

Divergent Thinking Styles of the Hemispheres: How Syllogisms Are Solved during Transitory Hemisphere Suppression

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Psychiatric patients solved syllogisms while recovering from transitory ictal suppression of one hemisphere by electroconvulsive therapy (ECT). The premises were familiar or unfamiliar, true or false. While the right hemisphere was suppressed, syllogisms were usually solved by theoretical, deductive reasoning even when the factual answer was known a priori, the premises were obviously false and the conclusions were absurd. While their left hemisphere was suppressed, the same subjects applied their prior knowledge; if the syllogism content was unfamiliar or false, they refused to answer. We postulate a left-hemisphere mechanism capable of decontextualized mental operations and a right-hemisphere mechanism, the operation of which is context-bound and incapable of abstraction. We show that each hemisphere tends to overextend its perspective on the problem and that in the intact brain they both contribute to an extent that depends on the characteristics of the problem at hand. © 1996 Academic Press, Inc.

INTRODUCTION

The Problem of Divergent Styles of Thinking

The idea of divergent styles of thinking as formulated by Levy-Bruhl (1922) asserts that “prelogical” or “primitive” thought characteristic of “primitive” societies (henceforth called “traditional”) does not die out in the course of cultural development but, together with “correct” thought,

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is preserved and actively utilized even by members of modern "civilized" societies of the European type.

Ethnological and cross-cultural psychological investigations have become the main focus of experimental studies and theoretical discussions connected with the problem of divergent thinking (Cole & Scribner, 1974; Cole, Gay, Glick, & Sharp, 1971; Levi-Strauss, 1958; Luria, 1976; Scribner, 1977; Scribner & Cole, 1981; Sharp, Cole, & Lave, 1979; Tulviste, 1979, 1988). One result was to endorse Levy-Bruhl's (1922) types: prelogical and logical thought in complexes and in scientific concepts (Vygotsky, 1922), concrete-operational and formal-operational (Piaget, 1971), wild and domesticated (Levi-Strauss, 1966), empirical and theoretical thought (Scribner, 1975, 1977). Specific characteristics ascribed by different authors to different types of thought as well as criteria for their classification are summarized by Tulviste (1988).

Mental development is another source of ideas about divergent thinking styles. Different authors describe different numbers of stages of mental development in children, use different criteria and procedures for their classification, name and characterize them differently, and point to different causes of the stage transition (Bruner, 1972; Leontyev, 1981; Luria, 1961; Piaget, 1967; Vygotsky, 1923; Werner, 1948). However, undoubtedly formal-logical, or theoretical, thought (i.e., the ability to draw deductive conclusions) emerges later than thought which is not logical in this sense. According to Piaget (1971), the ontogenetically earlier forms of thought are superseded by the later ones. If so the thinking style of the adult should be considered homogeneous: only the latest developed, "highest," form of thought remains and is used. However, if the earlier forms of thought are preserved and used together with the later ones, then the thought activity even of the adult human is divergent [cf. Leontyev, 1981; Luria, 1961; Vygotsky, 1922, 1923, and the culturologists from the Moscow-Tartu semiotic school (Ivanov, 1979; Lotman, 1978)].

Some authors assume that earlier (in the historical and ontogenetic senses) "simple" forms of thought are vestiges from the past that participate only in behaviors that are currently considered exotic (mythology, superstitions, magic) (Levi-Strauss, 1966; Levy-Bruhl, 1922). Others assume that relatively early forms of thinking are important and irreplaceable components of mental activity (Vygotsky, 1922).

Specifically, empirical (not deductive) thought is a necessary instrument in everyday life in all the historical periods and in all societies; it is naturally acquired as a "universal" of human thought (Tulviste, 1988, p. 243). In contrast, theoretical (formal-logical) thought serves such spheres of action as science. It is prevalent in modern societies in which such activities are widespread. The European type of schooling fosters formal-logical thought.

Nonetheless, there is no rigorous evidence that "prelogical" empirical forms of thought are really actively used by adult educated people. Different

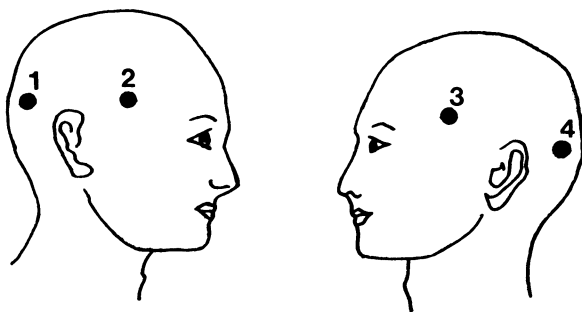


FIG. 1. Localization of electrodes used for unilateral stimulation. 1, 2, Right-sided positions; 3, 4, left-sided positions.

types of thought in the adult human are intimately interlaced and disguise each other. They are difficult to distinguish in their original form in healthy subjects. A step in this direction would be to determine the cerebral organization of the mental activities. Do the divergent styles arise from distinct brain structures and function? Unilateral ECT offered us the opportunity of exploring the syllogism-solving styles of the two cerebral hemispheres.

Unilateral Electroshock in Studying Brain Functional Asymmetry in Humans

ECT for mental diseases became prevalent at the end of the 1930s (Cerletti & Bini, 1938). From the early 1960s the method of unilateral electroshock has been used (Cannicott, 1962) (Fig. 1). This is better tolerated than bilateral shocks, and yet therapeutically equally effective (Balonov, Barkan, Deglin, Kaufman, Nikolajenko, Savranskaya, & Trachenko, 1979; D'Elia & Raotma, 1975; Stromgren, 1973). The safety and efficacy of ECT has recently again been documented (Sackeim, Prudic, Devanand, Kiersky, Fitzsimons, Moody, McElhiney, Coleman, & Settembrino, 1993) and it is considered "more firmly established than ever as an important method of treating severe forms of depression" (Potter & Rudorfer, 1993, p. 882), especially in psychosis.

Unilateral ECT differs from bilateral ECT (Balonov & Deglin, 1976; Balonov et al., 1979; Deglin, 1973, 1976). Unilateral ECT does not produce as profound and long a suppression of the brain as bilateral ECT because it influences brainstem structures much more weakly. A long suppression (during 60–90 min) of the right and the left hemisphere, takes place following bilateral ECT. Following unilateral ECT, that hemisphere only is suppressed, and the period of suppression is much shorter (30–40 minutes). Given a treatment schedule of multiple ECT at 1 to 2-days intervals, one can alternate right- and left-sided electroshocks.

Thus, unilateral ECT uniquely permits comparison of (1) the effects of

suppressing the right and left hemispheres in the same subject, (2) the effects of suppressing each hemisphere with the normal state in which both hemispheres are active, and (3) the restitution of functions of each hemisphere. Others have also taken advantage of unilateral ECT effects to study the functional asymmetry of the human brain (Annett, Hudson, & Turner, 1974; Fleminger & Bunce, 1975; Fleminger, Horne, & Nott, 1970; Kriss, Blumhardt, Halliday, & Pratt, 1978; Pratt & Warrington, 1972; Pratt, Warrington, & Halliday, 1971; Robertson & Inglis, 1978).

We shall present two experiments on the solving of syllogisms during the recovery from unilateral ECT.

Syllogisms call for the drawing of conclusions from two statements, or premises. Classical examples go back to Aristotle: All men are mortal (the major premise); Socrates is a man (the minor premise); Socrates is mortal (the conclusion). For experimental purposes the conclusion is usually preceded by a question, e.g., "Is Socrates mortal or not?"

In the early 1930s, the first cross-cultural investigation of syllogism solving was carried out with traditional subjects from middle Asia (Luria, 1976). Analogous studies by different authors working elsewhere confirmed Luria's data. They are remarkable for a striking likeness of the findings, irrespective of differences in the authors' theoretical positions, in the conceptual bases of the research, and in the interpretations of the findings themselves (Cole et al., 1971; Scribner, 1975, 1977; Sharp et al., 1979; Tulviste, 1979, 1985).

Two types of answers emerged when people solved syllogisms. The first type is the answer "out of the syllogism" (according to Luria's terminology), or the "empirical" answer (according to the terminology of Scribner, 1977). To answer the question that follows the premises the subject appeals to his own experience, to his knowledge of the relevant reality. If the syllogism content is familiar to the subject his answer can be correct (or incorrect, if what he knows about the theme contradicts assertions contained in the premises). If the syllogism's content is unfamiliar to the subject he would evade the answer. Such refusals are also considered to be empirical answers since they are occasioned by the absence of personal experience or knowledge. Thus empirical answers are evidence that theoretical thought is not taking place. Empirical answers are typically given by traditional subjects who never attended schools of European type and had little or no contact with members of "modern" societies.

The second type of answer is "inside the syllogism" according to Luria's terminology or "theoretical" according to Scribner. The subject arrives at a logical conclusion based on the premises, i.e., he solves the task with the help of deductive reasoning. Theoretical answers are correct and do not depend on the subject being knowledgeable about the realities which are referred to in the syllogism. They are typically given by subjects who experienced European type schooling irrespective of whether they belonged to modern or traditional societies.

The ability to solve syllogisms by deductive reasoning appears after several years of schooling. It emerges in concert with such mental processes as the formation of abstract concepts, classification in terms of categorical signs, establishing similarity of objects and differences between them according to generic-specific features, and differentiating between the concept and its referent (Tulviste, 1985). Thus deductive syllogism solutions exemplify theoretical thought.

During the period of theoretical thought formation (Tulviste, 1979, 1988), theoretical answers appeared earlier when the contents of the syllogisms were unfamiliar to the subjects; empirical answers persisted longer when the contents of the syllogisms were familiar to the subjects. In other words, theoretical thought is utilized, in the first place, when personal experience of and knowledge about the reality do not help.

Thus an analysis of the solutions offered for syllogisms can reveal the type of thought that was applied. This makes it possible to use syllogism solving to identify the mode of thought which characterizes each hemisphere.

EXPERIMENT 1

Solving Syllogisms under Conditions of Transitory Suppression of One Hemisphere

Materials and Methods

Subjects. Fourteen right-handed patients (9 women and 5 men) undergoing unilateral ECT therapy in a psychiatric hospital were investigated. In 8 patients schizophrenia and in 6 others manic-depressive psychosis were diagnosed. The patients' ages ranged from 23 to 47 years, most 30 to 40. All had at least a secondary education.

Stimuli. Ten syllogisms were used (Table 1). Each syllogism, with two premises and a question, was printed on a card. The contents of five syllogisms (NN 1, 3, 7, 8, 9, from Table 1) were connected with the subjects' own experience. The river Neva flows through St. Petersburg and most inhabitants know what kind of fishes one finds in it (syllogism N1). Everybody knows about traditions connected with tea drinking (syllogism N3). Everyone who lives in St. Petersburg is acquainted with white nights (syllogism N7), knows the names of streets and the rules for driving through them (syllogism N9). All the subjects, given their educational levels, have often used the dividing by 5 sign (syllogism N8). These syllogisms will be referred to as familiar. Premises and contents in the remaining five syllogisms (NN 2, 4, 5, 6, 10) were not related to the subjects' own experience. These syllogisms will be referred to as unfamiliar.

Procedure. The cards on which the syllogisms were inscribed were shown to each subject one at a time as in Table 1. The subject had to read the text and answer the question. If the subject found it difficult to answer the question immediately or the examiner was not sure that the subject understood what was written on the card, then the subject was repeatedly asked to read the syllogism and to repeat it aloud. After he had given his answer, correct or not, he was asked "Why do you think so?" If the subject refused to answer the syllogism question he was asked to explain why. Motivations ascribed to the responses were analyzed.

Each of the subjects was investigated three times: before ECT (control) and then after right-sided ECT (right hemisphere suppression) and after left-sided ECT (left hemisphere suppression), in randomized order between subjects. Investigations began in the postshock period,

TABLE 1
List of Syllogisms and the Order of Presentation to the Subjects

NN	Major premise	Minor premise	Question
1	There is fish in all the rivers where people put nets.	There are nets on Neva-river.	Is there fish in Neva-river, or not?
2	Every state has a flag.	Zambia is a state.	Does Zambia have a flag, or not?
3	Tanya and Olya always drink tea together.	Tanya drinks tea at 3 PM.	Does Olya drink tea at 3 PM, or not?
4	All precious metals do not rust.	Molybdenum is a precious metal. ^a	Does molybdenum rust, or not?
5	Every artist can draw a hare.	Durer is an artist.	Can Durer draw a hare, or not?
6	In all squares sides are equal.	The girl has drawn a square on the black-board.	Are the sides in this square equal, or not?
7	White nights are observable in summer at the latitude of Leningrad.	The town Primorsk is situated at this latitude.	Are white nights observable in Primorsk in summer, or not?
8	All the numbers ending in 5 can be divided by 5 exactly.	The number 705 ends in 5.	Can the number 705 be divided by 5 exactly, or not?
9	There are traffic lights in all major streets.	Dybenko street is major.	Are there traffic lights in Dybenko street, or not?
10	All mammals suckle their babies with milk.	The kangaroo is a mammal.	Does the kangaroo suckle its babies with milk, or not?

^a In this case the premise contains false information.

usually 10–15 min after the seizure had ceased, when speech contact, comprehension, and the ability to perform the task were restored (even when the left hemisphere had been suppressed). The testing continued for 20–25 min, until electroencephalographic and clinical signs of hemisphere suppression disappeared.

Unilateral ECT technique. A sinusoidal current of 50 cycles/sec frequency, 100–160 V, was used and applied for 0.3–0.8 sec through round rustproof metal electrodes, 25 mm in diameter. One electrode was located at the point 3–4 cm above the line that transects the corner of the eye and the acoustic meatus. The second electrode was located 4–5 cm behind the pinna's upper edge (Fig. 1). Threshold stimulation sufficient to evoke seizures was used; its intensity and duration most often amounted to 130 V and 0.5 sec.

Results

Control investigations. Before ECT most of the subjects (12 of the 14) motivated their answers theoretically, i.e., they responded in accordance with the rules of logical conclusions. For instance, being asked to explain a positive answer to the question of syllogism N1 a subject replied: "But it is

TABLE 2
 Percentage of Theoretical (T) and Empirical (E) Answers to Syllogism Questions in Control Investigations (C) and under the Right (R) and Left (L) Hemisphere Suppression

Type of syllogisms	Type of answers	C	R	L	The difference significance level, <i>p</i>		
					C vs. R	C vs. L	R vs. L
Familiar	T	94 ± 3	92 ± 3	49 ± 6	ns	<.001	<.001
	E	6 ± 3	8 ± 3	51 ± 6	ns	<.001	<.001
Unfamiliar	T	98 ± 2	100 ± 2	80 ± 5	ns	<.01	<.01
	E	2 ± 2	0 ± 2	20 ± 5	ns	<.01	<.01
Total	T	96 ± 2	96 ± 2	65 ± 4	ns	<.001	<.001
	E	4 ± 2	4 ± 2	35 ± 4	ns	<.001	<.001

written here that there are nets on the river Neva and that there are fish in all the rivers where people put nets." When asked to motivate a reply to the question of syllogism N2 a subject answered: "It is written here that each state has a flag, and that Zambia is a state. Therefore Zambia has a flag." Only two subjects gave empirical answers in accordance with their own experience. In response to syllogism N1 both of them answered: "Everybody knows that there is smelt in the river Neva." One of these subjects responded to syllogism N2: "I've never been to Zambia and know nothing about its flag." The other, answering syllogism N3, referred to the tradition: "No, they do not drink, one drinks tea in the morning". As seen in Table 2 and Fig. 2A, empirical answers were seldom given in control investigations.

Right hemisphere suppression. After right-sided ECT the tendency toward theoretical solving of the syllogisms became even more pronounced. As in control investigations, 12 of 14 subjects solved syllogisms in accordance only with the rules of logical conclusions, and only in 2 subjects was empirical reasoning observed. Besides, empirical answers were connected again with the most "provocative" syllogism, N1. One empirical answer was registered following presentation of syllogism N8: the subject tried to check the number dividing by practical division. It is noteworthy that solving syllogisms with unknown contents was never followed by attempts at empirical motivations of the answers and all the solutions were theoretical (Table 2, Fig. 2B, II).

Under right hemisphere suppression all the tasks were solved much more readily and with much more assurance than in the control condition. Even those patients who were uncertain under the control conditions gave theoretical answers with no hesitations and with minimal latencies following right-sided ECT. This state was also characterized by the patients' attempts to explain how they solved the syllogisms. Without waiting for additional questions the subjects spontaneously referred to the syllogism's premises, often

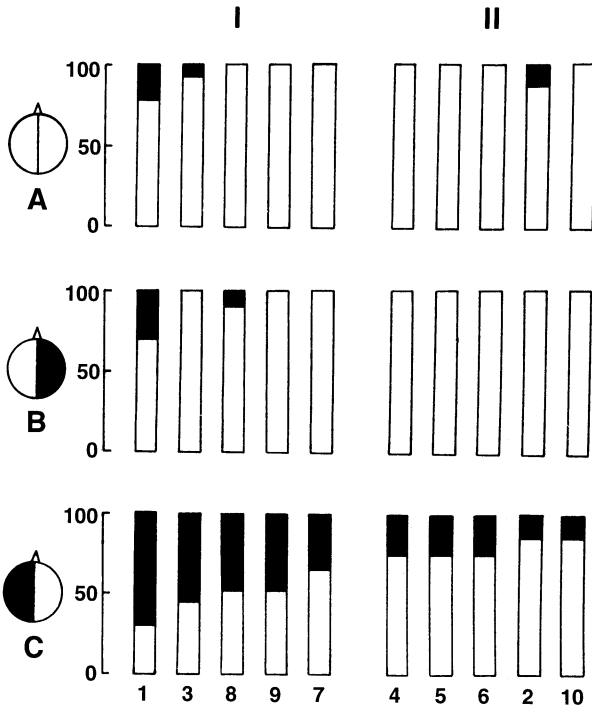


FIG. 2. Correlation between theoretical (white parts of the columns) and empirical (black parts of the columns) answers following presentation of "true" syllogisms. Under the columns are the syllogism numbers according to Table 1; on the ordinate are listed percentages of answers. On the diagrams the suppressed hemisphere is shaded. I, II, familiar and unfamiliar syllogisms, respectively. A, B, C, control, suppression of the right hemisphere, or suppression of the left hemisphere, respectively.

anticipating them by rhetorical questions. Typical examples follow: The answer to the question of syllogism N2: "Yes, there is a flag. Why? It is said here that Zambia is a state. Since every state has its flag, so Zambia has one too." The answer to the question of syllogism N5: "Durer can. But why? It is said here that every artist can draw the hare, and Durer is an artist, it is said."

Left hemisphere suppression. The same subjects behaved quite differently after left-sided ECT. The number of empirical answers increased dramatically (Table 2). Empirically motivated answers appeared in 11 of 14 subjects. Two of them gave only empirical answers; theoretical answers were completely absent. While in control experiment and under right hemisphere suppression only certain syllogisms (mainly N1) were followed by empirical motivations, under left hemisphere suppression such motivations appeared with every one of the syllogisms, both familiar and unfamiliar (Fig. 2, C). However, a certain difference between the syllogism groups was preserved:

while solving any of the syllogisms of the first group (NN 1, 3, 7, 8, 9) 40–70% of answers were empirical, whereas with the second group (NN 2, 4, 5, 6, 10) such motivations were observed in 15–30% of all cases. Under left hemisphere suppression the highest number of empirical answers was observed following syllogism N1, the lowest following syllogisms N2 and N10. Overall, when solving familiar syllogisms, half of all answers were empirical, whereas for unfamiliar syllogisms, one-fifth were empirical (Table 2, $p < .001$).

Differences between the two groups of syllogisms were not confined to different proportions of empirical and theoretical answers. Though subjects gave empirical answers quickly and with assurance, referring to their experience, when presented with familiar premises, they hesitated for a long time and their voices sounded doubtful when unfamiliar premises were presented to them. Together with refusal to give an answer (positive or negative) rather often nonmotivated answers appeared: “I think so,” “That is how it seems to me.” Only persistent questions revealed why the answers were uncertain and nonmotivated: the subject’s ignorance of corresponding realities, lack of personal experience.

Under left hemisphere suppression empirical answers became more extended and more detailed. The subjects tried to tell everything they knew about the given topic. Persistent attempts to elucidate and specify as many realities as possible connected with the syllogism contents also characterized this state. Here are typical answers: to syllogism N1: “Of course there are fish in the river Neva. If I myself fried smelt, it can be marinated as well,” or “Once upon a time there were all sorts of fishes in Neva. But now they poisoned Neva and all the fish died out.” The answer to syllogism N9: “Oh, Dybenko street! It is near my house. But I don’t remember whether there are traffic lights or not. (The investigator asks the subject to read the card once again and draw a conclusion from what is written.) I have just told you that I don’t remember. It seems there are, I often went there.” The answer to syllogism N10: “I’ve heard that kangaroos carry their babies in pouches on their bellies. The babies are small, all the children like milk.” The response to syllogism N2: “Is there really such a state, Zambia? Where is it? Who lives there?” The response to syllogism N5: “Is there really such an artist, Durer? Is he a Russian artist? Is he alive or has he died?” Typical answers given by the subjects in the alternative states are presented in Table 3.

Discussion of Experiment 1

Thus one and the same subject solves one and the same task in a different way when in each of the two different states. Under conditions of right hemisphere suppression syllogisms are solved according to the laws of formal logic. As a rule the answers are of theoretical character. Empirical answers

TABLE 3
 Typical Answers of the Patients under Conditions of Right (R) and Left (L) Hemisphere Suppression

Subject	R	L
S-ov	(N1) ^r Since it is said here that in all the rivers where people put nets there is fish and the Neva is a river, people put nets on it, so there is. (N2) Each state has a flag, Zambia has also.	Of course there is, but inedible, there can not be edible, there is much machine oil. Smelt should be.
E-va	(N3) Since it is said that they drink tea together, then they are also drinking now, when it is 3 PM.	Who knows it, this Zambia, how can I know whether it has a flag or not. I don't know either Tanya or Olya, who knows about them, whether they drink tea or not?
S-ko	(N4) Since molybdenum is a precious metal, then it does not rust.	But I don't know what it is . . . Is it really precious? I don't know whether it rusts or not.
K-va	(N6) It is a square, so its sides are equal, so she has drawn a square, nevertheless. The sides are equal.	I don't know any girl, who knows about her, what she has drawn.
S-na	(N7) If it is said that at the latitude of Leningrad white nights are observable in summer, and Primorsk is at this latitude, then there are white nights also.	No, Primorsk, it is in the east. And white nights, is it along the latitude or along the longitude? I do not know what nights are like there.
J-na	(N8) Yes, if it said that all numbers ending in 5 can be divide by 5 exactly, then 705 can be also divided.	Probably it can be divided, it can be calculated with the help of a pen (she is taking a pen and dividing): it can be divided.
M-va	(N9) There are traffic lights since the street is wide.	I don't know, and is there Dybenko street really?
S-ko	(N10) It is written on the card that mammals suckle their babies with milk, and kangaroo, it is written, is a mammal, then it suckles.	Suckles probably, I have heard that they have a pouch and the baby sits there.

^r Number of syllogisms according to Table 1 is given in parentheses.

are seldom observed: only in some subjects and only for syllogisms with quite familiar contents. In this state when subjects explain their reasoning, they spontaneously reveal a deductive mode of solving the problems.

Under left hemisphere suppression, this preference for a formal–logical way of syllogism solving is lost. Empirical answers become approximately equiprobable with theoretical ones. They are given by most of the subjects, and some of them give only empirical answers, while theoretical answers disappear completely. In this state empirical answers appear not only for familiar syllogisms but also for syllogisms with unfamiliar contents. Noteworthy with left hemisphere suppression is the subjects' attempt to obtain as much information as possible about syllogism contents and to report as much information as possible related to syllogism contents, i.e., to correlate the task with reality and personal experience.

Thus the data lend support to the concept of divergent styles of thinking. That the empirical way of solving tasks is preserved and therefore is potentially used by people who are fully capable of formal–logical ways of thought is experimentally proven. In contrast to theoretical thought, which is based on the activity of the left hemisphere, empirical thought is based on right hemisphere activity. Thus, different types of thought are spatially dispersed within the brain. The data also support characterizations of right hemisphere functions as “concrete,” “imaginative” and left hemisphere functions as “abstract,” “logical.”

The type of answer also depended on the contents of the syllogism. The probability of empirical answers proved to be higher for syllogisms with familiar contents. In other words, if the subject is given an abstract data base absent from his experience of life, then the theoretical “left-hemisphere” mode of thought is actualized and the task is solved in a deductive way. However, if the task invokes familiar material, the empirical “right-hemisphere” mode of thought can be also actualized and the task be solved on the basis of information in personal experience or by analogy with familiar situations. When both types of answers are observed, theoretical answers appear earlier and predominate for syllogisms with unfamiliar contents, whereas empirical answers appear earlier and predominate for syllogisms with familiar contents.

Within the context of the culture in which syllogisms exist (i.e., of European type civilization) empirical answers are inadequate. This is why the control data approximated the data obtained during isolated functioning of the left hemisphere. Normally the “right-hemisphere” mode of thought is not usually applied to syllogism solving. Only in the artificial situation of left hemisphere suppression do empirical solutions become prevalent.

In this connection a question arises: is not what we encounter, under conditions of left hemisphere suppression, a disinhibition of a rudimentary function which is normally suppressed? Is it legitimate to infer that empirical thought is normally actively utilized by modern humans? It was mentioned

in the introduction that empirical thought operates within the sphere of everyday life. However, does it take part in the mental activity which is designated scientific or theoretical? A hint that it does is offered by the greater facility that subjects exhibited in adopting the "theoretical" attitude when under right hemisphere suppression than in the normal bihemispheric state. Does this mean that normally the right hemisphere's empirical style has some control over thinking even in modern subjects given formal-logical tasks? The following experiment addresses this question.

EXPERIMENT 2

Solving Syllogisms with False Premises under Conditions of Transitory Suppression of One Hemisphere

Two observations during the previous experiment induced us to carry out the experiment reported below. One concerned the answers to syllogism N4 (Table 1). Due to our oversight the minor premise in this syllogism was false: that molybdenum is a precious metal. Under right hemisphere suppression one of the subjects answered: "I am not sure that molybdenum is a precious metal, but judging by this card it does not rust." The second observation concerned the answers to syllogism N8. The major premise of this syllogism contained a sign of division by five. One subject, a final year university student in engineering, when under right hemisphere suppression, answered: "Of course it is divisible, it is a well known sign for dividing by five." However, under left hemisphere suppression the same subject exclaimed "Ha! I don't believe it!" and demanded a pencil for purposes of calculation.

Thus in the above case, during relatively isolated functioning of the left hemisphere, dubious information contained in the task did not worry the subject and he used the information as though it were reliable. However, under conditions of relatively isolated functioning of the right hemisphere, when the information seemed doubtful to the subject, he demanded verification. These observations suggest that the reliability of the information contained in the task was not a matter of indifference for the right hemisphere.

This same idea was supported by the fact that under left hemisphere suppression, the subjects, before giving an answer, often tried to specify details connected with the syllogism's contents. This wish to clarify information that was not pertinent for solving the problem was already discovered by Luria (1976) working with traditional subjects.

So a new problem became apparent, connected both with divergent styles of thinking and with brain functional asymmetry: the subject's relation to the initial data for problem solving. To investigate this problem the subjects were asked to solve syllogisms with false premises. How would the subjects behave in this ambiguous if not "conflict" situation? We know of no previous studies of solving syllogisms with false premises.

TABLE 4
List of False Syllogisms and the Order of Presentation to the Subjects

NN	Major premise	Minor premise	Question
11	All trees sink in water. ^a	Balsa is a tree.	Does Balsa sink in water, or not?
12	All precious metals glitter.	Copper is a precious metal. ^a	Does copper glitter, or not?
13	Northern lights often are seen in Africa. ^a	Uganda is in Africa.	Are northern lights seen in Uganda, or not?
14	All monkeys climb trees.	The porcupine is a monkey. ^a	Does the porcupine climb trees, or not?
15	Winter is cold in tropical countries. ^a	Equador is a tropical country.	Is it cold in winter in Equador, or not?

^a This premise is false.

Materials and Methods

Subjects. Ten right-handed patients taking courses of unilateral ECT (all women) took part in the experiment. In seven patients schizophrenia was diagnosed; the other three suffered from manic-depressive psychosis. The patients' ages ranged from 27 to 53 years. Most of them, as in the previous experiment, were aged 30-40. They all had a secondary education. Some had graduated from university.

Stimuli. Five syllogisms were constructed in which one of the premises, either the major or the minor one, contained a statement which was clearly false (Table 4). These syllogisms will be called false. Only those patients took part in the experiment who possessed the necessary knowledge: what the climate is like in the tropics, what kind of animal a porcupine is and how it looks, which metals are considered precious.

Procedure. False syllogisms alternated with syllogisms with true premises. As the data relating to solving "correct" syllogisms fully coincided with those obtained in Experiment 1, they will not be presented here. If in the course of solving the syllogisms the subjects did not notice that the premises were false, their attention was specifically drawn to this. In other respects the procedure was the same as in Experiment 1.

Unilateral ECT techniques were the same as in experiment 1.

Results

Control investigations. Before ECT two types of responses were encountered. First, rejection of the false premise and refusal to solve the syllogism, e.g., "No, trees sink. If balsa is a tree, it will not sink" (syllogism N1); "Wrong, tropical countries don't have cold winters" (syllogisms N15). Such answers can be qualified as empirical ones since the subjects left domain of the syllogism and appealed to reality. In control experiments empirical answers were the ones most often encountered, they amounted to 2/3 of all the answers (Table 5). For each of the false syllogisms empirical answers were registered in more than 50% of cases (Fig. 3A). Empirical answers were observed in all the subjects, in six of them these answers amounted to 80% of the total, and in one subject all the answers were empirical.

TABLE 5

Percentage of Empirical (E) and Formal (F) Answers to Syllogism with False Premises in Control Investigations (C) and under the Right (R) and Left (L) Hemisphere Suppression

Type of answers	C	R	L	The difference significance level, <i>p</i>		
				C vs. R	C vs. L	R vs. L
E	66 ± 7	26 ± 6	86 ± 5	<.001	<.05	<.001
F	34 ± 7	74 ± 6	14 ± 5	<.001	<.05	<.001

The second type of answer was a formal–logical conclusion from the premises, in which the lack of correspondence between one of the premises and reality was ignored: “Yes, balsa sinks in water, because balsa is a tree, and all trees sink in water,” “Yes, it is cold in Equador in winter because it is a tropical country,” etc. Such answers can be qualified as theoretical, because the subjects strictly followed the rules of deductive reasoning. However, because these answers contradict reality (though they are operationally “correct”) it seems more adequate to call them formal answers. In control investigations formal answers were encountered half as often as empirical answers (Table 5). They did occur, though not very often, following presentation of every syllogism (Fig. 3A). Individual formal answers were registered in six subjects, and in three subjects they dominated. Rather often the subjects had difficulties in resolving the syllogisms; they did not know what to select: the formal-logical, but false conclusion, or the conclusion they knew to be right. In these situations the answers were ambivalent: “Due to the structure of what is written here the answer should somehow be positive, but I think that northern lights never occur in Africa. I have never heard of it,” or “Must I answer as it is written here? Then the porcupine climbs trees. But it does not climb, it is not a monkey.” In such cases we ascertained which of the alternatives the subject preferred.

Left hemisphere suppression. After left-sided electroshocks rejection of false premises was observed much more often. While in control investigation the number of empirical answers amounted to 2/3 of total, their proportion was nearly 0.9 under left hemisphere suppression (Table 5). In 3 of 10 subjects formal answers disappeared entirely, in 7 others they were infrequent. One of the syllogisms (N13) was never resolved by formal answers, and such answers were encountered in no more than 30% of instances in response to other syllogisms (Fig. 3B). In these cases there was an impression of “absentmindedness” of the subjects: the moment the patient’s attention was drawn to the falsity of the premise, she would reject the formal solution.

Noteworthy was a frequently occurring emotional reaction to false premises: “It’s a lie!”, “Nonsense!”, “Rubbish!”, or even “Doctor, you’ve gone mad!”. This indignation was often followed by corresponding vegetative and motor responses: the subjects flushed, clenched their fists, genuine

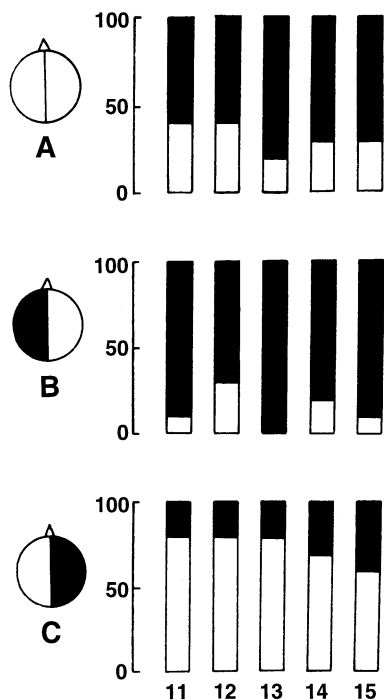


FIG. 3. Ratio between formal (white parts of the columns) and empirical (black parts of the columns) answers following presentation of "false" syllogisms. Under the columns are the syllogism numbers according to Table 4; on the ordinate are listed the percentages of answers. A, B, C, control, suppression of the left hemisphere, or suppression of the right hemisphere, respectively. Other designations as on Fig. 2.

anger was heard in their voices. (These reactions endorse the intactness of hypothalamic mechanisms after unilateral ECT.)

As compared to the control responses, denials of false premises were motivated in more detail and extended. Sometimes they amounted to a spontaneous monologue: "Balsa? What is it, balsa? No, balsa does not sink. Not every tree sinks in water. Trees float; they do not sink. And I don't know balsa. Balsa does not sink, trees do not sink" (syllogism N11); "This is a lie! Northern lights never occur in Africa. They occur at the North Pole. Maybe, though, they occur in the south of Africa, near the Antarctic" (syllogism N13); "It is warm in Equador! Rubbish! It is a tropical country. It can't be winter there, because it is in the south. What is written here is wrong!" (syllogism N15).

Right hemisphere suppression. After right-sided ECT the same subjects changed their answers dramatically. The number of formal answers more than doubled and the number of empirical answers correspondingly decreased as compared with the left hemisphere suppression condition (Table

5). Four subjects did not give empirical answers any more, and solved all the syllogisms through formal reasoning. In four other subjects only a few empirical answers were observed, and only in two subjects did their number remain unchanged. One of our subjects who gave exclusively empirical answers both under control conditions and following left hemisphere suppression, gave only formal answers under right hemisphere suppression. The observable changes concerned all the syllogisms: the number of formal responses to each of them exceeded 50% (Fig. 3C).

Subjects' attitude to false premises changed radically. The subjects who showed pronounced emotional responses to false premises under left hemisphere suppression, now performed formal-logical operations quite calmly, with confidence, and remained unmoved by the absurdity of the information offered by the premises. However, most striking was that even repeatedly drawing the subjects' attention to the falsity of the premises had no influence on their answers. Fully admitting the absurdity of the premise the subjects preferred logical conclusion to empirical one: "Here this is written," "Here that is said."

Below we compare the answers of one and the same subject in response to the same syllogisms presented in different states.

In the records which follow, the questions put by the investigator are in italics and his descriptions are in parentheses.

Extracts from the Records of Patient F

Control Investigation

—Please, read what is written here and answer the question (syllogism N15 is presented):

—Probably not.

—Why do you think so?

—According to what is written here, the answer should be positive, but I think that Ecuador is in Africa and it is always warm there.

Investigation following Left-Sided Electroshock

(The same syllogism is presented, the patient shrugs her shoulders, reads again):

—Winter is not cold in tropical countries! It's a lie!

Investigation following Right-Sided Electroshock

(The same syllogism is presented. The patient read it quickly and answered it immediately):

—It's cold in winter in Ecuador, because Ecuador is a tropical country.

—Oh, is winter really cold in a tropical countries?

—I think so. Winter is cold there and summer is warm.

Are you sure of this?

—No, I am not.

—Ecuador is a tropical country, then, can it be cold there?

—No, it can't be since it is a tropical country.

(Continued in 5 min):

—Is it cold in winter in Ecuador?

No, Ecuador is a tropical country.

(The same syllogism is presented):

—It is cold in winter in Ecuador because Ecuador is a tropical country.

—But you do know that it is not so.

—But it is written here.

*Extracts from the Records of the Investigations of the Patient S**Control Investigations*

(Syllogism N13 is presented):

—Northern lights occur in Uganda because Uganda is in Africa.

Investigation following Left-Sided Electroshock

(The same syllogism is presented):

—Oh, what nonsense?! What is it, Uganda? There is no such country.

—*There is such a country in Africa.*

—All the same, northern lights can't occur in Uganda. Northern lights do not occur in Africa.

Investigation following Right-Sided Electroshock

(The same syllogism is presented):

—They happen, because Uganda is in Africa.

—*Do you know, where northern lights occur?*

—I do, at the North Pole.

—*And do they occur in Africa?*

—Probably not.

(The syllogism is presented again):

—Northern lights occur in Africa, since that is written on the card.

*Extracts from the Records of the Investigations of the Patient K**Control Investigation*

(Syllogism N14 is presented):

—It does not climb, the porcupine runs on the ground.

—*And how does it look?*

—It is prickly.

—*It is like a monkey?*

—No, it is not.

Investigation following Left-Sided Electroshock

(The same syllogism is presented):

—Porcupine? How can it climb trees? It is not a monkey. It is prickly like a hedgehog. It's wrong here! (She is speaking with indignation.)

Investigation following Right-Sided Electroshock

(The same syllogism is presented):

—The porcupine climbs trees since it is a monkey.

—*But is the porcupine a monkey?*

—No, the porcupine is prickly, like a hedgehog.

—*Can it climb trees?*

—No, it can't, trees, it can't.

(The syllogism is presented again):

—Since the porcupine is a monkey, then it climbs trees.

—*But you do know, that a porcupine is not a monkey.*

—It is written so on the card.

This work was accomplished with subjects who were sufficiently mentally ill to require the benefits of ECT. Can the results be generalized to the general population (it being obvious that normal people cannot be subjects for similar observations)? It is reassuring in this respect that in the control condition (Experiment 1), responses were in line with the normative data in the litera-

ture. The subjects' responses in the experimental conditions, though not without interindividual variability, showed common, systematic effects of the conditions and the nature of the tests materials. We see no evidence that psychopathology biased subjects' attitudes to the test. Nor is there any evidence that the fundamental design characteristics of the hemispheres differ as between mentally normal and mentally ill people (Kinsbourne, 1989). We therefore generalize from the results in the discussion as follows.

Discussion of Experiment 2

In different states the same persons demonstrate different attitudes to the same initial data contained in the task. Under left hemisphere suppression and relatively isolated functioning of the right hemisphere the subjects do not accept false premises and refuse to use them. They try to refute false premises, their words carry conviction. Moreover, in this state, presentation of false premises produces acute emotional reaction in the subjects, extreme indignation. Under right hemisphere suppression and relatively isolated functioning of the left hemisphere the same subjects, as a rule, attach no importance to the fact that the information contained in the premises is false and use it with confidence. The subjects' indifference about false premises in this state is striking. Even repeatedly drawing attention to the false information contained in the initial data does not change their attitude to this information and does not prevent them from using it and from arriving at an absurd conclusion, in accordance with the rules of formal logic. The authority of what "is said" or "written" usually serves as a justification.

Thus, solving syllogisms with false premises has demonstrated much more distinctly (if not grotesquely) the regularity found with solving syllogisms with true premises: the right hemisphere connection with empirical thought and the left hemisphere connection with theoretical thought. However, the data obtained in Experiment 2 are important in one more respect. They offer insight into the meaning of divergent thinking and answer the questions posed earlier in this article. For this purpose the differences between theoretical and empirical modes of task-solving will be further considered. Psychological differences between different types of responses were first described by Luria (1976) and more recently reviewed by Tulviste (1988).

Different modes of thought operate in different spheres of human activity and address tasks of different types: empirical thought operates in tasks connected with everyday life. Theoretical thought operates in the scientific sphere. The facts obtained during the investigation of solving false syllogisms indicate that empirical thought deals with the task which escapes from the limits of everyday life experience. Empirical thought secures verification of the postulates which are operated on by theoretical thought and protects theoretical activity from ill founded conclusions. In Experiment 2, theoretical thought could not solve the task without basing itself on empirical thought.

Remarkable in this respect are the control data in which false syllogisms mainly elicited empirical answers. (Only under right hemisphere suppression did theoretical responses predominate.) This constitutes a radical difference between the Experiment 2 control investigations and those of Experiment 1, in which the answers were mainly theoretical. The modern cultural norm is syllogism solving according to the rules of formal logic, i.e., using a "left-hemisphere" mode of thought (as in control investigations in Experiment 1). However, given contradictions between the syllogism premises and reality (experiment 2), the "right-hemisphere" mode of thought is most frequently actualized and the cultural norm is rejected. Thus, empirical "right-hemisphere" thought is not a functionless vestige: it was demonstrably significant in the normal "two-hemisphere" state.

Revealing are also different emotional attitudes to false premises in different states. Under left hemisphere suppression and reciprocal activation of the right hemisphere, when empirical thought dominates, false premises evoke negative emotional responses. Under right hemisphere suppression and reciprocal activation of the left hemisphere, when theoretical thought dominates, false premises are calmly accepted. Apparently defense against information which is poor in quality (presumably a right hemisphere function) demands powerful emotional support. This would be congruent with the emotional specializations of the hemispheres. Negative emotions are connected with the right hemisphere activation (Davidson & Tomarken, 1989; Deglin & Nikolajenko, 1975; Flor-Henry, 1983; Gainotti, 1972; Nikolajenko, Deglin, & Balonov, 1977; Rossi & Rosadini, 1967). In this case the cognitive and emotional specializations of the hemispheres prove to be interconnected (Kinsbourne, 1989).

GENERAL DISCUSSION

Two Hemispheres, Two Different Mental Mechanisms

In general, mental activity during isolated functioning of the left hemisphere is characterized by the inclination to use formal-logical operations in any situation, and even to overextend its use when this is unnecessary or inadequate. Mental activity during isolated functioning of the right hemisphere is characterized by the tendency to incorporate already existing knowledge about real facts, even it is called upon to assume counterfactuals. The right hemisphere seems incapable of the willing suspension of disbelief.

Of the two mechanisms, one provides for the purely operational, procedural aspect of the mental activity. It is responsible for the formal correctness and consistency of mental operations. It is indifferent to the nature of the material operated on by the thought. This mechanism is in the left hemisphere. The human brain also possesses a mechanism that assures the quality of the material operated on by the thought, the correspondence between the thought and reality (cf. Zaidel, 1987). This mechanism is in the right hemi-

sphere. The dichotomy expands on Goldstein's (1948) distinction between the abstract and the concrete attitude and offers it a hemispheric basis.

Neurolinguistic Interpretation of the Divergent Thinking Styles

Solving syllogisms is a language activity, and the thought types (theoretical and empirical) are verbal types of thought since they are realized in the signs of the natural language. Therefore the regularities which characterize sign systems, and language in particular, can be applied to them.

Neurolinguistic investigations performed under conditions of single hemisphere suppression, showed that different hemispheres provided for different aspects of language signs, or more widely, for different aspects of semiosis (Balonov & Deglin, 1976; Balonov, Deglin, & Traugott, 1977; Chernigovskaja & Deglin, 1986; Chernigovskaja, Balonov, & Deglin, 1983); earlier neurolinguistic data by the above authors were also discussed by Jakobson (Jakobson, 1980; Jakobson & Waugh, 1979). The left hemisphere "comprehends" conventionality and arbitrariness of language signs, "createdness" of words. In other words, in the left hemisphere a word and the out-of-language reality which is denoted by the word (its referent) distinctly differ from each other. The word has potential connections with other words (paradigmatic and syntagmatic), i.e., a capacity for combination with other words according to different principles. Thus, for the left hemisphere syntactic relations are especially pertinent. At the same time, semantic relations between the sign and its referent are weakened.

The right hemisphere does not "appreciate" the conventional nature and arbitrariness of language signs. For it, the word is a part or a characteristic of the thing. The word belongs only to the thing it names (like it does for an infant just beginning to speak (Kinsbourne & Lempert, 1979). Thus for the right hemisphere semantics are especially pertinent and the syntactic aspect is weakened. The left hemisphere provides for syntactics of language signs, whereas the right hemisphere is constrained by their denotative semantics.

Divergent Styles of Thinking and the Brain

Solving syllogisms with false premises showed that theoretical thought can become a parody of itself when it is not based on a semantic mechanism. It is also difficult to imagine empirical thought free of syntactic connections. Both theoretical and empirical thoughts must utilize mechanisms of both hemispheres to an extent that depends on the nature of the problem to which they are applied. The territorial separation of context-bound and context-free mechanisms offers the possibility of precisely "tuning" the mental processes according to the problems being solved.

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