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FREE-HAND COPYING OF A GEOMETRIC PATTERN AS A TEST FOR SENSORY-MOTOR DISTURBANCE[1,2,3]

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Summary.—Detailed measurements of freehand copies of a geometric figure were made in order to assess the utility of such drawings for reflecting changes in skilled manual performance. For normal *Ss*, reliability was satisfactory only for short time-intervals and for certain parameters. However, measures of size of drawings and the placement of spiral lines appeared to show differential sensitivity to stimulant, tranquilizer, and stress conditions.

Free-hand copies of geometric figures, despite their presumable sensitivity to degrees of sensory-motor coordination and their procedural simplicity, have had limited use in the objective analysis of movement disturbances. One reason for this comparative neglect lies in the laborious measurement and computation involved in thorough analysis of such figures. Much depends upon *E*'s choice among the potentially affected parameters; it has been the usual procedure therefore to rely upon qualitative judgments and, as in the case of the clinical use of the Bender-Gestalt test, the identification of diagnostic signs (Cronbach, 1960).

Choice of suitable figures has posed a related problem; a useful design would be one which was simple in terms of requirements for instructing *S* and making basic measurements, but problematic in the sense of requiring several exact and careful performances by *S*.

The rapid repetitive operations performed by the computer assisted our resolution of these methodological problems. The work presented in this paper is a preliminary examination of the utility of hand-drawn copies of geometric figures for detecting effects of drug and stress. We have chosen a figure which seems representative of a class of symmetrical forms. With the assistance of a computer, changes in the dimensions of drawings could be extensively and readily tested. These dimensions or parameters were examined for stability and for sensitivity to a drug and stress. Some indications of limitations and usefulness of the drawing procedure have been obtained.

METHOD

The Task and Derived Scores

Geometric, particularly symmetrical, figures are easily reduced to numerical expression; a few points measured on a drawing permit use of the computer to extract several parameters for statistical treatment.

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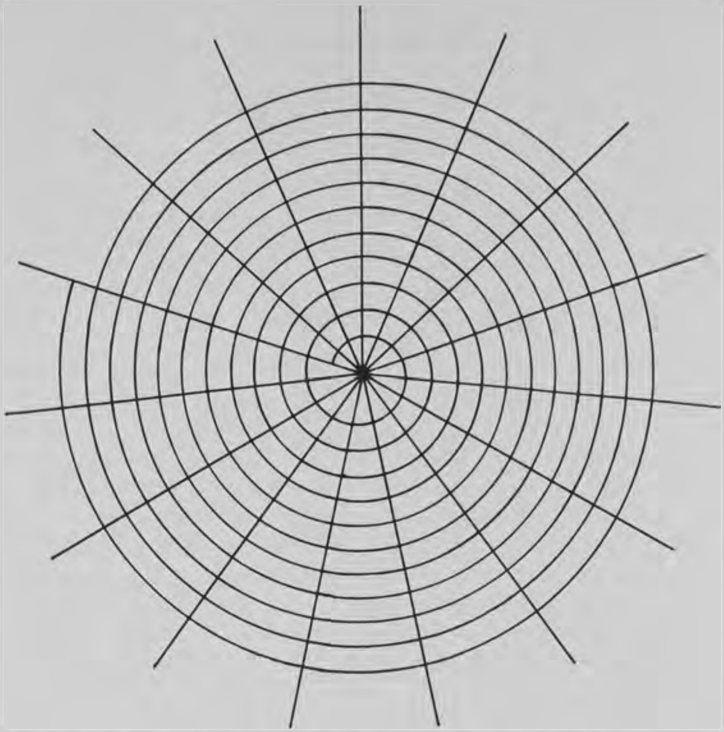
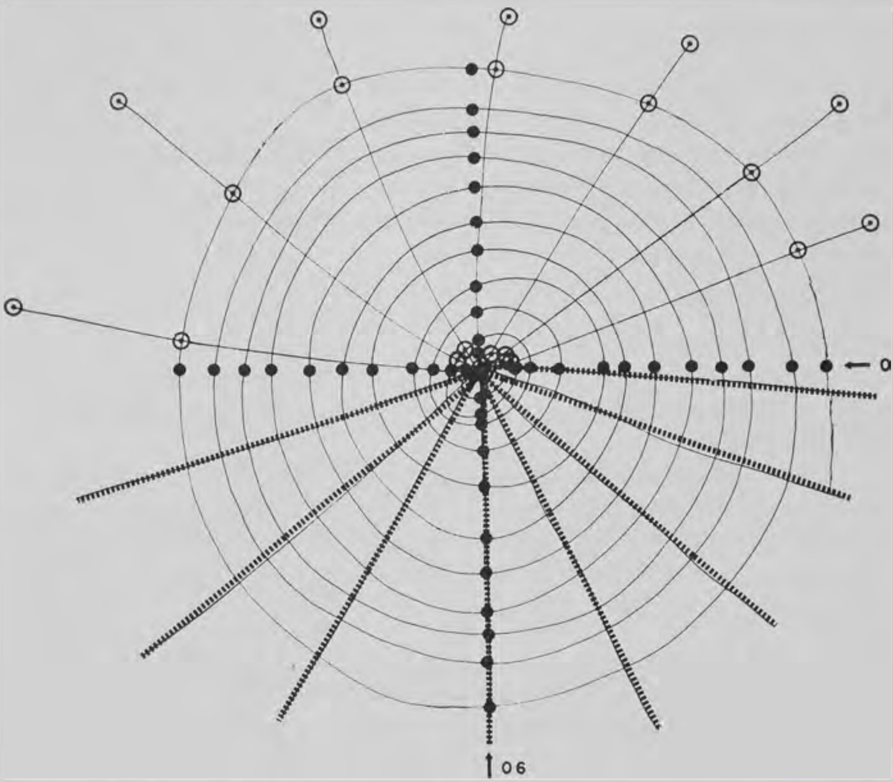


FIG. 1. Test figure; length of radius in the original was 8.5 cm

The model used in our experiments is shown in Fig. 1. It was placed before *S*, who copied it on 8.5- by 11-in. paper in accordance with the following instructions: "Starting from the center, draw 15 radii. Start with the left horizontal radius and proceed clockwise, copying the sample as closely as possible. Do not rotate the paper, do not pre-measure. Draw in sequence; do not go back to any finished line; do not erase. Then, starting on the left horizontal radius (peripherally) draw, in a single continuous movement, a spiral with 11 turns, copying the example as closely as possible, ending on the same radius from which you started. Do not rotate the paper; do not pre-measure; do not erase."

Several measurements (see Fig. 2 for examples) were made on each drawing: (1) the polar angle of the end-point of each radial line (dashed lines); (2) the distance (mm from center) of the end-point and of the most peripheral spiral turn for each radius (open circles); (3) the distance of the spiral at each crossing of the two axes of origin (closed circles). Fig. 2 shows all measured points of the last kind; for the sake of clarity the first two kinds of measurement have been illustrated on only a few radii.

From the punched card data representing the measurements, an IBM 1620 computer generated 12 parameters (in addition to checking the number of radii and spiral turns): the central angles, the size of three areas (central, spiral and



correction: rotate 180°

FIG. 2. Sample drawing illustrating method of measurement. The filled circles indicate spiral turn distances measured at the four cardinal directions; dashed lines in upper half of drawing illustrate measurement of radii; open circles in lower half of drawing indicate measurements taken along each radius: center to inner spiral turn; to outer spiral turn and to end of radius.

extra-spiral regions), total length of pencil-drawn line, median angle, average size of mesh (area formed by adjacent radii and spiral turns), and number of oversized angles (any angle larger than the sum of two central angles adjacent to it). The following proportions were computed: North/South radii, East/West radii, width/length of spiral region and the ratio of the two non-spiral areas to the spiral area. In order to gauge regularity of placement of spiral and radii, adjacent measures were subtracted. For instance, each central angle was subtracted from the angle counterclockwise to it; the distribution and mean value of these differences were evaluated by χ^2 and t test when comparing webs drawn under experimental and control conditions. A similar procedure was used for measuring spiral regularity. All other parameters were compared by t tests performed by the computer.[4]

Certain assumptions and simplifications were made for the sake of measurement convenience. Radii drawn by *S*s were not straight, but curved lines. The spiral positions at the axes were taken to be representative of spiral positions about the whole circle. These assumptions precluded the detection of certain phenomena such as deviations from a smooth line (as in tremor) or drawing rate. The additional programming complexity required for detecting such phenomena seemed disproportionate to the effort of simply noting them while the drawing was being made. At any rate, identification and quantification of these events is not part of the present exploratory program.

The Four Studies

Reliability of Drawing Parameters

Ten male, second year medical students, after at least 5 preliminary practice trials, copied the geometric figure at specified intervals throughout the day, and 3 days a week for a month.

Table 1 contains the reliability coefficients for measures dealing with the size and shape of the drawing and with the spacing of elements of the design. These measures were chosen as representative of parameters and time-intervals. High reliability was attainable only for short intervals of time. It was at satisfactory

TABLE 1

Reliability of Representative Parameters of Size, Shape and Spacing for Copies Made by 10 *S*s at 3 Time Intervals

Parameter	Time Interval		
	2 hr.	4 da.	27 da.
Size:			
Total Area	.96	.52	.34
Line Length	.91	.53	.36
Shape:			
Width/length (Spiral zone)	.30	.40	.30
Spacing:			
Central/Spiral	.78	.16	.30
Spiral Regularity	.66	.06	.20
Angle Regularity	.00	.02	.25

[4] Further details and a copy of the computer program may be obtained from the authors or from the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. Order Document No. 8324, remitting $1.25 for photocopies or 35-mm. microfilm.

levels only below the 4-day interval, and differed for the several dimensions. Size, as measured by the area covered by the drawing and the total length of line, was the most reliable of the parameters (apart, of course, from number of radii and spiral turns). Over-all shape of the copies made by our *S*s did not distinguish *S*s reliably even in the case of short intervals.

Placement of lines yielded different reliabilities for particular features of the design. Thus, it was not possible to sort our *S*s reliably with respect to accuracy of drawing of radial lines, but the placement of the spiral turn produced somewhat more stable differences among *S*s.

Despite the fact that our sample was small and homogeneous, consisting of healthy *S*s of similar age and education, these findings suggest caution in the interpretation of drawing tests. The simplest features of test designs may be duplicated with essentially equivalent proficiency; intra-individual variation exceeds that among individuals.

We approached the question of whether experimental interferences in functioning could produce consistent group differences in drawing by incorporating the test into ongoing experiments and laboratory exercises.

Central Stimulant Effects

Three adult males (aged 30, 37, and 45), engaged in a study of visual effects of central stimulants, made free-hand copies of the design concurrently with visual examinations. They took, orally, each of three substances three times; d-amphetamine in the form of 15-mg spansules of Dexedrine (Smith, Kline & French); tranylcypromine in the form of 10-mg tablets of Parnate (Smith, Kline & French); and, as placebo, tablets of penicillin. One *S* was aware of the identity of the drugs.

The effects of d-amphetamine on healthy human *S*s at the dose level used in this experiment are generally described as appetite-depressant, mood-elevating and fatigue-preventing. While changes in experience and the function of the autonomic nervous system can be assessed readily, psychomotor behavior and cognitive performance have proved less consistent (Smith, Weitzner, Levenson, & Beecher, 1963; DiMascio & Buie, 1964; Evans & Smith, 1964).

Tranylcypromine is generally known as an antidepressant drug. Study of its effect on human *S*s seems to have been confined up to now to establishing a beneficial effect on psychiatric, chiefly depressed, patients (Bartholomew, 1962; Spear, Hall, & Sirland, 1964; Janacek, Schiele, & Vestre, 1963).

Drawings were made immediately following administration of the drug at 9 A.M. (hence prior to any drug effect) and at each of the following times: 10 A.M., Noon, 2, and 4 P.M. One of the substances was given to each *S* on the same day each week for 9 wk., i.e., the sequence drug-placebo-drug was repeated three times for each *S* (each had d-amphetamine, tranylcypromine, and placebo three times).

TABLE 2

DRAWING PARAMETER VALUES AT PRESUMED HEIGHT OF EFFECT FOR TWO CENTRAL STIMULANTS AND PLACEBO

Parameter	Placebo $M \pm SE$	d-amphetamine $M \pm SE$	Tranylcypromine $M \pm SE$
Angle Regularity	5.05± 0.32	5.94± 0.51	5.40± 0.36
Width/length	0.98± 0.01	1.01± 0.16	0.99± 0.01
Radius North/South	1.04± 0.03	1.02± 0.02	1.01± 0.02
Radius East/West	0.93± 0.01	0.93± 0.01	0.91± 0.01
Spiral Regularity	1.52± 0.09	1.84± 0.11*	1.86± 0.16*
Area of Frame, cm^2	88± 6.41	95± 6.64	85± 7.56
Area of Spiral, cm^2	211±15.33	214±15.81	209±17.21
Area of Center, cm^2	8± 1.15	9± 1.37	8± 1.37
Frame/spiral	0.42± 0.16	0.46± 0.03	0.42± 0.03
Center/spiral	0.04± 0.01	0.04± 0.01	0.04± 0.01
Line length, m	5.43± 0.22	5.55± 0.21	5.35± 0.24
Mesh width, mm^2	128± 9.39	129± 9.62	127±10.31

*Significantly different from placebo level ($p < .01$).

As is the case in all the studies reported here, *S*s were required to become practiced in copying the test figure before participating in the study.

Table 2 contains the values for all drawing parameters at the presumed height of the drug effect (the trials occurring 1 and 3 hr. after drug administration). Only one alteration in the drawings was observed: the placement of the spiral during the stimulant period is significantly less precise than for placebo conditions and for drawings made the same day prior to drug action. While change is apparent in the mean figures of the table, the significance test employed was the chi square test performed by the computer on the distribution of spiral differences in the two conditions of drug and control. The findings are consistent for both d-amphetamine and tranylcypromine, and, as will be seen, differ from those found for tranquilizer and stress conditions. We have at least suggestive evidence that the complex motor sequences required to produce an accurate free-hand spiral are adversely affected by the central stimulants. Proficiency in spiral-drawing had returned to placebo levels of skill by the time of the afternoon trials at 2 and 4 P.M.

It may be noted parenthetically that visual acuity measures—*S*'s ability to discern the position of a single thin opaque line against a uniformly illuminated field—showed no change in threshold on any drug trials.

Tranquilizer Effects

Five of the medical students who had provided the reliability data also took diazepam in the form of 5-mg tablets of Valium (Hoffman-LaRoche) on two separate days and under the same time arrangements as those described for the preceding stimulant study. *S*s, who were engaged in a laboratory exercise, were aware of the identity of the drug on both occasions.

In addition to its tranquilizing effect, the drug is reported to have muscle-relaxant properties. Psychomotor performance (cancellation and pegboard test) was found to be slightly impaired at the 5-mg dose-level (Lawton & Cahn, 1963). There have been reports of decrease in spasticity of palsied patients (Payne & Ishmael, 1963) at the 5- to 20-mg level (per day), and improvement of visual-motor control in depressed patients receiving 30 mg/day (Mulero, Kelley, & Fauth, 1963). On the other hand, no improvement in manual dexterity and handwriting was found in cerebral palsy patients with 2-mg doses (Fischer & Houts, 1963).

TABLE 3
DRAWING PARAMETER VALUES ($M \pm SE$) PRECEDING AND AT PRESUMED HEIGHT OF EFFECT OF A TRANQUILIZER

Parameter	Pre-drug	After Diazepam*
Angle Regularity	5.29± 0.61	5.87±0.42
Width/length	1.06± 0.02	1.08±0.01
Radius North/South	1.01± 0.03	1.04±0.03
Radius East/West	0.91± 0.02	0.91±0.01
Spiral Regularity	1.30± 0.10	1.44±0.10
Area of Frame, cm^2	49± 9.16	52±5.50
Area of Spiral, cm^2	167±10.42	140±8.02
Area of Center, cm^2	83±10.74	36±3.23*
Frame/spiral	0.29± 0.05	0.36±0.03
Center/spiral	0.05± 0.01	0.03±0.00*
Line length, m	4.94± 0.18	4.29±0.13*
Mean width, mm^2	101± 6.30	85±5.04

*Difference significant at $p < .01$.

Table 3 contains the parameter-values at the time the drug was taken, i.e., before the appearance of a drug effect and during the presumed height of the drug effect. The drawings showed a significant diminution in size ($p < .01$ for t test) under the drug condition. In addition, the final spiral turns converged closely on the origin of the radii (as shown in smaller center area values and reduced center-spiral ratio).

The disturbance of spiral noted for the central stimulants did not appear in the tranquilizer data. When drug days were compared with control days, the same pattern of drawing effects was found. In drawings made 5 or more hours after drug administration, no significant differences appeared among drawings produced under diazepam, or pre-drug or control conditions.

Diazepam did not seem to affect precision of placement so much as expenditure of effort. The drawing changes appeared to be a curtailment of exertion. The subjective reports of the students were consistent with that interpretation: within an hour of ingestion of the tranquilizer they found themselves tired, apathetic, lethargic, or bored. In drawings made 5 or more hours later, the effects were not apparent, while the subjective effects (for all but 1 *S*) had diminished in 6 hr.

Ss' knowledge of the drug was an unavoidable consequence of the circumstances under which the drug was administered. We may note, provisionally, the consistency of the effect for all *Ss* and the subtle nature of the effect, but further verification is obviously required.

Examination Stress

Increased catecholamine excretion under many types of stressful conditions, has been observed repeatedly (Elmadjian, Hope, & Lamson, 1958; Pekkarinen, Astren, Iisalo, Koivusalo, Laihine, Simola, & Thomasson, 1961), and has become virtually an index of stress. Psychological measures have yielded complex relationships: figure-drawings have been disturbed while cognitive abilities involved in serial subtractions and memory for digits have remained intact (Basowitz, Persky, Korchin, & Grinker, 1955; Craddick & Stern, 1963; Hartogs, 1950).

Drawing and urine specimens were collected from the 10 medical students on each of two examination days. The examinations took place on Wednesdays; control data were taken on Mondays and Fridays of each of the examination weeks (which were 3 wk. apart). The examinations were scheduled from 9 A.M. to 10:30 A.M. Drawings were made at 9 and 10:30 A.M., at noon, and at 3 and 5 P.M. Urine was collected on arising, immediately after the examination and at 4 P.M. Apart from an instruction to void before going to bed on evenings before sample days, no attempt was made to regulate work, diet, or sleep patterns.

Catecholamine excretion was measured to provide verification of the supposition that the examination was stressful. Procedures were conducted by the students under supervision. The fluorometric method of von Euler and Floding (1956) was used rather than the more recent modification of von Euler and Lishajko (1959, 1961) since it permitted more direct comparison with other reports, was adequate for index purposes, and was more suitable for use by students.

A significant increase in total catecholamine excretion was found in the pre-examination period, while the specimens taken immediately after the examination and in the afternoon had values at control levels. Subjectively, the students identified the eve and morning of the examination with the peak of anxious feeling.

The only significant change which appeared in the drawing parameters occurred not in the tests immediately surrounding the examination, but in the drawings made later in the day at 3 and 5 P.M. Spiral placements were more regular than those made on control days (χ^2 test, $p < .01$). Both examinations, separated by 3 wk., showed the same pattern of changes. Unlike the drug findings, these results indicate that the sensory-motor efficiency required for the drawing task remained unimpaired in pre- and post-examination periods. The paradoxical improvement in spiral drawing, resembling a pharmacological rebound phenomenon, may be related to the state of relaxation which the students credited to the post-examination period.

Discussion

As is the case for the spider's web which it resembles (Reed, Witt, & Jones, in press), the pencil-drawing described in this report may be viewed as a record of highly-skilled movements.[5] Paillard (1960) has described "the very particular and privileged role of the human hand as the most elaborate instrument for skilled activities . . . [that is, for] the performance of various technical acts which have as common characteristics the delicacy of their adjustment, the economy of their execution and the accuracy of their achievement" (p. 1679).

Drawing is a highly technical act. Given an exactly-prescribed task, variability in execution might be expected with interferences in sensory-motor control. The chief purpose of the present study has been to inquire whether relatively simple geometric figures provide any sufficient record for detecting such interferences. We have chosen a figure with dimensions readily treated by modern computer techniques and sufficiently intricate to require fine motor control and meticulousness on the part of *S*.

Because of the limitations of sample and the preliminary nature of our experiments, only qualified answers to the inquiry may be given. First of all, caution is required when comparing performances, except for those separated by very brief periods of time. Copying geometric figures, by normal *S*s at least, seems appropriately used only as a test for short-term effects, preferably those occurring within a day.

Within that brief interval of time, the drawing performances of *S*s could be distinguished reliably for some indexes of performance and not for others. Thus, *S*s reliably differ in the size of the drawings they make but not in the proficiency with which they reproduce the over-all form of the test pattern. The drawing of spiral lines permits a distinction to be made between *S*s' skills; the drawing of radial lines does not. Whether these observations can be generalized to designs such as those of the Bender-Gestalt is an empirical question. We would expect, however, that area measures and execution of curves would prove more sensitive to individual differences than would the placement of straight lines and production of rectilinear shapes.

Drawings seem sensitive to interference effects, the nature of the disturbance of the drawing depending upon the interference. Placement of the spiral lines became significantly less regular during the height of drug effect for the two central stimulants used in this study. Execution of equidistant spiral turns was affected by d-amphetamine and tranylcypromine, and hence possibly by other central stimulants.

[5]The resemblance is not accidental. The information yielded by a computer program for extensive survey of the experimental alteration of web pattern encouraged modification to provide a test for human motor performance.

The tranquilizer, diazepam, by contrast, did not affect the precision requirements of the copying task, apart from a shift of the spiral toward the center of the drawing. This alteration seems comprehensible as part of a strategy to conserve effort, rather than loss of precision. Such an interpretation is in accord with findings of Heimann and Witt (1955), who studied the effects of another tranquilizer, chlorpromazine, and found apathy and disturbance of initiative in healthy human *S*s.

In the data collected before and after the academic examinations, relatively complex motor achievement was retained despite what appeared to be, on the basis of the biochemical data, a stressful experience, at least in anticipation. A paradoxical rebound or relaxation effect was observed instead.

Our experiments were concerned exclusively with normal adult *S*s. It may be the case that reliable long-term distinctions can be drawn from the drawings made by patients with neurological or psychiatric disturbances. Some preliminary observations of records obtained from cerebral palsied children appeared to show a correlation between drawing disturbance and involvement of the upper limbs; simplified figures had to be devised for these *S*s, i.e., figures consisted of four radial lines and three circular, rather than spiral, turns.

We conclude that changes in the skilled motions of the hand may be detected by objective measurement of free-hand copies of geometric figures, but apparently under limited circumstances. Some short-term changes induced by drugs and by stress appeared in our experiments and were characteristic for the kind of interference. We regard our results as preliminary but encouraging.

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