Reprinted from: THE THERAPEUTIC POTENTIAL OF MARIHUANA (1976)
Edited by Sidney Cohen and Richard C. Stillman
Book available from: Plenum Publishing Corporation
227 West 17th Street, New York, New York 10011

CHAPTER 15

MARIHUANA, COGNITIVE STYLE, AND LATERALIZED HEMISPHERIC FUNCTIONS

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NOTE: This study was conducted as part of a research program on the Pharmacological Effects of Cannabinoids in Man, supported by U. S. Public Health Service Contract HSM 42-71-89, whose principal investigator was Dr. Sidney Cohen, co-principal investigator Dr. Ira Frank.

ABSTRACT

Two hypotheses concerning the psychological effects of marihuana are proposed: (a) that the process of becoming "high" on marihuana consists, in part, of shifting into a new cognitive style or mode which involves less reliance on analytical, sequential, verbal processing, and more reliance on synthetic, holistic, imagistic processing; (b) that one of the ways that marihuana produces this shift is by decreasing left, and increasing right hemisphere participation in cognitive activities. To test these hypotheses, 25 male subjects were administered a battery of psychological tests which tap either analytic or synthetic (or "mixed") cognitive processes by means of tasks lateralized either to the left or to the right hemisphere (or both hemispheres). Each subject was tested in both nonintoxicated and intoxicated states, according to a counterbalanced design. A differential pattern of marihuana effects was observed: verbal analytic tasks were impaired, holistic-nonverbal closure tasks were facilitated, and "visualization" tasks showed mixed results. Performance on "low level" perceptual tasks was not affected. To further test the relationship between marihuana effects and brain lateralization, the subject sample was split into a "high lateralized" and a "low lateralized" group, based on nonintoxicated performance on dichotic listening tasks. Separate analyses indicated that "low lateralized" subjects showed no enhancement of closure ability when intoxicated, whereas "high lateralized" subjects showed a strong enhancement of this ability. Further differences in drug effects were also noted, consistent with the hypothesis that an individual's reaction to marihuana depends, in part, upon his particular pattern of brain lateralization.

INTRODUCTION

Source of the Experimental Hypotheses

If one compares "normal" cognition with that which is reportedly experienced during marihuana intoxication, one finds a pattern of differences which seem to parallel recently established differences between the cognitive functioning of the left and right cerebral hemispheres. Those cognitive activities reportedly experienced as impaired or less prominent during marihuana intoxication often resemble those cognitive functions which have been found to be more characteristic of the left hemisphere. Similarly, those reportedly experienced as enhanced or more prominent during marihuana intoxication often resemble cognitive functions found more characteristic of the right hemisphere. A short summary of the relevant neuropsychological and psychopharmacological data will serve to bring out this parallelism.

Hemisphere specialization data. There is an increasing body of evidence which indicates that the left and right cerebral hemispheres in man are specialized to perform higher-level processing in different ways (for reviews, see Blakemore, Iverson, and Zangwill, 1972; Bogen, 1969; Dimond and Beaumont, 1974; Milner, 1971). While the specialization of the left hemisphere for language and the right for certain visuo-spatial functions is well established (see reviews just cited), the discovery of additional hemispheric specializations has led some authors (for example, Bogen, 1969; Levy, 1969, 1973; Ornstein, 1972; TenHouten and Kaplan, 1973) to suggest a broader interpretation of each hemisphere's role. They propose that the information processing methods of the left and right hemispheres may represent two different cognitive "modes" which play fundamental and complementary roles in human thought: the left hemisphere is characterized as using verbal, analytical, linear-sequential processing, while the right hemisphere is characterized as nonverbal, nonanalytical, nonlinear, and as using instead synthetic, gestalt-holistic, parallel processing.

Marihuana intoxication data. Experiential reports of the marihuana intoxication state (for example, Anonymous, 1969; Solomon, 1966, section two) and in particular the results of a questionnaire study of 150 marihuana users (Tart, 1971) suggest that being "high" may involve a coordinated shift in perceptual and cognitive activities which might be appropriately described as a change in cognitive "mode." There is a reported impairment or decrease in verbal and linear-sequential cognitive activity and a reported enhancement and increase in nonverbal processing, particularly for musical, visual, and kinesthetic stimuli.

Specific parallels. The evidence for the parallelism between these two types of data can be developed in terms of specific examples.

(a) Reported impairments: At higher levels of marihuana intoxication, experiential reports commonly mention verbal difficulties such as "I find it difficult to read while stoned" (Tart, 1971: 172), "memory span for conversations is somewhat shortened," and "I may forget what the start of a sentence was about even before the sentence is finished" (Tart, 1971: 154). Such reported effects can be interpreted as indicating an impairment of left hemisphere verbal functions, since there is evidence supporting left hemisphere mediation of reading comprehension (Weisenburg and McBride, 1935) and verbal short- and intermediate-term memory (Black, 1973; Cohen, Noblin, and Silverman, 1968; Milner, 1962, 1967, 1971). These experiential reports have been verified in several laboratory experiments with intoxicated subjects (for example, Clark, Hughes, and Nakashima, 1970; Weil and Zinberg, 1969). Laboratory studies have also indicated interference (at high doses) with complex, sequential thought processes (for example, Melges, Tinklenberg, Hollister, and Gillespie, 1970) which is also consistent with left hemisphere impairment.

(b) Reported enhancements: On the other hand, at both moderate and strong dose levels, marihuana users frequently report enhancement of musical perception, enhanced visual depth sensation, and the enhanced perception of "patterns, forms, figures, meaningful designs" in material that might normally seem "just a meaningless series of shapes or lines" (Tart, 1971: 59). Each of these enhancement effects relates to a cognitive or perceptual process which is predominantly a function of the right hemisphere. (For experimental evidence on the right hemisphere lateralization of these functions, see the following: re aspects of music, see Bogen, 1969; Gordon and Bogen, 1974; Kimura, 1964; Milner, 1967; re depth perception, see Kimura, 1973; Kimura and Durnford, 1974; re closure for visual patterns, see Bogen, DeZure, TenHouten and Marsh, 1972; DeRenzi and Spinnler, 1966; Lansdell, 1970; Newcombe, 1969; Warrington and James, 1967.) In addition, marihuana users report a general enhancement of various kinds of nonverbal awareness and cognition, including bodily sensations not usually in awareness, imagery, and "intuitive insights" (Anonymous, 1969; Solomon, 1966; Tart, 1971). While there is little specific data on the lateralization of such functions, their experiential enhancement seems consistent with a shift toward the cognitive mode postulated for the right hemisphere. Evidence that marihuana enhances waking suggestibility (Crawford, 1974) is also relevant, in light of recent evidence

(Gur and Gur, 1974) that hypnotic suggestability is associated with right hemispheric functioning.

Statement of the Hypotheses

The parallels described above lead naturally[1] to the following hypotheses:

(1) The process of becoming "high" on marihuana consists, in part, of shifting into a new cognitive style or "mode" which involves less reliance on analytical, sequential, verbal processing, and more reliance on synthetic, holistic, imagistic processing.

(2) One of the ways that marihuana produces this shift is by decreasing left, and increasing right hemisphere participation in cognitive activities.

These two hypotheses are to some extent independent. It is possible, for example, that (1) could be true and (2) disconfirmed by subsequent experimental test. In order to clarify how this could happen, we must explain the notion of a "cognitive style shift" independently of any reference to hemisphere functions. We must also explain what sort of cognitive changes would not constitute a shift in "cognitive style" or "cognitive mode," so that hypothesis (1) does not seem to be trivially true.

The idea of "cognitive style" antedates the idea that there are different cognitive processing "modes" for the two cerebral hemispheres. For over thirty years, psychologists have been comparing the ways that different individuals organize and use their cognitive-perceptual processes (for example, see Tyler, 1965, Ch. 9 for a review). We are merely extending that notion to include possible differences in "cognitive style" within the same individual across different states of consciousness.

While the term "cognitive style" suggests an easily modified choice of cognitive approach to a problem, many of the "styles" studied by psychologists consist of firmly rooted patterns of behavior that contribute to (or are caused by) differences in ability to use particular cognitive approaches. For example, highly "field dependent" subjects (see below for definition) are generally unable to change to a more analytic style, even when the task demands it, whereas highly "field independent" subjects are unable to adopt a more global approach when this would be beneficial. It is this stronger interpretation of "cognitive style" that is used in this paper.

Not all changes in consciousness would constitute a change in cognitive style. For example, the various effects of marihuana apparently include impairment of attention and memory (see, for example, Darley, Tinklenberg, Roth, Hollister, and Atkinson, 1973; DeLong and Levy, 1973). But such changes in abilities do not in themselves provide evidence of a change in cognitive style; they might merely indicate less efficient performance in the same cognitive style. However, we have noted above that experiential reports of marihuana intoxication often include impressions of a reduction in verbal-sequential processing and simultaneous impressions of enhancement of several forms of nonverbal-holistic processing. Such reports suggest a selective pattern of shifts in several related cognitive abilities. If such a systematic pattern of changes in abilities could be objectively verified, it would indicate a shift in cognitive style.

We are not the first to suggest an interpretation of marihuana's effects in terms of "cognitive style." Dinnerstein (1968) has speculated that marihuana intoxication might move subjects toward a more "field dependent" mode (where the perception of an element is more strongly influenced by the surrounding perceptual field, see Witkin, Lewis, Hertzman, Machover, Meissner, and Wapner, 1954; Witkin, Dyk, Faterson, Goodenough, and Kays, 1962). Dinnerstein's suggestion is not incompatible with our hypotheses. In fact, the interpretation he suggests might be a special case of the more general cognitive shift which we hypothesize (see Cohen, Berent, and Silverman, 1973). However, the relationship between "field dependence" and hemisphere functions is not yet well established. For example, the Embedded Figures Test, which is often used to measure "field dependence," probably taps functions of both hemispheres (see discussion below). To date, marihuana studies incorporating tests of "field dependence" have obtained mixed results (Carlin, Bakker, Halpern, and Post, 1972; Hollister and Gillespie, 1970; Jones and Stone, 1970; Meyer, Pillard, Shapiro, and Mirin, 1971; Pearl, Domino, and Rennick, 1973). One advantage of the broader cognitive and neuropsychological hypotheses proposed here is that they are subject to a wider variety of experimental tests.

METHOD

The hypothesized shifts in cognitive style and hemispheric participation were tested by administering a battery of cognitive, perceptual, and preference tests (Table 1) to 25 subjects, and comparing their performance in the intoxicated vs. nonintoxicated state, counterbalanced for treatment order. The tests are so selected that lowered scores on one subset of tests and unchanged or raised scores on another subset would indicate a shift in cognitive style.[2] A more or less uniform change across all cognitive tests would indicate a general sedative or stimulant effect with no specific effect on cognitive style.

In addition to their role in the measurement of cognitive abilities, many of the psychological tests selected for this study were chosen because they tap lateralized functions (i.e., functions which tend to be localized in a single cerebral hemisphere). For example, the Street and Gollin tests of closure ability, as well as very similar closure tests, have previously been used to study the effects of unilateral brain damage and are known to be much more impaired by right hemisphere damage than by left hemisphere damage (Bogen, DeZure, TenHouten, and Marsh, 1972; DeRenzi and Spinnler, 1966; Lansdell, 1970; Newcombe, 1969; Warrington and James, 1967). More information on lateralization of tests is provided in Appendix 4. For those tests which are known to tap lateralized functions, systematic patterns of change

Table 1

Classification of Major Psychological Tests and Variables

I. Cognitive Ability Tests and Variables

A. "Verbal" (analytical-verbal propositional (P) function)

1. Nonsense Syllogisms
2. Inference Test
3. Composite "Verbal" Score (sum of A1 + A2 raw scores)

B. "Closure" (holistic-nonverbal appositional (A) function)

1. Street Test
2. Gestalt Completion Test
3. Harshman Figures
4. Gollin Figures (error score)
5. "Closure" Composite Score (sum of B1 + B2 + B3 - B4 raw scores)

C. "Cognitive Style" indices

1. A/P Ratio (closure composite divided by verbal composite)
2. A-P Balance (closure composite minus verbal composite)

D. "Disembedding" (mixed analytic-holistic-nonverbal)

1. Hidden Figures Test

E. "Visualization" (originally hypothesized to be mostly A function, however more recently discovered to be mixed analytic-holistic-nonverbal)

1. Form Board
2. Surface Development
3. Paper Folding
4. "Visualization" Composite Score (sum of E1 + E2 + E3 raw scores)

II. Perceptual Ability Tests and Variables

A. Nonverbal (right hemisphere, low level appositional (A) functions)

1. Timbre Test
2. Arc-Circle Test

B. Verbal (left hemisphere, low level propositional (P) functions)

1. Matched Syllables Dichotic Test
2. Matched Words Dichotic Test

III. Preference Tests

A. Preference for type of stimulus (aesthetic preference)

1. Design Judgment Test

B. Preference for type of cognitive task (verbal vs. spatial)

1. Grouping Test

C. Unconscious preference for processing mode in test performance can provide indirect evidence of shifts in cerebral participation in perceptual-cognitive activities.

Testing Procedure

Experimental design. To insure that testing was accomplished during the period of 1 to 1.5 hours after intoxication, the battery of tests was divided into two parts (A and B), which were administered in separate intoxication periods on two successive mornings. Tests were given according to the schedule in Table 2. In this schedule, tests of right and left hemisphere functions were distributed throughout each testing period to balance the effects of any changes in intoxication level during the testing session. Order of conditions (intox vs. nonintox) and of parallel test forms were counterbalanced across subjects. Each subject was assigned to one of four test conditions: nonintox, form A (six subjects); intox, form A (six subjects); nonintox, form B (seven subjects); intox, form B (six subjects). Subjects were administered the opposite treatment and form conditions on retest.

Subjects. Twenty-five male subjects between the ages of 21 and 35 were obtained from a larger study of the effects of chronic marihuana intoxication.[3] All subjects were heavy users of marihuana before joining the research project and were carefully screened for physical and psychological problems before being admitted to the chronic study. Once admitted, each subject lived in special quarters at UCLA for 94 days where he participated in various testing programs (including this study) according to a standardized schedule. Subjects were paid $800 for their 94 days of participation, plus additional fees earned by performing specific tasks. Every subject admitted to the 94-day chronic study after September, 1973 participated in this cognitive style/hemisphere dominance study; 27 subjects began testing; however, one subject dropped out before retest and one had invalid data due to experimenter error.

Drug administration and testing conditions. Subjects were individually tested in a private office adjacent to their living area at UCLA. When tested in the nonintoxicated condition, subjects had not smoked for at least two days prior to testing. When tested in the intoxicated condition, subjects had been smoking marihuana on previous days. On the morning of testing, each subject refrained from smoking until just before the beginning of the testing session. At that time, he completely smoked one marihuana cigarette containing approximately .9 grams of marihuana assayed at 2.2 percent natural THC (19.8 mg THC). He was then tested for 1 to 1.5 hours after which he resumed other activities connected with the 94-day project.

Approximately two weeks elapsed between test and retest. However, because of scheduling conflicts or other problems, a few subjects were retested as few as 8 or as many as 21 days after initial test.

Table 2
Testing Schedule

	Test Name (Source)	Length	Cognitive Function Tested	Lateralization
Part A (first morning)				
1.	Street Test (Street)	1.5 min	gestalt closure	Right
2.	Gestalt Completion (ETS)	3 min.	gestalt closure	Right
3.	Nonsense Syllogisms (ETS)	4 min.	verbal analytic syllogistic	Left
4.	Form Board Test (ETS)	8 min.	visualization	Right (?) ***
5.	Inference Test (ETS)	6 min.	verbal analytic syllogistic	Left
6.	Surface Development (ETS)	6 min.	visualization	Right (?) ***
7.	Grouping Test (Galin)	1-4 min.*	verbal-spatial preference	L-R preference (?)
8.	Harshman Figures (Harshman)	20 sec. x 11	gestalt closure	Right
9.	Gollin Figures (Gollin)	5 sec. x 50	gestalt closure	Right
10.	Paper Folding Test (ETS)	3 min.	visualization	Right (?) ***
11.	Hidden Figures Test (ETS)	10 min.	non-verbal analytic	Left bilateral
Part B (second morning)				
1.	Timbre Test (Seashore)	4.2 min.	auditory tone quality perception	Right
2.	Matched Syllables (Berlin)	5 min.	(dichotic monosyllables)**	L-R use
3.	Matched Words (Benson)	5 min.	(dichotic words)**	L-R use
4.	Matched Words, Part II	5 min.	(dichotic words)**	L-R use
5.	Matched Syllables, Part II	5 min.	(dichotic monosyllables)**	L-R use
6.	Timbre Test, Part II	4.2 min.	auditory tone quality perception	Right
7.	Arc-Circle Test (Nebes)	10-30 min.*	part-to-whole judgment	Right
8.	Design Judgment Test (Graves)	2-5 min.*	aesthetic judgment (?)	Right (?)
9.	Reflective Eye Movements (Bakan, Day, Kinsbourne, etc.)	5-10 min.*	---	L-R use

* No time limit.

** Dichotic listening tasks are not used as tests of a cognitive function proper, but rather as a means of getting left and right ear scores which can be compared to measure hemispheric use asymmetry during a controlled task of a precise kind (in this case, syllable and word perception/discrimination/identification under conditions of dichotic competition).

*** Subsequently reevaluated and determined to be mixed left and right. See Appendix 5.

The Test Battery

Table 1 presents a list of the major tests (and related composite variables), classified into three basic groups: cognitive ability tests, perceptual ability tests, and tests of preference for particular stimuli or modes of cognitive processing ("preference tests"). Of these three groups, the largest and most important for our hypothesis testing is the group of cognitive ability tests. Most of these tests were selected from the Educational Testing Service's "Kit of Reference Tests for Cognitive Factors" (French, Ekstrom, and Price, 1963), and were thus believed to represent relatively factorially pure measures of the ability in question. Test descriptions and references are given in Appendix 3 and 4.

Composite variables. In order to obtain more reliable estimates of each cognitive ability under examination, several different tests of each ability[4] were included in the test battery. Because of the relatively small number of subjects tested in this study, interesting trends exhibited by a single test might fall short of statistical significance (see Appendix 1, "Problems of sample size"). However, with composite variables spanning several related tests, we have a better chance of detecting a real difference as statistically significant, since these composites are more stable and reliable. Further, since composite scores are less affected by peculiarities of any single test's format, they provide the most appropriate means of representing the general ability common to several closely related tests. In this study, composites were computed by simply summing raw scores of the constituent tests.

Two special composite variables were constructed to contrast different cognitive abilities. These are the Cognitive Style Indices listed under Section I-C of Table 1. They provide a means of directly measuring the predicted shifts in cognitive style. To explain these indices, however, we must first provide some additional background and terminology.

Definition of "Appositional," "Propositional," and the "Cognitive Style Indices." We will adopt the terminology suggested by Bogen (1969) for describing the distinctive cognitive modes of the left and right hemispheres. He proposed that the term "propositional" (first suggested by Hughlings Jackson) be adopted to represent the analytical-verbal-sequential functioning mode of the left hemisphere, and that the term "appositional" be used to refer to the holistic-nonverbal (and not yet well understood) functioning mode of the right hemisphere.

Subsequently, Bogen, DeZure, TenHouten, and Marsh (1972) have suggested that the overall relative emphasis or relative development of these two modes in one individual be measured by comparing his performance on appositional vs. propositional tasks. Specifically, they suggested a simple "A/P Ratio" as a measure of cognitive style. In their article they had only one appositional and one propositional task, and they simply took the ratio of the raw scores on these two tasks (Street Closure Test and WAIS Verbal Similarities) to compute their ratio. Since we have several tasks representing each of these cognitive abilities, we used the closure composite score as the appositional numerator and the verbal composite score as the propositional denominator for our A/P Ratio.

In addition to the (nonlinear) ratio measure suggested by Bogen et al. (1972), we also compared the relative magnitude of the A and P scores by computing an A-minus-P "balance" score. This provides a slightly different (linear) supplementary measure of cognitive style.

Experimental Predictions

With the terminology and variables defined above, we can now state more precisely the predicted changes implied by the experimental hypotheses. The first (cognitive style shift) hypothesis implies the following results:

> 1. Relative Cognitive Shift Predictions. During marihuana intoxication, the relative performance of a subject should shift in the direction of appositional functions:
>
> (a) the A/P Ratio should become larger;
> (b) the A-P Balance should shift in the positive direction.

These predictions would be fulfilled if marihuana changed cognitive performance in any one of five ways: (a) it could depress both A and P functions, but have a greater depressant effect on P functions; (b) it could selectively depress only P functions; (c) it could selectively stimulate A functions; (d) it could stimulate both A and P functions, but have a significantly greater facilitory effect on A functions; or (e) it could stimulate A functions and depress P functions. Considered by themselves, these alternative modes of action might seem to be decreasingly likely as one proceeds from (a) to (e). However, consideration of the second experimental hypothesis (of a "hemispheric shift") leads us to predict what otherwise might seem the least likely of these modes of action:

> 2. Absolute Cognitive Shift Predictions. During marihuana intoxication, the absolute performance levels of a subject should be altered as follows:
>
> (a) A functions should be enhanced;
> (b) P functions should be depressed;
> (c) Mixed A-and-P tests should show mixed results, depending on the relative importance of A vs. P functions for performance on each test.[5]

RESULTS AND DISCUSSION I: COGNITIVE AND HEMISPHERIC SHIFTS

First, we will consider cognitive task data since they provide the most direct test of the "cognitive shift" hypothesis, as well as an indirect test of the "hemispheric shift" hypothesis. Subsequently, we will consider data for the perceptual tasks, which allow experimental testing of additional predictions implied by the "hemispheric shift" hypothesis.

Cognitive Ability Tests

Relative-shift results. An A/P Ratio and A-P Balance score were computed separately for each subject in both nonintox and intox conditions. Adjusted means for each condition were then computed across subjects (see Appendix 1 for details). The results are shown in Table 3. Both cognitive style indices show a statistically significant shift toward greater "appositionality," consistent with predictions 1-a and 1-b.

Absolute-shift results. Adjusted means for each cognitive ability composite are presented in Table 4 and Figure 1. In the intoxicated condition, the "appositional" closure composite score is significantly higher, consistent with prediction 2-a, while the "propositional" verbal composite score is significantly lower, consistent with prediction 2-b. At the same time, the A-P "mixed" disembedding score shows only a small shift. While a small shift on this test is consistent with prediction 2-c, the observed shift is even smaller than would be expected. Performance on this test might have been more clearly depressed if the test had been given earlier in the session; it was the last test of Session A, administered 50-60 minutes postintox, and the level of intoxication for most subjects (as indicated by pulse and subjective high ratings) had begun to drop somewhat.

Table 3

Relative Shifts: Effect of Marihuana on Indices of Cognitive Style

Index	Adjusted Means			Significance Level
	Intox	Nonintox	Difference	
A/P Ratio*	1.183	0.943	0.240	$p < .05$
A-P Balance*	1.068	-2.749	3.817	$p < .005$

* See text for definition

Table 4

Absolute Shifts: Effect of Marihuana on Cognitive Ability Scores

Score	Adjusted Means			Percent change from Nonintox	Significance level
	Intox	Nonintox	Difference		
Verbal Composite	11.921	13.565	-1.644	-12.12%	$p < .05$
Closure Composite	12.989	10.817	+2.172	+20.08%	$p < .05$
Disembedding	4.083	4.174	-0.090	-2.15%	n.s.
Visualization Composite	71.092	75.954	-4.862	-6.40%	n.s.

The result for the visualization composite score is not consistent with our original predictions. We originally thought that visualization tests would tap mostly appositional functions (since they are nonverbal and spatial); therefore, we predicted that such scores would be higher in the intoxicated state. Instead, the visualization composite score showed a small (nonsignificant) dedecrease with intoxication (see Table 4 and Figure 1).

In light of these results, we have reexamined the specific tasks used to test visualization and searched out further neuropsychological data on their lateralization. A simple, though post hoc, explanation has emerged: our "visualization" tasks are in fact cognitively complex, and although some of the cognitive abilities involved may be enhanced (e.g., visualization), other abilities involved in performing the same tasks are impaired (e.g., sequential memory). Thus, the effect of marihuana on these visualization tasks is seen as consistent with prediction 2-c. (Evidence for this interpretation is summarized briefly below.)

Results for individual cognitive tests. Data for the individual cognitive ability tests are summarized in Table 5 and Figure 2. With the small number of subjects tested in this study, it is difficult to demonstrate significant changes in "higher level" cognitive abilities by means of single tests rather than composite scores (see Appendix 1, "Problems of sample size"). Thus, it is interesting to note that despite this handicap, two of the individual cognitive ability tests show a significant difference between nonintox and intox conditions. Further, the pattern of shifts demonstrated by these two tests supports both the relative and absolute cognitive shift predictions. Scores on the Inference Test, an analytical-verbal test, are significantly lower in the intox condition, while those for the Harshman Figures, a holistic-nonverbal test, are significantly higher. Most of the other tests show trends in the predicted directions. Several of the individual tests, however, do not show the expected trends, and thus warrant further discussion.

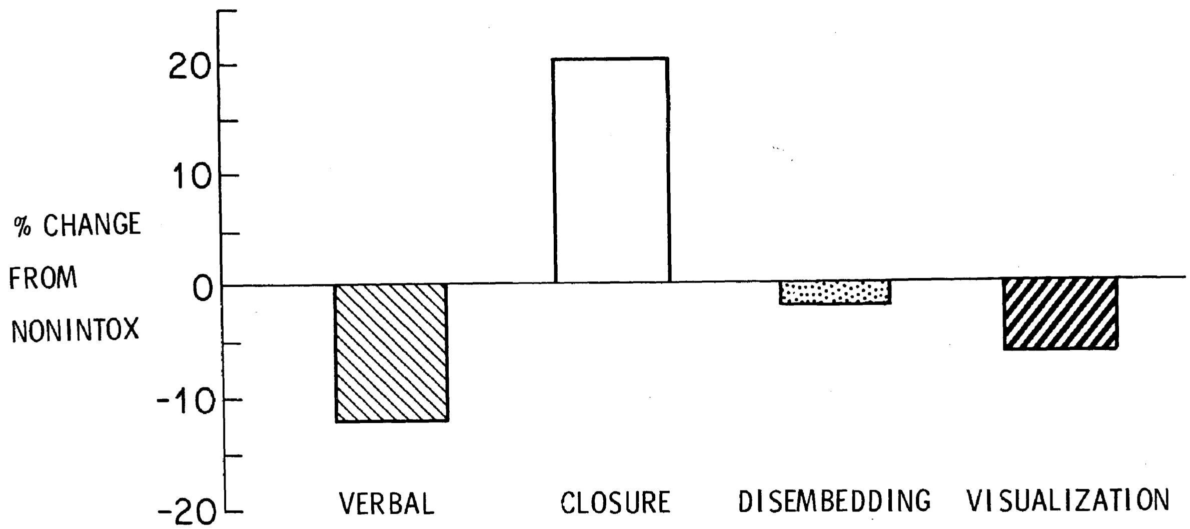


Figure 1. Effects of Marihuana on Composite Cognitive Ability Scores

Table 5

Effects of Marihuana on the Individual Tests of Cognitive Abilities

Test Name	Adjusted Means: Intox	Nonintox	Difference	Percent change from Nonintox	Significance Level
Nonsense Syllogisms	5.359	6.128	- .770	-12.55%	n.s.
Inference Test	6.563	7.438	- .875	-11.76%	p <.02
Street Test	3.009	3.093	+ .006	+ 0.21%	n.s.
Gestalt Completion Test	7.979	8.080	- .104	- 1.29%	n.s.
Harshman Figures	8.025	6.963	+1.060	+15.25%	p <.02
Gollin Figures (errors)	6.114	7.322	-1.210	+16.50%*	n.s. (p <.10)
Hidden Figures Test	4.084	4.174	- .090	- 2.15%	n.s.
Form Board Test	45.522	52.003	-5.580	-10.54%	n.s.
Surface Development Test	19.497	18.752	+ .744	+ 3.97%	n.s.
Paper Folding Test	5.073	5.198	- .025	- 2.41%	n.s.

* Sign changed to indicate enhanced performance due to drop in errors.

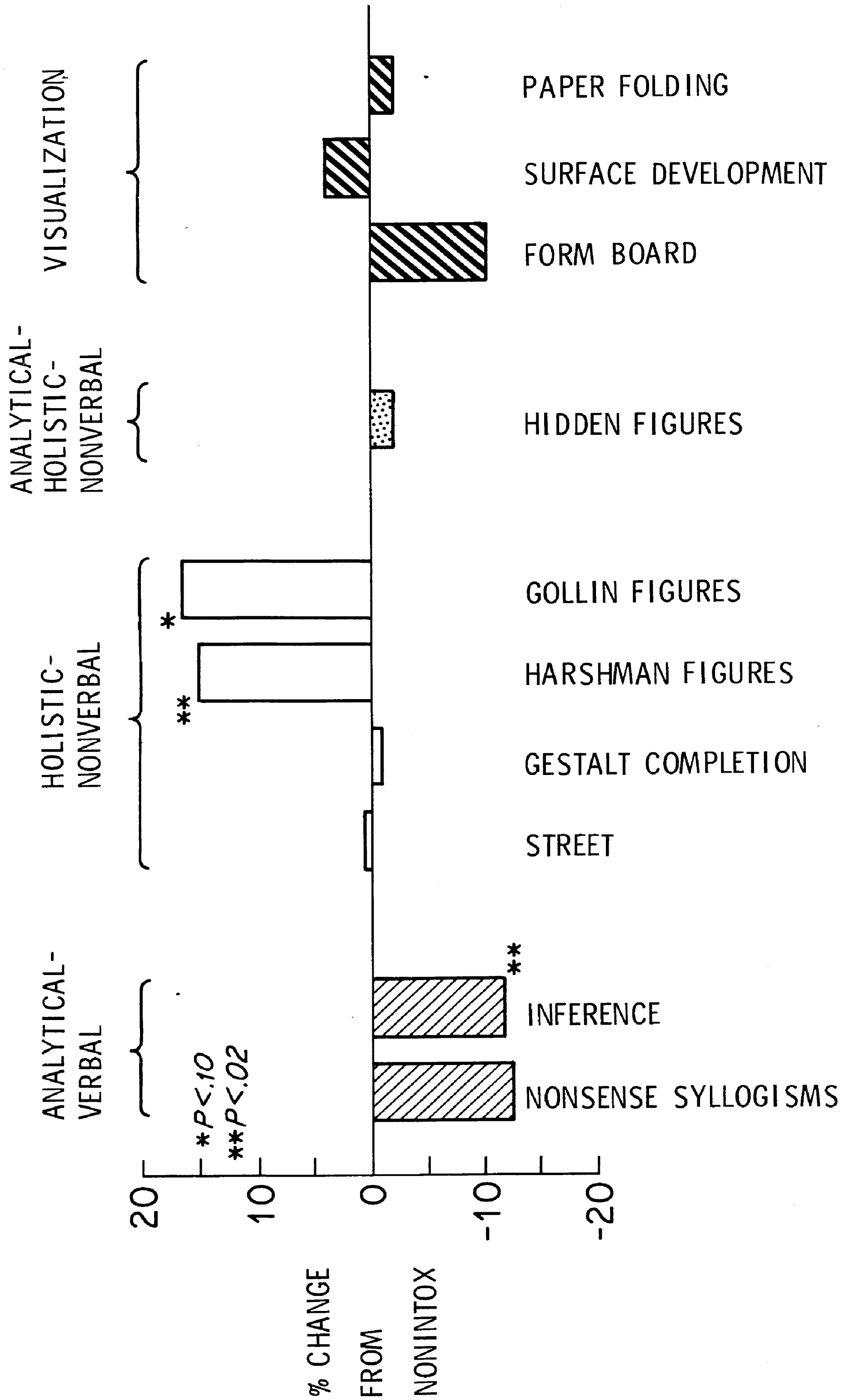


Figure 2. Effects of Marihuana on Individual Cognitive Ability Tests

While two of the four closure tests show substantial improvements with intox, the other two (the Street and Gestalt Completion tests) show essentially no change (Table 5). There are several possible distinguishing characteristics of these latter two tests which might account for their failure to show an enhancement. These include psychometric flaws, differences in timing procedures, differences in effective level of intoxication (due to place in the testing schedule), and possible differences in test content.[6] The fact that subtle differences in these closure tests may have substantial effects on the observed performance with marihuana points out the difficulties of obtaining reliable measures of the effects of marihuana on "higher" cognitive functions. (Multiple tests of a given ability become almost essential.

Results for the visualization tests present a more complicated picture. Performance on the Surface Development Test improved with intoxication, but the change was small. The Paper Folding Test showed a very slight decrease, and the Form Board Test showed a larger decrease in performance with intoxication (Table 5, Figure 2). We now interpret these varied results as due to the cognitive complexity of the tasks used in this study to test visualization. The small observed shifts are interpreted as resulting from the incomplete cancellation of opposing effects of marihuana intoxication on different aspects of the tasks. The direction of shift for a particular test reflects the relative importance of marihuana effects on the analytic vs. holistic processing components of that task. While this interpretation is admittedly post hoc, it is supported by three types of independent evidence: (a) factor analysis of task content (for example, French, 1951), (b) performance data from split-brain patients performing similar tasks (for example, D. Zaidel, personal communication, 1975), and (c) complex and statistically significant patterns of correlations between the change scores on the visualization tasks and the change scores on other cognitive tests.

Perceptual Ability Tests

The perceptual ability tests (which we presume to not be dependent upon "higher level" cognitive functions of a given hemisphere but rather to tap more preliminary levels of lateralized data processing) are relevant for the evaluation of the second "hemisphere shift" hypothesis, dependent upon how generally this hypothesis is stated. Exploring in more detail our functional models of the hypothesized changes in interhemispheric relationships during marihuana intoxication, it is possible to distinguish between certain functional models which would predict and others which would not predict that marihuana will cause hemisphere-related shifts in performance on lateralized perceptual tasks.

Perhaps the simplest model of a shift in hemispheric participation in cognition is the "general activation" model which predicts a systematic shift in performance on lateralized perceptual tasks. Thus, the general level of cortical activation of the right hemisphere is increased while the left is decreased during marihuana intoxication. If there is a generalized shift in relative cortical activation, performance shifts would be expected in both cognitive and perceptual lateralized tasks.

Table 6 summarizes the perceptual task data. All of the perceptual tasks remain unaffected by marihuana intoxication.

The data do not show any evidence of a systematic hemisphere-related shift in perceptual abilities; thus, they do not support the "generalized hemispheric activation" model. We might ask, then, what sort of model would be consistent with a selective cognitive or "higher level" shift.

One possible model consistent with these data hypothesizes an "altered locus of executive control" after marihuana intoxication. This model postulates that for most nonintoxicated persons, the "locus of executive control" of attention and cognition is usually in the left hemisphere. Thus, the left hemisphere often interferes with the ability of the right hemisphere to carry out more complex cognitive processing by retaining control of attention and inserting interfering verbal and analytic stimulus transformations into the incoming stimulus field. During marihuana intoxication, however, the right hemisphere is (hypothetically) given a greater degree of "executive" control, allowing attention

Table 6

Effects of Marihuana on Tests of Perceptual Abilities

Left Lateralized Tests (dichotic listening)	Adjusted Means			Percent change from Nonintox	Significance Level
	Intox	Nonintox	Difference		
Matched Syllables					
Left Ear	16.584	17.479	-0.895	- 5.12%	n.s.
Right Ear	19.170	19.399	-0.229	- 1.18%	n.s.
Matched Words					
Left Ear	13.213	13.582	-0.369	- 2.72%	n.s.
Right Ear	16.928	17.110	-0.182	- 1.06%	n.s.
Right Lateralized Tests					
Timbre Test	41.857	41.655	+0.202	+ 0.48%	n.s.
Arc-Circle Test (errors)					
Circles	1.694	1.708	-0.014	- 0.82%	n.s.
Large Arcs	2.139	2.194	-0.055	- 2.51%	n.s.
Small Arcs	6.444	5.639	+0.805	+14.28%	n.s.

to be focused (or defocused) for a longer period of time in a manner appropriate to holistic higher level processing, with less intruding verbal or analytic processing from the left hemisphere.

This model would attribute the selective effects of marihuana on "higher level" cognitive processing to the relatively greater dependence of such "higher level" processing on appropriate executive control. Simple sensory or perceptual processing (such as would be involved in recognizing two tones or two curvatures as similar) would take place so quickly and involve so few mental operations that it would be relatively unaffected by frequent interruptions from the left hemisphere, even in the nonintoxicated state. Thus, with marihuana intoxication it would not show a significant improvement. Conversely, dichotic syllable recognition would be simple and quick enough so that the intoxicated subject could complete his left hemisphere processing before a return of control to the right hemisphere would interfere with performance. Thus, he would not show significant impairment with intoxication.

On the other hand, longer analytic sequences (such as those required by the Inference Test or Nonsense Syllogisms Test) would be frequently disrupted by episodes of right hemisphere control more characteristic of the marihuana intoxicated state. Thus, such activities would be impaired by marihuana intoxication. However, increased right hemisphere executive control would be advantageous for tasks requiring "higher level" holistic interpretive processing (e.g., closure), since this type of processing is "blocked" as long as the left hemisphere maintains control and imposes an analytic framework on the incoming perceptual field.

It should be emphasized that an "executive control" model of marihuana's effects is not here proposed as a final or complete interpretation of the data from this study. (For one thing, it is not clear how it can account for the transformations of perceptual experience which are reported by intoxicated persons, for example, enhancement of subjective depth.) Nonetheless, it provides an example of the more complex type of model which may be necessary to account for some of the selective effects of marihuana on "higher level" lateralized cognitive functions.

Other implications. The stability of the perceptual task scores demonstrates a relative lack of subject or procedural bias in favor of either intoxication or nonintoxication conditions. These nonsignificant shifts in scores are particularly significant in any consideration of possible biasing in motivation. The dichotic task is particularly difficult and frustrating and yet subject scores remained approximately the same in both conditions.

Preference and Other Tests

Since the three preference tests and questionnaire data are less crucial to the major experimental hypotheses, results will be only briefly noted. Intoxication produced the following results: (1) on a verbal vs. spatial sorting task (Galin Grouping Test), subjects tended to make more spatial and fewer verbal choices ($p < .10$); (2) there was no change on the Design Judgment Test, a measure of aesthetic preference or judgment; (3) conjugate lateral eye movement measurements of preferred cognitive mode showed a paradoxical result contrary to expectation. There was an increase in right movements (indicating more left hemisphere preference). However, this increase in right eye movement to reflective questions was from an extremely strong left-looking, right-hemispheric eye movement pattern in the normal condition and shifted to a less consistent, more bilateral pattern when intoxicated. This shift was much less apparent in those subjects who showed low lateralization according to dichotic listening (see below). While not well understood, these latter findings give credence to a marihuana-induced reduction in functional asymmetry in highly lateralized subjects.

Relation of These Results to Previously Published Findings

Verbal-analytical tests. The decrease in verbal-analytical cognitive ability is consistent with other published results (Clark et al, 1970; DeLong and Levy, 1973; Drew et al, 1972; Melges et al, 1970; Miller and Drew, 1972; Weil and Zinberg, 1969).

Closure tests. Previously published data on closure ability during marihuana intoxication have been inconclusive. Pearl et al (1973), combining the Gestalt Completion Test items with another closure test, found no impairment at a moderate dose level (5 - 15 mg THC depending upon subject's intake) yet found impairment of certain verbal tasks. At a high dose level (10 - 30 mg THC) they found a significant decrease in performance. To determine high dose level subjects were encouraged to smoke until they felt too "high," which resulted in negative side effects in some subjects. Barratt, Beaver, White, Blakeney, and Adams (1972) used the parallel forms of a closure test from the Moran battery (Moran and Mefferd, 1959). The observed trend (improvement with marihuana) was not significant, and was confounded with learning effects since the same five subjects were repeatedly tested. However, there was a significant increase in variability of closure scores when subjects were intoxicated, suggesting that some effect of marihuana was present.

The data which are perhaps most comparable to ours come from an informal pilot study by Marsh and Chemtobe (personal communication, 1973). They used the Street Test, but with a method of administration which differed from ours. While we split this test into two parallel halves, they gave the entire test, intoxicated half of their subjects, and then readministered the test and measured the improvement. Their 12 intoxicated subjects showed significantly greater improvement than 12 nonintoxicated controls.

Visualization tests. Barratt et al (1972) tested visualization using forms from the Moran battery (Moran and Mefferd, 1959) and found a nonsignificant trend toward enhancement with marihuana. But, as with their closure results, this finding was difficult to interpret because of confounding with learning effects and the small sample size (5 subjects).

Disembedding test. The decrease on the Hidden Figures Test, if reliable, is also consistent with previously published results for this test. Significant impairment on Hidden Figures during marihuana intoxication was observed by Carlin, Bakker, Halpern, and Post (1972) and a nonsignificant decrease was reported by Meyer, Pillard, Shapiro, and Mirin (1971). On similar tests of disembedding, decreases were noted by Pearl, Domino, and Rennick (1973) and Hollister and Gillespie (1970).

A marihuana-induced decrement in disembedding is consistent with our hypotheses concerning marihuana's action and current evidence as to the lateralization of this type of test. The relatively small amount of decrease might be attributable to the involvement of both hemispheres in the task (Poeck, 1973; Teuber and Weinstein, 1956; Zaidel, 1973), while the presence of decrease rather than enhancement might be attributable to the particular sensitivity of the task to language-related processes (Poeck, 1973; Teuber and Weinstein, 1956) and to the greater relative involvement of the left hemisphere in performance (Zaidel, 1973). (This description of the components contributing to the disembedding performance is also consistent with factor analytic descriptions of the test, for example, Thurstone, 1944; French, 1951.) It should be noted that at higher dose levels performance disruption may be due more to interference with attention and motivation than with cognitive style shifts, since this is a difficult test requiring prolonged concentration.

Perceptual tests. The lack of perceptual effects reported here is consistent with other studies which also failed to find changes on "low level" perceptual tests when moderate doses were used. Like the present findings, Klonoff, Low, and Marcus (1973) found no change on the Timbre Test while reporting significant impairments of motor performance and verbal-analytical ability at dose levels of 13.6 mg THC.

RESULTS AND DISCUSSION II: FURTHER TESTING FOR A "HEMISPHERIC SHIFT"

The evidence presented previously provides indirect support for the hypothesis of altered hemispheric participation in cognition during marihuana intoxication. By comparing the performance level of left lateralized and right lateralized functions, we are indirectly comparing the performance of the two hemispheres, and any shift in the ratio or balance of these scores suggests a shift in the relationship between the hemispheres. However, other mechanisms might also cause such a shift in performance, and therefore more "direct" tests of the activity of the two hemispheres are needed.

EEG Data

Perhaps the best measure would have been EEG data on the activity of the two hemispheres, collected while subjects were performing the tasks used in this study. Such data are not available. Nonetheless, we were gratified to learn that preliminary results of EEG analyses on some of the same marihuana subjects were conducted by John Hanley, Eleanore Tyrrell, and Pierre Hahn (see Cohen, 1975a) and appeared to show an increase in left hemisphere alpha activity and a decrease in right hemisphere alpha activity after intoxication. Subsequent statistical analysis by Hanley et al (see Cohen, 1975b) indicated that these differences, while substantial, were not statistically significant because of large inter-subject variability. Still, the direction of these trends is interesting, since this same pattern of alpha amplitude shift is seen when nonintoxicated subjects are deliberately moved from propositional to appositional processing by the use of spatial tasks (see, for example, Galin and Ornstein, 1972). Since reduction in alpha amplitude is usually associated with greater arousal or "mental activity," the observed shift indicates a shift toward greater relative proportion of cerebral processing in the right hemisphere, as would be predicted by our second experimental hypothesis.

This relative alpha shift was only found in the temporal-frontal placement, not in the parietal-occipital placement. Such a pattern is suggestively analogous to our result that "higher level" functions were selectively affected by marihuana. Once again, the "general hemisphere activation" interpretation is not supported. Of course, any identification of these different recording placements with "higher" vs. "lower" functions is certainly oversimplified, but perhaps has some value as a stimulus to more precise investigation.

If these preliminary EEG trends are replicated, using larger samples or more specific mental tasks to stabilize inter-subject variations (subjects were recorded in the eyes-closed resting state), they could provide important support for the "hemispheric shift" hypothesis of this study.

Dichotic Listening Data

The most direct measure of asymmetrical hemispheric functioning in our study is provided by comparing the accuracy of the right and left ears during the dichotic listening task. While several factors seem to influence performance on this task, a well-established result is that verbal stimuli are usually better perceived by the right ear while musical, environmental, and certain other nonverbal stimuli are usually better perceived by the left ear (see Kimura, 1967, for a discussion of these results). These ear asymmetries are reversed in individuals with reversed cerebral dominance as tested by intracarotid injection of sodium amytal (Kimura, 1961).

It is a consequence of the mechanisms presumed to underlie dichotic listening (see Kimura, 1967, for discussion) that the right ear advantage for verbal stimuli is a function of (a) the degree of left hemisphere specialization for the type of verbal perception involved, and (b) the degradation of the left ear's sensory information as it passes from the right hemisphere across the cerebral commissures to reach the specialized processing "centers" in the left hemisphere. Thus, ear asymmetry scores, on the average, provide some indication of the degree of lateralization of verbal perception in a group of individuals, although other factors will also affect the scores.

Dichotic listening scores were collected on both test and retest for all but one subject. Scores for each condition were based on two sets of stimuli: (a) 30 pairs of syllable-contrastive nonsense stimuli (for example, pa vs. ka, ba vs. ta); and (b) 30 pairs of monosyllabic words ending in "ought" (for example, "pot" vs. "cot," "bought" vs. "tot"). See Appendix 4 for a more detailed description. These 60 stimuli were presented twice, with earphones reversed for the second presentation, providing 120 dichotic pairs in all, and thus providing a fairly stable measure of the subject's performance on this task.

The effect of marihuana on dichotic listening scores would depend on its mode of action in the brain. If, for example, it altered the information transfer properties of the corpus callosum, then it should have affected the left ear scores. A decrease in callosal transfer would have selectively lowered left ear scores, raising dichotic ear asymmetries. An increase in callosal transfer would have had the opposite effect, raising the left ear score and bringing the two ears closer together. If marihuana seriously interfered with the perception of consonants by the left hemisphere, the right and left ear scores should both have been lowered (in fully lateralized individuals for whom this task is performed, for both ears, by the left hemisphere).

The results are shown in Table 6. Marihuana did not have an appreciable effect on the performance of either ear, although there is a small, nonsignificant drop in left ear performance and an even smaller drop in right ear performance.

To further examine the effects of marihuana on ear asymmetry, we computed for each subject an intox and nonintox score using each of the various standard ratio and difference indices of ear asymmetry: POE = the left ear's errors divided by the total errors; Phi = the correlation between accuracy and side of presentation across trials; POC = the right ear's correct divided by total correct; R-minus-L = the difference between the percent accuracy of the two ears. None of these measures shows a significant or appreciable difference between nonintox and intox conditions.

These results suggest that marihuana does not produce a substantial blockage or facilitation of the transmission of auditory sensory information across the cerebral commissures. If marihuana does affect callosal information transfer, it would appear that it acts on pathways other than those used for transmission of (pre-phonetic) auditory information from the right to the left hemisphere.

Differing Marihuana Effects Related to Subject Lateralization

If one of the ways that marihuana produces the observed cognitive and preference shifts is by affecting the functional relationship between the cerebral hemispheres, then individuals who have reduced or atypical hemispheric specialization might be expected to show reduced or atypical responses to marihuana.

In order to further explore the relationship between marihuana's effects and hemispheric lateralization of function, the total subject sample was divided into two groups of 12 subjects each, on the basis of a median split of their <u>non-intox</u> dichotic listening POE lateralization scores (dichotic data was missing on one subject, so he was omitted from the analysis). Separate analyses were then performed to determine the drug effects on those subjects who were above the median (the "high lateralization" group) as compared to those subjects who were below the median (the "low lateralization" group). The results are summarized in Figure 3.

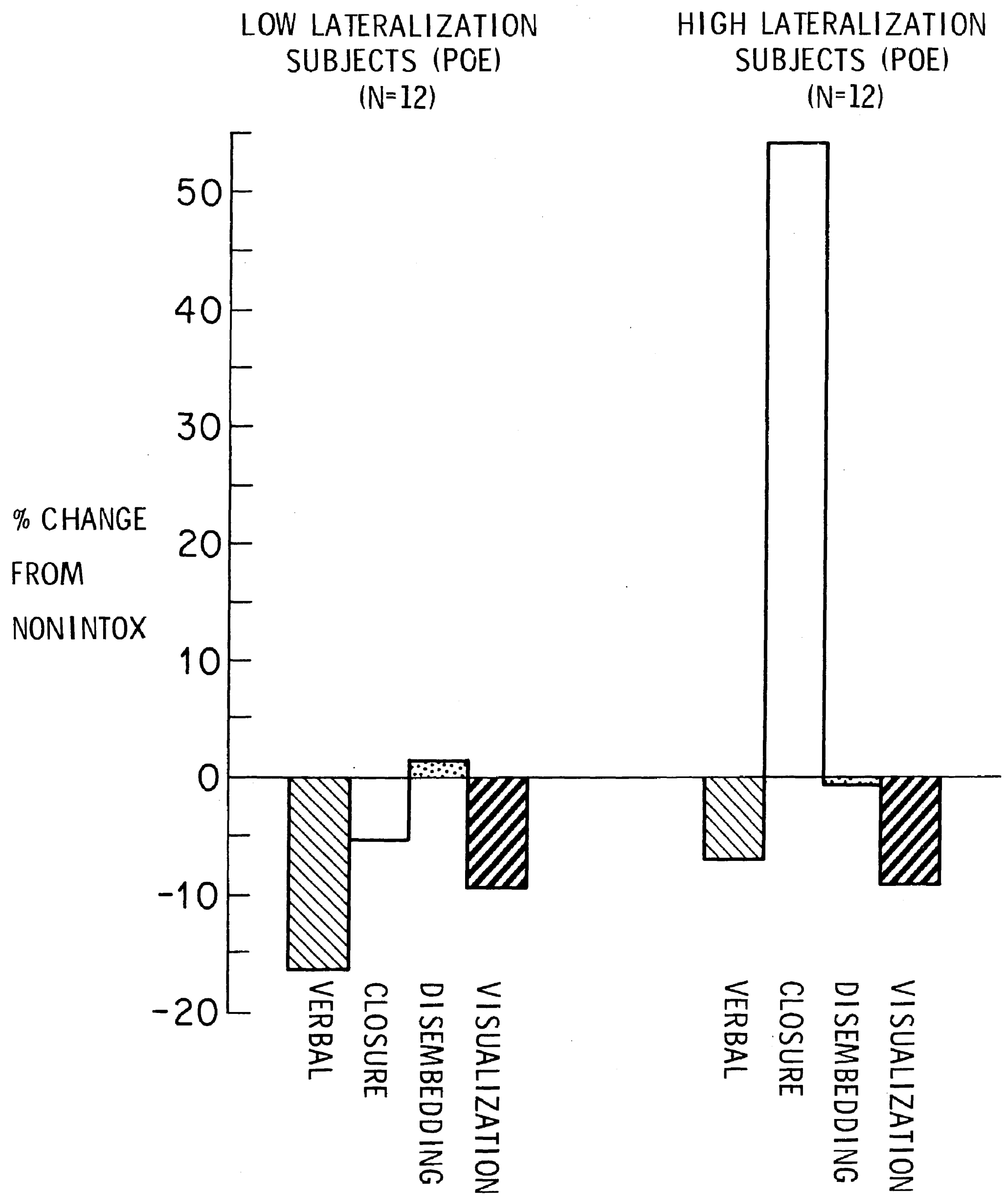


Figure 3. Marihuana Effects for High vs. Low Lateralized Subjects

These two groups of subjects show different patterns of response to marihuana intoxication. "Low lateralization" subjects show a stronger impairment of verbal-analytical abilities and show no improvement of closure when intoxicated. "High lateralization" subjects show a smaller impairment of verbal-analytical abilities and a strong enhancement of closure ability when intoxicated. Despite the small N of 12, the "high lateralization" group's closure enhancement was statistically significant ($p < .05$, for 10 d.f., 2Q). None of the "low lateralization" group's changes was statistically significant, although the depression of verbal-analytical performance approached significance ($.05 < p < .10$). The results obtained using POC to measure lateralization were similar, but not quite as dramatic. (When the subjects were divided at the median POC score, one subject in the POE "low" group changed to the POC "high" group, and one in the POE "high" group changed to the POC "low" group.)

To test the statistical significance of the relationship between lateralization and response to marihuana, correlations were computed between size of drug effect and degree of lateralization. (Size of drug effect was measured by intox minus nonintox difference scores, and lateralization was measured by nonintoxicated dichotic listening scores. Partial correlations, with the effects of treatment order partialed out, were used to test these hypotheses in order to minimize contamination from learning or marihuana-learning interaction effects.)

Several significant correlations were found (Table 7). The partial correlation between lateralization and enhancement of closure during intoxication is approximately .36 ($p < .05$, 1Q). More lateralized subjects show significantly more enhancement of closure ability when intoxicated. While no other linear correlation involving composite variables is significant, inspection of scatter diagrams for these relationships suggested that systematic nonlinear relationships might be present. This impression was strengthened by separate analysis of the "middle" vs. "extreme" lateralization groups. The sample was divided into four quartiles on the basis of lateralization scores (POE) and a separate analysis was performed for the middle two vs. the extreme two quartiles.

The most striking result was obtained with respect to visualization. The "middle lateralization" group showed a 10 percent increase in visualization performance when intoxicated, although this increase was not statistically significant. On the other hand, the "extreme lateralization" group showed a 24 percent decrease in visualization performance when intoxicated, and this change was highly significant ($p < .002$, for 10 d.f., 2Q).

To test these trends, nonlinear correlations were computed. (Lateralization scores were transformed into parabolic functions, symmetric about the mean, according to the relation: nonlin = $(\text{lin-mean})^2$). As Table 7 shows, highly significant nonlinear correlations were obtained between lateralization

Table 7

Effect of a Subject's Lateralization on His Response to Marihuana:
Partial Correlations between Intox-minus Nonintox Cognitive Change Score and
Nonintox Dichotic Listening Lateralization Scores (Controlling for Treatment Order)

Variable	Dichotic Listening Lateralization Scores (d.f. = 21)					
	POE	Phi	POC	(POE-mean)^2	(Phi-mean)^2	(POC-mean)^2
I-N Change in Verbal Composite	.21	.23	.22	.33	.32	.29
I-N Change in Closure Composite	.38*	.37*	.35*	-.17	-.26	-.31
I-N Change in Visualization Composite	-.16	-.12	-.08	-.28	-.15	-.06
I-N Change in A/P Ratio	.15	.13	.12	-.42**	-.48**	-.50**
I-N Change in A-P Balance	.19	.17	.16	-.39	-.47**	-.49**

* N = 24; $p < .05$; one-tailed test
** N = 24; $p < .05$; two-tailed test

Explanations of Dichotic Listening Lateralization scores given in Method section.

and shifts in cognitive style. The nonlinearity of these effects on cognitive style indices is apparently due mainly to the nonlinearity of the effects on the verbal components entering into them, although the verbal change scores showed only a nonsignificant trend toward nonlinearity when considered by themselves (combined linear-nonlinear polynomial regression produced a correlation of around .45, which had borderline significance, $.05 < p < .10$, 2Q). On the other hand, despite the apparent trends in the scatter diagrams and in the middle vs. extreme group analyses, the nonlinear relationship between visualization drug effects and lateralization was not statistically significant when tested by this technique.

The reason for the nonlinearity of cognitive style correlations with lateralization is not clear, but it might, in part, reflect differences in drug response arising from differences in nonintoxicated ability. These subjects showed a significant nonlinear relationship between nonintoxicated verbal-analytical performance (verbal composite scores) and degree of lateralization (polynomial regression showed a $p < .025$, 2Q). Further, those subjects who do best nonintoxicated show the largest drop when intoxicated (partially, perhaps, a regression toward the mean). This may induce a nonlinearity into the change scores. On the other hand, no relationship -- linear or nonlinear -- was found between nonintoxicated closure performance and degree of lateralization. Possibly as a consequence, the relationship between closure drug effects and lateralization was a simple linear one, with increasing drug effects correlating, as expected, with increasing lateralization.

The relationships between degree of lateralization and drug effects, as tentatively suggested by these data, are diagrammatically summarized in **Figure 4.**

These correlational results should, of course, be viewed as highly tentative and preliminary until replicated. This is particularly true of the linear correlations. While all nonlinear correlations were tested using a two-tailed test, the linear correlations were tested with one-tailed tests. It might be argued, however, that our prediction of a greater drug effect for more lateralized subjects was too tentative to justify the use of a one-tailed test. According to such a highly conservative approach, the closure-change-vs.-lateralization correlations become only "borderline" in significance ($.05 < p < .10$), and the evidence for statistically significant relationships between

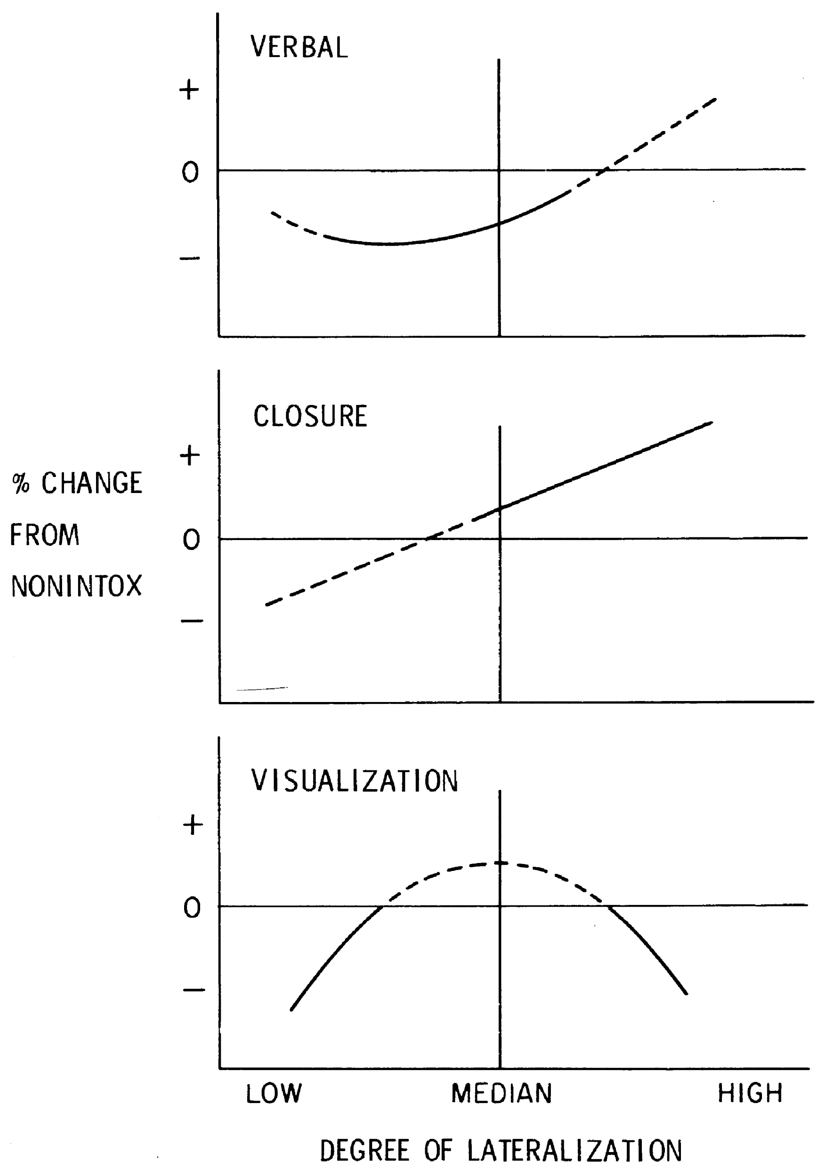


Figure 4. Patterns of Change of Marihuana Effects as a Function of Subject's Lateralization Score

drug effect and lateralization rests more heavily on the surprising nonlinear correlations between lateralization and cognitive style shifts.

Nonetheless, the overall pattern of results (for example, Figure 3) is strikingly consistent with the hypothesis that some of marihuana's effects are related to hemispheric lateralization. With our small sample size, we are at a handicap in trying to demonstrate statistical significance, and so the borderline nature of some of these correlations (and the nonsignificance of others) should not be too surprising or discouraging. Many more "significant" correlations between lateralization and drug response have been found than would be expected by chance with these data, and therefore we are encouraged to look further into this type of relationship. The possibility of finding a physiological basis for some of the individual differences in responses to marihuana provides strong motivation for continuing the investigations.

CONCLUSION

The data of this study tend to support both the hypothesis of a cognitive style shift and the hypothesis of a shift in hemispheric participation in cognitive processing during marihuana intoxication. These results must be replicated, however, before they can provide firm support for any interpretations concerning the effects of marihuana on cognitive functioning. Furthermore, it is not yet known whether the pattern of enhancement will extend to include better ("purer") tests of visualization and to additional right hemisphere functions; further studies of the generality of these effects are needed.

In this study, the types of cognitive tests which showed the clearest shifts during intoxication were those which are the most clearly lateralized according to published neuropsychological evidence, and scores on these tests shifted in the predicted directions. Additional support for the hypothesis that marihuana alters the relationship between the left and right cerebral hemisphere was provided by the contrasting patterns of drug effects exhibited by "low" vs. "high" lateralized subjects.

We are not yet ready to propose specific models of the brain mechanisms that might underlie these observed effects. Many aspects of these data suggest that marihuana causes a change in interhemispheric communication, but the stability of dichotic lateralization scores across nonintox and intox conditions would seem to argue against this (unless only a selective effect on certain callosal pathways is involved). Any neurological model proposed to explain these data would have to more clearly specify, for example, the hypothesized nature of the reduced lateralization in "low lateralized" subjects. Perhaps future findings will lead us closer to a concrete model of marihuana's effects on hemispheric functioning, along with a more detailed model of individual differences in patterns of hemispheric specialization of the human brain.

APPENDIX 1

Statistical Procedures: Definitions, Methods, and Rationales

The basic statistics computed for this report were (a) "adjusted means" for the intox and nonintox conditions, (b) a difference score across conditions, (c) a "percent change from nonintox" score, (d) a statistical significance level for the observed change, based on (e) a repeated measures analysis of variance.

The rationale, interpretation, and computing procedures (or programs) used for these analyses are explained in the following paragraphs. In addition, there is a discussion of the issue of sample size.

Adjusted means. Test performance is summarized by the use of "adjusted means" for the nonintox and intox conditions. These means are "adjusted" in order to correct for unequal N's in the two treatment-order groups. Instead of weighting each subject equally, the 12 subjects in the intox-first treatment order are given the same total weight as the 13 subjects in the nonintox-first treatment order. (This is done by simply averaging the two treatment order submeans.) In practice, this adjustment has only a slight effect on the mean values.

Percent change from nonintox. For each pair of adjusted means, a difference between conditions is computed (intox minus nonintox), and this performance difference is then expressed as a percentage of the normal (nonintox) performance level for that task. This provides a percent change in performance level "due to" intoxication, perhaps the most meaningful expression of the size of the marihuana effect for a given task. This percentage is computed as follows: $PC = ((I-N)/N) \times 100$.

Significance level. The statistical significance of the observed change with intoxication is evaluated on the basis of the F value for the main effect of drug condition in the analysis of variance, described below. One-tailed tests (1Q) are used for all main effects of condition where the direction of change was predicted by the experimental hypotheses. Two-tailed tests are used for all other comparisons.

Analysis of Variance. The statistical significance of differences among the means for a given test was evaluated (initially) by performing a repeated measures analysis of variance. Two main effect terms and one interaction term were extracted from the data.

The main effect term for drug condition was used to test the significance of marihuana effects, i.e., overall differences between nonintox and intox scores on a given task.

The main effect term for order was used to test overall differences between the scores of the intox-first group of subjects and the nonintox-first group. (Such a difference might arise, for example, if the disadvantages of performing a given task in the intox condition on first test carried over to the nonintox retest and lowered scores there also. Presumably, this would indicate an effect of marihuana on learning as well as on simple performance.) Normally, this term is not expected to be significant. When it is, interpretation is not simple, and depends on the particular case in question. However, this main effect term arises as a natural consequence of the experimental and analysis design and provides the basis for generating the condition-by-order interaction term, which does have a straightforward interpretation.

The condition-by-order interaction term was used to test for overall differences between test and retest scores on a given task. Usually, a significant interaction occurred when the intox scores were better in order 1 than 2, whereas nonintox scores were better in order 2 than 1. Since in order 1 the intox was on retest, and in order 2 the nonintox was on retest, this interaction pattern reflects a generally superior performance on retest compared to test, that is, a simple task learning effect. However, since parallel forms rather than identical tests were used for retest, any learning effect was not due to memory of test content, but instead -- and more interestingly -- to learning of successful performance strategies for that type of cognitive or perceptual task. These results have not been discussed in any detail here, but a number of significant learning effects were observed. Plots of the means suggested that some tests also showed marihuana-learning interactions.

As a precaution, we also performed analyses of variance incorporating an additional main effect term for test form (and, as a consequence, interaction terms for form with condition, form with order, and a three-way interaction of form with order with condition). These analyses were done on all tests employing two parallel forms (that is, cognitive ability and preference tests; the perceptual tests did not have a memorizable content, and thus did not have parallel forms). Although there was an occasional significant two- or three-way interaction term, it was usually neither interpretable nor informative. Therefore, these more complicated analyses are not discussed here.

All analyses of variance were performed at the UCLA Campus Computing Network, using the BMD P2V computer program from the P-series Biomedical Computer Programs (Dixon, 1975). This program performs repeated measures analysis of variance with unequal N's and complex designs. (In BMD terminology, the design used for the analyses in this study was "1G,2 (nY)".) For more details on the program, see Dixon (1975).

Problems of sample size. In this study, it was difficult to demonstrate the statistical significance of an observed pattern of changes in mean scores because of the small number of subjects tested. This may seem at first implausible since other published marihuana studies, and a number of medical studies in the 94-day project, worked successfully with a sample almost as small. However, it is important, when evaluating the size of a subject sample, to keep in mind the type of data obtained, the reliability of the measures involved, and the amount of uncontrollable variability to be expected in relation to the size of the systematic effects one wants to detect.

While it is true that published physiological studies sometimes use 20 or fewer subjects, published psychological studies of mental traits, particularly correlational multivariate psychometric studies, almost always use at least 50 and often several hundred subjects. One reason for the larger N's in psychological studies is that techniques of measurement for psychological variables are often less reliable than for physiological variables. Larger N's are needed to "average out" fluctuations due to larger errors of measurement. Furthermore, psychological variables are often affected by a greater number of influences difficult to control experimentally. Specifically, the effect of marihuana on cognitive functions is quite variable from individual to individual and from one occasion to the next, much more so, for example, than its effect on pulse rate. A great number of personality and mood variables can influence a particular cognitive response to marihuana. To study or control for the interrelations of these many factors, more complicated experimental designs are required, which need a larger number of subjects to fill all their "cells." Even the simple counterbalanced design of this study required dividing the subjects into two groups of 12 and 13 subjects each (not counting the further division into groups taking Form A on intox vs. Form B on intox in each group). This counterbalancing further restricted our effective N's for many comparisons.

The handicap of a small number of subjects (for the type of data and experimental design involved) was partially overcome by the use of several tests of each important cognitive ability being examined, and by looking at broad patterns of change across several variables rather than concentrating on changes on a single test. These broader comparisons, more appropriate for the type of hypotheses involved, were accomplished through the use of composite variables.

APPENDIX 2

Analyses of Variance for Composite Variables

Table A2-1

A/P Ratio (Closure Composite/Verbal Composite)

Source	Degrees of Freedom	Mean Square	F	Prob. F Exceeded
Mean	1	56.3795	80.3996	0.000
Order	1	0.0073	0.0105	0.919
Error	23	0.7012		
Condition	1	0.7211	3.0054	0.048 (1Q)
Condition x Order	1	0.2571	1.0717	0.311
Error	23	0.2399		

Table A2-2

A-P Balance (Closure Composite minus Verbal Composite)

Source	Degrees of Freedom	Mean Square	F	Prob. F Exceeded
Mean	1	35.2622	0.2823	0.600
Order	1	18.7814	0.1503	0.702
Error	23	124.9113		
Condition	1	181.7795	8.2394	0.004 (1Q)
Condition x Order	1	46.8408	2.1231	0.159
Error	23	22.0619		

Table A2-3

Verbal Composite Score

Source	Degrees of Freedom	Mean Square	F	Prob. F Exceeded
Mean	1	8106.8984	209.3654	0.000
Order	1	5.7617	0.1488	0.703
Error	23	38.7212		
Condition	1	33.7390	2.9732	0.049 (1Q)
Condition x Order	1	4.5793	0.4035	0.532
Error	23	11.3473		

Table A2-4

Closure Composite Score

Source	Degrees of Freedom	Mean Square	F	Prob. F Exceeded
Mean	1	7072.7968	81.6027	0.000
Order	1	45.3474	0.5232	0.477
Error	23	86.6735		
Condition	1	58.8901	3.2609	0.042 (1Q)
Condition x Order	1	80.7128	4.4694	0.046
Error	23	18.0589		

Table A2-5

Disembedding (Hidden Figures Test)

Source	Degrees of Freedom	Mean Square	F	Prob. F Exceeded
Mean	1	782.8522	36.7787	0.000
Order	1	1.0605	0.0498	0.826
Error	21	21.2854		
Condition	1	0.0928	0.0111	0.458 (1Q)
Condition x Order	1	7.7015	0.9272	0.347
Error	21	8.3057		

Table A2-6

Visualization Composite Score

Source	Degrees of Freedom	Mean Square	F	Prob. F Exceeded
Mean	1	269847.1250	318.7741	0.000
Order	1	23.0234	0.0272	0.870
Error	23	846.5148		
Condition	1	294.9397	1.8119	0.191 (2Q)
Condition x Order	1	1384.9626	8.5082	0.008
Error	23	162.7791		

APPENDIX 3

Instructions and Sample Items from Representative Cognitive Tests

Gestalt Completion Test -- Cs-1

This is a test of your ability to perceive a whole picture even though it is not completely drawn. You are to use your imagination to fill in the missing parts.

Look at each incomplete picture and try to see what it is. Write on the line beneath it a word or a few words telling what the picture is. You need not describe it in detail; just name the picture or its important parts.

Try the sample pictures below.

A ____________________________

B ____________________________

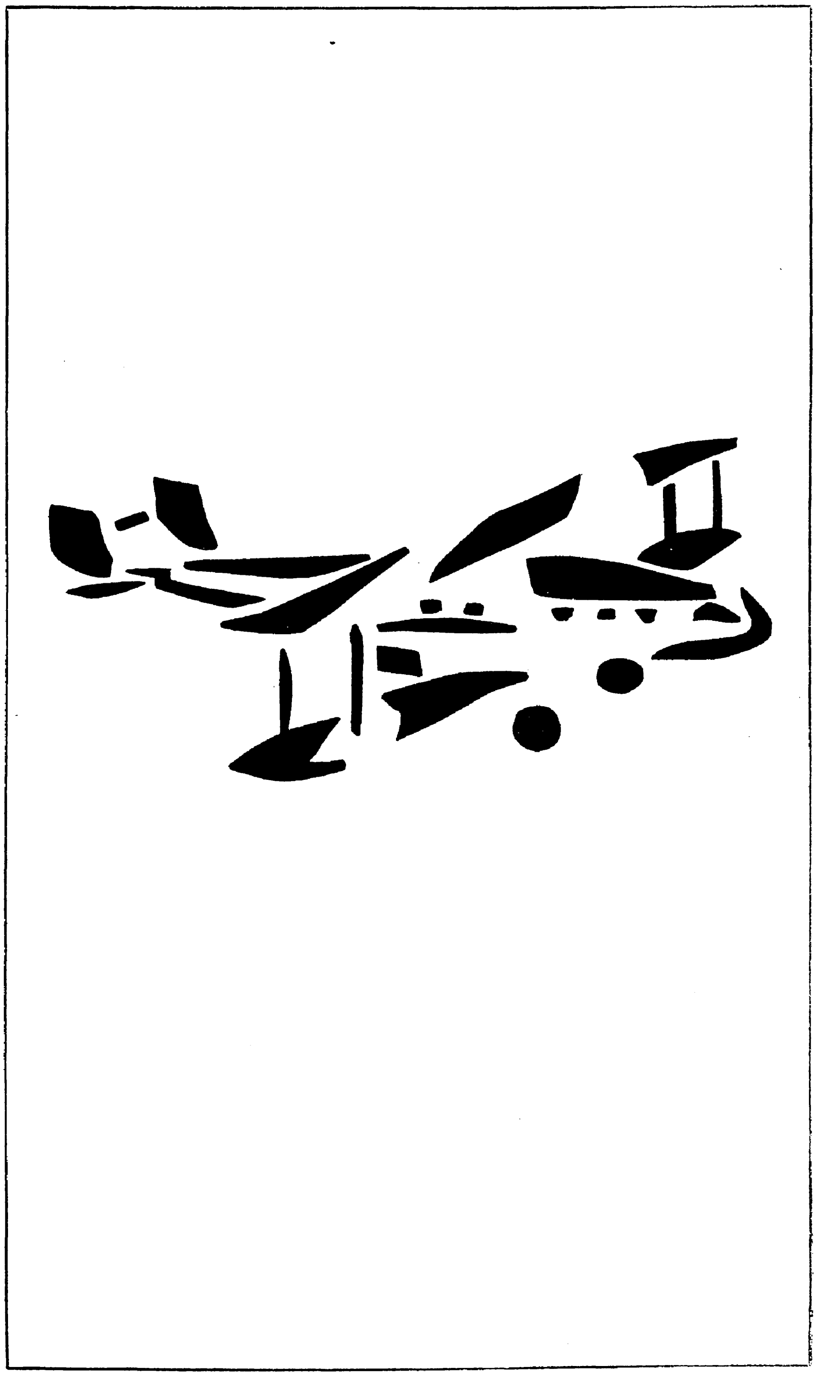
Picture A is a flag and picture B is a hammer head.

Your score on this test will be the number of pictures identified correctly. Even if you are not sure of the correct identification, it will be to your advantage to guess. Work as rapidly as you can without sacrificing accuracy.

You will have 3 minutes. There are 2 pages of items.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

B



Sample item from the Street Test

Inference Test -- Rs-3

In each item on this test you will be given one or two statements such as you might see in newspapers or popular magazines. The statements are followed by various conclusions which some people might draw from them. In each case, decide which conclusion can be drawn from the statement(s) without assuming anything in addition to the information given in the statement(s). There is only one correct conclusion.

Mark your answer by putting an X through the number in front of the conclusion that you select.

Consider the following sample item:

Bill, a member of the basketball team, is 6 feet, 2 inches tall and weighs 195 pounds. To qualify for the team, a person must be at least 5 feet, 10 inches tall.

1-The larger a man is, the better basketball player he is.
2-Basketball players are often underweight.
3-Some players on the team are more than 6 feet tall.
4-Bill is larger than the average man.
5-The best basketball players come from the ranks of larger-than-average men.

Only conclusion 3 may be drawn without assuming that you have information or knowledge beyond what the statements give. The statements say nothing about how good different players are, nothing about whether they are underweight, and nothing about average or taller-than-average men.

Your score on this test will be the number marked correctly minus some fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 6 minutes. There are 3 pages, with a total of 10 items.

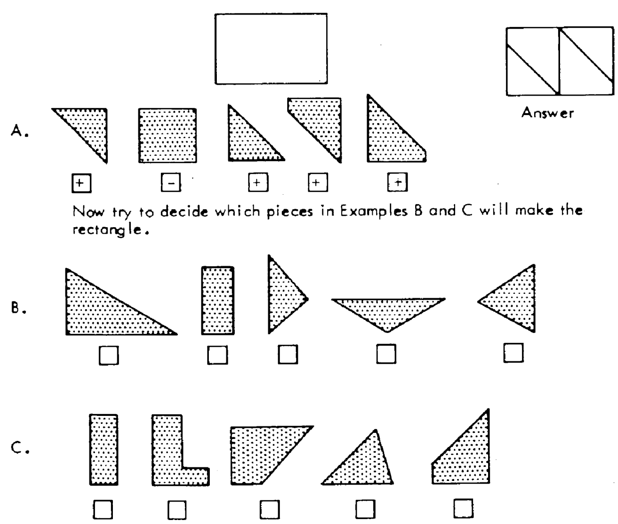
DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Suggested by Inference Test by J. P. Guilford

Form Board Test -- Vz-1

This is a test of your ability to tell what pieces can be put together to make a certain figure. Each test page is divided into two columns. At the top of each column is a geometrical figure. Beneath each figure are several problems. Each problem consists of a row of five shaded pieces. Your task is to decide which of the five shaded pieces will make the complete figure when put together. Any number of shaded pieces, from two to five, may be used to make the complete figure. Each piece may be turned around to any position but it cannot be turned over. It may help you to sketch the way the pieces fit together. You may use any blank space for doing this. When you know which pieces make the complete figure, mark a plus (+) in the box under ones that are used and a minus (-) in the box under ones that are not used.

In Example A, below, the rectangle can be made from the first, third, fourth, and fifth pieces. A plus has been marked in the box under these places. The second piece is not needed to make the rectangle. A minus has been marked in the box under it. The rectangle drawn to the right of the problem shows one way in which the four pieces could be put together.



In Example B, the first, fourth, and fifth pieces are needed. You should have marked a plus under these three pieces and a minus under the other two pieces. In Example C, the second, third, and fifth pieces should be marked with a plus and the first and fourth with a minus.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you have some idea whether or not the piece is correct.

You will have 8 minutes for this test. It has 2 pages.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

APPENDIX 4

Test Descriptions and/or References, Plus References on Test Lateralization

Cognitive Tests

ETS Tests. Most of the cognitive tests were taken from the Kit of Reference Tests for Cognitive Factors published by the Educational Testing Service. Tests from this source are followed by the notation (ETS) in Table 2. Descriptions and bibliographies for each of these tests can be found in French, Ekstrom, and Price (1963). Instructions and sample items for these tests can be found in Appendix 3. These tests were administered according to the time limits and instructions found on the tests themselves, except that these instructions were modified to reflect the fact that only one of the two parallel parts of each test was administered in a given session. The tests were scored as recommended in French, Ekstrom, and Price (1963).

Lateralization of these tests was determined on the basis of similar tests which have been administered to brain damaged subjects. For lateralization of verbal tests, see Newcombe (1969) and Weisenburg and McBride (1935). For lateralization of closure tests, see Bogen, DeZure, TenHouten, and Marsh (1972); DeRenzi and Spinnler (1966); Lansdell (1970); Newcombe (1969); Warrington and James (1967). For a discussion of lateralization of visualization, see Footnote 6, and for a discussion of lateralization of disembedding, see "Relation of These Results to Previously Published Findings" in this chapter.

Street Test. Our version was based on the version by Street (1931). From his original 13 pictures, two parallel forms were constructed as follows: Form A consisted of items 1, 3, 5, 9, 11; Form B consisted of items 2, 4, 6, 8, 10. Items 7, 12, and 13 were discarded (largely because of factor-analytic evidence that they were poor measures of closure, see TenHouten, 1973). After examining a sample item, subjects were given a booklet containing five pictures and were asked to identify as many as possible on an answer sheet in 90 seconds. Score = number correct (maximum: 5).

For specific data on lateralization of the Street, see Bogen, DeZure, TenHouten, and Marsh (1972) and DeRenzi and Spinnler (1966).

Harshman Figures. Two parallel sets of 11 items each were selected from a larger set of preliminary items. The subject was shown each item for 20 seconds, followed by five seconds of no stimulus in which he could record his identification on an answer sheet. Score = number correct (maximum: 11).

Gollin Figures. Our version was based on a test described by Gollin (1960). There are five versions of each picture, each version including more of the picture than the last. To increase difficulty, we presented each picture for only five seconds, followed, if necessary, by five seconds of no picture, so that the subject could record his answer. On the basis of preliminary testing, two parallel forms were constructed as follows: Form A consisted of items a, g, h, i, m, n, o, p, s, t; Form B consisted of items b, c, d, e, f, j, k, l, q, r. Subjects were shown an example before testing (Example III for Form A, Example II for Form B). Score = number of errors (maximum: 50).

For specific data on lateralization of the Gollin Figures, see Warrington and James (1967).

Perceptual and Preference Tests

Timbre Test. For a detailed description, norms, etc., see the test manual (Seashore, Lewis, and Saetveit, 1960). This test consists of 50 pairs of complex tones. The subject must decide whether the two tones in each pair are the same or different. Score = number correct (maximum: 50).

For specific data on lateralization of the Timbre Test, see Milner (1962).

Matched Syllables. The original tape was provided by Charles Berlin, Kresge Laboratories, Louisiana State University. This test consists of two presentations of Berlin's dichotic tape. The tape contains 30 pairs of dichotic monosyllables, comprising all of the different combinations of distinct monosyllables from the set /pa, ta, ka, ba, da, ga/. Stimuli are presented over earphones; one monosyllable of each pair is presented to the right ear while a different monosyllable is presented to the left ear. The subject is instructed to write down both monosyllables (guessing if necessary) in either order, without regard to ear of presentation. Prior to the test, sample stimuli are presented both monotically and dichotically to familiarize the subject with the task.

Matched Words. This tape was provided by Peter Benson, University of California at San Diego. This test is similar to the matched syllables, except that each syllable ends with the consonant "t," transforming it into an approximation of a meaningful English word. The thirty pairs consist of every combination of distinct words from the set /"pot," "tot," "cot," "bought," "dot," "got"/.

Test Sequence. The timbre and dichotic tests were assembled into a standardized test tape which included subject instructions, stimulus examples, etc. Each test is presented twice on this tape in order to provide greater reliability, with the earphones and test sequence reversed between presentations to counterbalance possible sources of error (see Table 2). Thus, each subject received a total of 120 dichotic stimulus pairs, and 100 Timbre Test items during a given testing session.

For a discussion of lateralization and the right ear advantage, see "Dichotic Listening Data" of this chapter; also see Berlin, Lowe-Bell, Cullen, Thompson, and Loovis (1973), and Kimura (1967, 1973).

Arc-Circle Test. This test is based on the test developed by Nebes (1971). The subject must find the correct circle, out of three circles, which matches the circle or fragment of a circle which he is presented with. Both the three target circles and the fragment are behind a curtain so that the task is performed by touch alone. In addition to fragments of four different sizes, whole circle control items are also included. In our version, three sets of 15 stimuli are presented in pseudo-random order. Seven training items preceed test items. Scores = number of errors (maximum: 45), subscores for circle-circle comparisons (maximum: 18), circle-large arc comparisons (maximum: 9); circle-small arc comparisons (maximum: 18). Lateralization is discussed in Appendix 5.

Design Judgment Test. This test was developed by Matland Graves (1948) and consists of pairs (or occasionally triples) of pictures or simple designs. The subject picks out the one which he prefers from each set. To construct parallel forms, odd items were used for Form A and even items for Form B. Score = number correct (maximum: 45). Results are discussed in Cohen (1975b, pages 31-34).

Galin Grouping Test. This test was developed by David Galin, and is briefly described in Galin and Ornstein (1974). It consists of sets of three items from which one can be eliminated on the basis of words, and a different item can be eliminated on the basis of pictures. For a more detailed discussion of the test, as well as the results obtained, see Cohen (1975b, pages 28-31).

Reflective Eye Movements (CLEM). For a discussion of the rationale and procedure, as well as results obtained with this test, see Cohen (1975b, pages 34-39). For a discussion of the relation between eye movements and lateralization, see Bakan (1969), Day (1964), Galin and Ornstein (1974), and Kinsbourne (1972).

APPENDIX 5

The "Perceptual" vs. "Cognitive" Classification of the Arc-Circle and Dichotic Listening Tasks

It is a question of interpretation whether the Arc-Circle Test (and, to a lesser extent, the dichotic listening tests) should be classified as "perceptual" or "cognitive." Thus, our decision to classify these tests as perceptual requires further explanation.

Dichotic Listening Tests

The dichotic listening tests require the subject to distinguish and identify two syllables, differing only in initial consonant. These syllables are presented simultaneously, one to each ear. There is evidence that this identification task involves a "feature processor" located in the left hemisphere. However, such identification is restricted to the rapid discrimination among a small fixed set of elements, in terms of a small number of features, and thus might be considered perceptual rather than cognitive. In the dichotic task used in this study, there were six consonants (p, t, k, b, d, g) which linguists usually classify in terms of two features, "voicing" and "place of articulation"; these consonants are usually identified very quickly. In contrast, the closure tasks appear to involve a greater degree of processing. They require the interpretive integration of a large number of simultaneously presented elements, and result in identification of objects or scenes from an "infinitely" large set of possibilities. Further, closure seems to require a number of seconds of processing time for all but the easiest pictures (although subjects cannot usually verbalize any distinctive phases of the processing that transpired during that period, and final solution appears to the subject to resemble a sudden insight). Likewise, the Inference Test and Nonsense Syllogisms Test appear to involve a greater degree of processing than the dichotic task, since they involve extended logical analysis, interpretation of verbal material, and use of conceptual relationships.

Arc-Circle Test

The Arc-Circle Test poses the most serious problem of interpretation with respect to classification as either "perceptual" or "cognitive." R. D. Nebes, who developed the test (see Nebes, 1971), specifically intended it to be a test of "part-whole matching." He interpreted "part-whole matching" as a cognitive ability distinct from simple curvature perception and similar to closure. His "split-brain" subjects showed a specific right hemisphere (left hand) superiority on the arc-to-circle matching task which was <u>not</u> shown on two control tasks of circle-to-circle and arc-to-arc matching. This evidence provided strong support for his interpretation of this task as a "higher level" part-to-whole matching task, rather than a simple curvature matching task.

When our subjects performed this task, however, they did not seem to be comparing each arc to the complete circles. Rather, they would feel the arc and then feel a similar sized portion of each circle. This strategy, seen repeatedly with our subjects, transformed the "part-whole" task into a simple arc-arc comparison task. Perhaps, for these subjects, the further aspect of mentally projecting the arc into a circle and then feeling the whole comparison circle was more of a distraction than a help. (The accuracy level of our subjects was about 75 percent on the arc-circle comparisons and 90 percent on the circle-circle comparisons. This is comparable to Nebes' subjects on the arc-circle comparisons, but distinctly better on the circle-circle comparisons.)

But if this arc-circle task is best performed as a simple curvature comparison task, then why did the "split-brain" subjects fail to perform much above chance on the arc-circle task when they used their right hand? Why couldn't the right hand (left hemisphere) of a "split-brain" subject simply use the same curvature comparison ability on the arc-circle task which it had used so successfully on the arc-arc matching task? By matching curvatures (on the arc-arc task), the right hand of these subjects achieved a correct identification rate comparable to that obtained by the left hand on the arc-circle task, and comparable to that obtained by either hand on the circle-circle task. Nebes' interpretation of his data does not (to us) appear to provide an adequate explanation for the puzzling failure of his subjects to resort, when necessary, to a curvature-matching strategy, particularly since this strategy seemed to be actually preferred by many of our subjects in situations where both this and the part-whole strategy were available. Nonetheless, it is just this paradoxical failure of performance for the right hand which Nebes relies on to establish his "cognitive" interpretation of the results.

A further check on the closure or part-whole interpretation of the arc-circle task is provided by examining its correlation with the closure tasks in our battery. Nebes' interpretation might predict almost as high a correlation between closure tasks and the arc-circle task as among closure tasks themselves. However, analysis of our nonintox data shows only low (.1 to .2) and nonsignificant correlations between the Arc-Circle scores and closure scores, compared to moderately high (.5 to .65) correlations among the half-length closure tasks themselves (except for the half Street Test, which is particularly unreliable; see Appendix 4). This evidence is further supported by a factor analysis of nonintox scores. All the closure tests came out on a common closure factor (the Street less clearly). The Arc-Circle did not load on this factor but instead on a different right hemisphere factor with some other right lateralized perceptual tests.

On the basis of the various types of evidence described above, from Nebes' study, from our observations of our own subjects, and from our preliminary correlational and factor analytic results, we concluded that the Arc-Circle Test was best classified as a perceptual task. However, this was not a firm classification. As is apparent from the discussion above, the data do not yet allow the status of the Arc-Circle Test to be clearly resolved.

Footnotes

[1]The same (or generally similar) hypotheses have been independently deduced, on similar grounds, by others, including John Marsh and Claude Chemtobe (personal communication, 1973), Richard Stillman (personal communication, 1975), Robert Ornstein (1974), and Stephen Szara (personal communication, 1975). Earlier, Joseph Bogen made closely related suggestions about possible implications of lateralization and the function of the corpus callosum for the study of psychopharmacological agents (see Bogen, 1970). Since this article was written, a study by Weckowicz et al (1975) has been published which is directed at similar hypotheses.

[2]In interpreting differential shifts, it is important also to consider the effects of factors such as impairment of attention, which might be more crucial for some tests than others. However, impairment of attention might also encourage a shift into a more parallel processing mode, and this corresponds to a cognitive style shift.

[3]Pharmacological Effects of Cannabinoids in Man, principal investigator Dr. Sidney Cohen.

[4]Because of the likely bilaterality of disembedding, the long length of the available tests, and the availability of previous data on the effects of marihuana on these tests, it was decided to include only one disembedding test in the battery.

[5]It should be noted that the shifts predicted in (2) could also come about by some mechanisms other than a shift in relative hemisphere participation (for example, selective stimulation of certain types of neural tissues and depression of other types of neural tissues, regardless of hemisphere). Conversely, a shift in relative hemisphere participation could occur without causing the absolute performance shifts predicted in (2) (for example, if there were also an overall depression of performance in addition to the hemisphere shift, this would mask the enhancement of right hemisphere functions, making them appear as merely less depressed than those of the left hemisphere; such an effect might be likely at higher doses of marihuana). Nonetheless, if the pattern of performance shifts predicted in (2) were observed, it would provide additional support for the second ("hemispheric") hypothesis of this study.

[6]The Gestalt Completion Test suffered from a "ceiling effect" because it was too easy for our subject population. Almost one third of all subjects made a perfect score in the nonintox condition, and many others scored 80 percent or higher, leaving little room for improvement with intoxication. The Street Test suffered from a different psychometric flaw -- poor reliability (as suggested by correlation analysis). This was probably due to the small number of items in each form (five) and the fact that, of these five items, several were either too easy or too difficult to discriminate among levels of ability.

Timing procedures were different for these tests; the Street and Gestalt Completion Tests were timed as a whole, and the subjects could move back and forth freely among items, whereas each item on the Harshman and Gollin Tests had its own time limit, and subjects could not "go back" to look at past items again.

The Street and Gestalt Completion were the first two tests administered (see Table 2), thus they came immediately after intoxication, whereas the Gollin and Harshman Figures were eighth and ninth in the session, placing them at least 25-35 minutes after intoxication. The effective levels of intoxication (or type of drug effects) may have been different at these two points in the post-intox response curve.

The four closure tests may not have been measuring exactly the same abilities. (It is interesting to note, for example, that the change scores (Intox minus Nonintox) for the Street Test correlate +.65 with those for the Surface Development Test, whereas the Harshman Figure change scores show only a very low correlation with those of the Surface Development Test.) Perhaps the Street Test (in particular) may tap some other abilities in addition to closure (this interpretation is also suggested by factor analytic data on the Street; see, for example, French, 1951).

Acknowledgements

The authors would like to thank Sidney Cohen for placing this study in the 94 day program, Roger Remington and Karen Niemi for assistance in the early phases, particularly with construction of tests and running pilot subjects, and Joseph Bogen and Stephen Krashen for valuable suggestions. We are also very grateful for the help and cooperation of the staff of the 94 day project: Phyllis Lessin, Michael Hofman, Carol Brach, Jeannine Frank, Patty Majcher, Jerry Marsh, Perry Nelson, Bob Nowlan, Jim Tehan, and Olga Wright. We particularly want to thank Sheri Berenbaum for helping by contributing scientific insights and assisting in the data analysis, pointing out errors and fuzzy arguments in earlier versions, correcting English style, typing the manuscript, and staying up many nights to see that it all got done.

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