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Comparable results have been obtained in *hypoglycaemia*. Essentially, progressive signs of neurological dysfunction appear at unchanged tissue concentrations of ATP, ADP and AMP, and it is only when the EEG becomes isoelectric that energy failure occurs. It is of interest that cerebral oxygen uptake is well maintained even in profound degrees of hypoglycaemia. Since supply of exogenous glucose is curtailed, maintained oxidative metabolism occurs at the expense of endogenous substrates. As a result of this mobilization of endogenous substrate there is a pronounced disturbance of cerebral amino acid metabolism. Conceivably, this contributes to the functional aberrations observed. Recent results also demonstrate that hypoglycaemia reduces the rate of acetylcholine synthesis.

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On dividing the self: Speculations from brain research

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Let them perish from thy presence. Oh God, as perish vain talkers and seducers of the soul, those who observing that in deliberating there were two wills, affirm that there are two minds in us of two kinds, one good, the other evil — myself, when I was deliberating upon serving the Lord my God now — it was I who willed, I who nilled, I myself.
 St. Augustine

The idea of self is one of the central dogmas of western civilization. It is the unit of the behaving organism which is ultimately held to be accountable for our personal actions. Our entire social structure moves from the premise that there is a unified self, and it alone must be considered the agent of thought and action. Without this notion our present jurisprudence system, for example, would make very little sense. I am not one to take St. Augustine's views lightly, but I think that he is wrong about what the self is and is not.

It is precisely this idea of the unity of conscious awareness, of self, as it is commonly understood, that comes under direct challenge from split brain studies (Gazzaniga, 1970; Sperry et al., 1969). The new idea that emerges from these data is that, quite literally, there are several selves to man, and what I want to argue is that they are not necessarily conversant with one another internally. Self 'one' is known to self 'two' only through observing the behavior produced by self 'one.' The same is true for self 'three' to self 'n,' with the control of behavior being exchanged between the selves in a not necessarily orderly or equal fashion. Indeed the objective of this report is to argue that it is the 'verbal self' that (a) allows for our subjective sense of self-awareness, and (b) that during life it is the verbal system which is continually rationalizing as well as structuring our belief system by observing and reacting to our actual behavior whether or not it be external, physical and overt or internal, chemical and covert. Put differently, I will be maintaining that it is the verbal system that is the *sine qua non* of human consciousness and once so identified allows us to begin to

isolate and identify some of the behavioral mechanisms it uses to construct our personal sense of conscious reality.

Thinking along these lines started some years back with our studies on the psychological consequences of splitting the brain in man. These observations led to the view that the normal state of consciousness could be discretely tampered with and altered in predictable ways by dissociating the two cerebral hemispheres through surgical section of the corpus callosum.

In earlier reports, we have made the claim that brain bisection produced two separate conscious entities. Actually, that idea better represented a logical extension of the split-brain story than it did a demonstration of the fact. Indeed, it was Sir John Eccles along with Prof D.M. MacKay at the Papal Conference on Consciousness in 1964 who pointed out that the early studies showed the right hemisphere to be little more than an automaton.

In the 13 intervening years we have been able to extend our observations. In particular, we will describe our observations on one truly unique individual, case P.S. of the new series of split-brain patients operated on by Dr Donald Wilson of the Dartmouth Medical School and tested by Dr Joseph LeDoux and myself. P.S.' uniqueness amongst split-brain patients centers around the psychological robustness of his right hemisphere. Although only his left hemisphere can talk, other linguistic skills are extensively represented in both half-brains, and most of what follows deals with observations made possible by this special neurological circumstance. Although these observations involve P.S., a split-brain patient, this report is neither about P.S. nor split-brains, but, instead, is about how P.S., whose brain is split, provides a special window through which the inner workings of the human mind may be viewed.

Self-identity and language: The necessary conditions

In a series of linguistic tests presented to the right hemisphere we showed that P.S. could spell out answers to questions exclusively asked to the right half brain by arranging a set of wooden letters (Gazzaniga et al., 1977). The capacity to respond in this manner raised the question of whether he might also be able to spell his answer to subjective and personal questions directed to his mute right hemisphere. This seemed to be the opportunity to assess whether the right hemisphere, along with the left, possessed its own self-identity.

Presenting questions exclusively to the right hemisphere was accom-

plished by verbally stating the question, except that key words in the question were replaced by the word 'blank,' and then the missing information was exposed in the left visual field, which effectively lateralized visual input to the right half-brain. Subsequently, P.S. was asked to spell his answer.

The first question asked was 'Who (blank)?' The key words lateralized to the right hemisphere on this trial were 'are you?'. As his eyes scanned the 52 letters available, his left hand reached out and selected the 'P,' set it down, and then proceeded to collect the remaining letters needed to spell 'Paul.' Next, we asked, 'Would you spell your favorite (blank)?' Then, 'girl' appeared in the left visual field. Out came the left hand again, and this time it spelled 'Liz,' the name of his girlfriend at the time.

These observations (see Gazzaniga and LeDoux, 1978, for complete report) suggested to us that the right hemisphere in P.S. possesses qualities that are deserving of conscious status. His right hemisphere has a sense of self, for it knows the name it collectively shares with the left. In other tests, we showed it has feelings, for it can describe its mood. It has a sense of who it likes, and what it likes, for it can name its favorite people and its favorite hobby. The right hemisphere in P.S. also has a sense of the future, for it knows what day tomorrow is. Furthermore, it has goals and aspirations for the future, for it can name its occupational choice.

Since P.S. is the first split-brain patient to clearly possess double consciousness, it seems that if we could identify the factor that distinguishes his right hemisphere from the right hemisphere of other split-brain patients, we would have a major clue to the underlying nature of conscious processes. That factor is undoubtedly the extensive linguistic representation in P.S.' right hemisphere. As we have seen, his right hemisphere can spell, and, in addition, it can comprehend verbal commands, as well as process other parts of speech and make conceptual judgments involving verbal information. While it is possible that the conscious properties observed in his right hemisphere are spuriously associated with these linguistic skills, the fact remains that in all other patients, where linguistic sophistication is lacking in the right hemisphere, so too is the evidence for consciousness.

Verbal attribution and multiple mental systems

After having clearly established that P.S. truly possessed a double conscious and self-awareness, thereby putting to rest the earlier

objections of Eccles and Mackay, it becomes of great interest to observe how mind left with its ongoing language and speech systems interprets actions explicitly produced by mind right. This can be done experimentally as we have shown elsewhere (LeDoux et al., 1977; Gazzaniga et al., 1977; Gazzaniga and LeDoux, 1978) and it is these unique data that direct us towards my second point and to one of the major psychological mechanisms responsible for establishing our sense of conscious unity.

In brief, we simultaneously presented each hemisphere with a different object-picture, and the subject was required to select from a series of picture choice cards the one that best related to the flashed stimuli. Thus, if a 'cherry' was one of the stimuli flashed, the correct answer might have been an 'apple' as opposed to a 'toaster', 'chicken', or 'glass', with the superordinate concept being, of course, 'fruit'.

It was clear that each hemisphere under the simultaneous presentation could perform. Only rarely did the response of one side block a response from the other. In general, each hemisphere pointed to the correct answer on each trial.

What is of particular interest, however, is the way the subject verbally interpreted these double field responses. When a snow scene was presented to the right hemisphere and a chicken claw was presented to the left, P.S. quickly and dutifully responded correctly by choosing a picture of a chicken from a series of four cards with his right hand, and a picture of a shovel from a series of four cards with his left hand. The subject was then asked 'What did you see?' 'I saw a claw and I picked the chicken, and you have to clean out the chicken shed with a shovel.'

In trial after trial, we saw this kind of response. The left hemisphere could easily and accurately identify why it had picked its answer, and then subsequently, and without hesitation, it would incorporate the right hemisphere's response into the framework. While we knew exactly why the right hemisphere had made its choice, the left hemisphere could merely guess. Yet, the left did not offer its suggestion in a guessing vein, but rather as a statement of fact as to why that card had been picked.

It is observations of this kind which convince us that we are looking at a basic mental mechanism common to us all. We feel that the conscious verbal self is not always privy to the origin of our actions, and when it observes the person behaving for unknown reasons, it attributes cause to the action as if it knows, but in fact it does not. It is as if the verbal self looks out and sees what the person is doing, and from that knowledge, it interprets a reality. Put differently, one's sense of reality, one's system of beliefs about the world, arises as a consequence of considering what one does.

Verbal identification of mood states

Other studies of ours show that the left hemisphere verbal system can also very accurately read changes in emotional states established by the right half-brain.

On a verbal command test, where a word is lateralized to the right hemisphere and P.S. was instructed to perform the action described by the word, his reaction to the word 'kiss' proved revealing. Although the left hemisphere of this adolescent boy did not see the word, immediately after 'kiss' was exposed to the mute right hemisphere, the left blurted out, 'hey, no way, no way. You've got to be kidding.' When asked what it was that he was not going to do, he was unable to tell us. Later, we presented 'kiss' to the left hemisphere and a similar response occurred: 'No way, I'm not going to kiss you guys.' This time, however, the speaking half-brain knew what the word was. In both instances, the command 'kiss' elicited an emotional reaction that was detected by the verbal system of the left hemisphere, and the overt verbal response of left hemisphere was basically the same, regardless of whether the command was presented to the right or left half-brain. In other words, the verbal system of the left hemisphere was able to accurately read the emotional tone and direction of a word seen only by the right hemisphere. In a follow-up study this finding was reconfirmed in detail (LeDoux et al., 1977).

At the psychological level, the observation that the verbal system can accurately read the emotional tone precipitated by an external stimulus without knowing the nature of the stimulus allows speculation concerning the nature and variability of our mood states. In brief, the idea that we are intrigued with is that the person is not always aware of the origin of his moods, just as he is not always aware of the origin of his actions. In other words, the conscious self appears to be capable of noticing that the person is in a particular mood without knowing why. It is as if we become subtly conditioned to particular visual, somatosensory, auditory, olfactory, and gustatory stimuli. While such conditioning can be, it is not necessarily within the realm of awareness of the conscious self. When in Florence, for example, one can be focused on David and feel so aroused, awed, and inspired that unbeknownst to the verbal system, the brain is also recording the scents, noises and the total Gestalt of that most remarkable city. The emotional tone conditioned to these subtle aspects of the experience might later be triggered in other settings because of the presence of similar or related stimuli. The person, puzzled by his affective state, might ask himself, 'Why do I feel so good today?' At this point, if the Florentine experience is not recalled (registered by the verbal system),

the process of verbal attribution might take over and concoct a substitute, though perhaps very plausible, explanation. In short, the environment has ways of planting hooks in our minds, and while the verbal system may not know the why or what of it all, part of its job is to make sense out of the emotional and other mental systems, and, in so doing, allow man, with his mental complexity, the illusion of a unified self.

We thus feel that the verbal system's role in creating our sense of conscious reality is crucial and enormous. It is the system that is continually observing our actual behavior, as well as our cognitions and internal moods. In attributing cause to behavioral and psychological states, an attitudinal view of the world, involving beliefs and values, is constructed, and this becomes a dominant theme in our own self image.

Towards the normal case

It is exactly at this point that it is necessary to ask whether multiple mental systems could be a feature of normal life. While split-brain man represent an explicit instance and indeed it is the data from these studies that raise the more general questions, it must be shown that the model is useful and applicable to the normal brain.

We have just completed a study on neurological patients who are not aphasics but who have left hemisphere damage of one kind or another and who have to undergo cerebral angiography (Gazzaniga, 1972; Risse and Gazzaniga, 1977).

As is sometime the case, amytal testing is also carried out and we have taken this medical opportunity to study problems in memory organization. Prior to injection of the anesthetic, we place an object, for instance, a pencil, into the left hand and out of view. The patient is asked to identify it. When done correctly this signals us that the stereognostic or touch information has coursed normally from the left hand to the right hemisphere, where it is relayed via the corpus callosum to the left speech hemisphere.

Then the left hemisphere is put to sleep, which means the patient is no longer conversant or capable of comprehending or producing natural language in any way. The opposite, right-half of the body also becomes flaccid. At the same time, however, the left half-body and the right hemisphere are both functional because the drug only affects the injected side of the brain. Another object is placed in the left hand at this time, say a spoon. The subject feels it and after a few seconds the spoon is removed. A few minutes later the subject awakens, the drug

having now dissipated, and the left hemisphere returns to consciousness.

The patient is asked 'What was placed in your hand?', and the typical response is 'nothing', or 'I do not know.' To test for a given recall ability the patient is then asked, 'What was placed in your hand before?', and they commonly say, 'Do you mean the pencil?'

Even with the greatest amount of encouragement or prodding, no verbal report is forthcoming for the object placed in the hand during the anesthesia. A card with several objects attached to it is then placed in front of the patient and almost instantly the left hand points to the object, in this case, the spoon.

We have interpreted these data to mean that information stored in the absence of language cannot be accessed by language when the verbal system reappears and becomes functional. The engram or memory transfer for the spoon is encoded in neural language X and speech is represented in neural language Y. The two languages are then insulated from one another and not conversant with each other inside the brain.

These data allow for the rather radical hypothesis advanced above which is namely that during development a constellation of mental systems are established within us and each has its own values and response probabilities that can remain independent of other mental systems. If this were true then as maturation continues, the variety of behaviors that these separate systems emit are being constantly observed by the one system we come to use more and more, the verbal natural language system. Gradually a concept of self-identity (and self-control) develops such that the verbal system comes to know the other impulses for action which arise from all the other non-verbal systems and it either tries to inhibit these or free them as the case may be.

In the foregoing I have indicated how our studies on the commissure sectioned patients have revealed basic behavioral mechanisms used by man to establish our sense of conscious awareness and sense of personal unity. While it might be prudent to end on that note, I find it hard to resist pointing out some implications of these views for a variety of longstanding problems in psychology.

Implications for a theory of memory

The memory mechanism psychologists have been studying ad nauseam the verbal processing system. Yet, what if this is but one of the systems of memory, and while it is working away, simultaneous activity is going

on in several other non-verbal systems, which have as their only way of responding a gesture or movement? In other words, what if the memory systems that exist, say in non-speaking animals, are also present and working in us along with our admittedly unique language and speech systems? If such an arrangement obtained in man, then one can indeed look at an embarrassingly huge number of previous studies on human memory and come to some unique conclusions about their meaning.

The classical distinction, for example, between recognition and recall, dissolves almost instantly. This, of course, is the well reported and widely experienced phenomenon that a person can recall only a small part of a body of information given to him whereas he can recognize a lot more. In the present model the recall phase is only calling upon the verbal system for response. The verbal system, however, only reports a small amount of information because, just as with the other independent systems, it has a limited capacity. When the recognition phase is introduced, however, the name of the game is quite different. Now the other non-verbal systems have an opportunity to express themselves. This is by non-verbal behaviors such as pointing to a series of objects, and with that kind of response possible, all of the information the several non-verbal systems store can now be reported, making the entire system appear more resourceful. Recognition tests have long been considered to be more a sensitive measure for information stored because it allows for expression of stimuli stored with weaker values of some kind or another. In the present model such a continuum between recognition and recall skills becomes more the product of the expression of several equally capable storage systems each given an equal chance to demonstrate what it knows.

There is another aspect to this model. Psychologists have for years been trying to understand the network of our associative memory. The assumption is that it is huge and complex and interrelated in some kind of mind-boggling way. What is being argued here would encourage quite a different model. The seeming interconnection is more apparent than real and is the product of actually behaving. The verbal system becomes aware of possessed knowledge by one of the non-verbal systems emitting a behavior, which is to say memory.

Implications for cognitive theory

It was Festinger (1957) who developed the theory of cognitive dissonance which to my mind is one of the most powerful ideas on the nature of behavioral process ever stated. The phenomenon in broad terms is this: When a person's opinion, belief, or attitudes are met with

disagreement as a consequence of a freely produced behavior of his own, a state of dissonance is obtained. His cognition prior to his behavior is in conflict with his just completed behavior and that state of dissonance is not allowed by the organism. Consonance is demanded and is usually achieved by changing the prior value or belief.

Let us take an imaginary example. George is married and full of fidelity. Then a set of circumstances develop which finds George involved in an affair with another woman. George does not believe in such behavior and does not condone extra-marital affairs. So, immediately after the experience, George is very much in a state of dissonance after his recent behavior. George initially attributes it to being drunk or being seduced. That helps, but George is soon involved again with his new friend. As this continues his dissonance increases and something must change. What usually changes is George's attitude about his marriage. Before long he attributes his behavior to domestic tensions and comes to believe they are much worse than he had previously thought. As a result, George shortly finds himself in divorce court. He concluded he must be having the affair because his marriage was awful. These rationalizations and actions are the changes that resolve George's dissonance. Divorce becomes an unavoidable consequence and George's fate was sealed after the first night.

There are millions of examples of dissonance theory at work and hundreds have been worked out under strict experimental conditions in the laboratory. What is not understood is why the organism seeks consonance. Why cannot dissonance be a viable and chronic state for the biological organism?

Let us take a step back and consider a prior question. Why did George suddenly find himself involved with Molly in the first place? What is the mechanism for eliciting a dissonant behavior from the beginning? The behavior was clearly contrary to his existing (verbally stored) belief about such matters and normally the verbal system can exert self-control. The reason I propose is that yet another information system with a different reference and different values existed in George, but because it was encoded in a particular way, its experience was not known to George's verbal system and, therefore, was outside of its control. That is, it was not known until one day it grabbed hold momentarily and took charge of his behavior and elicited a behavioral act that caused great consternation to George's verbal system. This other side of George was not known to him until a set of environmental and biological circumstances came together and elicited this new behavior. Once elicited, however, George's verbal system had no choice but to account for it and to adjust his verbal perceptions and guidelines for behavior to take this newly discovered aspect of his personality into

account. In this view it is the verbal system that is the final arbiter of our many modes of consciousness most of which we only come to know by actually behaving. Behavior elicited is the way to discover the multiple selves dwelling inside. Behavior is the way these separate information systems communicate with one another. It is probable that very little communication goes on internally.

The multiple self and free will

The last implication of this model that I would like to consider surfaces right on the question of the nature of personal responsibility. As I said in the beginning most of our social institutions are built on the notion that man is personally responsible for his actions, and implicit in that statement is a notion that man has a unitary nature embodied in the self. What are we now to do with that view, given the new knowledge that multiple selves exist and each self can control behavior at various moments in time.

Let us go back a step and look at the concept of free will as it has stood up in our scientific age. This is extremely important because up until now the issue of responsibility (whether it is personal or social) has been argued on the merits of a unitary self and the concept of free will. Up until recently, the scientific community had pretty much written off such concepts as free will as hold-overs from the dark ages and anyone making the case for a personal responsibility was largely ignored. Science is reductionistic by nature and most scientists believe in fact the world is as mechanical as clockwork. Things do not just happen. There are inputs to every system and knowing the inputs will find one able to explain and predict the outputs. That is the line of thought any way.

At the level of human behavior, this meant that when I felt I was freely choosing which lass to ask to marry, I was, in fact, only doing what I could do as a result of a set of forces working upon me. That I was doing it freely was pure illusion. Behavior is lawful and the exacting product of past experience according to the behaviorist and reductionist, like B.F. Skinner. Any view to the contrary is simply out of step with what is known about the physical nature of the universe.

The only man that really addresses the problem is D.M. Mackay. Mackay (1967) deals with the problem head on and puts man right back on top, and in personal control of his behavior. His argument goes like this.

Man can be considered as mechanical as clockwork and still be considered to be personally responsible for his actions. That is, he is

personally free in his decisions. This is true because, put simply, if someone is told they will eat apples for lunch because of some fantastic knowledge you possess of their past behavior, all they have to do to prove you wrong is not to eat apples. At first glance, there would seem to be an easy solution to that which would not violate the idea of reductionism. The next time the person, whose actions are being predicted, will not be told what the predictor predicts about their behavior. Instead, it will be written down and after the critical event the predictions will be examined and with this condition the predictor will prove to be correct.

That still will not work, however, as Mackay has pointed out because when you think carefully about it, in order for something to be true it must be valid for all people. The critical point here is that while the prediction may be true for the predictor, it is not binding on our victim and consequently not valid for both parties. A true and valid proposition must be set out for all to see and once that is done our victim can do or not do what it says as he sees fit.

It is a powerful argument, and one that apparently logicians and philosophers have agreed to. It shows that even in a mechanistic universe there is this situation which Mackay has called a 'logical indeterminacy of a free choice'. While I tend to believe his point, my point is that the formulation of the problem moving from the assumptions of a unitary consciousness will not apply to the case for multiple selves. While his unique argument may well apply to a 'self' system, how would it apply to a collection of 'selves'? If indeed our cranium houses many mental systems we should have to ask how his idea applies in the sociological instance as opposed to the presumed unified psychological character of the human being.

Summary

To return to our opening example of the self and jurisprudence system, the model proposed here raises serious questions for how we currently view man and society. If the individual is to be viewed as more of a sociological entity than a single psychological entity, which 'self' of a convicted felon should receive punishment? While this question is perhaps best left at the level of metaphor for now, it nonetheless seems clear to me the brain sciences are continually and at an ever increasing rate discovering facts about the psychological mechanisms active in developing and sustaining subjective conscious experience. I feel the time is rapidly approaching where these findings are going to have to be taken into account by social policy with the inevitable consequence

that many of our public programs and attitudes about the nature of man will have to be updated. Can there be any doubt that the brain sciences sit at the center of the primary scientific and intellectual questions of our time?

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Predicting outcome after severe head injury*

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The need to accumulate a data bank of severely head injured patients, as a basis for evolving a predictive system, led us to initiate the present study in Glasgow 10 yr ago. After 4 yr we invited two Netherlands centres to join us: Rotterdam (Dr Braakman) and Groningen (Prof Minderhoud); later we collected data from Los Angeles County Hospital (Dr T. Kurze). Three years ago Dr Plum suggested that our system might be applied also to predicting outcome following coma from nontraumatic conditions — and a collaborative study involving the New York Hospital, the San Francisco General Hospital (Dr Caronna) and the Royal Victoria Infirmary at Newcastle-upon-Tyne, U.K. (Prof Shaw and Dr Cartledge) was set up. Dr Caronna gives the preliminary results of that study, whilst this paper deals with the methodology which is common to both, and with the analysis of the first 1000 head injured patients.

It has always been considered difficult to predict in the first few days after severe head injury what the final outcome will be. It is common to hear about remarkably good recoveries after very bad injuries, and disappointing results from some which seemed less severe. It appeared to us that this uncertainty was likely to derive from inexact definition either of the initial severity or of the ultimate outcome — or of both. Much effort was therefore expended on methods of assessing the degree

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