Carry-Over Effects of Marijuana Intoxication on Aircraft Pilot Performance: A Preliminary Report

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Ten experienced licensed private pilots were trained for 8 hours on a flight simulator landing task. They each smoked a cigarette containing 19 mg of Δ^9-tetrahydrocannabinol (THC), and 24 hours later their mean performance on the flight task showed trends toward impairment on all variables, with significant impairment in number and size of aileron changes, size of elevator changes, distance off center on landing, and vertical and lateral deviation on approach to landing. Despite these deficits, the pilots reported no awareness of impaired performance. These results may have implications for performance of complex tasks the day after smoking marijuana.

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The widespread recreational use of marijuana in both the private and military sectors suggests the need for more detailed research concerning its effects on pilot performance. For the past 10 years cases of its use by flight trainees, active pilots, and pilots in fatal accidents have been documented (1, 2). A 12-year-old study (2) revealed that some 250 of the 500,000 people who applied to the Federal Aviation Administration (FAA) for medical certificates freely admitted to previous use of marijuana. We suspect that actual use by today's pilots is much higher.

How long is the behavioral and cognitive performance of complex tasks affected by Δ^9-tetrahydrocannabinol (THC)? While plasma concentrations are usually negligible 3–4 hours after smoking, urine screens for THC metabolites remain positive at least 48–72 hours after oral administration (3, 4). Recent accidents involving railroad crews performing complex tasks have documented positive urine THC screens (5). The pilot in a recent fatal commercial air crash was found to have smoked THC some 24 hours before the crash (6). A particular concern is whether using the drug can lead to impaired piloting performance (a complex task) after a 1-day delay, i.e., a carry-over effect.

Although the topic is widely discussed, we have found only one scientific investigation of the effects of THC on pilot performance (7–9). In a comparison of THC and placebo, observer-rated performance was evaluated after pilots smoked cigarettes containing approximately 0.09 mg of THC per kilogram of body weight. The pilots were trained to fly holding patterns on an ATC-510 instrument flight simulator (a simulation without an outside visual display). Despite the limitations of the simulation and a relatively insensitive quantification method, significant effects on all dependent measures were found up to 4 hours after smoking. To date, no further studies have examined the persistence of THC effects on piloting tasks.

The purpose of this study was to examine THC carry-over effects on a simple piloting task 24 hours after smoking of the drug. The task chosen was a standard maneuver involving a simple landing procedure. The dependent measures related to how precisely the landing was performed. We reasoned that a simple piloting task would provide a conservative test of THC effects 24 hours after administration. If any effects were found on simple piloting tasks, we would be justified in further investigation of THC effects on complex piloting tasks. We employed a highly quantified, computerized flight simulator in this study. Since on-line computerized quantification is a precise measuring technique, it provides a more sensitive measure of prolonged drug effects on pilot performance than previously used methods (10).

METHOD

Testing Device and Quantification

The experiment was conducted in a computerized laboratory specifically designed for pilot performance research (AIRSIM-R; the simulations cited are available from Dr. E. Kurtz, MSC Corp., P.O. Box 506, Northampton, MA 01061; 413-586-6463). The com-

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puter-generated visual displays, instrument read-outs, and aircraft control systems are controlled by a 6502 microcomputer and 6502 coprocessor. Data about the aircraft's orientation, position, altitude, and speed are collected every 0.5 second. The data collected during experiments are transformed and stored by a 68000-based microcomputer. The data analyses are completed on an IBM 3081 mainframe computer.

The subjects are seated in the aircraft simulator chamber. The chamber is sound attenuated and the interior is designed to simulate a generic small aircraft cockpit. The aircraft controls consist of a standard yoke that controls the elevators and ailerons. Flaps and engine speed controls are located at approximately the same distance (20 cm) from the pilot as those same controls in a Cessna 172. All instruments are displayed across the bottom and lower right side of an 18-in. CRT. The visual angle (retinal image) of these instruments approximates those found in a Cessna 172. AIRSIM-R includes a computer-generated graphic display of landscape (as seen from the pilot's perspective). This display includes horizon, mountains, buildings, and airport runways. The landscape perspective is corrected every 0.5 second in response to the subject's manipulation of the aircraft controls.

There are two typical methods of quantifying pilot performance. These are the "measure everything" approach and the measurement of certain critical points on selected maneuvers (10). Our approach combined aspects of both. We measured every control yoke and throttle movement to determine general changes in method of controlling the flight simulator, and we measured critical points of certain maneuvers to determine how well the overall procedure was performed. The maneuver involved a takeoff, a climb to 700 feet, two turns, and a descent and landing. The pilots were instructed to maintain a stable descent rate of between 100 and 200 feet per minute and to land as near the runway threshold and center line as possible. Every adjustment of the aileron, elevator, and throttle during the maneuver was recorded by the computer. These three control characteristics were used to measure the pilot's attempts to manipulate the simulator. Also recorded were seven different aircraft situation parameters: latitude, longitude, altitude, angle of bank, angle of climb, rate of climb, and velocity. Together these data can be used to calculate overall measures of performance, e.g., average lateral deviation from an ideal glideslope and glidepath or number of feet off-center from the runway center line on landing. Once calculated, these performance data are ready for statistical analyses and for graphic display. Figure 1 shows a graphic display of one pilot's flights at baseline and 1 hour after smoking THC.

Before this experiment we compared the performance on the flight simulator of eight nonpilot volunteers and eight pilot volunteers with more than 200 hours of flying experience. Using the same task as in our THC studies, we trained the subjects until they were able to make three successful landings in a row. We found that the nonpilots required significantly more practice landings to reach that criterion: mean$\pm$SD=6.2$\pm$ 2.6 for the nonpilots versus 2.9$\pm$1.7 for the pilots ($t=3.05$, $df=7$, $p<.02$). We also found that on the three landings completed successfully, the pilots performed substantially and significantly better in terms of deviations from glidepath and glideslope. The average lateral deviation for nonpilots was 72.7$\pm$34.7 feet, and for the pilots it was 30.3$\pm$16.8 feet ($t=3.11$, $df=7$, $p<.02$). The average vertical deviations for the two groups were 46.8$\pm$21.4 feet and 12.6$\pm$4.5 feet. Thus, we found a correspondence between performance on the simulator and previous piloting experience.

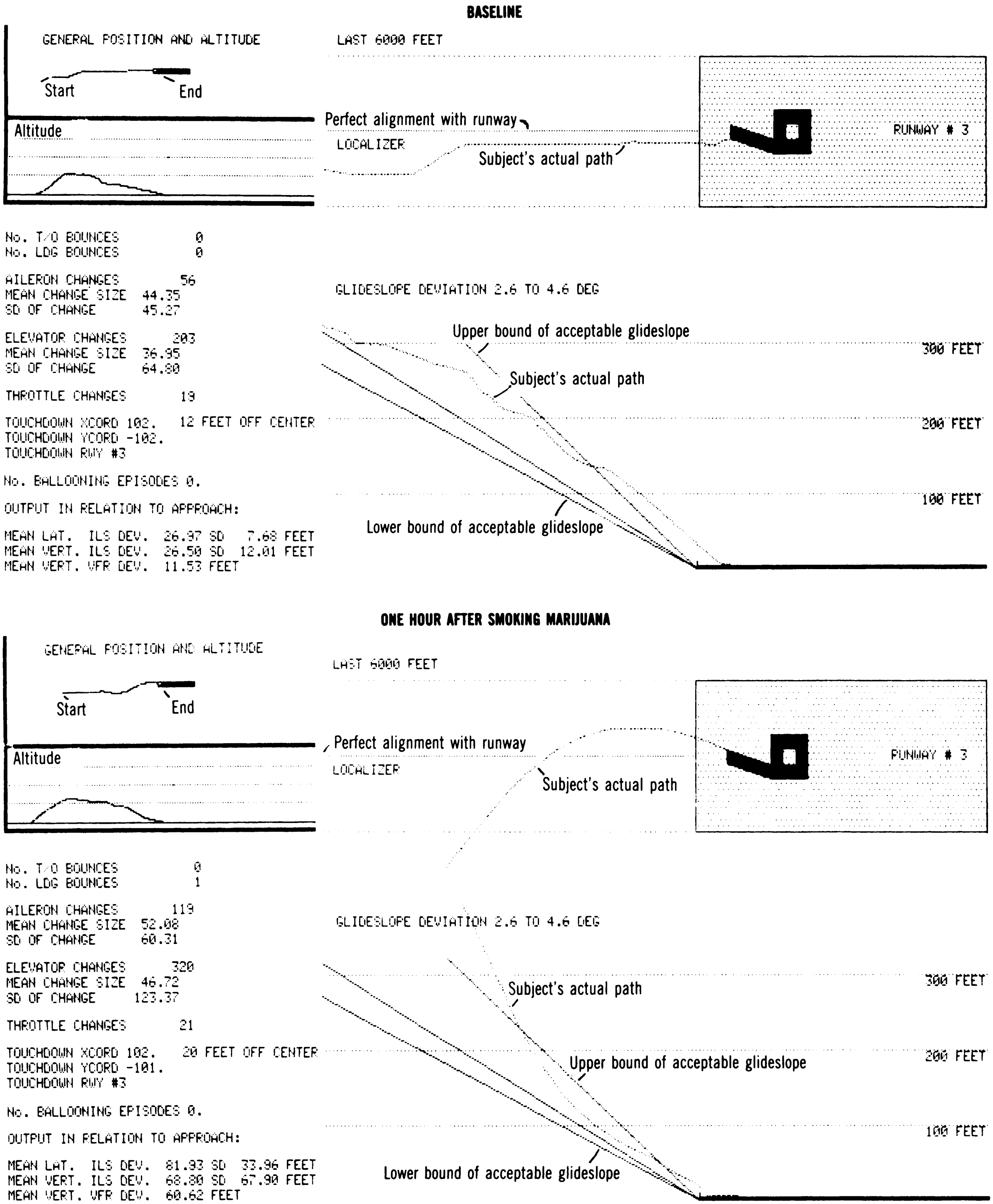
Subjects and Procedures

The subjects were 10 pilots recruited by advertisement at a local airport. All volunteers were currently licensed private pilots with a (Class III) medical certification. They had a mean age of 29 years and a mean of 303 hours of flying experience. Only subjects experienced in smoking marijuana were used, but subjects were admitted only if they smoked it less than daily and if they could abstain from THC and other drug use for the period of testing. Before the subjects smoked the marijuana, samples of their urine were screened for other drugs of abuse. All subjects gave informed consent for the project.

The subjects were trained for 8 hours on the flight simulator landing task. During the testing periods, which were clearly distinguished from practice flights, they were told to take the task as seriously as if they were on an FAA examination flight and to perform to the maximum of their ability. On the day of testing, baseline performance was measured between 8:00 and 9:00 a.m. and consisted of one recorded flight, which was preceded by two practice flights. At 9:00 a.m. a marijuana cigarette furnished by the National Institute on Drug Abuse and containing 19 mg of THC was smoked. This is probably the equivalent of a strong social dose. The entire cigarette was smoked at a rate comfortable to the subject. At 9:30 a.m. and 12:30 p.m., performance on the task was tested again (hour 1 and hour 4). The subject returned at 8:00 a.m. the following day and took two practice flights, and then a flight was recorded. No placebo was used, since prior studies using the same cigarette found that 90% of the subjects could identify the active drug. Subjective ratings on a 10-point scale of "high," "anxiety," "happiness," and "alertness" were obtained at each testing session.

We were also concerned that the subjects might be tempted by alcohol or marijuana during the evening before the final performance test. Since there is no way to quantify the results of urine tests (or breath analysis) to rule out such possibilities, the subjects were strictly informed (verbally and on the consent forms) that they should not use any alcohol or other drugs of potential abuse during this period and that they would in fact be

FIGURE 1. Output[a] From Highly Quantified Computerized Flight Simulator for One Pilot at Baseline and 1 Hour After Smoking Marijuana



[a]The upper left-hand corner shows 1) the general position of the aircraft as it takes off, turns left then right, and lands and 2) an altitude map in 500-feet increments. The lower left-hand corner lists the quantified data produced for one flight; these were used to compute the overall results in table 1. The right-hand side of the figure shows a detailed view of the last 6,000 feet of the approach to landing. The ideal position is shown by the "localizer," which defines the center line of the approach, and by the "glideslope," which defines the proper (3.6°) angle of descent (the center of the three descending straight lines).

TABLE 1. Flight Simulator Performance of 10 Licensed Private Pilots at Baseline and 1, 4, and 24 Hours After Smoking Marijuana

	Baseline		1 Hour After THC			4 Hours After THC			24 Hours After THC		
Dependent Measure	Mean	SD	Mean	SD	t[a]	Mean	SD	t[a]	Mean	SD	t[a]
Distance off-center on landing	12	6.5	32	14.0	−3.57[b]	29	8.5	−6.38[c]	24	8.2	−3.52[b]
Mean lateral deviation	19	6.4	56	26.7	−4.42[b]	45	15.9	−7.41[c]	34	11.2	−3.25[d]
Mean vertical deviation	26	13.0	61	37.6	−4.00[b]	45	12.9	−4.08[b]	40	18.4	−1.90
Aileron											
Number of changes	60	6.7	102	25.2	−4.87[c]	82	6.9	−6.66[c]	76	13.8	−3.66[b]
Mean size	53	7.6	68	10.6	−7.31[c]	65	6.0	−3.79[b]	65	10.5	−2.61[d]
Elevators											
Number of changes	264	56.0	361	59.8	−4.42[b]	306	65.8	−1.74	285	61.8	−0.83
Mean size	54	15.0	88	32.4	−3.29[d]	76	18.2	−3.40[b]	74	28.6	−2.46[d]
Number of throttle changes	22	0.9	29	9.8	−2.56[d]	27	13.2	−1.53	25	6.2	−1.83
Subjective ratings											
High	0	0	9.3	0.9	−31.01[c]	1.7	0.5	−11.12[c]	0.1	0.3	−1.00
Less alert	1.3	0.7	5.2	1.5	−7.41[c]	1.7	1.6	−0.60	1.1	0.3	0.80
More anxious	1.6	0.8	3.9	1.2	−3.98[b]	1.3	0.5	1.15	1.3	0.7	0.90
More happy	2.4	0.8	3.3	1.4	−1.59	1.5	0.7	5.01[b]	1.6	1.1	2.06

[a]Paired test of baseline versus 1-, 4-, or 24-hour values; two-tailed p.
[b]$p<.01$.
[c]$p<.001$.
[d]$p<.05$.

tested for those substances. Any variance with the protocol was reason for exclusion from the study and from payment of the experimental subject fee.

RESULTS

Table 1 summarizes the mean flight simulator performance at baseline and 1, 4, and 24 hours after marijuana smoking. The variables of interest are the number of aileron (lateral control), elevator (vertical control), and throttle changes; the size of these control changes; the distance off the center of the runway on landing; and the average lateral and vertical deviation from an ideal glideslope and center line over the final mile of the approach. Compared to baseline performance, significant differences occurred in all the variables 1 and 4 hours after smoking, except for the number of throttle and elevator changes at 4 hours. At 24 hours, there were trends in all variables toward impaired performance and there was significant impairment in number and size of aileron changes, size of elevator changes, distance off-center on landing, and vertical and lateral deviation on approach to landing. The subjective measures of anxiety, alertness, happiness, and high did not differ between 24 hours and baseline. In separate calculations we found a significant increase in variance between baseline and performance at 24 hours on the number of aileron and elevator changes.

DISCUSSION

The difficulty the subjects experienced in aligning and landing precisely at the center of the runway is a particular cause for concern. It may be related to the trend toward more and larger aileron changes on approach. Elevator control seems less affected by the drug. It is important to note that the near doubling of lateral deviation on a landing at 24 hours may be an extremely serious error. In actual flight, where there is wind and turbulence, such errors can easily lead to crashes. One of the pilots did land off the runway 24 hours after THC ingestion. Despite these performance changes, the pilots reported no significant subjective awareness of impaired performance at 24 hours. It is noteworthy that the recent fatal crash in which the pilot had a positive THC screen involved a similar landing misjudgment (6).

There is an extensive literature on THC use and human performance under the influence of THC. Several studies have shown effects on memory, attention, and perception; however, these effects were only rarely significant 4 hours after smoking. Kielholz et al. (11) found general impairment in driving performance to last as long as 6 hours after the intake of THC. One study by the FAA (12) found impaired performance on a number of cognitive tasks some 14 hours after enough alcohol had been ingested to produce a blood level of 0.1 mg/dl (12). The current data, from an even more complicated task, indicate impaired performance 24 hours after smoking THC. Thus, it appears that our ability to identify drug effects may depend on the complexity of the task tested.

These results suggest a need for concern about the performance of those entrusted with complex behavioral and cognitive tasks within 24 hours after smoking marijuana. The subjects in this experiment were unaware of any effects on their performance, mood, alertness, etc. Some results may be applicable to other tasks, such as operating complicated heavy equipment or railway trains and switching procedures. Further research on these complex tasks should continue in an attempt to define the point after smoking THC at which the performance of complex tasks returns to baseline. Such research should be objectively measured and precisely quantified; otherwise, important differences in performance may go unrecognized.

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