Forebrain Commissurotomy and Conscious Awareness

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The left and right cerebral lobes of the mammalian brain in the natural state are largely separate anatomically except for cables of cross-connecting fibers, the cerebral commissures, most prominent of which is the enormous corpus callosum, the largest fiber system of the brain, estimated to contain in man over 200 million fibers. Experimental investigation of the functional role of the cerebral commissures was stimulated during the early 1940s by a series of clinical reports in which complete surgical section as well as congenital absence of the corpus callosum had seemingly failed to produce any consistent or distinct behavioral symptoms detectable in extensive neurological and psychological testing (Akelaitis 1943; Bremer 1958; Bremer, Brihaye, and André-Balisaux 1956). Animal studies started in the early 1950s, mostly on cats and primates (Myers and Sperry 1953; Sperry, Stamm, and Miner 1956; Sperry 1961; Downer 1962; Myers 1962), showed consistently, however, that each hemisphere after surgical separation functions independently to a very large extent in most higher activities, including perception, learning, and memory. In objective behavioral tests involving sensory discrimination learning, each surgically disconnected hemisphere was found to sense, perceive, learn, and remember independently of the other.

Although deep surgical bisections are possible experimentally that include the roof of the mid-brain, the supramammillary commissure, and even the cerebellum (Sperry 1964), it was sufficient merely to cut the

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forebrain commissures that mediate cross communication between the hemispheres proper to prevent interhemispheric transfer of perceptual learning and memory. The collected animal evidence (Sperry 1961) supported the conclusion that each of the disconnected hemispheres develops its own private chain of learning and memory experiences that are cut off from, and inaccessible to, recall through the opposite hemisphere.

Not only did learning remain lateralized to the one hemisphere receiving the critical sensory input but also the two hemispheres could be trained concurrently to perform mutually contradictory tasks (Myers 1962). It was shown further by Trevarthen (1962) that with an optical system of light-polarizing filters the separated hemispheres could be made to perceive two different things occupying the same position in space at the same time. Under these conditions (see fig. 1), in which one or the other of two stimulus panels is selectively activated in a series of trial-and-error responses, one hemisphere perceives itself to be receiving rewards for selecting, for example, circles and avoiding crosses, while at the same time with the same responses the other hemisphere sees itself being rewarded conversely for avoiding circles and selecting crosses. The animals tend to work with one hand in this situation, and the hemisphere controlling the working hand tends to learn more rapidly than does the more passive hemisphere. By forcing use of the inactive hand after learning is established, and by restricting vision to the more passive hemisphere, the cerebral dominance can be shifted, and the animal can be shown to have been learning with the second hemisphere the reverse of what was being learned with the first hemisphere.

Thus the objective animal evidence suggests that in each disconnected hemisphere conscious experience (assuming cats and subhuman primates have consciousness) is cut off from conscious experience in the other. Lack of cross communication of awareness between the two hemispheres is further evident in the inability of the split-brain animal to cross compare or integrate sensory information projected simultaneously partly to one and partly to the other hemisphere (Sperry and Green 1964). However, the same kinds of perceptual cross integration that fail with complete surgical deconnection are readily achieved if the anterior commissure or a small one-centimeter strand of the posterior corpus callosum is left intact (Tieman and Hamilton 1974; Doty 1975). The interhemispheric mediation of higher activities can thus be forcibly narrowed down by surgical and other experimental procedures to a small band of roughly several hundred thousand fibers. Such studies hold promising possibilities for the further dissection and analysis of the anatomical substrate of awareness. Whether the impulse traffic crossing such a minimal remnant of the cross communication system should be regarded as an intrinsic part of the conscious process per se will be considered below in more detail.

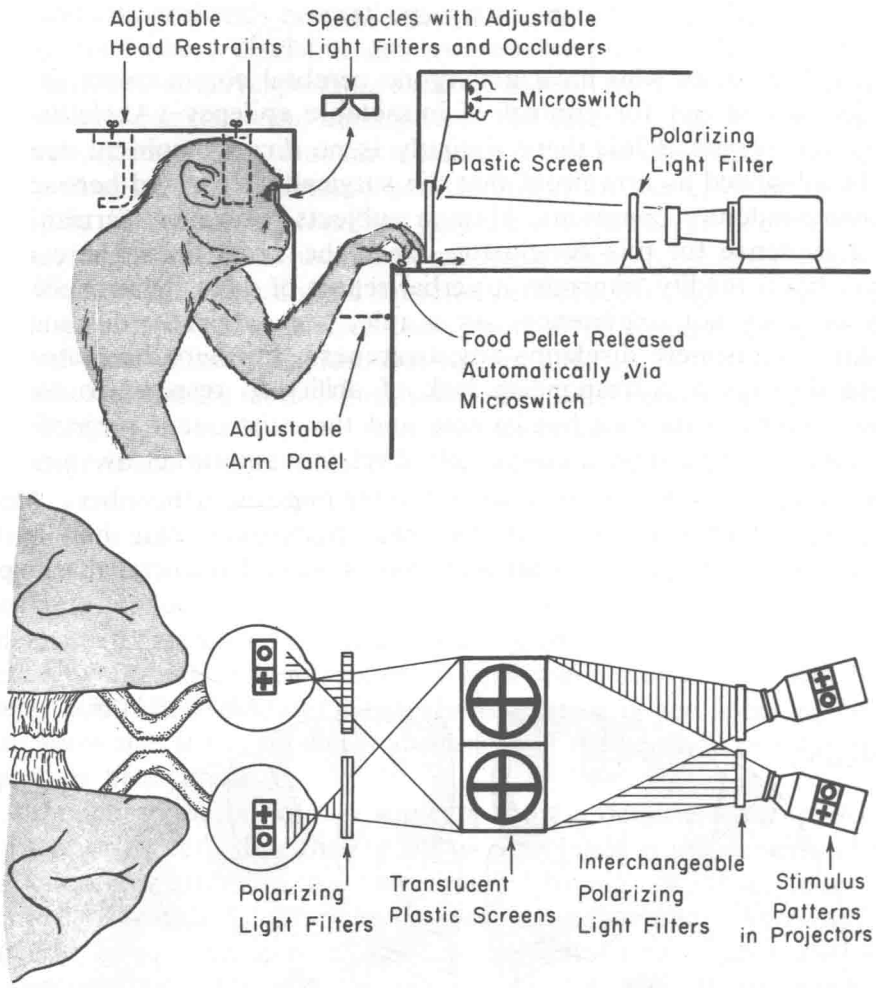

FIG. 1.—Technique of Trevarthen (1962) for showing split-brain monkey can perceive two different things occupying the same position in space at the same time. Left and right hemispheres trained under these conditions learn mutually contradictory discrimination habits from the same set of trial-and-error responses (from Sperry 1961).

Although there is no way to prove firmly that the surgically disconnected hemispheres in the bisected brain of subhuman mammals are separately conscious, this conclusion would seem to follow if one is willing to accept a starting assumption that cats, monkeys, and other mammals normally possess consciousness. The position taken here is that consciousness may be inferred to be present in animals by much the same logic that we infer it to be present in other persons (compare aphasics who have been rendered temporarily mute by brain damage, drugs, or hypnosis, and who may then after recovery be able to recount their conscious experience during the mute period).

SPLIT-BRAIN MAN

In human patients who have undergone cerebral commissurotomy (see fig. 2), carried out for control of intractable epilepsy (Akelaitis 1943; Bogen and Vogel 1976), there similarly is no direct empirical data that can be advanced as firm proof that the surgically separated hemispheres are independently conscious. Human subjects, however, furnish more direct evidence for this conclusion, since the vocal hemisphere of the human brain readily transmits a verbal report of what it introspectively does or does not experience. As a rule, the surgically disconnected speaking hemisphere disclaims any awareness. Further, the mute hemisphere displays a corresponding lack of ability to respond to stimulus sensory input to its own hemisphere and the subsequent subjective effects. At the same time it conversely disclaims any direct awareness of stimulus input that has been restricted to the opposite hemisphere. Meantime, the nonvocal, mute or "minor" right hemisphere can show by the use of manual signs, nonverbal pointing, or tactual retrieval that it per-

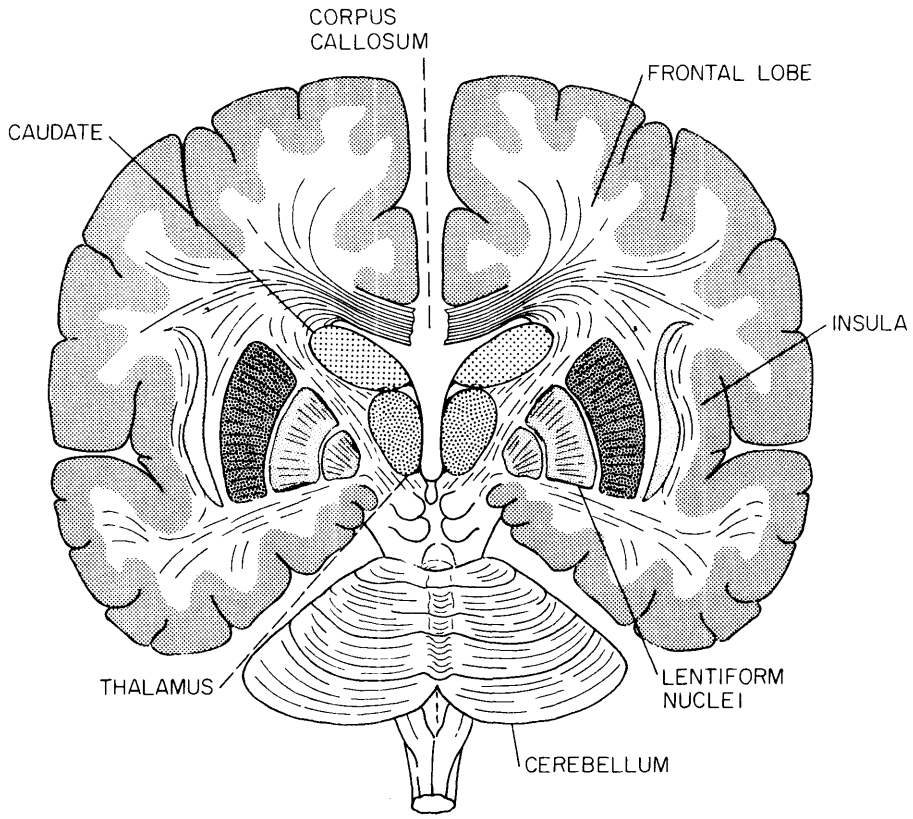

FIG. 2.—Extent of anatomical separation produced by forebrain commissurotomy, schematic (from Sperry 1974*a*).

ceives and comprehends correctly the same stimulus input for which the speaking hemisphere disclaims any awareness. Further, the mute hemisphere displays a corresponding lack of ability to respond to stimulus input restricted to the vocal hemisphere. The foregoing applies in general to all sensory modalities thus far tested that can be lateralized, including visual, somaesthetic, olfactory, and auditory. In the case of auditory stimulation the natural bilateralized projection to the cerebral cortex from each ear necessitates the use of competitive dichotic stimulus input in order to obtain lateralization of conscious effects. This apparently works through suppression of conscious perception of the weaker input from the ipsilateral side (Milner, Taylor, and Sperry 1968).

Studies along the above line have repeatedly confirmed over many years of testing the oblivious unawareness of one hemisphere for conscious experience in the other. This applies not only to perception of the sensory input itself but also to more central phases of cognitive processing. It is standard procedure in our human testing to ask the vocal hemisphere, following completion of a task performance by the mute hemisphere, to describe what was in the test performed by its silent partner, the contents of the test material, or what had been done or selected by the silent hemisphere. Where the sensory input has been properly controlled and lateralized, the responses of the speaking hemisphere show that it has no direct awareness of the cerebral processing of the partner hemisphere.

Although commissurotomy subjects show a definite tendency to direct attention selectively either to left or right input at the expense of the other, conscious attention to a task confined to one hemisphere does not necessarily switch off conscious awareness in the other. As described above for the split-brain monkey, it is possible to show also that both hemispheres can commonly be coconscious concurrently in split-brain humans and can perform, in parallel, different and even mutually antagonistic, cognitive tasks. For example, in tests involving right hemisphere performance, the vocal hemisphere often tends to offer throughout a running commentary based on those aspects of the situation not restricted to the mute hemisphere. Because this parallel activity of the second hemisphere may often interfere with the performance of the test hemisphere, the subject is usually instructed to remain silent. Occasionally the commissurotomy subject may become so absorbed in a right hemisphere task that speech and other left hemisphere functions are temporarily depressed to the extent that one questions whether consciousness may not have been shifted entirely to the one working hemisphere. This state of affairs occurs more frequently in the reverse direction, that is, where the vocal hemisphere is dominantly active. Parallel cognitive processing is greatly facilitated when left and right tasks involve a common central background of postural and mental sets and is corre-

spondingly disrupted when the background of cerebral and postural sets are in conflict.

Like the split-brain monkey, the human commissurotomy subject also can be made to perceive two quite different things occupying the same position in space at the same time, something rejected, of course, by the normal brain. The method (Levy, Trevarthen, and Sperry 1972) involves the use of compound left-right stimuli composed of the left and right halves of different pairs of stimulus items joined at the vertical midline (see fig. 3) and projected half to one hemisphere and half to the other. By the laws of perceptual completion and closure each hemi-

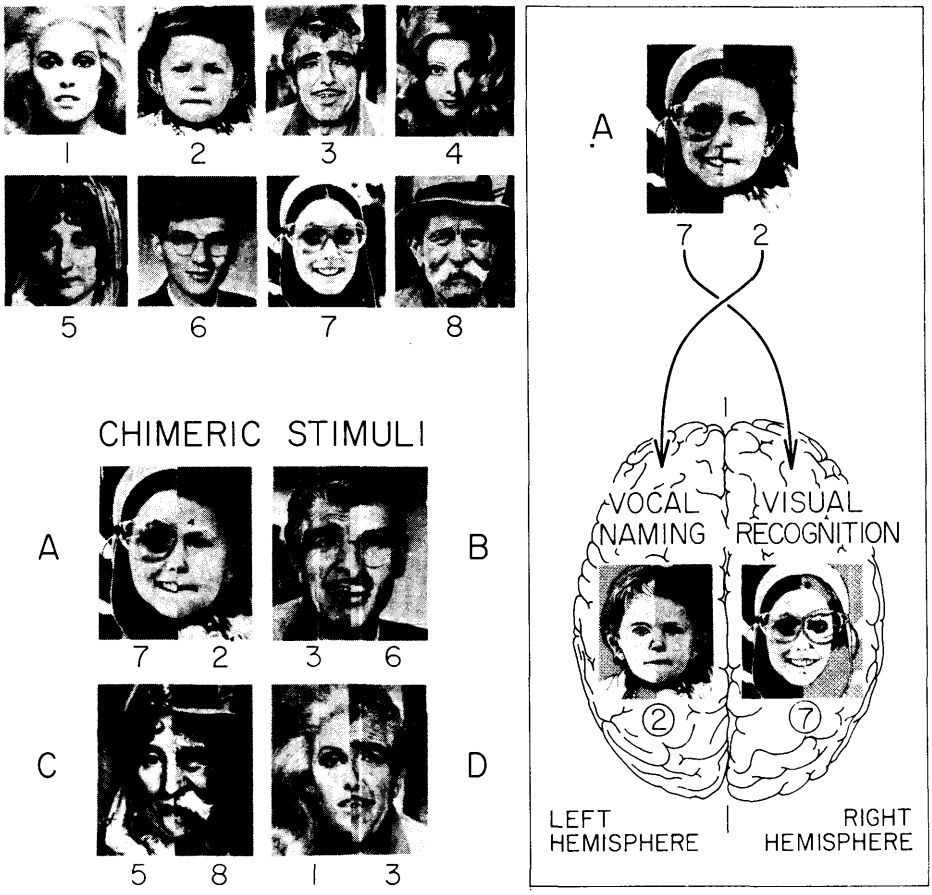

FIG. 3.—Method by which two hemispheres of split-brain human subjects may be shown to perceive two different and mutually exclusive things at same point in space at same time. With gaze centered on nose of composite stimulus figure, each hemisphere sees a different half stimulus, the missing half of which is automatically completed in each hemisphere to form a bisymmetric whole (from Levy et al. 1972).

sphere automatically tends to fill in its half stimulus across the midline to form a whole bisymmetric percept on each side (Trevarthen 1976).

Other kinds of evidence further confirm that, while one hemisphere is performing, the nondominant less-active hemisphere, though overtly passive in not exerting control over the motor system, may nevertheless be alert and consciously cognizant of what is going on externally. This is indicated, for example, in disgusted shaking of the head or irked facial expressions triggered from the minor hemisphere after it has heard its speaking partner making what it knows to be an incorrect answer. Also, it is not uncommon, while the informed right hemisphere is performing, for the vocal hemisphere to make remarks like, "Now, why did I do that?" "What's the matter with me anyway?"

In sum, cerebral commissurotomy appears to divide not only the brain but also the mind. Two separate realms of subjective awareness are apparent: one in each disconnected hemisphere, and each in itself seems to be remarkably whole, unified, and capable of supporting behavior comparable in many respects to that of the combined intact system. This latter is most impressive with respect to the dominant left vocal hemisphere, the high-level linguistic and related logistic capacities of which seem largely responsible for earlier impressions that cerebral commissurotomy fails to produce any definite behavioral symptoms. It may be remembered in this connection that brain bisymmetry provides each hemisphere with a full complement of basic cerebral mechanisms.

Emotional tone appears to be an exception to the rule that each disconnected hemisphere during lateralized testing remains oblivious of the conscious experience of the partner hemisphere. Emotions are rather promptly transferred from one hemisphere to the other, presumably through intact brain-stem mechanisms. Similarly some sensory, attentional, and alertness aspects of awareness are also projected bilaterally via the intact brain stem to both hemispheres, as discussed more fully below. For the present it is important to note that each hemisphere thus contains in functional terms much more than the half mind one might predict at first thought without taking into account the extensive bilateral redundancy in brain organization. With the foregoing in mind, and with some further qualifications to be mentioned below, we can accept the general conclusion that brain bisection yields two conscious minds or selves within the one cranium.

FUNCTIONAL ASYMMETRY

The two disconnected hemispheres of man not only function as if each is independently conscious but also as if each possesses distinctive qualitative properties not equally shared with the other. Linguistic, perceptual,

cognitive, motor, attentional, and mnemonic asymmetries have been found (Bogen 1969; Gazzaniga 1970; Levy 1972; Levy et al. 1972; Milner and Taylor 1972; Zaidel 1973; Zaidel and Sperry 1973; Milner 1974; Nebes 1974; Sperry 1974*a*; Dimond 1976; Franco & Sperry 1977), most of which presumably reflect corresponding differences in the content and quality of subjective experience. Most conspicuous among these functional asymmetries is the presence of speech, writing, reading, and calculation in the left hemisphere and the relative absence of these same functions in the right hemisphere.

Prior controversy and uncertainties of the early 1960s as to whether the nonvocal hemisphere has simply lagged behind in human evolution or alternatively has evolved advanced nonverbal specialties of its own (Denny-Brown 1962; Hecaen 1962) seem now to be effectively settled in numerous studies involving direct left-right comparisons within individuals where many otherwise complicating variables cancel out, and in which the so-called subordinate and relatively passive hemisphere has proven to be the superior and dominant hemisphere. It has been possible further to extend the concept of hemispheric specialization to basic modes in cerebral information processing.

Led by Levy (Levy-Agresti and Sperry 1968; Levy 1972), one may interpret hemispheric specialization in man to be a result of the evolutionary differentiation of two mutually conflicting modes of cerebral processing, holistic-spatial and analytic-sequential in nature. In ordinary mental testing of any series of brain-damaged patients, one tends to take for granted that they will show individual differences in cognitive style and in the kinds of mental strategies employed in approaching test tasks. However, when one sees the same individual consistently approaching and solving a set of problems in two distinct ways, like two different persons, depending on whether the left or the right hemisphere is in use, even subtle left-right cognitive differences become meaningful. Prior doubts and uncertainties resolve and the way is clear to further delineate the nature, extent, and functional role of the left-right differences in cerebral processing.

The demonstrated specialties of the minor hemisphere are, first, nonverbal and nonmathematical and mostly involve spatial and visualizing abilities in which a single mental image is more effective than a long series of words. Geometrical discriminations of topological forms, for example, are performed at a high level by the right hemisphere but seem to be extremely difficult or impossible for the left hemisphere (Franco and Sperry 1977). The prevailing neurological doctrine of the early 1960s, based mainly on symptoms of unilateral brain lesions, had depicted the minor hemisphere as being typically mute, agraphic, word blind and word deaf, and correspondingly agnostic in language-related faculties (Geschwind and Kaplan 1962; Geschwind 1976). This older

view has now receded before mounting evidence of positive language performance of the minor hemisphere after commissurotomy. The capacity of the disconnected minor hemisphere to comprehend spoken instructions and even read words flashed to the left field of vision (Gazzaniga and Sperry 1967; Sperry and Gazzaniga 1967; Sperry, Gazzaniga, and Bogen 1969) was found from the start to be much more developed after commissurotomy than anticipated in view of the severe receptive aphasias that have been reported to follow unilateral lesions of the language centers in the dominant hemisphere. Initial inclinations to interpret these right hemisphere language abilities in our commissurotomy cases as an exception to the rule, caused perhaps by diffusing effects of long-term epilepsy or just by individual differences, have now given way to a revised view in which the minor hemisphere of the typical right hander is credited with substantial, though limited and selective, language functions.

The linguistic faculties of the minor hemisphere have been measured more thoroughly and precisely in recent years by Zaidel (1973) using our two best commissurotomy cases and also three hemispherectomy patients, one of the dominant hemisphere. Zaidel (1975) uses a "stabilized image" technique in which a half field occluder is mounted on the eye on a scleral contact lens. The system allows prolonged exposure of visual material with occular scanning up to one half hour. A high-level vocabulary for the comprehension of single spoken words is confirmed showing in two patients a mental age for the minor hemisphere of eleven and sixteen years, respectively, only two years below that for the vocal hemisphere in these same subjects on the same Peabody Picture Vocabulary Test. In contrast to our earlier results, no specialization was found for nouns as opposed to verbs. The minor hemisphere lexicon appears to follow instead the frequency of word usage. Zaidel finds the right hemisphere to be capable of syntactic and phonetic as well as semantic discriminations.

With respect to reading, writing, and speaking, the results have not much changed our earlier impressions based on tachistoscopic tests. We anticipated that the long exposure and examination of whole sentences instead of single words might reveal a higher level of reading ability, but this is not the case. In general, the ability of the minor hemisphere to process single words stands in marked contrast to its inability to deal with words in series, at least in prose. These limitations do not apply in the same way when words are strung together in singing a familiar melody or in emotional exclamations. In any case, with regard to issues concerning the presence and quality of consciousness in the minor hemisphere, one should keep in mind that the cerebral processing of this hemisphere, though it does not support much speech, is in the current view not at all devoid of linguistic dimensions.

The conclusion that cerebral commissurotomy results in the presence of two largely independent conscious entities, one based in each hemisphere, has not gone unchallenged. Some authorities have preferred to think that the unity of the conscious self is preserved in these subjects with its center in the vocal left hemisphere or in a metasystem in the intact brain stem (MacKay 1966; Penfield 1966; Eccles 1973). These and other theoretically possible ways of interpreting the commissurotomy and related findings have been reviewed in a comprehensive philosophical perspective by Nagel (1971).

Our own impression that both hemispheres, the minor as well as the major, are separately conscious after commissurotomy and that the two disconnected hemispheres may commonly be coconscious in parallel, even in mutually conflicting experiences, is based mainly on the kinds of things that the minor hemisphere has been shown to be capable of doing in the course of a long series of tests over many years. The subjective experience of the minor hemisphere has to be inferred almost entirely, of course, from nonverbal manual performance, although facial, linguistic, and emotional expression generated in the minor hemisphere are also involved. Mute test performances of the minor hemisphere show that it can sense, perceive, learn, and remember all at a characteristically human level. The disconnected mute hemisphere can center and hold a focus of attention, perform high-level spatial reasoning and spatial transformation, generate concepts, make cognitive decisions, and carry out volitional actions. It displays goal preferences and can act on value priorities, and it shows typical human emotional responses in reactions to affect-laden stimuli and situations. It further comprehends spoken single words at a moderately high level and to a lesser extent can also read and comprehend single printed words.

In the face of accumulating evidence along the above lines, earlier claims that the speechless hemisphere is not conscious are now giving way to intermediate positions contending that we must remain agnostic about consciousness in the minor hemisphere or that the minor hemisphere possesses only an elemental form of consciousness not sufficiently advanced to be the basis of a conscious human person or self. Specifically, the nonvocal hemisphere has been interpreted to be lacking in self-awareness (DeWitt 1975). Self-awareness rates as a comparatively advanced and characteristically human form of consciousness appearing relatively late phylogenetically in primate evolution and also late ontogenetically in childhood.

In recent efforts to explore further the upper levels of conscious awareness in the disconnected mute hemisphere (Sperry and Zaidel 1973), we have used the stabilized occluder technique developed by

Zaidel to test for a sense of self-consciousness and for general social awareness. If these higher peculiarly human levels of conscious awareness can be shown to be present, one may infer that the lower levels of awareness must be there as well. The subject in these tests wears a scleral contact lens on which is mounted a small optical system with an opaque screen that moves with the eye and blocks out the selected half field of vision wherever the gaze is directed. The procedure is to present to the subject for examination a choice array of pictures or photographs, usually four (see fig. 4), including items for which the subject might have some familiarity, preference, or an emotional response, such as pictures of the subject, of family, relatives, pets and belongings, political, historical and religious figures, and well-known figures from the entertainment world. After leading questions and remarks by the examiner to establish desired mental sets and associations, the subject is asked to point to the item in the choice array he or she would select for a given situation or reason, the one that he or she most likes or dislikes, might recognize, and to differentiate by "thumbs-up" or "thumbs-down" his or her feelings about selected individuals, etc.

The kinds of reactions obtained from the mute hemisphere in the two

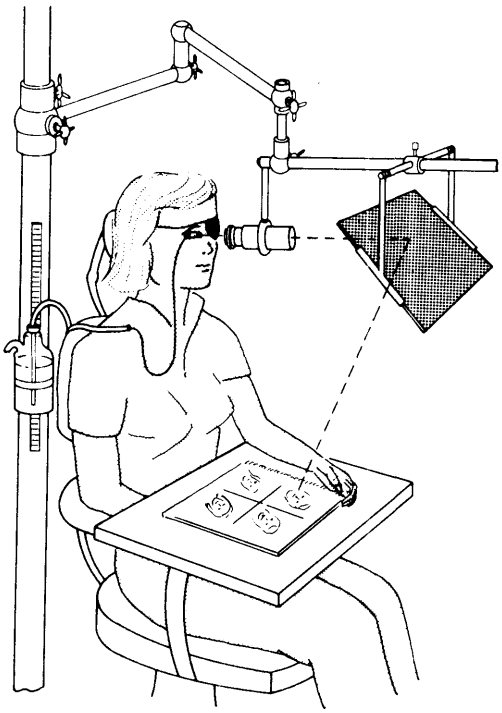

FIG. 4.—Setup employing contact lens technique of Zaidel which continuously blanks out visual input to one hemisphere, used here to test for upper levels of awareness in minor hemisphere.

patients thus far fitted with the required corneal contact lens (L. B. and N. G.) strongly indicate a characteristic self and social awareness that is generally normal and roughly comparable to that of the language-dominant hemisphere. If anything, the emotional responses generated in the right hemisphere in these two subjects were more intense and less inhibited than those from the left. Minor hemisphere reactions included appropriate emotional outbursts when pictures of the subject's self were introduced by surprise among the test items in an unexpected or unseemly context. The emotional tone of these responses promptly crossed to the other hemisphere, presumably by brain-stem mechanisms, and affected the vocalization of the blinded hemisphere changing the tone of voice, evoking exclamations, etc. From the content of the speech, however, which included comments like "what are they?" "something nice," "whatever it was," it was clear that the speaking hemisphere remained unaware of the particular visual material that had triggered (via the mute hemisphere) its emotional reaction. When the speaking hemisphere was allowed a series of follow-up guesses, however, and eventually came to ask, "Was it me?" "Myself?" the minor hemisphere recognition of the audible stimulus as correct had some kind of a central effect that was registered across and recognized in the speaking hemisphere which thereon settled with satisfaction on this as the answer.

When the subjects were asked directly if they could find a portrait photo of themselves inserted among similar photos in the choice array, they had no trouble doing so, working with either hemisphere. Pictures of pets, other belongings, and of scenes in and outside the home were readily recognized by either hemisphere and evoked appropriate responses. Pictures of well-known public or historical figures, relatives, and acquaintances also were readily pointed out by the minor as well as the major hemisphere. Evaluative judgments from the right hemisphere expressed by preferential pointing and by "thumbs-up" "thumbs-down" gestures were consistent with those obtained verbally from the other hemisphere of the same subject and also in free vision. For example, in a series of trials with L. B., a twenty-one-year-old male subject, the response from the right hemisphere was "thumbs-up" for Churchill, pretty girls, Johnny Carson, and a ballet scene, and "thumbs-down" for Hitler, Castro, and a war scene. A photo of Nixon (the date of testing was pre-Watergate) evoked some indecision, ending in an intentional and definite horizontal neutral. A photo of the subject himself inserted at the end of this same series evoked a definite "thumbs-down" response, but in this case unlike the others, the response was accompanied by a distinct wide, sheepish, and (we think) self-conscious grin generated in the mute hemisphere.

Again, follow-up verbal questioning by the examiner, as well as spontaneous remarks of the subject during testing, indicated that the

vocal hemisphere had remained quite unaware of the contents of the test material presented to the minor hemisphere. However, if such verbal questioning were pursued, the subject's left hemisphere was commonly able, with the combined cues from himself and the examiner, to narrow in, after a few exchanges, on the correct category and sometimes on the specific test item. It was concluded that the mute disconnected minor hemisphere does indeed possess self- and social awareness at levels quite comparable to those of the left hemisphere and of the intact brain as a whole.

INCOMPLETENESS OF PSYCHOLOGICAL DIVISION

Although the foregoing and many similar lateralized tests indicate that each surgically disconnected hemisphere has a conscious domain of its own and that the bulk of the content of mental experience in each hemisphere remains cut off from any direct awareness through the other hemisphere, there are important qualifications to be kept in mind in thinking about the degree and nature of this mental separation. This applies especially to behavior under natural nonlateralized conditions. Many unifying factors can be enumerated (Sperry 1968, 1974*a*) that tend to make at least components of the inner experience of the two disconnected hemispheres similar or identical in orientation and content especially during ordinary unrestricted behavior. The bilateral sensory projection systems of the brain, like those for cutaneous sensibility of the face, ensure a bilateral reduplication of symmetric sensations in both hemispheres. Thus, with conscious attention focused on facial, auditory, or other stimuli that get bilateral representation, both hemispheres presumably develop a full bilateral percept with no vertical split between right and left aspects. Scanning movements of the eyes yield a similar duplication with respect to vision (Sperry 1970*a*, 1974*a*). The overall effect in some respects is thus more like a twinning or doubling of the conscious domain of the self rather than midline division. This bisymmetric reduplication of sensory input from proprioception and from some external sources provides a considerable background of left-right unification in the functional organization in both hemispheres and has been an important factor in the concept of two separate minds or selves in the bisected brain. Insofar as mental activities are identical in the two hemispheres, there is no way to prove behaviorally that the two are separate; this can only be extrapolated from analogous conditions where the functions differ.

Unity in conscious experience after hemisphere deconnection tends to be preserved also by cross-integration systems of the intact brain stem like those referred to above that mediate a prompt bilateralization of emotion generated unilaterally. This brain-stem cross-integration we pre-

sume involves also mood, alertness, and perhaps subtle shades of these as in the more elemental dimensions of mental sets and attention. This latter is inferred from the ability of the vocal hemisphere in tests for social awareness to sense orientational, categorical, or attitudinal cues generated in the mute hemisphere which then enable the vocal member to center in on the correct general category of a mute hemisphere experience. Cross transmission of some components of auditory verbal images at brain-stem levels remains a possibility. At any rate, some affective, cognitive, and attentional aspects of consciousness seem to be effectively transmitted from one side to the other to further help the two disconnected hemispheres to function together in harmony and in some respects as a unit.

Whether the neural cross integration involved in the foregoing as, for example, that mediating emotional tone, constitutes an extension of a single conscious process or is better interpreted as just a transmission of neural activity which triggers a second and separate bisymmetric conscious effect in the opposite hemisphere remains open at this stage. In any case, it is pertinent to remember that the bilateralizing and unifying mechanisms are largely of the nonfocal, general background category, whereas conscious awareness tends on the other hand to be correlated predominantly with attentional and focal aspects of cerebral function.

When all unifying factors like the above are taken into account in combination with the evidence for functional deconnection, one is led to conclude with respect to ordinary behavior that the bulk of conscious experience after cerebral commissurotomy is separated into two distinct hemispheric domains but that these are usually similar in their attentional focus and have a large common overlap in general content. Differences contributed by the lateral specialization of the hemispheres will, of course, be accentuated whenever the cerebral processing becomes centered exclusively around specialties of either hemisphere like speech, calculation, or topological reasoning.

During lateralized testing, prolonged use of a single hemisphere with deprivation of focal input to the other not uncommonly leads to a state in which there is a suppression of functional alertness in the nonworking hemisphere to the point where several trials may be required with input to this hemisphere to restore a state of proper function. In ordinary unrestricted behavior, on the other hand, it is rare that conditions would thus selectively restrict sensory input or central processing to one hemisphere for an extended period. Thus typically the two disconnected hemispheres appear to be actively, but separately, conscious in parallel, each working and contributing in its own way to the performance on which attention is focused.

The inference that the disconnected hemispheres are commonly in a state of simultaneous separate coconscious awareness receives additional

support from many bilateral tests that involve concurrent but different sensory input and different motor response from each hemisphere. The conclusion is reinforced as well by numerous incidental observations like those involving cross-cueing which variously require that the second hemisphere be actively alert while the other is performing. Coconscious involvement is indicated also in Zaidel's (personal communication, 1976) recent evidence that scores for commissurotomy subjects with free vision are superior to those of either hemisphere working alone on the visual reception subtest of the Illinois Test of Psycholinguistic Abilities. Coconsciousness is further inferred from tests involving competitive double performances, like reading aloud or whistling while counting or sorting blocks with left and right hand. When the two tasks involve the same hemisphere there is severe interference, while tasks performed in separate hemispheres can be carried through in parallel (Franco, in press).

IMPLICATIONS FOR CONSCIOUSNESS IN THE NORMAL INTACT BRAIN

It has been argued by Anderson (1974) that, if one can have two coconscious entities occupying the same cranium concurrently, as in commissurotomy subjects, and if two or more different persons can occupy the same body successively, as in multiple personality or fugue states, it follows logically that it is no longer correct to identify a "person" or "self" as being correlated one-to-one with a body. The concepts and definitions of "person," "self," and related terms need accordingly to be more precisely refined in terms of the critical brain states involved. Such definitions become important for medicolegal issues concerning, for example, comatose, anencephalic, or severely deranged mental conditions, in evaluating donors for vital organ transplants, in dealing with different stages in fetal development, etc.

An interesting position in regard to the concept of "personal identity" has been taken by Puccetti (1973, 1976) and Bogen (1969) who infer that each hemisphere must have a mind of its own—not only after brain bisection but in the normal intact state as well; a conclusion apparently accepted also by DeWitt (1975) with the qualification that only the left cerebral member has self-awareness and is therefore qualified as a person. The argument goes like this: if cutting the cross connections between the hemispheres leaves two coconscious minds, and if surgical removal of a whole hemisphere, that is, hemispherectomy, leaves one conscious person or self, regardless of which hemisphere is removed, then there must have been two present to start with. Puccetti contends that we are, therefore, all of us, really a compound of two conscious persons that coexist in the normal brain, one based in each hemisphere, and that this goes undetected when the commissures are intact and the

normally conjoined hemispheres work in perfect synchrony. Because a similar proposal regarding the inherent duality of mind was made back in 1844 by Wigan (see Zanguill 1974), modern dual-mind proponents are known as "latter-day Wiganites." Again one is impressed with the need for sharpening definitions of mind, person, self, and related concepts. Regardless of terminology, however, the question of whether the normal intact brain contains only one unified realm of conscious awareness or alternatively maintains two separate conscious systems, or minds, one centered in each hemisphere, poses a rather clear dichotomy that should be subject eventually to a definite empirical answer.

My own position on this question has been a relatively conventional one. I see consciousness and the conscious self as being normally single and unified, mediated by brain processes that typically involve and span both hemispheres through the commissures. This interpretation implies: first, that the fiber systems of the brain mediate the stuff of conscious awareness as well as the switching mechanisms, synaptic interfaces, or other interaction sites of the gray matter; and second, that the fiber cross connections between the hemispheres are not different in this respect from fiber systems within each hemisphere. Third, this interpretation is based on a theory of consciousness that goes back to the early 1950s (Sperry 1952) in which the subjective unity in conscious experience, along with other subjective effects, is ascribed not so much to corresponding spatiotemporal unity in neural activity or to other isomorphic or topological correspondence but rather to the operational or functional effects in brain dynamics. What counts in determining subjective meaning on these terms is the way a given brain process works in the context of cerebral organization. Subjective unity is accordingly conceived in terms of organizational and functional relations which in turn leads to the idea of a functional (thus causal) impact.

When I tried to put some of these threads together back in the mid-1960s, I found to my initial consternation (as well as that of immediate colleagues) that what seemed to be emerging was a conceptual formula for the way that conscious mind could move matter in the brain and exert causal influence in the direction and control of behavior—in direct contradiction, of course, to the central founding precepts of behaviorism and of twentieth-century scientific materialism generally, and contrary to everything that we had always been taught and believed. When this "unthinkable thought" nevertheless continued to hold up under repeated reexamination, I decided to risk a trial-run publication in a humanist lecture (Sperry 1965, 1966) that might allow me to save face should it promptly be shot down. When, instead, it held up in the marketplace with favorable feedback, it was presented more seriously four years later to the National Academy of Sciences (Sperry 1969*a*), since when it has had a

fairly wide exposure in the literature (Sperry 1969*b*, 1970*a*, 1970*b*, 1972, 1974*b*; 1976*a*, 1976*b*, 1976*c*, 1976*d*, 1977). The longer it survives, of course, the less casually it is taken.

Since the main concepts have been presented recently in some detail elsewhere, they are reviewed below in rather brief outline to permit added regard for some of the broader implications and humanistic impact. In essence, consciousness was conceived to be a dynamic emergent of brain activity, neither identical with, nor reducible to, the neural events of which it is mainly composed. Further, consciousness was not conceived as an epiphenonmenon, inner aspect, or other passive correlate of brain processing but rather to be an active integral part of the cerebral process itself, exerting potent causal effects in the interplay of cerebral operations. In a position of top command at the highest levels in the hierarchy of brain organization, the subjective properties were seen to exert control over the biophysical and chemical activities at subordinate levels. It was described initially as a brain model that puts "conscious mind back into the brain of objective science in a position of top command . . . a brain model in which conscious, mental, psychic forces are recognized to be the crowning achievement . . . of evolution" (Sperry 1965, 1966). It must be emphasized at the outset that no direct empirical proof is available, any more than proof is available for the opposing behaviorist position. At this stage, we have only a balance in credibility, all things considered, and the most that can be said is that many of us have now come to regard these psychophysical-interaction concepts as being a little more credible in several respects than the older behaviorist-materialist stance.

Broadly speaking, one of the more important revisions brought by the current concepts is a shift in the scientific status of consciousness. In the past, consciousness has been variously dispensed within science as some kind of parallelistic epiphenomenon, aspect, or correlate of brain processing, and has been considered to be entirely passive in cerebral operations without influence on the stream of physical causation in brain activity, and therefore something that objective science could safely ignore. On our new terms, consciousness, as a holistic systemic property and an active dynamic part of high-order brain processing, is now put within the province of science and is something that cannot be ignored where science wants an explanation of higher brain activities. In effect, this change means that the whole value-rich qualitative world of inner-conscious, subjective experience, the world of the humanities, that has long been explicitly excluded from the domain of science on materialist principles, is now reinstated. In the revised scheme, subjective phenomena have a place and a use in brain function and a reason for having been evolved in a physical system.

An overall consequence of this change is that many of the more objectionable materialistic, mechanistic, deterministic, and reductionistic aspects of science that the humanities have always found difficult to accept and relate to, and which have consistently drawn the fire of antiscience, no longer apply in the new framework. Science, behavioral science in particular, acquires a new look in this perspective to become much more mentalistic, subjectivistic, and humanistic. The swing we have witnessed in recent years toward an increased recognition of conscious subjective experience and referred to variously as the "humanist" or "third resolution" in psychology, the "cognitive revolution" or just the "new psychology," can be seen to be more than just a matter of changing attitudes in science or a reflection of general trends of the time. The new subjectivism in psychology has authentic support and grounding in basic theoretical changes in fundamental mind-brain concepts.

The past strength of the materialist-behaviorist movement has rested in no small measure on the seeming inconceivability that the causal march of neuromechanisms could be influenced by the contents of subjective experience. The present undermining of prior convictions in this area has resulted in a floodgate release of all the pent-up subjectivist pressures held back for decades by behaviorist doctrine. All those disciplines in behavioral science which by preference or by necessity work with subjective experience directly, such as the clinical, cognitive, and humanist schools, also acquire in the new framework a corresponding shift in scientific status. Parallel changes have occurred also in philosophy dealing with mind/brain relations. Today one finds mentalists, dualists, and psychophysical interactionists surfacing again in numbers after having been essentially silent and invisible for decades.

It is important to caution that there is nothing in the current theoretical change that makes subjective experience any easier to work with by scientific methodology and that therefore many of the old arguments against the use of introspection in experimentation still apply. One must caution further that the above legitimate changes toward an increased recognition of subjective mental experience supported by theory have been accompanied in recent years by a series of corollary developments not similarly supported by theory but which have opportunistically ridden along on the same upsurge of new interest in mental phenomena. Things like mysticism, occultism, astrology, faith healing, and parapsychology also have enjoyed a new vigor and popular acceptance in the past eight or nine years. The current view of consciousness as an emergent property of the living brain in action with all its anatomical and physiological constraints hardly increases the likelihood of things like mental telepathy, precognition, psychokinesis, or the existence of mental domains of experience separate from brain activity.

FORMULA FOR PSYCHOPHYSICAL INTERACTION

Perhaps the simplest and quickest way to approach and explain our current mind-brain concept is to compare it with better-known preexistent theories and thus, largely by elimination, to state what the present view is by describing what it is not. First, consciousness in the current view is not an acausal epiphenomenon as widely held in materialist theory. Second, consciousness is not just an "internal aspect" of brain activity as in "dual-aspect theory." An internal aspect is conceivable for all neural processing, but consciousness is special. Third, conscious experience is not conceived to be identical to neural events as in "psychophysical-identity theory." In the present view, conscious phenomena are different from, more than, and not reducible to, neural events, though it is correct to say that conscious phenomena are built of neural events as elements and perhaps also of glial and other cerebral events. Fourth, consciousness is not a pseudoproblem conjured into our thinking by semantic gymnastics, or something that will disappear with a proper linguistic approach. In brief, we can thus bypass previous interpretations of the epiphenomenal, parallelistic, passive correlate, dual aspect, psychophysical identity, and semantic pseudoproblem types in order to focus on consciousness as an emergent property of brain activity, as upheld especially by the Gestalt school of psychology in ideas that peaked during the 1930s and early 1940s under Kohler (1929), Koffka (1935), Kohler and Held (1949), and others (see Boring 1942).

It then remains to distinguish our present model from these earlier emergent Gestalt concepts. First, the emergent properties of the present view are not conceived to be correlated with, nor derived from, electrical field or volume current conduction effects in the cortex. They are conceived rather in terms of traditional nerve circuit and nerve integration theory. Second, the brain processes of consciousness are not conceived to depend on isomorphic or topological correspondence with the mental event. Conscious meaning is a functional derivative conceived in terms of functional impact and potential. Third, while the current view agrees with Gestalt theory that the conscious phenomena are not reducible to the neural elements, it does not take the extreme Gestalt position that categorically rejects analysis and explanation in terms of the parts. Fourth, and most important, the emergent properties in the present view are not interpreted to be mere passive, parallel correlates, or passive aspects or byproducts of cortical events, but as active causal determinants essential to the normal cerebral control.

A conceptual explanatory model for psychoneural interaction is provided, stated in terms acceptable to neuroscience without violating the monistic principles of scientific explanation. The main focus is on the

feature of causality. By all prior theories of consciousness, at all recognized by science, consciousness was interpreted to be acausal in brain function, and brain research could accordingly confine itself to the neurophysiology, chemistry, and biophysics of brain processing, totally ignoring consciousness, and expect this approach to lead, in principle, to a complete explanation of brain function. This of course is not the case with the present view in which consciousness (to repeat) plays a causal role and is neither identical to, nor reducible to, the neural events.

Given our present perspectives, it is not difficult now to stretch the meaning of terms such as "neural events," "brain events," "brain processes," etc., to include their emergent (i.e., holistic, configurational, organizational, gestalt, pattern) conscious properties and to thus bring psychophysical identity theory into line with the current emergent interpretation. On these terms identity theory tends to fuse with emergentism and is then forced to espouse reductionist philosophy to retain identity. Either way we come around to much the same concept. It has been pointed out (Sperry 1970*b*, 1976*c*) that the theoretical and semantic distinctions that prevailed in philosophy prior to 1965 no longer hold in the same way in the context of current perspectives.

Even after the meaning of neural events is stretched to include the holistic conscious properties, our current model still differs from identity theory in that it identifies consciousness only with the holistic properties of *select* brain processes and then not with their neurophysiological, biophysical, and chemical infrastructure. The holistic conscious properties are recognized to be distinctive "real" phenomena in their own right with their own distinctive causal properties. Though mainly composed of neural events, conscious phenomena are not conceived to be "nothing but" neural events.

The causal power attributed to the subjective properties is nothing mystical. It is seen to reside in the hierarchical organization of the nervous system combined with the universal power of any whole over its parts. Any system that coheres as a whole, acting, reacting, and interacting as a unit, has systemic organizational properties of the system as a whole that determine its behavior as an entity, and control thereby at the same time the course and fate of its components. The whole has properties as a system that are not reducible to the properties of the parts, and the properties at higher levels exert causal control over those at lower levels. In the case of brain function, the conscious properties of high-order brain activity determine the course of the neural events at lower levels (Sperry 1966). The term "interaction" for the psychophysical relation is perhaps not the best descriptively but is used for its historical connotations which still apply in the sense that mental phenomena are conceived to exert causal control influence on neural events.

Emergent properties are generally assumed to have causal potency

elsewhere at all levels, and one need merely insist that no exception should be made in the case of the yet-to-be-described aspects of cerebral processing responsible for consciousness. On the foregoing terms, psychology and psychiatry are best interpreted as distinct disciplines in their own right, not reducible or identical to neuroscience or behavioral biology. In other words, "The meaning of the message will not be found in the chemistry of the ink." This exaggeration, however, should not be taken to the extreme of depreciating the tremendous explanatory value of analysis and of subdisciplines in science generally, at least those close to the level of the causal unknowns under investigation. Our concepts of the emergent subjective properties and their causality are still, of course, at a general, abstract level. It remains by this and by any other theory thus far available to explain those critical organizational differences that distinguish brain processes with subjective properties from those without, and to define in exact operational and neural terms the essential functional role played by subjective awareness.

From the standpoint of functional control, one may ask what benefits precisely are conferred by the introduction in evolution of subjective conscious effects? Thinking concerning this question is still preliminary and speculative along lines like the following: consider the tactical difference between responding to the world directly and responding to inner conscious representations of the outside world. Wherever displacements in time or in space are advantageous, as, for example, in mental recall, in thinking, and in the formation of anticipatory sets, the use of inner representations has indispensable organizational advantages. The real world can hardly be manipulated as can inner images. Responses involving perceptual constancies in shape, size, position, etc., would seem also to be more effectively managed through the use of inner representations. Further, the employment of implicit trial-and-error responses to inner mental models, and the avoidance thereby of overt response commitments, with possible errors in the real world, is a central rationale in the evolution of thinking.

The development of an inner subjective world may thus be viewed broadly as part of the evolutionary process of freeing behavior from its initial primitive stimulus-bound condition, providing increasing degrees of freedom of choice and of originative central processing. The subjective effects have additional advantages in the driving and directing of behavior as motivational elements and as positive and negative reinforcers. It is difficult to conceive an efficacious motivational system without subjective properties like pain, pleasure, hunger, etc. These subjective effects evolve into controlling ends in themselves in much of human behavior.

Conscious experience may be conceived as a rather distinct entity built into brain organization and expressly designed for specific functional effects, as opposed to viewing it as a general pervasive property of

complex neural integration. There is reason to believe it is present in the higher brain centers but not in the spinal cord, for example, or lower brain stem, and probably not in the cerebellum either. The commissurotomy evidence indicates that the system for inner conscious representations in primates and cats, at least, is confined mainly to the cerebral hemispheres proper and the upper brain stem. We assume it to be rather diffusely represented within the forebrain but by no means extending throughout all neural activity at forebrain levels. On the input side of the conscious system, a great deal of the sensory processing is completed automatically and unconsciously. The integrations required for constancy effects like those for perceived position in space during head, eye, and body movements, or for the union of monocular two-dimensional patterns into novel three-dimensional percepts, or the processing of elemental auditory sounds into perceived speech, etc., are extremely complex neural functions but appear to be processed without conscious mediation. Similarly, on the output side, most or all of the complicated processing required to translate conscious aims, percepts, and volitional intent into appropriate motor-behavior patterns also takes place automatically and unconsciously. The intricate arrays of requisite muscle-contraction patterns involve a complexity that goes far beyond the ability of the conscious mind to understand and direct. This is another reason to identify the conscious properties with the relatively simple holistic features rather than with the whole intricate inframechanism of brain processing.

Though representing a rather small fraction of the total brain activity in physiological terms, the conscious properties are of prime importance from the organizational standpoint. For example, the laying down, storage cataloging, and retrieval of memories seems to proceed very largely on the basis of their holistic conscious properties rather than those of the neuronal inframechanisms. Most higher brain processing in many can be viewed as being designed for, and directed toward, the generation, maintenance, or expression of aspects of conscious awareness. Older stimulus-response and central-switchboard concepts of brain organization that arose out of spinal cord physiology and were congenial to behaviorist interpretation may be replaced by a model in which the brain is seen to be organized as a decision-making control system monitored with value priorities, and in which conscious phenomena confer certain operational advantages over and above those obtainable in systems that lack consciousness.

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