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THE ANTERIOR COMMISSURE IN MAN: FUNCTIONAL VARIATION IN A MULTISENSORY SYSTEM

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Abstract—The anterior commissure, which has been presumed to play a minor role in interhemispheric communication, was tested for the transfer of visual, auditory, and olfactory information in patients with complete sections of the corpus callosum. Four of five patients tested with presumed intact anterior commissures demonstrated interhemispheric transfer of verbal and pictorial stimuli presented visually to a single hemisphere. Evidence was also obtained for auditory and olfactory transfer, although successful interhemispheric communication in all three modalities was not found for any one patient. The data suggest that the human anterior commissure is capable of mediating multisensory, interhemispheric messages of a complex nature and provide evidence of functional plasticity in a phylogenetically early cerebral structure.

MODERN psychological investigations of brain bisected humans have convincingly demonstrated the dependency of each cerebral hemisphere on an intact and fully functioning commissural system for successful reception of information from the opposite half brain. Specifically, it has been shown that little or no interhemispheric transfer of visual, tactual, auditory, olfactory, or motor information occurs subsequent to complete forebrain commissurotomy [1–6]. Because the majority of these reports have been based on patients who have undergone not only section of the entire corpus callosum, but the anterior and hippocampal commissures as well, the results on transfer capacity have, by necessity, been interpreted in terms of a single functional system. While this approach has contributed much to a vast theoretical framework for the understanding of normal interhemispheric relations, it has provided little possibility for studying modality specific aspects of the transfer mechanism.

Recently, the neuropsychological testing of patients with only partial section of the commissures has enabled more accurate localization of some modality specific information traversing the corpus callosum [7,8], particularly with regard to the visual system. These reports on surgical cases have also served to confirm a much older body of literature on the interhemispheric transfer of visual information through the splenium, studies based primarily on case reports of patients sustaining natural vascular or neoplastic lesions to this area [9–12].

To the present time, however, the clinical literature has not reported on the functional significance of the anterior commissure, a phylogenetically and anatomically prominent forebrain fiber pathway connecting major portions of the temporal lobes. The lack of functional, correlative clinical data associated with this structure can be attributed mainly to

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the rarity of natural lesions which selectively affect the anterior commissure, leaving surrounding areas, including the corpus callosum, intact. In the animal literature, however, a number of anatomical and electrophysiological studies have described visual, olfactory, and auditory components within this interhemispheric system [13–18]. Fibers connecting the olfactory nuclei of the two hemispheres have been recognized for some time as comprising the older anterior limb of the commissure [15], and more recently, a number of anatomical studies in both monkey and man have demonstrated a well-developed posterior limb containing neocortical fibers from visual and auditory association areas in the temporal lobes [16–19].

Behavioural data confirming the contribution of the anterior commissure to the transfer of visual information is now well established in the non-human primate literature [20–23]. These studies have shown the anterior commissure to be capable of sustaining a high level interhemispheric exchange within the visual modality. Behavioural evidence of auditory and olfactory transfer via this route, however, is lacking, due to the difficulty of testing these functions in non-human species.

The present report describes the results of a number of sensory-specific tests of interhemispheric transfer carried out on patients who have recently undergone commissurotomy for the relief of intractable seizures. Unlike previous "split-brain" cases, the surgical section involved only the corpus callosum, leaving the anterior commissure completely intact [24].

METHODS

Case reports

Case D.H. is a 16 yr-old male who developed normally until the age of ten, when he contracted herpes encephalitis. The disease resulted in diffuse damage to the right hemisphere, and during his illness, he underwent an emergency craniotomy in which a portion of the right anterior temporal lobe was removed. Subsequent to his recovery, he began experiencing severe seizures which were intractable to medical management, and in July 1975, underwent complete surgical section of the corpus callosum. The inability of this patient to reliably identify smells in either nostril as reported below, is suggestive of some damage to the olfactory system, which is likely to have resulted from the encephalitis. A more complete medical history is published elsewhere [24], as is a detailed description of his pre and post-operative performance on a number of cognitive tests [25].

Case P.S. a 15-yr-old male, experienced a severe series of epileptic attacks at about two years of age, with a seizure focus in the left temporal region. Following this early activity, he apparently developed normally until age ten when the seizures recurred spontaneously, and became uncontrollable. In January 1976 he was operated on for complete surgical section of the corpus callosum.

Case J.Kn. is a 20 yr-old male who has been subject to frequent partial complex seizures since birth, apparently emanating from the left hemisphere. This patient underwent commissurotomy in 1972 in a procedure that presumably included complete sectioning of the corpus callosum and anterior commissure. Since that time, however, he has consistently demonstrated the ability to transfer visual information between the hemispheres [8], leading to speculation that some portion of the interhemispheric visual system was left intact. The original belief was that fibers of the splenium must have been spared, but in light of the present findings on more recent cases, as well as the fact that this patient successfully transfers olfactory information (as discussed below), we intend to reinterpret his behavioural data as possibly reflecting the functions of an intact anterior commissure.

In addition, S.P., a 14 yr-old male with multiple seizure foci of the right hemisphere, and D.S., a 20 yr-old male with left frontal focus, will be briefly discussed. These two cases underwent callosal section with sparing of the anterior commissure in January 1977, and have only been administered preliminary visual transfer tests to date.

Procedure

Visual tests. The method employed was similar to that previously described for the visual testing of commissurotomy patients [5]. Briefly, the subject is seated 2–3 ft from an opaque screen and instructed to fixate on a dot appearing in the center of the screen. Using a standard Kodak Carousel 650 slide projector fitted with an electronic shutter, stimuli are presented to the right or left of the fixation point for a duration of 100–150 msec. This brief exposure is necessary to ensure the subject does not deviate his gaze during

exposure, and bring the stimulus into view in the opposite visual field. Stimulation of a single hemisphere is further controlled by the random presentation of stimuli in either field, as well as by close observation of eye movements.

Initially, the patients were tested for their ability to verbally identify objects or words tachistoscopically presented to the left or right hemisphere in random order. The stimuli consisted of fifteen colored slides of common objects and sixteen word slides containing simple three-letter words spelled horizontally in large letters. Six of the word slides contained double stimuli, one word appearing in each field. Success in naming items projected to the right hemisphere (left visual field) was considered positive evidence of interhemispheric transfer in the visual modality. If this occurred, the patient was further tested with a more difficult series of stimuli, consisting of forty black and white line drawings of common objects, designed to eliminate color cues.

If a patient did not demonstrate transfer during initial visual testing, he was given the opportunity to nonverbally identify objects through visual–visual and visual–tactile matching tasks. These procedures are important in confirming that intrahemispheric functions are intact, and that the deficit is indeed one of inadequate transfer between the hemispheres. The stimuli were identical to those used in the initial naming task, but instead of verbally describing each stimulus, the patient was required to point to a matching object offered with several irrelevant items. In the case of visual–tactile matching, the response consisted of tactually retrieving the correct item out of view. The trials again alternated randomly between left and right hemisphere presentation of the stimuli, and patients were instructed not to say anything, but just to "point to the right one", or "find the right object in the box." In the pointing task, use of the hand contralateral to the hemisphere receiving the stimulus on any given trial was encouraged if it did not occur spontaneously. During tactile retrieval, however, the patient was specifically instructed to use this hand in searching for the match.

Tactual tests. All patients were routinely tested for their ability to name and match a small series of objects presented to the left hand out of view. This test is particularly important in ruling out right hemisphere speech as an explanation of successful report of visual information appearing in the left visual field.

Olfactory test. Interhemispheric transfer of olfactory information was assessed by requiring the patient to verbally identify each of ten familiar smells from substances concealed in small opaque glass bottles. Each hemisphere was tested separately through the ipsilateral nostril while the opposite nostril was pinched tightly shut. The stimuli included peanut butter, tobacco, perfume, mint, garlic, vinegar, mentholatum, nail polish, coffee, and water, which served as a control item. The right nostril-hemisphere was always tested first, and the patient was not informed of the possible choices. Correct verbal identification under these conditions of primary right hemisphere presentation was considered indicative of olfactory transfer to the left hemisphere.

Auditory tests. The relative lateralization of auditory information was achieved through the technique of dichotic stimulation according to a method previously described for testing commissurotomy patients [26].

The stimuli consisted of pairwise combinations of natural speech consonant–vowel (C–V) syllables selected from among /pa, ta, ka, ba, da, ga/ and presented at a level of approximately 80 dB SPL. The patient was told that two syllables would be presented on every trial and that his task was to report the letter corresponding to the initial sound of each syllable. Guessing was encouraged. The response sheet was composed of rows of six boxes, each box containing one of the six initial consonants. The patient was instructed to use his left or right hand, depending upon the experimental condition, to draw a line through the appropriate boxes on each trial.

All patients were tested audiometrically, and, unless otherwise noted, found to have hearing within normal limits in each ear.

RESULTS

Because of variation in test administration, as well as differences in the pre-surgical pathology of each case, the results will be presented by patient rather than by task.

The results of all tests administered to case D.H. are presented in Table 1. This patient demonstrated the ability to name a variety of stimuli presented in either visual field, indicating successful interhemispheric transfer of visual material. The possibility that the right hemisphere could be naming in this case must be ruled out since D.H. consistently failed in attempts to name objects presented to the left hand, while demonstrating left hand matching ability.

D.H. performed poorly on the olfactory test, successfully reporting only two out of ten smells presented to the right nostril, and five out of ten presented to the left nostril. While testing of D.H. on the olfactory tasks was complicated by possible damage to the olfactory cortex, it is nonetheless significant that he named two right nostril (right hemisphere)

Table 1

Case D.H.

Surgical lesion: Complete section of CC; AC intact.
Seizure focus: Diffuse right hemisphere foci; onset age ten.
Other pathology: Partial removal of right anterior temporal lobe; probable damage to olfactory tubercles.

	Right hemisphere	Left hemisphere
Visual		
Naming words	81%	100%
Colored pictures	100%	100%
Line drawings	90%	100%
Tactual		
Naming	0%	100%
Matching	60%	100%
Olfactory		
Naming	20%	50%
Auditory	L. ear	R. ear
C–V Syllables	Pre-op 37%	Pre-op 81%
	Post-po 36%	Post-op 94%

Per cent correct responses for each hemisphere in four sensory modalities. Because complete visual transfer was demonstrated, the matching tests were not administered. CC, corpus callosum; AC, anterior commissure.

stimuli. As D.H. was not informed beforehand as to the nature of the stimuli, correct naming of any right nostril stimuli is not likely to have been accounted for by guessing. Guesswork, however, could have augmented his performance on the second encounter with the stimuli, which occurred on the left hemisphere trials. This could account for the better performance of the left hemisphere.

In contrast to the almost total left ear extinction shown by other commissurotomy patients in the dichotic C–V task [26], D.H. successfully identified 36% of the syllables presented to his left ear post-operatively. Chance performance for that ear is 29%, assuming that the right ear is performing close to 100% (as is the case with D.H.). Performance remained at this level independent of the hand used to respond.

The results of case P.S. are presented in Table 2. Unlike D.H., this patient was unable to offer a verbal report of any stimulus presented in the left visual field. When pressed for a

Table 2

Case P.S.

Surgical lesion: Complete section of CC; AC intact.
Seizure focus: Left temporal lobe; onset age two.
Other pathology: Severe hearing loss in left ear of peripheral etiology.

	Right hemisphere	Left hemisphere
Visual		
Naming	0%	100%
Matching	80%	100%
Tactile object retrieval	80%	40%
Tactual		
Naming	0%	100%
Olfactory		
Naming	70%	90%
Auditory	Not tested	Not tested

Per cent of correct responses when sensory specific stimuli were presented to a single hemisphere.

response on these trials, he insisted that he saw nothing, or sometimes would report a "flash of light", or a "blue flash" which described the background light visible in the right visual field. When given the opportunity to respond nonverbally however, he was nearly always correct in pointing to the object which matched the left visual field stimulus. Performance was equally good when he was required to retrieve the match tactually with the left hand. In fact, his left hand was twice as accurate in retrieving the appropriate object as his right, when the stimuli were flashed to the right and left hemispheres respectively. When required to use the ipsilateral hand-hemisphere combination, his responses fell to chance and below. The patient, who is normally cooperative and friendly toward the experimenters, became notably irritated when asked to perform "crossed" responses. On one trial in which the stimulus was flashed to the left hemisphere and he was told to use his left hand, he said, "Boy, I'm going to kick you in the ass", and then seemed embarrassed by his outburst.

P.S. was also unable to name objects palpated by the left hand, but could, as noted above, perform visual–tactile matches correctly.

On the olfactory tests, he reported seven of the ten smells when first presented (without prior exposure) to the right nostril-hemisphere, indicating olfactory transfer to the left hemisphere. On the second trial, when the stimuli were presented to the left nostril, he reported nine of the ten smells accurately.

Dichotic testing could not be carried out with this patient, due to a severe hearing loss in his left ear.

Table 3.

Case J.Kn.		
Surgical lesion:	Uncertain; possibly complete CC section with AC intact.	
Seizure focus:	Left hemisphere diffuse; onset at birth.	
Other pathology:	None known.	
	Right hemisphere	Left hemisphere
Visual		
Naming words	90%	80%
Colored pictures	94%	94%
Tactual		
Naming	25%	100%
Olfactory		
Naming	80%	40%
Auditory	L. ear	R. ear
C–V syllables	3%	93%

Per cent correct responses to specific sensory stimuli lateralized to a single hemisphere.

Table 3 contains the test results of case J.Kn. This patient has consistently demonstrated the ability to verbally report stimuli presented in the left visual field since his surgery in 1972. The data for colored pictures and words presented here were obtained in 1973, and are based on a greater number of trials than the other two patients.

Performance on tactile transfer tasks was similar to the previously reported cases, the ability to name objects explored with the left hand being extremely poor. Occasional successful tactile naming can be explained by cues available to the left hemisphere through other sensory modalities. For example, J.Kn. correctly identified a ballpoint pen by clicking it, and after accurately naming an orange held in his left hand, he confessed, "I smelled it".

On the olfactory test, J.Kn. named eight of the ten smells correctly when stimuli were first presented to the right nostril-hemisphere, but only named four of the ten when the stimuli were then presented to the left nostril.

On the dichotic listening task, this patient identified only 3% of the C–V syllables presented to his left ear and 93% of the right ear items, regardless of the hand used to respond.

Table 4

	Case S.P.	
Surgical lesion:	Complete section of CC; AC intact.	
Seizure focus:	Diffuse right hemisphere.	
Other pathology:	None known.	
	Right hemisphere	Left hemisphere
Visual		
Naming words	100%	100%
Line drawings	100%	100%
	Case D.S.	
Surgical lesion:	Complete section of CC; AC intact.	
Seizure focus:	Left frontal; onset age four.	
Other pathology:	Partial removal of left anterior frontal lobe.	
	Right hemisphere	Left hemisphere
Visual		
Naming words	100%	100%
Line drawings	100%	100%

Per cent correct responses for each hemisphere to visual stimuli presented for a duration of 150 msec.

Table 4 presents preliminary visual transfer data recently obtained from cases S.P. and D.S. Although careful measures of interhemispheric transfer in other sensory modalities are not yet available, these data are consistent with results obtained from cases D.H. and J.Kn. in that both patients appear to be highly proficient in the interhemispheric integration of visual input projected to a single hemisphere.

DISCUSSION

These data suggest that the anterior commissure plays a prominent role in the interhemispheric integration of modality-specific sensory information. Although the patients had widely differing histories and extracallosal brain damage, evidence of interhemispheric transfer of sensory information was obtained in every case following complete section of the corpus callosum.

The most compelling evidence that a meaningful sensory exchange can be mediated by the anterior commissure is the observation of complete visual transfer in four of the five patients tested. This previously undocumented function finds support in the neuroanatomical connections of the temporal lobes, as well as from behavioural data obtained from commissure-sectioned animals, as discussed above. The absence of visual transfer in Case P.S. is most likely attributable to the fact that P.S. suffered serious trauma to the left temporal region at a very early age, a lesion which is likely to have disrupted or prevented the establishment of normal functional connections between the left and right temporal lobes. Case D.H., on the other hand, developed normally until ten years of age, when he sustained a surgical lesion of the right temporal pole, an area which is not believed to be critically involved in visual functions [30]. Similarly, cases J.Kn., S.P. and D.S., who also demonstrate visual transfer, are not known to have suffered early temporal neo-cortical damage.

The assumption that visual transfer through the anterior commissure may be established

during development encounters some resistance in anatomical interpretations of the widely recognized clinical syndrome of alexia without agraphia. In this condition, a patient may develop an inability to read as a result of a posterior lesion of the left hemisphere. Such a lesion disconnects the primary visual cortex from the language association areas of the temporo-parietal region and simultaneously blocks transfer of visual information from the right hemisphere via the splenium [12]. Why is the anterior commissure unable to sustain the visual transfer of words in these cases?

Geschwind has suggested that the anterior commissure may be limited in its transfer capacity to non-verbal information [27]. This view is supported by the observation that alexics, while unable to name words, can sometimes name objects. However, no dissociation between words and objects was found in our patients.

Perhaps the incomplete transfer seen in the alexic syndrome is not really attributable to inadequate interhemispheric integration via the anterior commissure, but instead to poor intrahemispheric integration of visual–verbal messages subsequent to successful transfer. Object naming, according to this interpretation, could be spared because it involves different circuitry than is involved in reading.

Evidence of the long-presumed interhemispheric olfactory component of the anterior commissure is best illustrated in Case P.S. Without any prior knowledge of which items would be presented, he correctly named seven of the ten olfactory stimuli presented to the right nostril. J.Kn. also performed well with his right nostril, providing further evidence of an intact anterior commissure. The relatively poor performance of this patient when stimuli were then presented to the left nostril probably reflects generalized left hemisphere damage to subcortical, limbic structures, the apparent origin of his seizure activity [24]. D.H. performed poorly with both nostrils, which is probably attributable to damage of the olfactory nuclei commonly known to occur with herpes encephalitis [28]. However, it is notable that he did name some right nostril stimuli correctly.

Consideration of the anterior commissure as a possible interhemispheric route for auditory information has not previously been approached in human behavioural studies. Preoperatively, D.H. demonstrated a very large right ear advantage, which, while atypical for normals, is predictable from his right temporal lesion [29]. Following his surgery, however, D.H. did not show the decrease in left ear performance from its preoperative level that would be expected from data obtained with other commissurotomy patients [26,31]. His post-surgical right ear performance did conform to expectation, approaching 100%.

These results are compatible with the interpretation that different interhemispheric pathways may be mediating left ear performance in D.H. preoperatively and postoperatively, with the anterior commissure responsible for the transfer of left ear information to the left hemisphere after surgery. The data argue against the possibility that both pre- and post-operative reports of left ear stimuli may merely reflect the ipsilateral projection from left ear to left hemisphere, since the right ear demonstrates release from dichotic interference following the surgery.

The anterior commissure thus seems to be capable of mediating multimodal interhemispheric transfer. The extent to which these functions may develop in the absence of an acute neuropathological stimulus is not known. However, the sensory functions we have described are consistent with the normal anatomical projections of the anterior commissure. The absence of tactile transfer in the present cases further supports this functional–anatomical correlation, since somatosensory processing is not believed to involve the projection field of the anterior commissure.

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Résumé :

On a examiné le rôle de la commissure antérieure, dont on admettait jusqu'ici qu'elle jouait un rôle mineur dans les communications interhémisphériques, dans le transfert de l'information visuelle, auditive et olfactive lors des sections complètes du corps calleux. On a démontré le transfert interhémisphérique du matériel verbal et d'images d'objets présentés visuellement à un seul hémisphère chez 4 des 5 malades examinés, chez lesquels il était admis que la commissure antérieure était intacte. On a obtenu aussi des preuves d'un transfert auditif et olfactif encore qu'une bonne communication interhémisphérique dans les 3 modalités n'était pas constatée chez un de ces malades. D'après ces données, il semble que la commissure antérieure de l'homme soit capable de transmettre des messages multisensoriels interhémisphériques de nature complexe et que ces faits témoignent d'une plasticité fonctionnelle dans une structure cérébrale phylogénétiquement ancienne.

Deutschsprachige Zusammenfassung:

Die vordere Commissur, die eine geringere Rolle bei der interhemisphärischen Kommunikation zu spielen scheint, wurde für den Transfer von optischen, akustischen und olfaktorischen Informationen bei Patienten mit kompletter Balkendurchtrennung geprüft. Vier von fünf Patienten, die man unter der Vorstellung testete, daß sie intakte vordere Commissuren hätten, ließen einen interhemisphärischen Transfer für verbale und bildhafte Reize erkennen, die einer Hemisphäre angeboten wurden. Es war also deutlich, daß ein akustischer und olfaktorischer Transfer stattfand, während eine erfolgreiche interhemisphärische Kommunikation für alle drei Modalitäten bei keinem Patienten festgestellt werden konnte.
Die Daten sprechen dafür, daß die menschliche vordere Commissur multisensorielle interhemisphärische Nachrichten im komplexer Form vermitteln kann und daß eine gewisse funktionale Plastizität für eine phylogenetische ältere Hirnstruktur vorhanden ist.