en règle peu de trouble fonctionnel quand "l'output" sensitif et moteur impliquait le même hémisphère, mais un trouble important et une incapacité complète étaient évidents quand l'intégration croisée droite-gauche était requise. Ces résultats et d'autres similaires dans le présent cas suggèrent qu'en l'absence d'atteinte cérébrale pendant l'enfance, l'interaction transcalleuse est d'importance extrême pour l'utilisation des données somesthésiques ipsilatérales, spécialement lorsque les extrémités gauches participent aux activités concernant les fonctions symboliques de l'hémisphère dominant.

Zusammenfassung—Bei Anwendung verschiedener Methoden zur Prüfung der sensiblen Qualitäten am Körper stellte sich bei einem Kranken nach neurochirurgischer Commissurotomie eine sehr bemerkenswerte Spaltung der Empfindungswahrenehmung zwischen der rechten und linken Körperhälfte, einschliesslich Extremitäten, dar. Ein Überwiegen der kontralateralen Projektionsleitung für die Körperfühlsphäre war evident. Eine irgendwie geartete ipsilaterale Afferenz schien, bis auf die Nackenregion, zu fehlen. Eine doppelseitige Projektion liess sich für Gesicht sowie Vorder- und Hinterkopfregion beiderseits nachweisen. Demgegenüber schien die funktionale Behinderung in der sensomotorischen Aktion relativ gering zu sein, soweit man ipsilaterale Anforderungen stellte. Dagegen erwies sich die Gebrauchsbehinderung bis zur kompletten Unfähigkeit behindert, wenn Anforderungen, wechselweise gekreuzt, von Hemisphäre auf kontralateraler Körperhälfte gestellt wurden. Solche und ähnliche Ergebnisse, wie sie der dargestellte Fall bot, legen es nahe, dass bei unbehinderter cerebraler Entwicklung in der Jugend die durch den Balken vermittelten funktionalen Einflüsse zwischen den Hemisphären und der sich darauf aufbauenden Sensomotorik der Peripherie von entscheidender Bedeutung sind. Nur durch die entsprechende Nutzbarmachung ipsilateraler Empfindungen einer Körperhälfte gelingt es z.B., auch die linksseitigen Gliedmassen in eine von der dominanten Hemisphäre geplanten und gesteuerten Handlungsfolgen von Ausdruckscharakter einzubeziehen.