Marijuana Effects on Simulated Flying Ability

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The authors studied the effects of marijuana intoxication on the ability of 10 certified airplane pilots to operate a flight simulator. They used a randomized double-blind crossover design to compare the effect of active versus placebo marijuana. They found that all 10 pilots showed a significant decrease in measurements of flying performance 30 minutes after smoking active marijuana. For a group of 6 pilots tested sequentially for 6 hours, a nonsignificant decrease in flying performance continued for 2 hours after smoking the active drug. The authors conclude that the effects of marijuana on flying performance may represent a sensitive indicator of the drug's psychomotor effects.

ALTHOUGH THE USE OF MARIJUANA by the young adult population of the United States has dramatically increased in the last decade, virtually no information is available concerning its use by airplane pilots (1–3). Our informal inquiry has revealed that "social" marijuana smoking is not an uncommon practice among pilots, some of whom reported that they have flown aircraft while "high" on marijuana. For this reason, we felt that it was relevant to study the effects of smoking social doses of marijuana on the ability to operate an airplane flight simulator.

METHOD

We studied the effects of marijuana intoxication on the ability of certified pilots to operate a general aviation model ATC-510 instrument flight simulator (Analog Training Computers, Inc.). Seven professional and 3 private male pilots were recruited for the study. All had smoked marijuana socially for several years. Their ages ranged from 21 to 40. Three could be described as infrequent marijuana users (at the time of the study they were smoking marijuana twice a week or less), and 7 could be described as moderate marijuana users (they were smoking marijuana three or more times a week).

The pilots were familiarized with four consecutive 4-minute "holding pattern" sequences requiring a total of 16 minutes' "flight time," which included maneuvers typically encountered in instrument flight (e.g., straight and level flight, turns, three-dimensional maneuvering, and radio navigation). These tasks require psychomotor coordination as well as such cognitive abilities as short-term memory, concentration, and orientation in time and in three-dimensional space.

As described in appendices 1 and 2, the first and fourth 4-minute flight sequences consisted of a standard holding pattern. The second and third sequences consisted of a standard holding pattern modified by incorporating altitude changes. A low level of "turbulence" was also added to all four sequences so that the pilot would be required to continually manipulate the controls to compensate for the effect of the turbulence. These changes were carefully chosen to demand a high level of flying skill to correctly complete each sequence.

After the 10 pilots had attained proficiency in operating the simulator and in performing the four specific flight sequences, marijuana containing 2.1% Δ-9-tetrahydrocannabinol (Δ-9-THC) was administered in a dose of .09 mg of Δ-9-THC per kg. One week before or after active drug administration, a matched placebo containing a nonpharmacological amount of Δ-9-THC was administered. The pilots smoked the active or placebo marijuana in a pipe for a 10-minute period using a standardized smoking technique that consisted of the following: 10 seconds of inhalation, 20 seconds of holding breath, 5 seconds of exhalation, and 5 seconds of normal breathing. A randomized double-blind crossover design was used for the administration of active and placebo marijuana.

Thirty minutes after smoking active or placebo marijuana the 10 pilots performed the flight sequences. Their pulse rates and their self-ratings of degree of intoxication were recorded at this time. For the self-rating of degree of intoxication, each pilot was asked to

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rate his "high" on an open-ended scale on which 10 was designated as his usual social high and 0 represented his normal state.

We videotaped each pilot's flight sequence after both active and placebo marijuana smoking as well as just before smoking to establish baseline levels. These videotaped 16-minute flights were analyzed at 10-second intervals for deviation from the standardized flight pattern, altitude deviation, and heading deviation. When appropriate, the course deviation indicator (CDI), a radio navigation instrument, was examined at 5-second intervals. Total heading, CDI, and altitude deviations were calculated for each 16-minute flight sequence for each subject.

In addition, the pilot's "major errors," defined as those which if committed in the actual flight situation would take the airplane out of its designated air space with potentially dire consequences (e.g., getting lost, fuel exhaustion, stalling, and gross altitude or navigational deviations), were transcribed from the videotaped sequence and summed. The pilots' "minor errors," defined as altitude deviations greater than plus or minus 100 feet or heading deviations greater than plus or minus 30°, were also observed on the videotape, transcribed, and totaled.

The performances of 6 of the pilots were also evaluated 2 hours, 4 hours, and 6 hours after smoking. Each of these pilots was used as his own control in analyzing the effects of active versus placebo marijuana in altering flying ability (by sign test).

RESULTS

Eight of the 10 pilots were able to distinguish the placebo from the active marijuana. The 2 who erred in identifying the drugs were the least experienced in using marijuana. Most of the pilots rated their level of intoxication after smoking the active drug as slightly greater than their usual social high.

Average data for the entire group of pilots will be presented rather than data for individual performances because individual performance varied considerably from pilot to pilot and from variable to variable. As shown in table 1, the self-rating of degree of intoxication was significantly higher after smoking active marijuana than after smoking placebo ($p<.01$, sign test). Most of the pilots subjectively felt that the flying task was more challenging when they were intoxicated on active drug and did not believe that they had adequately compensated for any drug-induced deficiencies.This feeling was confirmed experimentally: all of the pilots evidenced a significant decrease ($p<.01$, sign test) in performance on all measurements evaluated during the flight after smoking active marijuana (see table 1).

The average pulse rate observed after placebo smoking was significantly lower than that observed after active marijuana smoking ($p<.01$, sign test) (see table 1). The entire group also demonstrated a statistically significant increase in the average number of major errors ($p<.01$, sign test) and minor errors ($p<.01$, sign test) after smoking active marijuana (see table 1).

TABLE 1

Average Pulse Rates, Self-Ratings of Degree of Intoxication, and Flight Performances of 10 Airplane Pilots 30 Minutes After Smoking Active or Placebo Marijuana

Item	After Smoking Active Marijuana	After Smoking Placebo Marijuana
Pulse rate	107	73
Self-rating of degree of intoxication*	10.5	0.5
Altitude (feet)**	2,615	680
Heading (degrees)**	627	332
CDI (units)**	100	42
Number of major errors	2.9	0.4
Number of minor errors	4.5	0.7

* 10=usual social high; 0=normal state.
** Values indicate total deviation from assigned flight path during entire 16-minute flight sequence.

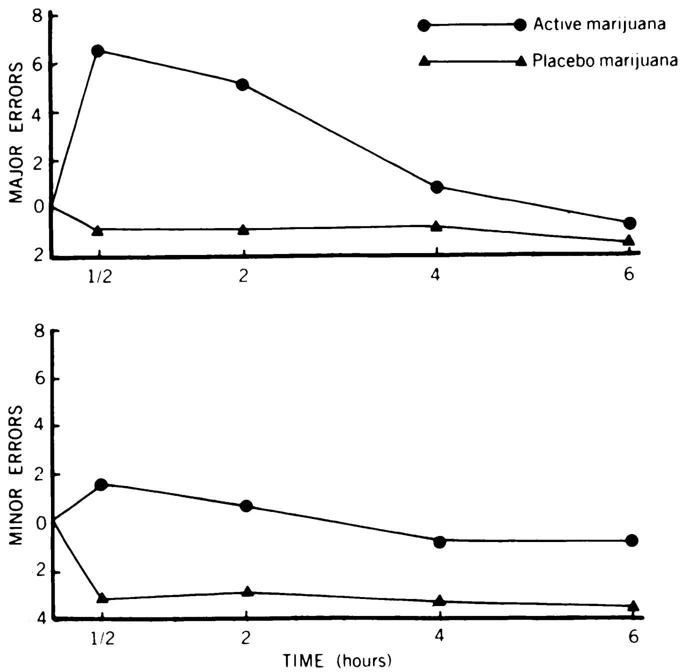
Data were also obtained for 6 of the pilots over a 6-hour period after smoking active drug or placebo to elucidate the time course of the marijuana-induced deterioration in flying performance observed initially at 30 minutes. The flying performances of these 6 pilots were relatively consistent over the 6-hour period after smoking placebo, suggesting that neither learning nor fatigue significantly affected flying performance (by sign test). A decrease in flying ability, not statistically significant, was apparent for most of the 6 pilots 2 hours after smoking active marijuana, but this diminished in magnitude when compared with the statistically significant decrease noted at 30 minutes. The performances of all 6 of these pilots returned essentially to baseline levels by 4 hours (see figures 1 and 2).

DISCUSSION

These results have a number of implications, both for aviation medicine and for the understanding of marijuana's pharmacologic properties. The level of marijuana intoxication in these 10 pilots was generally self-rated as equal to the level they reached when they were socially intoxicated. The time course of the effects of marijuana also followed that encountered when marijuana is smoked socially (1, 4). The results indicate that smoking marijuana in doses used socially (5) causes significant deterioration in simulated instrument flying ability for at least 30 minutes in experienced pilots. The effect probably lasts for 2 hours and disappears in 4 hours.

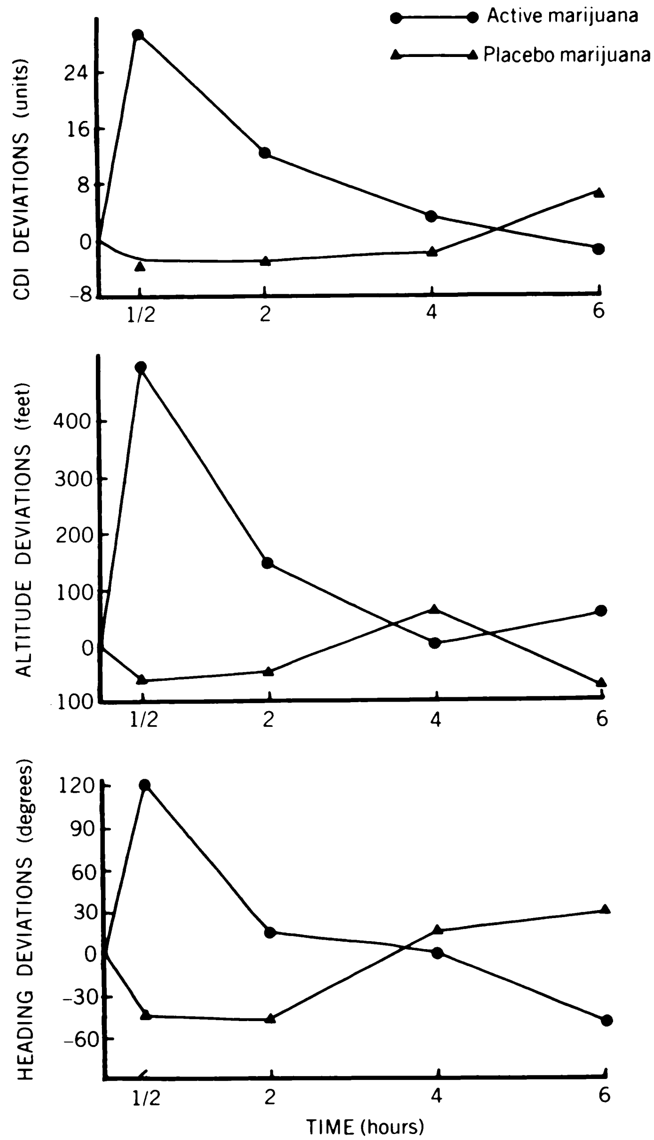
Although the gross detrimental effects of marijuana appear to last for less than 4 hours, more subtle effects, detectable with more sophisticated equipment, may conceivably persist for longer periods of time in actual flight situations or more complex simulated con-

FIGURE 1
Average Number of Major and Minor Errors* of 6 Pilots After Smoking Active or Placebo Marijuana



*The number of errors represents the average number made by the 6 pilots after smoking compared with the average number they made before smoking (baseline levels) during an entire 16-minute flight sequence.

FIGURE 2
Average Deviations from Baseline Levels in Flight Performances of 6 Pilots After Smoking Active or Placebo Marijuana



ditions. Furthermore, the effect of altitude and pressure changes upon the performance of pilots intoxicated with marijuana represents a variable not measured in our experiment. Our data do not support safe instrument flight for at least 4 hours after smoking marijuana.

It is important to note that our flight task was relatively simple and that only a limited number of variables were evaluated. We did not record certain measurements, such as airspeed control, angle of bank, and rate of control movement, in our simulated flight situation, although these measurements were part of the simulated flying task. Although the results noted are quite dramatic, one must note that simulated flying differs from actual flying. Our pilots performed a memorized flight sequence; they had the instructions for the pattern in front of them at all times. In actual flight situations, instructions come sequentially from an Air Traffic Control (ATC) controller and must be accurately noted and repeated (i.e., read back) by the pilot. We believe that the performance of a pilot under these circumstances would be even more adversely affected by marijuana intoxication than in our experimental setting. The level of motivation to perform optimally and the ability to use some visual and kinesthetic cues and radar vectoring by ATC differ in actual flight situations from the simulated flight situation (6).

The deficiencies noted in the performances of our 10 pilots probably reflect marijuana's ability to affect a complex, learned psychomotor test involving memory, skill, concentration, sense of time, and orientation in three-dimensional space and in the performance of multiple complex tasks (5–10). Operationally, the simulated flying task is probably best described as a four-dimensional, complex cognitive tracking test.

It appears to us and to the pilots we tested that the major problems incurred in flying the simulator while intoxicated with marijuana involved certain specific factors. The most important appeared to involve marijuana's ability to affect short-term memory and sense of time. After smoking the active marijuana, the pilots often forgot where they were in a given flight sequence or had difficulty recounting how long they had been performing a given maneuver, in spite of the presence of written instructions and a stopwatch.

Marijuana also appeared to cause alterations in concentration and attending behavior: the intoxicated pilots would concentrate on one variable to the exclusion of other variables or perhaps attend to intrusive thoughts. As an example, several pilots noted that following a momentary lapse in attending to the flying task, they could not tell how long they had been flying or where they were located in the flight sequence. The realization that such inappropriate focusing had occurred seemed to lead to overcontrolling (oversteering) in an attempt to compensate for variables previously ignored and suddenly noted. Thus subjects exhibited a complete loss of orientation at times with respect to the navigational fix, resulting in grossly unpredictable flight performances. This loss of orientation occurred when the pilots were either daydreaming, "lapsing," or focusing on a certain part of their specified routine to the exclusion of other required activities.

We feel that the effects of marijuana on flying performance may represent a rather sensitive indicator of marijuana's psychomotor effects. Because of its multiple requirements, the task of flying may accentuate marijuana's cognitive disruptive effects (5–10) and thus prove useful in evaluating marijuana's interactions with other psychoactive drugs, such as alcohol and barbiturates, which also affect piloting performance (11–15). Thus the use of trained pilots to perform a complex psychomotor task may be a sensitive "bioassay" of marijuana's effects on cognitive functioning that has implications beyond those obvious to the safety of the airplane pilot.

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APPENDIX 1
Standard Holding Pattern

Assuming a few simplifications, a standard holding pattern is oval in shape and is composed of four 1-minute segments, starting at a total elapsed time of 0 minutes, 0 seconds.

The first segment is a right-hand turn, performed at a standard turn rate of 3° per second. This turn is executed on reaching a navigational "fix," a locus defined variously by radio beacon, triangulation, and radar. Thus a standard turn lasting 1 minute results in a heading change of 180°, causing a course reversal (total elapsed time = 1 minute, 0 seconds).

The second segment, called the "outbound leg," is a straight and level flight lasting 1 minute (total elapsed time = 2 minutes, 0 seconds).

The third segment, also lasting 1 minute, is a right turn, ideally executed at the standard rate of 3° per second. However, the last portion of this turn, encompassing approximately the last 20 seconds, is normally used to align the aircraft on the proper course with respect to the navigational fix. The aircraft has now assumed the original heading (total elapsed time = 3 minutes, 0 seconds).

The fourth segment of a standard holding pattern, called the "inbound leg," employs radio navigation to enable the pilot to fly the aircraft accurately to the initial navigational fix. This also takes 1 minute and concludes the standard 4-minute pattern (total elapsed time = 4 minutes, 0 seconds).

In actual flight conditions, the pattern may be repeated many times and may incorporate climbs and descents to effect traffic separation, etc. In the experimental situation, the following criteria are employed: climbs—100% power, indicated airspeed (IAS) = 120 miles per hour (mph), and climb rate = 1,000 feet per minute; descents—50% power, IAS = 160 mph, and descent rate = 1,000 feet per minute; and standard turn rate—3° per second or 180° per minute.

APPENDIX 2
Specific Experimental Patterns

PATTERN 1

In the task demanded of the pilots, the first pattern flown is a standard holding pattern lasting 4 minutes, as defined in appendix 1. The pattern is flown at a target altitude of 2,000 feet.

PATTERN 2

On crossing the navigational fix at the conclusion of the first pattern (total elapsed time = 4 minutes, 0 seconds), the flight plan calls for a climb of 1,000 feet to the 3,000-foot altitude at a rate of 1,000 feet per minute, while simultaneously executing a standard right-hand turn of 180°. Since the maneuvers in both geometric planes take 1 minute, the pilot is required to simultaneously level the aircraft at 3,000 feet while rolling out of the turn on the appropriate reciprocal heading (total elapsed time =5 minutes, 0 seconds).

The aircraft is then flown on the reciprocal heading at a level altitude of 3,000 feet for 30 seconds, at which time (total elapsed time =5 minutes, 30 seconds) a descent of 1,000 feet to an altitude of 2,000 feet is begun. The standard holding pattern requires that a standard right turn begin 30 seconds later (total elapsed time =6 minutes, 0 seconds). The aircraft is to be leveled at 2,000 feet in the middle of this turn (total elapsed time =6 minutes, 30 seconds). The turn is completed after a total elapsed time of 7 minutes, 0 seconds, with the aircraft aligned with the inbound course to the navigational fix at an altitude of 2,000 feet. The aircraft then flies inbound toward the fix for 30 seconds at 2,000 feet (total elapsed time =7 minutes, 30 seconds), and a climb of 500 feet is instituted with the aircraft simultaneously reaching the navigational fix, leveling at 2,500 feet, and rolling into the standard right turn of the next pattern after a total elapsed time of 8 minutes, 0 seconds.

PATTERN 3

The first 30 seconds of this pattern is flown at an altitude of 2,500 feet while the standard-rate right turn is executed. At a total elapsed time of 8 minutes, 30 seconds, a climb of 1,500 feet to an altitude of 4,000 feet is begun. The aircraft is rolled out of the turn (total elapsed time =9 minutes, 0 seconds) and flown straight on the outbound leg while climbing to 4,000 feet. This altitude is reached at a total elapsed time of 10 minutes, 0 seconds, at which time a turn of 180° is started. Thirty seconds later (total elapsed time =10 minutes, 30 seconds) a descent of 1,000 feet to 3,000 feet is initiated. At a total elapsed time of 11 minutes, 0 seconds, the aircraft is once again positioned on the inbound course to the navigational fix. The pilot continues inbound toward the fix while continuing the descent to 3,000 feet. The descent is terminated at 3,000 feet (total elapsed time =11 minutes, 30 seconds), and the aircraft is assumed to reach the navigational fix at a total elapsed time of 12 minutes, 0 seconds.

PATTERN 4

The last pattern is a standard holding pattern flown at a level altitude of 3,000 feet. The experiment is terminated with the completion of this pattern after a total elapsed time of 16 minutes, 0 seconds.