Effect of Cannabis Use on Cognitive Functions and Driving Ability

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Background: Neither experimental nor epidemiologic approaches have so far given definitive answers to the question of the potential effect of cannabis on driving ability.

Method: To shed more light on this topic, we conducted a placebo-controlled double-blind study including 60 healthy volunteers (a negative urine drug screening test was prerequisite). On the first day, baseline data were obtained from a physical examination and a psychological test battery for the investigation of visual and verbal memory as well as cognitive perceptual performance. On the second day, subjects received a regular cigarette or one containing 290 μg/kg body weight of tetrahydrocannabinol. Physical and psychological assessments were performed immediately (15 minutes) after subjects smoked their cigarettes. Twenty-four hours later, physical and psychological examinations were repeated.

Results and Conclusion: Our results suggest that perceptual motor speed and accuracy, 2 very important parameters of driving ability, seem to be impaired immediately after cannabis consumption.

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Regardless of its current legal status, cannabis seems widely established as a socially accepted drug. Although the consumption of cannabis in various social environments is no recent development, modern research into the effects of cannabis in individuals only began less than 20 years ago.

The active ingredient of cannabis is trans-Δ^9-tetrahydrocannabinol (THC). The patterns of use range from different methods of inhaling to various forms of oral consumption. Of all these forms, THC is most rapidly absorbed when smoked, and its clinical effects appear within minutes; physiologic, emotional, and perceptual changes rarely last longer than 2 to 3 hours after consumption of a single cigarette.[1]

The patterns of cannabis effects in individuals are well established.[2,3] However, neither experimental nor epidemiologic approaches have so far given definitive answers to the question of the potential effect of cannabis on driving ability. One report suggested that drugs like cannabis may be causally related to fatal traffic accidents.[4] Therefore, the questions of its potential for impairing a driver and how to measure such impairment are of prime importance to both the forensic expert and the legislative bodies concerned with the effect of drug use on traffic safety.

There are good reasons to assert that the evaluation of drug effects on driving skills should include tests of perception and cognition. The theoretical approaches offered by Broadbent,[5] Fitts and Posner,[6] and Welford[7] place perceptual cognitive functions at the core of the models used for the analysis of man-machine interactions.[8]

Empirical reasons for examining the effects of psychotropic drugs on perception and cognition are found in the evidence that the majority of driver-related errors leading to accidents occur within the category of perceptual, especially attentional, failures.[9–11]

This double-blind placebo-controlled randomized study in healthy subjects was designed to evaluate the influence of standardized usage of THC on cognitive functions and its impact on driving ability.

METHOD

Subjects

Sixty volunteers (34 men, 26 women) were investigated in this placebo-controlled double-blind study. Only those found healthy with no history of substance use disorder (DSM-III criteria, excluding tobacco dependence) were randomly assigned to smoke either a regular or a cannabis cigarette, both visually identical. There was no difference in past history of cannabis use between pro-

Table 1. Demographic Data[a]

Characteristic	Placebo Group	THC Group
Probands, N	30	30
Men, N	19	15
Women, N	11	15
Age, mean ± SD, y	27.8 ± 5.0	27.6 ± 5.3
Cannabis dose, μg/kg	…	290
IQ, mean ± SD	122.83 ± 11.47	120.37 ± 14.59

[a]Abbreviation: THC = tetrahydrocannabinol.

bands randomized to the respective groups. All subjects smoked at least 20 tobacco cigarettes a day. Subjects were recruited from the staff of the hospital or were students of medicine or psychology attending classes at the Department of Biological Psychiatry, Innsbruck University Clinics.

After informed consent was obtained, subject IQ was estimated by using the Culture Fair Intelligence Test, scale 3.[12] We included only probands with an IQ of at least 90. The subjects were informed that the purpose of the study was to determine the acute effect of cannabis on cognitive functions. They were told that the cigarette they were expected to smoke during the study might or might not contain THC (290 μg/kg body weight), the active constituent of cannabis. They were also instructed neither to smoke cannabis nor to drink ethanol, tea, or coffee during the 3 days of study duration and not to drive a car. The study conformed to the declaration of Helsinki and was approved by the Ethics Committee of the Medical Faculty of Innsbruck University as well as the Austrian Ministries of Health and Justice.

Statistics

The Mann-Whitney U test (also known as the Wilcoxon rank sum test) was used for statistical evaluations between the 2 groups. The differences within the groups were analyzed using the Wilcoxon signed rank test.

Experimental Design

The 60 volunteers were randomly assigned to either the placebo or THC group (sample description, Table 1). The 3-day study consisted of a baseline examination and 2 follow-up examinations detailed below.

Baseline data, including psychiatric and medical history, a medical examination, and cognitive testing, were obtained on day 1 (baseline). On the next day (day 2), 30 subjects smoked a cannabis cigarette, and 30 subjects smoked a placebo cigarette. The THC cigarette contained 290 μg/kg body weight Δ^9-THC, a dose corresponding to the average dose used in comparable studies.[13] The cigarette was prepared and supplied by the University Institute of Forensic Medicine in Innsbruck. All probands smoked the cigarette in the same room, in a comfortable atmosphere with low background music. The same psychiatric exploration, physical examination, and psychological test battery were performed immediately after smoking and 24 hours later (day 3).

Neuropsychological Test Battery

Trail Making Test. The adult version (for subjects 15 years of age and older) of the Trail Making Test requires immediate recognition of the symbolic significance of numbers and letters and the ability to scan a page continuously to identify the next number or letter in sequence, as well as flexibility in integrating the numerical and alphabetical series and the ability to complete these tasks under time pressure. Speed and efficiency of performance are analyzed. The Trail Making Test is accepted to be a valid and reliable measurement of perceptual motor speed and efficiency.[14]

Efficiency Test System. Subtest 13 of the Efficiency Test System (LPS-13) is an effective and appropriate test to measure performance and motivation of probands.[15] It is a paper-and-pencil test with a column filled with numbers and letters. The proband's task is to cancel every eighth figure zero in a continuous order inside the column. After finishing that task, he or she has to start at the beginning once more, cancelling every eighth figure one and so on until the given time is over. Mistakes are added up. Perceptual motor speed and accuracy, as well as concentration, are measured by this part of the test system.

Intelligence Structure Test. The Intelligence Structure Test, subtest A (IST-A) judges verbal memory and assesses learning efficiency.[16] During this test, the proband has to learn 5 collective names with 5 subnames in each case within 3 minutes. Afterward, he or she has to answer questions under time pressure. The right answers are then counted.

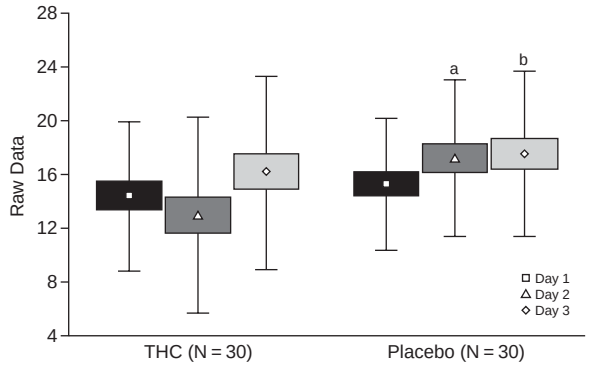
Benton Multiple Choice Form G. In our study, we used the multiple choice form G with instruction O (delayed presentation) of the Benton Test.[17] This part of the test is a very precise measuring system for visual memory and consists of 15 tables with 4 presentations on each one. Patients are shown 1 table and then asked to identify this table when given a choice of 15 similar tables after a certain amount of time has passed.

Comprehensive Psychiatric Rating Scale. The Comprehensive Psychiatric Rating Scale (AMDP) was used to judge drug-induced psychopathology.[18]

Physical Examination

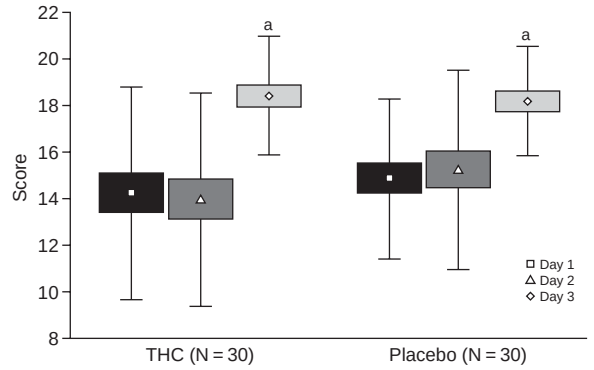
For the physical examination, we selected the standardized evaluation form used by Austrian medical officers (M.D.'s) when evaluating drivers potentially impaired by ethanol or other drugs. Neurologic parameters such as pupillary reaction, speech, tremor, nystagmus, and the Rhomberg test, as well as the injection rate of conjunctival blood vessels, were examined. Additionally, blood pressure and heart rate were assessed.

Figure 1. Efficiency Test System (Subtest 13)



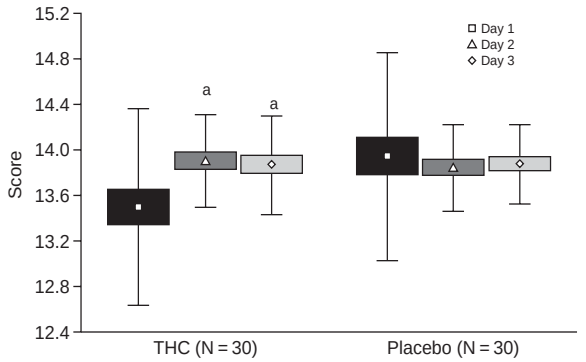
[a]p < .05, Mann-Whitney U test (between groups).
[b]p < .05, Wilcoxon signed rank test (within group).

Figure 2. Intelligence Structure Test



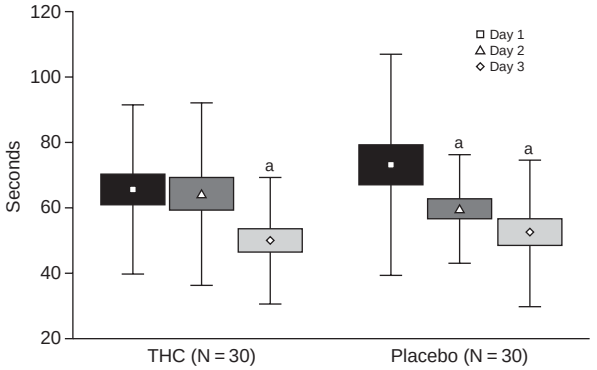
[a]p < .05, Wilcoxon signed rank test (within group).

Figure 3. Benton Test



[a]p < .05, Wilcoxon signed rank test (within THC group).

Figure 4. Trail Making Test



[a]p < .05, Wilcoxon signed rank test (within group).

The following questions were investigated:

1. What is the influence of cannabis on cognitive functions that are crucial for road safety?
2. How long is this effect sustained?
3. Does a standard driving ability test, as routinely used on drivers suspected of driving under the influence of ethanol, reflect the potential driving impairment as induced by cannabis?

RESULTS

Sixty volunteers were recruited for this study. The THC group (15 men/15 women) and the placebo group (19 men/11 women) each consisted of 30 subjects. The mean ± SD age was 27.8 ± 5.0 years in the placebo group and 27.6 ± 5.3 years in the THC group. The IQs of both groups were comparable (placebo group mean ± SD IQ = 122.8 ± 11.5; THC group mean ± SD IQ = 120.4 ± 14.6). THC dosage used was 290 μg/kg body weight, as administered by other investigators.[19,20] Demographic data are shown in Table 1.

Differences Between the Placebo and THC Groups

The statistical analysis comparing the groups on the LPS-13 (Figure 1), measuring perceptual motor speed and accuracy as well as concentration, presented the following results. While baseline and day 3 values were comparable between both groups, the THC group exhibited a significantly higher impairment of cognitive functions on day 2 ($p = .012$).

On the IST-A (Figure 2), measuring verbal memory, we found only marginal, nonsignificant differences between the 2 groups at any time of measurement.

The Benton Test, evaluating visual memory (Figure 3), and the Trail Making Test, reflecting perceptual motor speed and efficiency (Figure 4), also failed to show significant differences between the 2 groups at any time.

On the AMDP (Table 2), the items thought disorder, concentration difficulties, and sexual desire showed significantly higher scores in the THC group on day 2 in comparison with the placebo group. There were no other significant differences between the 2 groups for any other item at any time.

Table 2. Comprehensive Psychiatric Rating Scale (AMDP) Differences (mean ± SD) Between and Within Groups

	Placebo Group			THC Group		
Item	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
Sexual desire	1.0	1.03 ± 0.2	1.0	1.0	1.23 ± 0.5[a,b]	1.07 ± 0.4
Thought disorder	1.0	1.13 ± 0.3[a]	1.33 ± 1.8	1.03 ± 0.8	1.5 ± 0.7[a,b]	1.0
Concentration difficulties	1.17 ± 0.4	1.17 ± 0.4	1.0	1.13 ± 0.3	1.7 ± 0.8[a,b]	1.03 ± 0.2
Disturbances of sensory perception	1.0	1.07 ± 0.3	1.0	1.0	1.13 ± 0.3[a]	1.0
Headache	1.03 ± 0.2	1.27 ± 0.5[a]	1.03 ± 0.2	1.07 ± 0.3	1.37 ± 0.5[a]	1.03 ± 0.2
Euphoria	1.0	1.37 ± 0.7[a]	1.03 ± 0.2	1.0	1.3 ± 0.7[a]	1.13 ± 0.3
Nausea	1.0	1.33 ± 0.5[a]	1.1 ± 0.4	1.0	1.27 ± 0.5[a]	1.0

[a]Within-group difference: $p < .05$, Wilcoxon signed rank test (compared with baseline).
[b]Between groups: $p < .05$, Mann-Whitney U test.

The physical examination aimed at identifying ethanol- and/or drug-impaired drivers showed no significant differences between groups. Pulse rates were higher in both groups after smoking.

Differences Within the Groups

Regarding time course within the 2 groups, the AMDP showed significantly higher scores on thought disorder, headache, euphoria, and nausea on day 2 compared with baseline scores in both groups. No significant differences were found between days 3 and 1. The physical examination failed to show within-group differences as well.

Differences Within the THC Group Over Time

The LPS-13 (Figure 1) demonstrated no significant differences regarding time course within the THC group. On the IST-A (Figure 2), we found a slight, nonsignificant decrease from baseline to day 2. By day 3, the group scored significantly higher than on day 1 ($p = .00006$). The Benton Test (Figure 3) showed significantly higher scores on days 2 ($p = .008$) and 3 ($p = .02$) when compared with baseline values. There was a slight, nonsignificant improvement from baseline to day 2 on the Trail Making Test (Figure 4); this difference became significant by day 3 ($p = .0007$). On the AMDP (Table 2), we found significantly higher scores in concentration difficulties and disturbances of sensory perception and sexual desire within the THC group on day 2 than on day 1, but no significant difference between days 3 and 1.

Differences Within the Placebo Group

Within the placebo group, the LPS-13 (Figure 1) showed continuous improvement, reaching statistical significance on day 3 ($p = .0116$). A continuous increase of scores was also found on the IST-A (Figure 2), with a significantly higher score on day 3 in comparison with baseline ($p = .0001$). There were no significant changes of Benton Test scores at any time within the placebo group (Figure 3). Probands in the placebo group exhibited a significant improvement on days 2 ($p = .017$) and 3 ($p = .0002$) against baseline on the Trail Making Test (Figure 4).

DISCUSSION

For many years, ethanol has been the drug of greatest concern among law enforcement officials, since it is by far the most frequently recognized cause of drug-impaired driving. However, as the social use of unsanctioned drugs such as cannabis increases, attention must be directed toward these drugs as well.[4,21]

In the most general sense, impaired driving is seen as a failure to exercise the expected degree of prudence or control necessary to ensure road safety.[22] The operation of a vehicle is clearly a skilled performance that calls for controlled and flexible use of a person's intellectual and perceptual resources.[23]

The outcome of the verbal memory test (IST-A) within the THC group is of particular interest. On this test, we found a slight decrease of scores within the time course in the THC group, whereas the placebo group showed a clear continuous increase. The statistical evaluation of the Trail Making Test brought about similar results. Both tests show that, immediately after smoking cannabis, probands were not able to profit from their own test experience from the day before. By comparison, the placebo group demonstrated a clear and significant learning effect. The reason for the decrease in learning seen in the THC group might be a disinhibition of overlearned response and an increased susceptibility of recently acquired information to intrusions. This, in turn, may reflect parallel compromises in associative control that is acknowledged as a cognitive process inherent in memory function immediately after smoking cannabis.[24] Applied to the question of driving ability, the missing learning effect would signify that a driver under acute cannabis influence would not be able to use acquired knowledge from earlier experiences adequately to ensure road safety. Consequently, an impairment of driving ability immediately after drug consumption must be assumed.

This view is supported by the results of the LPS. A significant impairment immediately after smoking cannabis was shown compared with the placebo group on the scores on this test. The significantly higher score of concentration difficulties and thought disorder on the AMDP at the same time has additional impact on this finding. Disturbances of perceptual motor speed and accuracy as well as the impairment of cognitive components such as the ability to organize or to retrieve new information immediately after cannabis consumption may also bear responsibility for these results. Because these cognitive

functions are imperative for the demands of negotiating traffic, impairment supports the assertion that a safe and skillful driving performance is not ensured after acute cannabis consumption.

On the Benton Test, the improvement within the THC group on days 2 and 3 compared with baseline appears to be of mainly statistical relevance. Close inspection reveals that the statistical deviation is accounted for by less than one answer. It is therefore likely that this is relevant in a mathematical context rather than in a clinical situation.

The significantly higher scores on the items thought disorder, headache, euphoria, and nausea in both groups may be seen as an effect of tobacco in the context of the study setting and are consistent with the expectation of receiving a cannabis cigarette, while the higher scores on the items concentration difficulties, sexual desire, and sensory perception within the THC group immediately after smoking are well-known THC effects.

Of great importance are the higher scores on the items thought disorder and concentration difficulties in the cannabis group immediately after cannabis consumption compared with the placebo group. These psychopathologic symptoms certainly imply impairment of road performance and subsequently a reduction of road safety.

It has to be emphasized that these results are only representative for an acute cannabis-induced impairment in probands with no drug abuse history. From the results of the statistical evaluation within the groups, we assume that there is a complete recovery of the cognitive impairment within 24 hours after standardized cannabis administration. All evidence taken together suggests that changes induced by smoking THC, both on psychopathologic and cognitive levels, resolve within 24 hours after drug consumption.

As a by-product, our study showed, inter alia, that the standardized tools of physical examination used in individuals suspected to drive under the influence of psychotropic drugs may be defective with regard to the detection of driver impairment caused by cannabis consumption. Due to its almost exclusively neurologic orientation, this examination method is not useful in revealing the impairments described above. This is not surprising, considering that cannabis causes much less psychomotor impairment than does ethanol.

Given the fact that THC-impaired drivers obviously cannot be recognized by standardized evaluation forms aimed at identifying the characteristic patterns of ethanol, it will be necessary to develop and apply new evaluation forms to uncover the presence of drugs other than ethanol. Further research is needed to determine characteristic patterns of cannabis-impaired driving, and additional examinations and test batteries must widen the scope of probands and test situations. It is suggested that, among others, the use of a driving simulator should be explored. Unfortunately, a driving simulator was not at our disposal when the study was initiated.

From our study, we can draw the conclusion that 2 very important parameters of driving ability, namely perceptual motor speed and accuracy, seem to be impaired immediately after cannabis consumption.

REFERENCES

1. Hollister LE. Health aspects of cannabis. Pharmacol Rev 1986;38:1–20
2. Hollister LE, Richards R, Gillespie H. Comparison of tetrahydrocannabinol and synhexyl in man. Clin Pharmacol Ther 1968;9:783–791
3. Isbell H, Goridodetsky CW, Jasinski T, et al. Effects of (–)-delta-9-trans-tetrahydrocannabinol in man. Psychopharmacologia 1967;11:184–188
4. Mercer GW, Jeffery WK. Alcohol, drugs and impairment in fatal traffic accidents in British Columbia. Accid Anal Prev 1995;27:335–343
5. Broadbent DE. Decision and Stress. London, England: Academic Press; 1971
6. Fitts PM, Posner MI. Human Performance. Belmont, Calif: Brooks/Cole Publishing Company; 1967
7. Welford AT. Fundamentals of Skills. London, England: Methuen; 1968
8. Moskowitz H. Attention tasks as skills performance measures of drug effects. Br J Clin Pharmacol 1984;18:51S–61S
9. Clayton AB. An accident-based analysis of road user errors. J Safety Res 1972;4:69–74
10. Joscelyn KB, Treat JR. Tri-Level Studies of the Causes of Traffic Accidents. Washington, DC: US Dept Transportation, National Highway Traffic Safety Administration. Interim Report II, Report No. DOT MS-801 968
11. Perchonok C. Driver and Vehicle Characteristics as Related to the Precipitation of Accidents. Washington, DC: US Dept Transportation; May 1977. Report No. DOT HS 802-355
12. Baeumler G, Weiss RH. Über den Zusammenhang der Paulitestleistung mit Intelligenzleistungen (IST-Amthauer, CFT-Cattell). Psychologie & Praxis 1968;10:27–36
13. Marks DF, MacAvoy MG. Divided attention performance in cannabis users and non-users following alcohol and cannabis separately and in combination. Psychopharmacology (Berl) 1989;99:397–401
14. Reitan RM. The relation of the Trail Making Test to organic brain damage. J Consult Psychol 1955;19:393–394
15. Horn W. Leistungsprüfsystem L-P-S. 2. Erweiterte und verbesserte Auflage. Göttingen, Germany: Verlag für Psychologie; 1983
16. Amthauer R. Intelligenz-Struktur-Test I-S-T 70. 4. Unveränderte Auflage. Göttingen, Germany: Verlag für Psychologie; 1973
17. Benton AL. Der Benton Test. Bern, Switzerland: Verlag Hans Huber; 1986
18. Baumann U, Stieglitz RD. Evaluation of the system of the study group of methodology and documentation in psychiatry based on recent literature. Fortschr Neurol Psychiatr 1989;57:357–373
19. Barnett G, Licko V, Thompson T. Behavioral pharmacokinetics of marijuana. Psychopharmacology (Berl) 1985;85:51–56
20. Leirer VO, Yesavage JA, Morrow DG. Marijuana, aging, and task difficulty effects on pilot performance. Aviat Space Environ Med 1989;60:1145–1152
21. Soderstrom CA, Dischinger PC, Kerns TJ, et al. Marijuana and other drug use among automobile and motorcycle drivers treated at a trauma center. Accid Anal Prev 1995;27:131–135
22. Consensus Development Panel. Drug concentration and driving impairment. JAMA 1985;254:2618–2621
23. Cavanaugh JC. The importance of awareness in memory aging. In: Poon LW, Rubin DC, Wilson BA, eds. Everyday Cognition in Adulthood and Late Life. Cambridge, NY: Cambridge University Press; 1989:416–436
24. Hooker WD, Jones RT. Increased susceptibility to memory intrusions and the Stroop interference effect during acute marijuana intoxication. Psychopharmacology (Berl) 1987;91:20–24