Perceptual and Motor Skills, 1977, 45, 935-939.

EFFECTS OF MARIJUANA ON HUMAN REACTION TIME AND MOTOR CONTROL[1]

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Summary.—In this research were analyzed the effects of marijuana on human reaction time and on performance for motor responses involving both linear and rotary serial arm movements aimed at a target. A total of six experienced marijuana users served as subjects and three drug conditions (dose levels) were used, i.e., 0, 6.5, and 19.5-26.0 mg Δ^9-THC. The results showed that (a) (simple and complex) reaction time was not significantly affected by marijuana or by the interaction between drug conditions and the amount of information transmitted during the task, (b) linear movement time was significantly reduced after smoking marijuana, while rotary movement time was not significantly affected, (c) interaction between drug conditions and task complexity was insignificant in the case of both linear and rotary movements, and (d) error rates for the two types of motor movements increased significantly and especially for linear movements as the dose level increased.

Despite a large and growing number of published studies of the physiological and psychological effects of marijuana in man, there still remains considerable controversy regarding the nature of such effects. However, the evidence seems to indicate that the acute effects of marijuana in moderate doses are minimal and that significant decremental effects that have been established are related to higher doses, task complexity, and degree of experience with the drug. For reviews of such studies, reference is made to Miller (1974) and the report by the National Commission on Marihuana and Drug Abuse (1972).

The present study was concerned with the possible effects of marijuana on complex reaction time and motor control for which previous studies have reported conflicting findings; see, e.g., Miller (1974) and Weil, Zinberg, and Nelsen (1968) for references to such investigations. Furthermore, such reported studies of motor control have typically utilized pursuit meters and rotors, while no studies have involved motor control of accurate arm movements aimed at a target. In particular the effects of the interaction between the drug conditions (dose levels) and task complexity have not so far been investigated. Similarly the possible influence of marijuana on the relationship between complex reaction time and task complexity (uncertainty in the stimulus set, or amount of information transmitted) or, equivalently, the interaction between the drug conditions and task complexity, appears not to have been investigated.

[1]Results of this study were presented at the Annual Conference of the Ergonomics Research Society, Edinburgh, Scotland, April, 1976.
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The present study was designed to analyze such interactions for both reaction time and movement time for accurate motor responses as well as the main effects of the drug on reaction and movement time and on the rate of movement errors.

METHOD

Experimental Tasks

(1) Exp. I was a classical discrete choice or complex reaction-time experiment for which the subject was required to respond as quickly as possible to each visual stimulus by pressing the appropriate button. The amount of uncertainty (entropy) in the stimulus set was varied by varying both the number of possible stimuli which could occur and the probabilities with which they occurred.

(2) Exp. II, which was identical to that used by Fitts (1954), required the subject to tap with a light stylus back and forth between two parallel 12.7-cm long metal plates as fast as possible while trying to limit the error rate to about 5 to 10%, an error being defined as an overshoot or an undershoot of a target, i.e., a metal plate, by the stylus. The width of each target pair and the distance between them were varied during the experiment.

(3) Exp. III involved a task similar to that of Exp. II with the exception that rotary arm movements were used in Exp. III. Each subject moved a 6.35-cm pointer back and forth between two targets on a scale by turning a round control knob of 5.7-cm diameter; see Kvålseth (1974) for a detailed description of the apparatus. A control-display ratio of 1 was used. A number of scales were used with different target widths and different angular distances between the targets.

For each of the three experiments the subject was seated in front of a table on which the apparatus was placed. Each subject was permitted to choose the most desirable position.

Subjects

A total of six male undergraduate students ranging in age from 21 to 24 yr. and in weight from 55 to 84 kg were tested as unpaid and volunteer subjects during these experiments, of whom five performed Exp. I and three performed Exps. II and III. All subjects were experienced marijuana users, especially five of them, and half of them had tried harder drugs.

Material and Setting

The marijuana used in these experiments was of Mexican origin and consisted primarily of finely chopped leaves of Cannabis. It was administered in the form of cigarettes of standard size made with a hand-operated rolling machine. Each cigarette contained about 6.5 mg Δ^9-tetrahydrocannabinol (THC). Each subject took long puffs, inhaled deeply, and maintained inspiration for about 10 to 15 sec. These experiments were conducted in a neutral setting.

The subjects were made comfortable and secure in a pleasant room that did not resemble a sterile laboratory.

Drug Conditions

Three drug conditions with varying dose levels of the drug were used. First, a subject performed the experiments without any drug inhalation. Second, a low dose level (6.5 mg Δ^9-THC) was used. Third, a subject smoked continuously until he reached what he felt was a maximum "high" which, for the different subjects, required between three and four cigarettes (19.5—26.0 mg Δ^9-THC).

Experimental Procedure

For Exp. I the number of possible stimuli (lights) ranged from one to eight and the probabilities of occurrence of the stimuli were varied so that the amount of uncertainty in the stimulus set had 13 different values in the interval 0 to 3 bits. For each of these cases, the possible stimuli and their probabilities were identified for a subject prior to the start of the experimental run during which 10 reaction-time measurements were made.

For Exp. II eight different combinations were used for the movement amplitudes (between the center lines of two targets) of 10.16, 20.32, 40.64 cm and target widths of 0.64, 1.27, 2.54 cm. The corresponding values of the Fitts index of task difficulty (Fitts, 1954) ranged from 3.00 to 7.00 bits, i.e., bits/movement. The five combinations of amplitudes and target widths used in Exp. III involved 45°, 90°, 160° and 6°, 12°, 24°, respectively, with the resulting values of the Fitts index of task difficulty ranging from 1.94 to 4.91 bits. For each of these (eight and five) experimental conditions, the total number of moves made by a subject during a 15-sec. experimental run was recorded to yield the mean movement time. Prior to each experimental run, a subject was given a 10-sec. practice session followed by a rest period of about 5 sec.

For each of the three experiments, which were carried out during separate sessions, the various experimental runs were conducted according to a randomized complete block design in which the blocks represented the subjects. The experiments started about 15 min. after the marijuana had been smoked and were completed within approximately another 30 min.

Results and Discussion

Experiment I

For Exp. I the mean complex reaction time (RT) was related to the amount of information (INF) transmitted by the subjects (from the response set to the stimulus set). The parameters of this linear first-order model, the so-called Hick-Hyman's law (Hick, 1952; Hyman, 1953), were estimated by means of ordinary least squares regression. The estimated simple reaction time, i.e., the

constant or interception term of the model, ranged from 0.19 sec. to 0.38 sec. among different subjects and drug conditions, while the generated information rate (d[INF]/d[RT]) ranged from 9.1 bits/sec. to as much as 25.6 bits/sec. However, the results did not yield any consistent and systematic relationship between the marijuana dose level and either of these two model parameters. In fact, an analysis of variance with RT as the dependent variable and information at three levels (0—1, 1—2, 2—3 bits) indicated that the drug conditions did not have a statistically significant effect on RT ($F_{2,8} = 0.22, p > 0.05$). The interaction between drug conditions and information was also insignificant ($F_{4,16} = 2.01, p > 0.05$). Furthermore, the drug conditions had no significant effect on the mean simple reaction time, i.e., reaction time for the case of only one stimulus and one response ($F_{2,8} = 0.46, p > 0.05$).

Experiments II and III

The mean movement time (MT) between two targets was related to the Fitts index of task difficulty (or information measure) (ID), and the parameters of this so-called Fitts's law (1954) were estimated by means of ordinary least squares regression. The results indicated that the effect of marijuana appeared to have caused somewhat of an increase in the information rate d(ID)/d(MT), which ranged from 8.5 to 10.2 bits/sec. for linear movements and from 6.8 to 7.9 bits/sec. for rotary movements based on the average movement time for the subjects. However, an analysis of variance indicated that the effect of marijuana on movement time was insignificant in the case of rotary movements ($F_{2,4} = 0.86, p > 0.05$), while it did achieve significance for linear movements ($F_{2,4} = 15.74, p < 0.05$). The interaction between experimental conditions (task difficulty) and drug conditions had no significant effect in the case of both linear and rotary movements ($F_{14,28} = 1.50, p > 0.05$ and $F_{8,16} = 1.03, p > 0.05$, respectively).

Marijuana increased the error rates for all levels of task difficulty and for both linear and rotary movements. Average total error (for all subjects and values of the index of difficulty), which included over- and undershoots of a target and slipovers in the case of linear tapping movements, i.e., movements that terminated within a target but then slipped over the target boundary, increased from about 7% for the case of linear movements with no Δ^9-THC to 25% for the case with 19.5—26.0 mg Δ^9-THC, while the corresponding increase for rotary movements was from about 8% to 14%. Analyses of variance performed on these errors showed that such effects of marijuana were significant for both linear movements ($F_{2,8} = 12.82, p < 0.005$) and rotary movements ($F_{2,6} = 19.17, p < 0.005$).

Individual Differences

For the particular subjects used in these three experiments, significant per-

formance differences existed between the subjects' RT ($F_{4,150} = 30.75$, $p < 0.001$) and movement time for linear movements ($F_{2,28} = 26.57$, $p < 0.001$), with movement information rates ranging from 8.1 to 10.8 bits/sec. and tending to increase somewhat for all subjects as the dose level increased. No such significant individual differences existed in the case of rotary movements ($F_{2,16} = 3.26$, $p > 0.05$) for which the generated information rates ranged from 6.1 to 8.9 bits/sec. between individual subjects and drug conditions. The interaction between subjects and drug conditions had a significant effect on reaction time ($F_{8,150} = 9.39$, $p < 0.001$) but on neither linear nor rotary movement time ($F_{4,28} = 0.49$, $p > 0.05$ and $F_{4,16} = 2.15$, $p > 0.05$, respectively). The perceptions of the subjects as to how marijuana affected their performance also varied. When asked by the experimenter after the completion of the three experiments, half of the subjects believed that marijuana did not affect their performance, while the other half felt that their performance did suffer some impairment.

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Accepted September 7, 1977.