HEMISPHERECTOMY.*

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I. INTRODUCTION.

HEMISPHERECTOMY in man† (ablation of the cortex, the underlying white matter and nucleus lentiformis) was performed first by Dandy (1928, 1933), later by Gardner (1939) and a few others, on adult patients suffering from large infiltrating tumours of the subdominant hemisphere, with one exception (Zollinger, 1935). It was carried out by McKenzie (1939) apparently on a patient suffering from infantile hemiplegia with epilepsy. Krynauw (1950*a*, *b*) began systematic work of this nature on cases of infantile hemiplegia with epilepsy and personality disturbances. Apart from its therapeutic value, in carefully selected infantile hemiplegics, in the hope of lessening or curing epilepsy, and exerting a beneficial influence on behaviour and further mental development, the comparatively small loss of functions after removal of one hemisphere is most remarkable.

I hope to demonstrate this in five patients. In the paper following I shall try to show how one may understand, in principle at least, these amazing results. During the demonstration I shall touch on some aspects concerning the single patient, and it will become clear how much work has still to be done in order to comprehend the problems of, and do justice to, each individual patient. Some of these problems will be mentioned as far as they are relevant to the main theme. Problems not mentioned may yet turn out to be just as important as those mentioned; but their importance may not be appreciated by the present author.

II. FINDINGS (CASE DEMONSTRATION).

The five patients (all of Harperbury Hospital) operated on by hemispherectomy at the National Hospital, Queen Square (Mr. W. McKissock), had and have all some common and some individual features before and after operation. They are all sufferers from infantile hemiplegia with fairly low-grade mental deficiency. They all had epilepsy and personality disturbances before operation. From the operation they have all, with one exception (J. M—), benefited one way or the other, and none of them is mentally or physically worse after it,

* Case demonstration and paper read at the Annual General Meeting of the Mental Deficiency Section of the R.M.P.A. (Harperbury Hospital), 1 May, 1953.

† In monkeys, the first systematic studies were made by Karplus and Kreidl (1914), the most accurate description of the consequences of hemispherectomy in apes is by Fulton *et al.* (1938, 1949).

including J. M—.* Individually, they all offer mental and physical differences pre- and post-operatively, as can be seen from the case papers. Although, in this demonstration I am dealing essentially with the "non-psychological" aspect of the matter, I have at the end of each case paper given a few "mental" characteristics of the patient. The short statements on the cerebral pathological findings I owe to the kindness of Dr. Mair, and on the pre- and post-operative E.E.G.s to Dr. W. Cobb (through Dr. J. Bates), all of them at the National Hospital, Queen Square, London.

From the anatomical-pathological point of view these five patients fall into two groups. Two (D. G— and V. R—) had cysts in the distribution of the middle cerebral artery; the other three had more diffuse processes (A. L—, A. Z— and J. M—). For reasons which will become obvious later, the clinical findings have been written up in a somewhat unorthodox way.

All patients can speak, dress, are more or less well orientated in time and place and have no disturbance of the body image, irrespective of whether their r. or l. hemisphere has been removed. They all can hear equally well in both ears, there is no ataxia or gross disturbance of co-ordination. None of them shows forced grasping, forced circling, etc. They are all hemianoptic. The sense of smell could not be assessed very well, but it is to be presumed that they have lost it on the side of the operation. Having pointed more or less to what is common to them I want now to stress a few points in which they differ individually.

Case Papers.

A. L—. Date of birth: 12.iii.38. Operation: 19.i.50. First seen and treated at Shenley: 16.xi.50.

A right-sided hemiplegia (fairly typically spastic now, essentially athetoid before operation). Still a number of epileptic fits.

I. *Physical Functions.*

A. *Essentially bilateral central innervation:*

(i) *Motor:* Upper VII, r. somewhat worse than l. V3: r = l.; eye movements: free.
Speech: Somewhat bellowing. Muscles of neck and trunk: r. = l.

(ii) *Sensation:* Epicritic: touch possibly less well felt and localized on r.; protopathic: frightened of the needle.

(iii) *Co-ordination:* Slight nystagmus; more to the left (barbiturates); otherwise good.

(iv) *Vegetative:* Temperature of skin: r. = l.

B. *Essentially unilateral central innervation:*

Face: R. lower VII slightly worse than left. Tongue: midline; visual fields: r. hemianopia.

Limbs:

(i) *Motor:* R. arm and leg fairly typical spastic paresis, without contractures of arms, but of foot. Movements of wrist and fingers practically impossible. Fingers fairly flaccid, but spastic on extreme movements, and throughout when wrist is brought up to horizontal. Wrist clonus at times, no forced grasping.

(ii) *Sensation:* Epicritic: localization of touch not very good, finer examination impossible.

* They owe a great deal of their rehabilitation to Miss E. Bagley, the late, and Miss K. Rattray, the present Physiotherapist to Shenley Hospital.

(iii) *Co-ordination :* F.N.T. : normal. Diadochokinesis : r. impossible. On left (!) slight dysdiadochokinesis.
(iv) *Vegetative :* Temperature slightly colder right than left (fairly warm weather). Trophic : v. slight atrophy. Abd. refl. r. less than l.
Change after training : joints freed ; mass-movements of arm broken up somewhat into more isolated movements of large joints.

II. *Non-Physical Functions.*

A. *Essentially unilaterally innervated :*

(i) " Absolutely " dominant. Speech : bad, originally only telegram style ; now begins to speak short but full sentences. Three R's impossible. Praxia for objects and " concrete " construction good. " Symbolic " constructive praxia bad, cannot draw. Some dyspraxia of right shoulder movements and possibly of diadochokinesis.
(ii) " Relatively " dominant : functions of body scheme (sensory and motor) : good.

B. *Essentially bilaterally innervated* (" *co-dominant functions* ").

Orientation in place : good ; in time : worse (the latter most likely a consequence of low grade M.D.).
Behaviour in Shenley : A noisy, affectionate, easily contented boy who gives very little trouble. Before operation : ill-mannered, dirty, voracious, some attempts at running away, stubborn, occasionally aggressive when thwarted. Apprehensive, not shy.

Path. Anatomy.

Numerous gliosed lesions of the cortex and white matter scattered throughout the hemisphere. In these scarred regions the nerve cells and axons had disappeared.

E.E.G.

19.xii.49. Bad record. No alpha. Irregular low voltage slow background with some larger 4 c./s., a little better seen on right. Asymmetry slight. Left hemispherectomy 19.i.50.
3.iii.50. Considerable increase in right-sided alpha. Other activity about the same. Flat on left.
2.x.50. Left flat. Right ? normal for age with good alpha and some 3–7 c./s.
31.x.50. Restless—bad record. Some slower waves on right—? sleep. No P.C. with flicker—useless.
6.ii.51. (1) Artefacts, but flicker is fair at times and becomes more nearly symmetrical at higher frequencies (in occipital channels only).
6.ii.51. (2) Better. Slow waves, around 6 c./s. are surely more than normal for 13 years, but slower waves came up only on drowsiness from 6 gr. seconal. Fast activity not great but definite.
4.ii.52. Restless and unco-operative. Very poor record. Slow activity seems larger and more persistent than before, but this may be artefact.
10.i.53. Left flat. Right small irregular alpha and low voltage 4–7 c./s. with slower waves. 6 gr. seconal not very effective.

D. G—. Date of birth : 12.ii.1927. Operation : 16.viii.50. First seen at Shenley and treated : 29.xi.50.

A left-sided infantile hemiplegia with contractures of all joints of arm and v. slightly of foot. Still had epileptic attacks until about one year ago.

I. *Physical Functions.*

A. *Essentially bilateral central innervation :*

(i) *Motor :* Lower VII, V3, speech, neck, trunk : good (r. = l.). Eye movements : slight paresis of l. internus and rectus superior. No double vision.
(ii) *Sensation :* Epicritic : face : r. = l. (including localization of touch) ; localization on trunk l. a little worse than r. Protopathic r. = l.

(iii) *Visual fields :* L. hemianopia.
(iv) *Co-ordination :* Eyes : slight nystagmus, more to r. otherwise good (no barbiturates). Trunk : good.
(v) *Vegetative :* Temperature of skin r. = l.

B. *Essentially unilateral central innervation :*

1. *Motor :*

(a) *Face :* Lower VII l. trace worse than r. Tongue slightly to r. Slight diadochokinesis of tongue (l. frontal lobe damaged).
(b) (i) *Arm :* Contractures increasingly towards wrist, but not of fingers ; mobility of shoulder and elbow hampered by a slight spasticity, while wrist and fingers are unusually flaccid. Power in shoulder and elbow quite good. Wrist only very slight movements ; fingers : no isolated movements. Can grip and hold slightly. Thumb : extension very bad ; opposition and adduction better. Extension of other fingers slight ; flexion and opposition of five practically *nil* (demonstration). *Changes after training :* Original stiffness of all joints overcome ; mass movements of whole limb broken up into more isolated movements of individual joints. The possible movements can be carried out fairly quickly.
(ii) *Sensation :* Epicritic of hand fairly bad in every respect. Protopathic : l. about r.
(iii) *Co-ordination :* F.N.T.: r. = l. Diadochokinesis : l. impossible ; r. good.
(iv) *Vegetative :* Temperature of skin : r. = l. (in warm weather : somewhat worse in colder weather). Trophic : l. arm : about 2½ in. shorter.
(*c*) *Abdominal reflexes :* Cannot be tested ; too ticklish.
(d) *Leg :*
(i) *Motor :* Slight spastic paresis of l. leg with spastic reflexes. Foot : only slight plantar and very incomplete, dorso-flexion : toe movements better : No diadochokinesis possible (? also not quite good on r.). K. H. T. r. = l.
(ii) *Sensation :* No detailed examination possible.
(iii) *Co-ordination :* Good.
(iv) *Vegetative :* Temperature of skin as arm. Trophic : slight atrophy.

II. *Non-physical Functions.*

A. *Essentially unilaterally innervated :*

(i) *" Absolutely " dominant :* Speech good. Three R's not possible. Praxia good. Refuses to draw, etc.
(ii) *" Relatively " dominant :* Functions (motor and sensory) of body scheme good.

B. *Essentially bilaterally innervated.* (*" Co-dominance*) :

Orientation in place and time good. Knows usually r. from l.
Changes after operation : Has learnt to count up to 10. Behaviour at Shenley: Very touchy but ambitious (for time being) ; treatment had to be interrupted for two years as he refused to co-operate. Before operation, shy, solitary, moody, aggressive, anti-social, morose, window-breaker.
Anatomy : Presented a cyst in the distribution of the middle cerebral artery.

E.E.G. :

2.viii.50. Definite right-sided abnormality, but amplitude not great. Mainly 4 c./s. waves, some slower. Sharp waves in parieto-temporal region. Dubious silence in temporal.
15.viii.50. Asymmetry less obvious. After seconal minute fast rhythm in left frontal.
Right hemispherectomy 16.viii.50 temporo-parietal cyst.
24.viii.50. Poor record : nothing new on left. Right flat but lot of artefacts. Bilateral rhythms with common electrodes.

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7.ix.50. Alpha rhythm 7–8 c./s., some slow waves on left. Quite a lot on right, but only near midline. Trivial asymmetric fast response to Seconal.
28.ix.50. Slow alpha of better amplitude, but slower waves less apparent. Still quite a lot of right-sided activity, mainly near midline which sometimes seems indepedent in frequency and amplitude.
18.x.50. Similar.
28.iii.51. Slightly different from last. Dominant 6–8 c./s. blocked by visual attention mixed with 4–7 c./s. On right seems some irregular low voltage. *Flicker:* Small, equally seen on both sides. Seconal: Some fast on left.
13.ii.52. Unchanged from last.
9.xii.52. Unchanged from last.

V. R—. Date of birth: 8.ii.1929. Operation 23.xi.50. First examined and treated at Shenley 2.iv.51.

A right-sided infantile hemiplegia with epileptic equivalents (about two or three times a month) after operation, and before operation, many epileptic fits. Contracture of shoulder and wrist; wrist somewhat corrected by orthopaedic operation about one and a half years ago.

I. *Physical Functions.*

A. *Essentially bilateral central innervation:*

(i) *Motor:* Upper VII, r. = l. V.3. r. = l. Eye movements free. Muscles of neck and trunk r. = l. Speech: somewhat slow; improving.
(ii) *Sensation:* Epicritic (including localization) and protopathic; slightly disturbed after operation, slowly recovering, now r. = l.
(iii) *Co-ordination:* Eyes: slight nystagmus to l. (no barbiturates). No ataxia. (R. frontal pole damaged.)
(iv) *Vegetative:* Temperature of skin: r. = l.

B. *Essentially unilateral central innervation:*

(a) *Face:* Lower VII: r. slightly less than l. Tongue: v. slightly to r. Diadochokinesis of tongue: Good. Visual fields: r. hemianopsia.
(b) *Arm:*
(i) *Motor:* Mixture of spasticity and rigidity (varying in degree) in shoulder and elbow. Wrist: Surgically stiffened (arthrodesis in mid-position). Fingers flaccid, but spastic in extension on quick stimulation (stretch). Power in larger joints good. Closing of fist fairly good. (diminished immediately after operation.) Thumb extension slight, opposition, better, Despite flaccidity can use hand for holding and grasping (demonstration). No forced grasping. Very much improved after training. Can carry out very quick movements.
(ii) *Sensation:* Epicritic; cottonwool, bilateral touches: r. = l. Two point discrimination, joint sense for finest movements, recognition of surface structure, stereognosis less good than l., but improving under training (demonstration). Protopathic: r. = l. (also 2-point discrimination for pain).
(iii) *Co-ordination:* No ataxia. Diadochokinesis of fingers good.
(iv) *Vegetative:* Trophic: slight atrophy. Temperature of skin: r. slightly colder than l.
(c) *Abdominal reflexes:* R. slightly less than l.
(d) *Leg:*
(i) *Motor:* Slight spastic paresis r. On left: occasionally very slight spasticity of knee and ankle, toe fanning, Mendel-Bechterew, Rossolimo (? already present before operation).
(ii) *Sensation:* Epicritic, including joint sense, and protopathic good, not much difference between r. and l.
(iii) *Co-ordination:* Good.
(iv) *Vegetative:* Slight r. atrophy. Temperature of skin: r. slightly colder than l.

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II. *Non-physical Functions :*

A. *Essentially unilateral innervation :*

(i) *" Absolute " dominance :* Speech good ; reading, writing slowly improving. Arithmetic bad. Thinking : Not too good. No apraxia for objects or construction, can draw. Speech quicker after operation.

(ii) *" Relative " dominance :* Functions of body scheme (motor and sensory) good.

B. *Essentially bilateral innervation* (*" Co-dominance "*):

Orientation in place and time (can read clock), and r. and l. differentiation good.

Behaviour at Shenley : At times somewhat moody and slightly fatuous (usually before and after epileptic equivalent). Usually even tempered, fairly ambitious, very reliable, no trouble. A few years before operation he had, on slight provocation, attacks of violence with window-breaking, according to him, only when provoked.

Anatomy :

A cyst in the distribution of the middle cerebral artery.

E.E.G. :

Pre-operative : (4 records) right some alpha and much 3–7 c./s. Left flat in frontal and parietal. Posterior temporal focus of slow waves with spikes and sharp waves. Flattening not confirmed by seconal and sleep.

Post-operative : (5 records) on right at first similar to pre-operative, but becoming more normal. Now very nearly normal.

A. Z—. Date of birth : 10.iv.38. First seen 27.i.51. Operation : 7.iii.51. Treatment started at Shenley 12.v.51.

Left infantile hemiplegia. Epilepsy : cured (so far).

I. *Physical Functions.*

A. *Essentially bilateral central innervation :*

Motor : Lower VII, V3, eye movements, neck, trunk : good, unchanged after operation.

Sensation : Epicritic and protopathic of face, neck and trunk : practically normal, even localization of touch, unchanged after operation.

Hearing : Good, unchanged.

Co-ordination : Eye, neck and trunk movements : essentially unchanged ; normal.

Vegetative : Temperature of skin r. = l.

B. *Essentially unilateral central innervation :*

Face : Lower VII, left trace less than right (unchanged).

Visual fields : ? Left hemianopia before, definite hemianopia after operation.

Arm and Leg :

(i) *Motor :* Main characteristics : no contracture of arm or leg (except tenotomy of left foot 1948). Mobility of large joints almost normal. Power decreasing peripherally, practically *nil* in wrist, poor in foot. No isolated finger movements, some opening and closing of hand. Holding of objects somewhat favoured by rigidity, particularly thumb and next two lateral fingers (demonstration). Tonus of muscles of large joints : fairly free, but variable in elbow. Wrist fairly stiff. Neurological changes after operation : slight increase of tonus in wrist, fingers and elbow. No forced grasping. Changes by training : movements of fingers somewhat better ; some improvement in use of hand for grasping and holding (demonstration).

(ii) *Sensation :* Normal before operation. After operation, slight disturbance of localization and discrimination for touch (demonstration).

(iii) *Co-ordination :* No ataxia. Diadochokinesis of hand on left impossible, not too good in elbow and thumb ; on r. not always quite good (? dyspraxia).

(iv) *Vegetative :* Temperature of limbs : not tested before operation. Now left limbs much colder than right. Moderate atrophy of arm, slighter of leg (not much change).

II. *Non-physical Functions.*

A. *Essentially unilateral innervation :*

(i) *"Absolute" dominance :* Speech and Praxia : good. Three R's not possible, cannot draw. Thinking bad. Speech : stuttering pre-operative.

(ii) *" Relative " dominance :* Functions of body scheme : good.

B. *Essentially bilateral innervation* (" *co-dominance* ") :

Orientation for place good ; time : bad. R. and l. differentiation : bad.
Changes after operation : none .

Behaviour at Shenley : Very difficult. Jealous, hypersensitive, stubborn, spiteful and resistive when he has not his own way. Before operation these trends were still more outspoken, with frequent outbursts of the most violent aggression. He was frightened of epileptic fits.

Anatomy :

Most of the gyri appeared normal. The gyri in the island of Reil were small and gliosed.

E.E.G. :

Always difficult, and most records are in seconal sleep.

Pre-operative : (l. record) very pronounced asymmetry of fast rhythm, absent from r. side. On left 6 c./s. and slower waves, depending on depth of sleep. In right frontal, runs of very slow waves with spike or sharp wave.

Post-operative : (4 records) flat on right, less slow and some alpha on left and probably normal sleep responses.

J. M—. Date of birth : 23.iv.39. First examined : 1.ii.51. Operation : 12.iii.51. Treatment started at Shenley : 21.v.51.

Right-sided infantile hemiplegia, with slight total facial weakness on right, and also very slight pyramidal-lesion on left before operation. Still a number of epileptic fits.

I. *Physical Functions.*

A. *Essentially bilateral central innervation :*

(i) *Motor :* Upper VII r. less than l. (weakness very pronounced after operation ; now as before). V3 r. = l. Eye movements : free ; speech: no dysarthria. Muscles of neck and trunk, r. = l.

(ii) *Sensation :* Epicritic and protopathic : r. = l.
(iii) *Co-ordination :* No nystagmus, no ataxia.
(iv) *Vegetative :* Skin temperature : r. = l.
} No change.

B. *Essentially unilateral central innervation :*

(a) *Face :* Slight weakness of lower VII on r. After operation worse ; now as before.

Visual Fields : Full before operation, now r. hemianopia.

(b) *Arm :*

(i) *Motor :* Fairly typical hemiplegia with a mixture of changing rigidity and spasticity in shoulder and elbow (contracture of elbow for supination), and of wrist. Wrist and fingers at times hypotonic, at times spastic ; particularly thumb and radial fingers. Movements of arm poor ; usually only a mass movement in shoulder possible ; at times slight flexion in elbow if he understands what one wants. After operation : worse. After treatment : original stiffness of shoulder much lessened, otherwise not much progress ; attends treatment very irregularly, due to frequent epileptic attacks.

(ii) *Sensation :* Epicritic : satisfactory before operation, now disturbance of localization for touch. Protopathic : apparently r. = l. no change.

(iii) *Co-ordination :* No ataxia. Diadochokinesis : not possible on right. On left dysdiadichokinesis elbow and thumb.

(iv) *Vegetative :* Atrophy r. arm. Skin temperature r. = l, (at average room temperature).

(c) *Abdominal reflexes :* r. = l. before operation ; now r. less than left.
(d) *Leg :*
(i) *Motor :* Moderately severe spastic paresis r., with usually more flaccid contracture of foot, and spastic reflexes and spastic gait. Very bad after operation, now about as good as before, possibly with the exception that the slight foot movements, present before operation, are absent now (but he scarcely makes any attempts at movements). Very slight spasticity on l. with some spastic reflexes.
(ii) *Sensation :* About r. = l. ; apparently little change ; finer examination impossible.
(iii) *Co-ordination :* No gross disturbance (unchanged).
(iv) *Vegetative :* Skin temperature : r. foot usually colder. Trophic : r. leg atrophic, but less so than arm.

II. *Non-physical Functions.*

A. *Essentially unilateral innervation :*
(i) *"Absolute dominance" :* Speech and praxia : no gross disturbance ; 3 R's, drawing impossible. Thinking : very poor. No change.
(ii) *" Relative " dominance :* Functions (motor and sensory) of body scheme : no gross disturbance. No change.

B. *Essentially bilateral innervation (" co-dominance "):*
Orientation for place not grossly disturbed, for time bad, r. and l. differentiation impossible. Unchanged.
Behaviour at Shenley : Not very interested in training ; very playful but no trouble. At Harperbury, before and after operation : moody, solitary, aggressive towards patients and staff ; occasionally a window-breaker.

Anatomy :

Extensive damage mainly in the fronto-parietal region where loss of nerve cells and myelin, and glial scar formation had taken place.

E.E.G. :

13.ii.51. Lack of co-operation necessitated use of seconal and record commenced a quarter of an hour after 3 gr. Asymmetry was slight at first, but quickly increased as the patient became drowsy and slow activity at first around 4 c./s. appeared on the right side together with transients suggesting slow spike and wave complexes. As sleep deepened this activity became much more pronounced and frequently constituted an arousal reaction. Photic stimulation did not show any convincing differences and the response was small. Left hemispherectomy 12.iii.51. Fronto-parietal blood clot.

5.iv.51. Patient more co-operative. Record obtained without seconal, but not perfect. Relatively flat on both sides, anteriorly, but alpha rhythm posteriorly best seen in *left* occipital channels, i.e., those with one electrode on the occiput. Some irregular low voltage slow activity on the right side. Photic stimulation again inconclusive. Probably normal.

27.iv.51. Six gr. seconal. No sleep nor increase in fast rhythm. Right side not different from 13.ii.51 before sleep. Left side flat.

11.xii.51. Awake. Good alpha rhythm. Right frontal occasional single sharp waves, but on one occasion repeated regularly. Generalized low voltage slow and in the occipito-temporal region focus of 1½–2 c./s. waves occurring in long regular bursts.

24.i.52 : Further increase in slow activity and in frontal sharp waves which tend to occur in episodes at 2 c./s. for about 10 sec. Arise far forward on right and constant in site.

3.xii.52. Awake, left flat. Right low voltage alpha, some fast, some theta, occasional small sharp waves. Asleep : long runs of right frontal 2 c./s. spike and wave complexes, spreading and slowing in deeper sleep.

Individual Differences.

A. *Motor and Vegetative Functions.*

I. *The Cystic Patients (D. G— and V. R—) both with Pre-operative Damage to the Remaining Frontal Poles.*

Both have contractures in the upper limb, the fingers of both are very flaccid, but V. R—on very quick passive extension of the fingers shows spasticity, D. G— does not. While the eye-movements of both are quick into the hemianoptic visual field, V. R—'s eye-movements are free, while D. G—'s shows at times a very slight paresis of the left internus and rectus superior, without double vision. Both have a slight nystagmus towards the removed hemisphere (no barbiturates), and it may be worth while to remember that both have damage to the remaining frontal lobes. D. G— does not show any pyramidal signs on the right (healthy) side, while V. R— at times has some slight spasticity in the left ("healthy") leg, with usually some of the spastic small toe reflexes being present. The skin temperature of V. R— is, unless it is very cold, practically the same on right and left, while D. G—'s hemiplegic limbs are somewhat colder than V. R—'s, but much less so than those of the other three patients.

II. *The "Diffuse Group."* (I.Q. much lower than of the first group.)

Their hemiplegias are comparatively worse than those of the first group, and particularly that of A. L— which resembles that of a grown-up person. The reason for this, in the latter patient, is obviously due to the fact that, prior to operation he had some extrapyramidal, but practically no pyramidal disturbance. This means, he obtained a pyramidal lesion, not when he was an infant, but when he was 12 years old (by operation). J. M—'s hemiplegia of the arms was fairly severe too and is still; possibly due to the fact that both hemispheres are involved; he had, and still has, pyramidal signs on right and left. A. L— and A. Z— have no contracture of the upper limb, J. M— has. A. L—, who is on barbiturates, has a slight nystagmus, J. M. also on barbiturates has not; otherwise the eye-movements of all of them are free.

B. *Sensory Functions.*

In this respect I shall deal only with the first group (the I.Q. of the second group is much too low to make an exact examination possible) and want to make two points on "epicritic" sensation: (1) V. R—'s sensation is so good on the hemiplegic side, even on his hands, that he will rightly recognize direction of movements, and also touch with cotton wool, no matter whether the right or the left, or both sides together are touched. He also can often, though not always, differentiate whether an object is hard or soft, smooth or rough. However, two-point discrimination on the right hand is less good than on the left, particularly in the region of thumb and little finger, and the same holds good for very fine joint movements. But for practical purposes his epicritic sensation is unusually little damaged.

(2) The other point is of sensory training: before a very accurate examination of sensation had been carried out on V. R—, it was found that stereognosis with the hemiplegic hand was bad. Since then (during the last three weeks or so), a charge nurse at Harperbury has, on my suggestion, tried to train V. R—'s stereognosis, with the result that he will now usually recognize: key, fountain-pen, wooden brick, comb and a penny. However, he tires very easily in this, and once he has made one or two mistakes, he relies on guessing. This is a phenomenon quite well known to occur when there is cortical defect. As a "negative complement" to this, D. G—, in the beginning, due to frequent testing, was able to differentiate the direction of finger movements of the hemiplegic hand and to imitate then correctly with the other, unless the movement became very small. Then he relapsed and refused for two years to undergo treatment until about one month ago. His joint sense is now very bad indeed. It appears to me that the retraining of finer functions has to be rigorously maintained (i.e., that it has to be practised every day, of course, without fatiguing the patient), otherwise the newly "learned" function is very quickly "forgotten." I have had similar experiences with regard to the learning and "forgetting" of finer controlled finger-movements (V. R— and A. Z—). Altogether the training of these patients, except V. R—, demands a good deal of patience, consequent to their low I.Q., lack of attention and concentration, easy fatigue and very unbalanced personalities (particularly A. Z— and D. G—).

c. With regard to *mental improvement* the best success was with A. L—, who, soon after operation, became a very happy, sociable and affectionate, though somewhat noisy child, despite maintenance, and for a time even worsening of epilepsy, and the acquisition of a severe hemiplegia. In contrast, A. Z—, another "diffuse" patient, began only recently to settle down at Harperbury Hospital, while at Shenley he is still giving a good deal of trouble though gradually less than before. In contrast to A. L—, this boy has remained free from epilepsy. So this factor in these two patients does not play any rôle concerning "mental improvement." On the other hand, the co-influence of personality factors and psychogenic conditions cannot always be excluded. A. Z— is and was a difficult child with a, until recently, not very co-operative mother, while A. L—'s parents are very devoted to him. Similarly, V. R—, who still has epileptic "equivalents," about two or three per month, has definitely improved in spite of this. But there may be some "external" factors as well at work influencing his behaviour. On the other hand, D. G—, although free from epilepsy for the last year, is still extremely difficult indeed, and I am not sure that the present "improvement" will last. One may say that the reason for the lack of success in this case, as in that of J. M—, lies in the fact that both patients have their remaining hemispheres damaged. But then V. R— (also "cystic") has frontal brain damage "similar" to that of D. G—, plus a slight disturbance of the "better" pyramidal system. So these few patients show that the position is far from being clear, when and when not to expect mental improvement from hemispherectomy, unless the patients are "picked" with the greatest care.

Having emphasized some of the difficulties which confront us with the selection of the individual patient and the evaluation of the different factors

before and after operation, I want now to deal with some problems from a more general point of view.

III. Discussion. Facts and Hypotheses.

In this paper I shall deal with the more anatomo-physiological aspects of the following problems ; more shortly and at the end, the selection of operation and of patients ; more extensively with :

Hemispherectomy (H.E.), particularly in infantile hemiplegia, and in connection with the problem of production of symptoms and the possible replacement of function after interference by either a pathological process or the neurosurgeon's knife, causing elimination of that tissue which is usually thought to carry out the function concerned. By replacement of function I do not mean restitution of function which is due to the healing of a pathological process with restoration of the tissue to more or less its original state. I also wish you to understand that in this paper I speak of replacement of function essentially from the "practical point of view" ; neglecting e.g., that with a hemiplegia the chronaxy of the clinically unaffected side is altered, or that after right hemispherectomy (H.E.) in adults, according to Rowe (1937, 1938) and also Bell and Karnosh (1949), a slight lowering of emotional control and of memory function can be found when appropriate psychological tests are applied. I shall also neglect some transient disturbances after H.E. in infantile hemiplegics and adults operated on for brain tumours, such as profound loss of sensation (Krynauw, 1950*b*) or severe flaccid paresis of the hemiplegic side, or tremulousness of limbs, etc. (Cairns, 1951). On these transient findings not only nervous organization but operational factors may have an influence (Graham Brown, 1927).

Production of symptoms, according to Hughlings Jackson, is due to loss of function (negative signs) with or without the release of lower functions (positive signs). In principle, central nervous functions after loss of tissue can be replaced or maintained only when there are other parts of the C.N.S. anatomo-physiologically capable of carrying out such functions, spontaneously or after training. The classical neurological view has led us to believe that, "in man" at least, damage to function-bearing tissue may result in restitution but not in replacement of function. The most astonishing outcome of right H.E. in brain-tumour patients (later on referred to as "adults") is that, except for the loss of function, due to loss of essentially unilaterally innervated projection areas, the disturbance of other functions is negligible ; even the hemiplegia and loss of sensation in most cases are less severe than expected. In hemispherectomized infantile hemiplegias the only total neurological loss is, as in adults, homonymous hemianopia, with or without macular sparing. There is usually improvement of motor function, mainly due to training (case A. L— is an exception). Sensory loss is often amazingly slight, and retraining appears possible (D. G—, V. R—). More than this : removal of the so-called dominant hemisphere does not produce apraxia for objects, nor aphasia and kindred disturbances (all cases). On the contrary, speech may improve after operation (cases A. L—, V. R—, A. Z—, some of Krynauw's patients). Other loss of

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functions met with after "pathological" damage to association areas of the subdominant hemisphere will also not occur. This appears to prove true what has been assumed for a long time, as patients with early right infantile hemiplegia usually can speak well (some French writers are of a different opinion, e.g., Klein, 1949), that the very immature brain, possibly with undeveloped myelinization, is very "plastic" and that the better hemisphere can take on the association-functions of both hemispheres, becoming dominant and subdominant at the same time. The "plasticity" of the immature brain extends to a certain degree even to *projection* functions. The loss of motor and sensory functions in infantile hemiplegias is often less severe than in patients who received their lesions at a later time in corresponding areas. Most likely, in such early cases, the ipsilateral and subcortical systems are able to develop (spontaneously and/or by training) some of their functions to a higher degree. An exception to this is the visual field, with the possible exclusion of the innervation of the macula; crossing (or uncrossing) of fibres appears to be practically complete. Our patient A. L— proves the hypothesis that the brain has to be very immature in order to develop homolateral and/or subcortical motor and sensory functions after a lesion. A. L— was only 12 years of age when hemispherectomized. While before operation the motor disability was essentially extrapyramidal, he is now left with a very severe hemiplegia indeed.

It would be very superficial, however, to assume that "plasticity of the immature brain" gives the whole solution of the problem of production and replacement of function after cortical lesions.

(1) Even in adults subdominant H.E. does not produce either the disturbances we connect clinically with damage to the temporal and parietal areas, or the so-called homolateral frontal syndrome of the French authors ("extrapyramidal" disturbances and dis-coordination, Rouquier, 1948), and above all:

(2) If the plasticity of the immature brain could overcome everything, why is there infantile hemiplegia with mental and epileptic phenomena at all? Krynauw thought, and this was the rationale for his operation, the syndrome is not so much caused by loss of tissue as such, but by a pathological process whose upsetting influence spreads not only to many areas of the diseased hemisphere, but also through the corpus callosum and other commissural systems to the other hemisphere. Removal of the disturbed and disturbing hemisphere should allow the cortex of the other one to carry out and develop its functions, and we may add also the functions of the bilateral deeper parts of the brain. On the other hand, a number of functions in infantile hemiplegics remain damaged or become lost even after surgical intervention, so another factor apart from "disturbance by a pathological process" must exist.

We must therefore restate our problem of disturbance and replacement of functions consequent on surgical or pathological interference and ask: what kind of damage in what areas does, or does not, cause production of symptoms? You will remember from the way patients were presented that the crucial point appears to be whether damage is produced in "projection" or in "association" areas, and whether the functions, physical or not physical, are "innervated" or "localized" or "centrally" organized, or "represented"

if you prefer the Jacksonian term, essentially uni- or bilaterally in the cerebral cortex. I speak again from the practical point of view, because "theoretically" representation of function is distributed all over the brain, but "practically" concentrated in preferential parts, the so-called "centres." Functions are evoked by peripheral or central stimuli travelling along afferent pathways. They are then integrated in or by central systems, usually in and/or around (synapsis) cells, and their action, again central or peripheral, is carried out by effector systems through the integrated stimuli travelling along efferent pathways. The more complicated a function is, the more complicated is the nervous organization serving it and vice versa.*

Hughlings Jackson has taught us that functions are built up at different levels, subcortical and cortical. In the evolution and dissolution of functions many factors play a rôle. This is all somewhat complicated, but over-simplification of a problem obscures it.

Now let us turn our attention to the difference between pathological and surgical lesions. A pathological process, and particularly a diffuse one, may cause quite irregular lesions, unselectedly affecting one or several systems, or parts of them, to a varying degree, extensively and intensively. Such a lesion may not simply produce elimination of a system and loss of function, but from it inadequate and faulty innervation with distortion of function may result, the more so, the more systems are affected and the more complicated a system is: i.e., particularly in association systems. To this, the possible localization of a process, are added the many mechanical, chemical, physiological, vascular, direct and indirect, local and remote consequences of a lesion. Wertham and Wertham (1934) list about 35 different aspects of a demyelinating lesion. Thus, the consequences of pathological processes may spread far beyond their actual "anatomical localization" and influence ipsi- and contra-lateral hemispheric functions, and due to the interference with the association and commissural cells and fibres, the lesion and its consequences may disturb just those systems with which the damaged areas are most closely connected and which otherwise might be able to replace or maintain the functions locally disturbed or cut out. A pathological process is often something very much alive (and developing over many years after the original damage). Krynauw's and other neurosurgeons' ideas of spread of disturbance, not only of epileptic discharges, appear to be supported by the fact that the E.E.G. of the healthier side, usually abnormal before operation, as you remember from the Q.S. reports, becomes more normal afterwards. Krynauw (1950), Obrador and Laramendi (1950) and some electroencephalographists hold the view that the pathological spread is of a physiological, and not of an entirely physical nature. This

* The central organization of such areas is modified by the ratio of crossing/non-crossing pathways, and the quantitative organization of handedness (right, left, mixed) may be influenced by this ratio as well (Glees, 1952). This could partly account for differences found in the individual patients. Cortical organization "itself," quantitative and qualitative, will also play a rôle: "projection" areas e. g., do not only consist of the cells and layers which recieve or emit "projection" fibres (and the functions connected with them, e.g., "motor" or "sensory"), but also many others. One wonders whether, for instance, the differences in skin temperature in our different patients may be connected with vegetative homo- and bilateral representations in essentially motor or sensory "centres," because, as far as we could make out, the severity of the hemiplegia itself does not account for individual differences.

point is, however, still under discussion. Anyway, from the practical point of view, Krynauw's contention appears to explain both:

> (1) The reason why even a plastic immature brain is unable to cope with the influences of the pathological process and its consequences, and (2) why hemispherectomy relieves many symptoms. Surgical intervention will do away with the pathological damage, and although elimination of entire physiological systems may lead to loss of functions and possibly release of some positive signs, the creation, at least in many cases, of a clean symptomless scar, will bring to an end interference with ipsi- and contrahemispheric systems, and systems which can potentially replace or maintain functions are now enabled to do so.

With regard to transcallosal spread I am, however, touching a very dark field. We know from clinical and physiological facts that electrical and pathological stimuli can spread contrahemispherically, and clinical disturbances result from pathological lesions. On the other hand, a clean total surgical section of the corpus callosum and even at the same time, of one fornix does not lead to any appreciable disturbance of any function, not even to apraxia, or certain agnosias, unless such functions were damaged before section. People can learn new bimanual activities after section of the corpus callosum and one fornix. (Akelaitis *et al.*, 1941, 1942). One wonders what the normal functions of the corpus callosum is; although the results reported confirm in principle the different effects of surgical and pathological lesions.

Let us return to our subject: symptom-formation and replacement of functions, and let us discuss shortly the question of loss and replacement of function with regard to the main cortical projection and association systems. Anatomically and electrophysiologically this division does not hold entirely good any more. From our present clinical knowledge and for practical purposes it still appears that the main function of projection systems is reception or emission of simple or integrated stimuli. Destruction of "centres" appears to be equivalent with the interruption of the function-carrying axons. This may lead to abolition or weakening of function, to release of "positive signs," possibly also to some irregularities, but as the *function-carrying axons* come up from, or go down to the periphery and do scarcely cross through commissural systems to the other hemisphere, "interference" with function, if any, will be slight, even when there is bilateral representation.

The activity of association systems, on the other hand, is of a more complicated nature. They do not deal any more with originally physical stimuli, but with complicated nervous processes built up from them at a much higher level; or by "differentiating" such high level functions they lead to physical actions. Many of the function-carrying axons of these systems lead to other association-areas on the same or the other hemisphere. Consequently, disturbance, inadequate and distorted innervation is apt to spread homo- and heterohemispherically, and replacement or maintenance of functions by corresponding systems will become difficult or impossible, as these systems are now disturbed. This is one *possible* explanation of the phenomena which I am going to describe now, whether it is the *right one* I am not quite sure.

A. *Projection Systems.*

I. *With Essentially Unilateral Innervation.*

Loss of tissue as well as interference causes loss of function. Pathological processes may lead to epileptic discharge. There is little replacement, particularly of the highest functions. In principle: the more highly specialized, and more peripherally "lateralized" a function is, the less there is ipsilateral representation through uncrossed pathways (? unless there is anatomical ambidexterity). Any postnatal development of ipsilateral cortical functions after damage to the main contralateral system appears to be dependent on the age of the brain at the time of lesion and the massiveness of the lesion. Compare cases D. G— and V. R— with cystic disturbances and fairly good peripheral movements with the other diffuse cases which are worse. Remember again case A. L— with the severe post-operative hemiplegia caused by cutting of an originally functioning pyramidal-system which had not forced or enabled the ipsilateral hemisphere to develop these functions at an early age. The high achievement of epicritic sensation in fortunate cases (possibly ? ambidexterous) is also very interesting. V.R— learns now stereognosis. Also, D. G— had acquired some sense of joint feeling and lost it after not training for two years. with regard to motor function there are some cases in the literature which after more or less intensive training could carry out isolated finger movements (Foerster, 1936). The question arises which rôle subcortical systems may play, and it seems wise to me to preserve the caudate nucleus.* The reasons, apart from those given already, why pathological interference with function does not lead to spread may be:

(1) *Motor systems:* The arm and leg area of the so-called pyramidal system according to physiological experiments by Bailey, McCulloch and Garol (1941) have only few, if any, trans-callosal connections.

(2) *Sensory systems:* Multiple innervation is better developed. Although trans-callosal connections are plentiful they are most likely not of "function-carrying" nature, and also the sensory cortex like the motor most likely too, may be able to suppress to some extent disturbing stimuli. Apart from this, thalamic activity, possibly even for touch, may help to maintain normal function and to repress interference. A third reason for the minimum of spread may be as I have already said, the comparative simplicity of function in only one direction (peripherally) of afferent and efferent projection systems.

II. *With Essentially Bilateral Innervation.*

Replacement or maintenance of function after unilateral central disruption is good, due to bilateral innervation, unless the damage is very large (tumours, cysts with changing fluid content, etc.), and causes by mechanical pressure, or collateral oedema, or vascular processes, etc., the other hemisphere to become involved.

There are plentiful trans-callosal anatomo-physiological connections, but spread of pathological interference will be small for the reasons already given.

* As Krynauw demands.

To this may be added that adequate and appropriate innervation (afferent and efferent) possibly helps to suppress interference and faulty and inadequate innervation. Yet another factor may be the obscure nature of the commissural systems, generally, and with regard to different functions in particular. You may remember what I told you about the corpus callosum. Possibly there is, however, another entirely different explanation, as I shall show later: namely, that the role of anatomo-physiological spread is exaggerated altogether.

B. *Association Systems.*

These I have subdivided into those with essentially unilateral innervation and more absolute or relative dominance, and those with essentially bilateral innervation: co-dominance. This classification with a view to mixed-handedness and a good deal of clinical ignorance or obscurity has to be taken with quite a large grain of salt.

I. *Absolutely dominant* are those centrally represented functions, intimately connected with the motor, sensory and gnostic use and skill of the dominant hand and their respective projection systems; functions such as speech, possibly some forms of object-praxia and the more symbolic functions arising from them. Loss of function takes place after surgical and pathological interference. Replacement is better in immature than in adult persons. Due to their nature as association-systems, faulty and inadequate innervation and consequent dysfunction is frequent after pathological lesion. There may be spread to and interference with the possible compensatory functions of the subordinate systems, but apparently not, or not markedly so, the other way round, except in mixed handedness, although in these and other persons, retraining of the functions damaged and making the subordinate hand dominant, has often a beneficial effect. ("Shift of dominance," Nielsen, 1946, Orton 1937).

II. *Relatively dominant* are systems more or less intimately connected with the functions of the subdominant hand (Fleischhacker, 1947) and side of the body, and those afferent and efferent innervations of non-autonomous and autonomous nature, arising from both sides of the body, which build up the motor and sensory functions of what we call the image of the body, possibly also identification of persons (in this last respect I (1947) disagree with Nielsen (1946). When these systems become disturbed through pathological processes, in adults as well as children (on the right posterior half of the brain in right-handers), apraxia for dressing and disturbance of the body image is often the result. Possibly, the left hemisphere is relatively subdominant for some forms of eupraxia. However, after hemispherectomy, these functions are practically replaced by the relatively subdominant hemisphere, after a shorter or longer interval, in infantile hemiplegias and adults. Why pathological disturbances in the relatively *sub*dominant areas despite the many trans-commissural connections do "practically" not interfere with the functions of the relatively dominant ones, I find difficult to explain. Possibly, the "relatively dominant" systems are quantatitively more developed and provide therefore adequate innervation with the power to suppress disturbances from the

other hemisphere, which the subdominant have not ; or it may be that, at least with regard to the body image only the relatively dominant hemisphere (but not the subdominant one) contains " subjective " systems whose damage leads to disturbance of this function.

III. *Co-dominant functions* are essentially bilaterally represented. They appear to be very little dependent on the functions of a preferential limb or side of the body. Stimuli arise from " without," from all sides of space, essentially through eyes and ears, and from the organism itself, posturally, vegetatively, instinctually, etc. The functions concerned are, from our present knowledge, those of orientation in space and place, and those of a more " personal " or subjective nature, as character, temperament, mood, etc. However, even here we find a certain lateral dominance. Disturbance of will and mood and their influence on intelligence are more " localized " in the left frontal brain (Petrie, 1952). Restlessness, resistiveness are encountered more often when the right frontal brain (Fleischhacker, 1951) and impulsiveness and irritability when the right temporal lobe are more diffusely damaged. There is apparently close collaboration between the two hemispheres of the brain, and with pathological lesions interfering spread from one hemisphere to the other, particularly after damage to systems concerned with more " subjective " functions, occurs in immature and mature persons. On the other hand, surgical elimination of tissue will allow considerable replacement or maintenance of function (all infantile and adult cases, taking into account *the mental deficiency* of the former).

There is, however, another entirely different explanation of disturbances arising from pathological processes in co-dominant and possibly relatively dominant systems, which does not necessitate the assumption of anatomo-physiological spread through the commissural systems. Orientation, for example, is dependent on the way bilateral stimuli come in and are co-ordinated and fused. Now, if one hemisphere receives adequate and the other inadequate and distorted stimuli, this co-operation or fusion will not take place in an orderly fashion and confusion must arise. Indeed, Sherrington (1948) has shown that for the fusion of optic patterns in corresponding visual fields trans-callosal anatomical connections are not necessary, as long as the stimuli arrive adequately in time and place in corresponding parts of the retinae and calcarine areas (see also corpus callusom, p. 79).

This is what I had to say on some factors influencing the production of cortical symptoms and replacement of function after surgical or pathological lesions. Now I want to talk shortly on two other problems : the selection of operation and the selection of patients for operation. Krynauw, now supported by Carmichael (1953), thinks that infantile hemiplegia with character disturbance and epilepsy should always be treated by total hemispherectomy, irrespective of loss of some projection functions ; their argument is that there are patients who have become worse after partial-ectomy, and then improved when the rest of the hemisphere was removed. On the other hand, some French authors (Klein, 1949, and also Henyer, Feld and Hourmak, 1951), and also Wilder Penfield (1952) are of the opinion that removal of the pathological tissue is sufficient and the rest of the hemisphere left (after creation of a

clean surgical scar) will persist to function. The two main problems involved are apparently:

(1) Does one hemisphere, from the practical point of view, function as a whole? or, to put it differently, does a hemisphere of which large parts have been eliminated, become so disturbed that it will disturb the other to a high degree as well? This is not necessarily the case, possibly except for a period of temporary diaschisis, as we know from lobectomies. We know also that aphasia does not necessarily involve reading, writing, and eupraxia to a *great* extent, etc. On the other hand, we know from the investigations of Rowe (1937, 1938), and also Bell and Karnosh (1949) that total-ectomy of the so-called subordinate hemisphere *in adults* causes some character disturbances. From the physiological point of view, I would think that partial-ectomy is no contra-indication as long as systems are excised or interrupted in such a way that there is a minmium of faulty or inadequate innervation with all its consequences. (2) Is it always possible to remove all damaged tissue? This depends mainly on the nature of the process and the possibility of diagnosing this and its extension. In essentially diffuse (or dispersed) processes total hemispherectomy appears to be the best solution (cases A. L—, A. Z—). In more circumscribed processes (cysts and large solid scars) which have left the remainder of the tissue intact, a more local operation should suffice. But on this point there is no agreement, and we shall have to wait until greater knowledge is available.

I come now to my last subject: the selection of patients for the operation. One may ask the question: selection from which point of view: improvement or cure of epilepsy, or of personality disturbance, or both? In this respect we know very little. As pointed out in the beginning, A. Z— (diffuse process) and D. G— (cyst), have now been free from epilepsy since operation or for a year respectively (D. G— despite frontal brain damage), but A. Z—'s behaviour is only somewhat, D. G—'s scarcely better.* On the other hand V. R— (cyst), is still having occasional epileptic episodes, but despite this and damage to the remaining frontal pole and the "healthy" pyramidal system, he has mentally improved (some psychological factors may be involved), and A. L— (diffuse process), despite a temporary increase of epilepsy, and the occurrence of severe hemiplegia after operation became nearly at once an entirely changed person, and from the mental point of view he is the best of our group. From these contradictions it appears that much has to be learnt.

If one wants to be sure of total success, the postulates of Krynauw and Cairns (1951) that only one hemisphere is involved, the personality good and the grade of mental deficiency not too low, should be fulfilled. Possibly one might add that institutionalization should not have lasted too long, or better still, the process should still be active and threatening institutionalization. In younger patients, collaboration of parents should be good. A. Z— is very much influenced by environmental conditions (parental attitude, etc.). Much

* J. M— was known before operation to have both hemispheres involved, a very low grade M.D., rather severe hemiplegia and pyramidal signs on both sides.

more has to be known on the different causes of personality disorders. Developmental retardation or standstill, violence, temper tantrums and other kinds of lack of control, restlessness, moodiness, etc., may be due to quite different causes or combinations of these :

(1) They may be reactions of an easily frightened, depressed, but not necessarily unbalanced or bad personality, to the illness with all its consequences, including medication ;

(2) they may be the outcome of a very unbalanced personality, either originally so by constitution, or due to strong adverse psychoreactive situations later ;

(3) they may be the consequence of the disease proper, either affecting the whole brain or parts of it, uni- or bilaterally, cortically or subcortically, more focally or more diffusely, and, if unilaterally, with the possibilities of disturbing contralateral systems.

When I discussed association areas, several "localizing characteristics" of diverse personality disturbances were mentioned. Clinical psychiatry and psychology should try to achieve a better understanding of these problems, in order to give us guidance in this matter.

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