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ORIGINAL ARTICLE

The effect of cannabis on regular cannabis consumers' ability to ride a bicycle

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Abstract To assess the effects of cannabis on the ability required to ride a bicycle, repetitive practical cycling tests and medical examinations were carried out before and after inhalative consumption of cannabis. A maximum of three joints with body weight-adapted THC content (300 μg THC per kg body weight) could be consumed by each test subject. Fourteen regular cannabis-consuming test subjects were studied (12 males, 2 females). In summary, only a few driving faults were observed even under the influence of very high THC concentrations. A defined THC concentration that leads to an inability to ride a bicycle cannot be presented. The test subjects showed only slight distinctive features that can be documented using a medical test routinely run for persons under suspicion of driving under the influence of alcohol or drugs.

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Introduction

The prevalence of illicit drugs in the general driver population varies from country to country, and the total prevalence is considered to be approximately 1.9 % for the countries of the EU. Cannabis and cocaine are the most frequently detected illicit drugs in the general driver population (mean prevalence of cannabis, 1.32 %; mean prevalence of cocaine, 0.42 %). Pooled data of low and high concentrations of the different illicit drugs showed odds ratios between 2 and 7 for the increase in injury risk, corresponding to blood alcohol concentrations (BAC) between 0.5 and 0.8 g/l. The typical drivers that tested positive for the influence of drugs were males younger than 35 years of age [1].

Cannabis is considered to be the world's predominant substance of abuse, and the cannabis market continues to grow. Cannabis is increasingly decriminalized or legalized, e.g., in Uruguay or Colorado and Washington, D.C./USA, and legalization is politically discussed in several countries. Between 125 and 227 million people reportedly consumed cannabis in 2012 [2]. In the acute phase, cannabis is believed to affect mood, perception, cognition and psychomotor performance, as well as the cardiovascular and respiratory systems [3, 4].

Cannabis-related effects on simulated driving performances did regularly not show relevant impairments of motor behavior, and it is assumed that documented deficits are related to attention or perception [5, 6]. Estimates of risk are hard to obtain due to the rapid decline of THC concentrations in blood. After inhalative consumption of 250 or 500 μg of THC per kilogram of body weight, the highest THC concentrations

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were found just after finishing the cannabis cigarettes (approximately 6 h later the THC serum concentration of 10 test persons was below 1 ng/ml [7]). In Germany, cutoff values for the absolute impairment to drive a car or ride a bike are not available for other psychotropic substances other than alcohol, which is why every case is treated individually [8]. A cannabis influence factor (CIF) of 10 is considered to represent an acute influence of the drug, and a CIF of 10 was proposed as a threshold for a driving impairment [9]. When using the CIF, it must be kept in mind that the formula to calculate the CIF might significantly disadvantage one-time consumers and treat regular consumers preferentially.

THC consumption in doses up to 300 μg per kilogram body weight is considered to cause relevant cognitive and psychomotor impairments comparable to 0.5 g/l BAC [10]. Furthermore, THC concentrations of 7–10 ng/ml THC in serum are thought to evoke comparable impairments to 0.5 g/l BAC. THC serum concentrations below 10 ng/ml should not increase the risk of a traffic accident [11].

To examine the effects of cannabis regarding the ability required to ride a bicycle, practical cycling tests and medical examinations were carried out before and after inhalative consumption of cannabis (Cannabis flos, Bedrocan). The trial was pre-approved by the ethics committee of the University of Düsseldorf (study number: 4583R, registration ID: 2014022159).

Materials and methods

Test persons

Fourteen regular cannabis-consuming test subjects were included in the study (12 males, 2 females). The median age of the test subjects was 25 years. The mean age of the male test persons was 25.4 years (range 19–34 years) while the ages of the female test persons were 20 and 26 years. The regularly consumed amounts of cannabis varied between approximately 1 g per week and 1 g per day.

Inclusion and exclusion criteria

The following inclusion criteria had to be met: age (18–55 years), declaration of informed consent, ability to ride a bicycle (initial self-disclosure with check-up by the investigators at the course), healthy condition (including health certificate) and a history of regular consumption of cannabis (self-disclosure). The exclusion criteria were pregnancy, acute illnesses, history of substance abuse, intake of psychoactive medication, rare consumption of cannabis, and positive urine screening for drugs other than cannabis.

Course

The course described by Schewe et al. [13, 14] served as the basis for this study, and most of the course elements were adopted (driving straight ahead on a narrow track of 45 m in length, driving while slaloming between poles spaced at 1.20 m, driving around caps spaced at distances that decreased from 4 to 1.50 m, and circling clockwise) (for details, see [12]). However, the course (Fig. 1) was hindered by several new elements (reaction tests at a manually adjustable traffic light and stop lines; memory test of a random word that was presented on an LED display while driving; handling a complex situation—a ball rolling in front of the bicycle, a blocked path; being subjected to the glare of a torch light; verbal disturbances; and driving between moveable plastic barrels spaced at a distance of 1.20 m).

Safety arrangements and test area

The trials were carried out in a non-public area on a normal street ground in dry weather conditions. The trials lasted approximately 12 h. Special safety bicycles were used. To ride the bicycles, the test subjects had to wear a motorbike suit with knee, elbow, and spine protectors as well as a bicycle helmet.

Cameras

All rides were video recorded with a mobile camera (GoPro Hero3 Black Edition Outdoor, GoPro, USA) that was fixed to the handlebars of the bicycles and a second camera operated by a cameraman.

Basic experimental set-up

Before the trials started, each test subject underwent a breath alcohol test administered using Draeger 6510 Breathalyzers and a urine analysis for drugs other than cannabis. After the tests, the participants became familiar with the course (at least three cycling rounds or until the subjects felt secure). Then, the initial ("sober") test series were performed. For each test subject, trials were then performed shortly after each cannabis cigarette, and approximately 2 h after the cannabis consumption was terminated (Table 1). After each ride, a medical examination (examination report for suspicion of driving under the influence of alcohol or drugs) was performed, and a blood sample was taken by repeated venous punctures. Ophthalmological tests (time needed to read out a text of 50 words, time needed for completing a swinging test involving 10 touches of a moving fingertip, determination of the amplitude of fusion) were also carried out. Food and non-alcoholic beverages were provided during the trials.

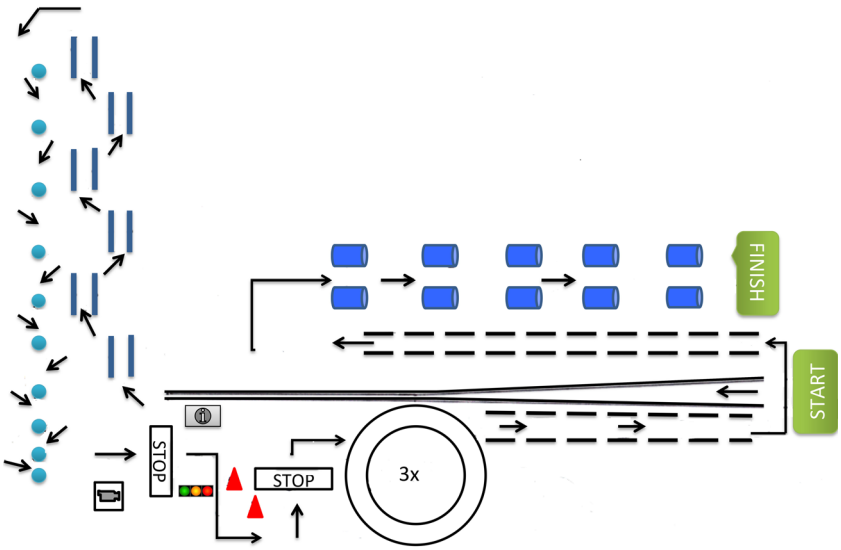

Fig. 1 Course

Toxicological analyses

The serum was stored in a fridge until analysis. All toxicological analyses were carried out by using fully validated gas chromatography/mass spectrometry (GC/MS) methods according to the current German forensic guidelines [15]. For the cannabis analyses, 20 µl of deuterated standard and 100 µl of isopropanol were transferred into a sample tube. Then, 0.5 ml of serum and 1 ml of acetonitrile were added, vortex mixed for 10 min, and centrifugated for 10 min at 14,000×*g* at 10 °C. Then, 1.4 ml of the organic layer was extracted by solid-phase extraction and evaporated to dryness at 50 °C. This residue was reconstituted in 200 µl of isooctane/MSTFA (200/10) and derivatised at 90 °C for 30 min. Then, 1 µl of the derivatised sample was injected into the GC/MS system using single ion monitoring mode.

For the liquid-liquid extraction of amphetamine and MDMA from serum, 50 µl of deuterated standard (D11-amphetamine resp. D5-MDMA) was added to 0.5 ml of the sample. Then, 0.5 ml of isooctane and 50 µl of 2 N NaOH were added, vortex mixed for 10 min, and centrifugated for 10 min at 14,000×*g* at 10 °C. Then, 0.2 ml of the organic layer was transferred into a glass vial, and 10 µl of MBTFA was added for derivatisation at 90 °C for 30 min. Then, 1 µl of the derivatised sample was injected into the GC/MS system using single ion monitoring mode.

Available cannabis

Dutch medical cannabis (Cannabis flos: Bedrocan, 22 % dronabinol, <1.0 % cannabidiol; supplier: Dutch Ministry of Health, Welfare and Sport, Office of Medicinal Cannabis, P.O. Box 16114, NL-2500 BC The Hague) was imported for the trials (import authorization no. E5304/2014) with allowance from the German Federal Opium Agency.

Cannabis consumption

The consumption of the cannabis cigarettes was standardized. Each joint contained 300 µg of THC per kilogram of body weight. The test persons were instructed to consume the joints in the following way: 4-s inhalation, 10-s holding breath, and 15-s exhalation. A maximum of three joints could be consumed.

Evaluation

To objectify the results of the practical cycling trials and the medical tests, demerits were allocated for certain distinctive features or driving faults (for details, see [12]). Regarding the driving faults, it was differentiated between coordinative faults (mainly motoric disturbances), concentrative faults (mainly due to cognitive impairments), and faults committed when a complex situation (e.g., a ball rolling in front of the bicycle) had to be handled. Within the coordinative faults, so called "severe coordinative faults" (*) were evaluated separately. The following demerits were allocated:

(a) Coordinative faults

- Leaving the track (circle or straight track) with both wheels = 3(*).
- Pushing over a barrel = 3.
- Leaving the track (circle or straight track) with one wheel = 2.
- Pushing over a pole or cap = 2.
- Difficulties initiating cycling = 2(*).
- Skipping an obstacle = 2.
- Driving in severely meandering lines = 2(*).
- Driving in moderately meandering lines = 1(*).

Table 1 Serum concentrations of THC, 11-OH-THC, and THC-COOH of test persons 1 to 14 (calibration ranges THC = 0–50 ng/ml, 11-OH-THC = 0–50 ng/ml, THC-COOH = 0–200 ng/ml; values above the calibration ranges were obtained by diluted serum analyses; asterisks (*) indicate cannabis consumption immediately before; Time (min) means the period of time between the start of the cannabis consumption and the draw of blood)

Test person	THC	11-OH-THC	THC-COOH	CIF	Time
1.1	9.0	2.1	125	9	–
1.2 (*)	114	9.0	110	>30	29
1.3 (*)	117	14	122	>30	91
1.4 (*)	81	14	135	>30	205
1.5	18	6.2	114	23	323
2.1	1,4	0.5	23	8	–
2.2 (*)	61	9.0	75	>30	31
2.3 (*)	23	5.6	73	>30	197
2.4 (*)	30	5.9	78	>30	320
2.5	10	3.8	77	19	390
3.1	4,4	1.4	131	4	–
3.2 (*)	117	8.9	118	>30	23
3.3 (*)	113	13	138	>30	110
3.4 (*)	88	14	159	>30	205
3.5	17	5.8	158	15	319
4.1	3,0	1.9	117	4	–
4.2 (*)	76	13	135	>30	23
4.3 (*)	39	13	155	>30	172
4.4 (*)	37	12	172	>30	320
4.5	10	5.9	149	11	372
5.1	0,6	0.2	14	0	–
5.2 (*)	18	3.6	29	>30	25
5.3	3,0	1.5	21	23	120
5.4 (*)	6,1	2.7	24	>30	198
5.5	1,8	1.1	18	17	315
6.1	<LOD	<LOD	11	0	–
6.2 (*)	6.8	2.0	16	>30	35
6.3 (*)	4.5	1.8	14	>30	100
6.4 (*)	7.3	3.1	23	>30	245
6.5	2.0	1.5	18	21	327
7.1	0.4	0.2	18	0	–
7.2 (*)	56	7.5	61	>30	26
7.3 (*)	31	8.3	71	>30	143
7.4 (*)	8.5	3.4	50	25	306
8.1	0.3	<LOD	3.6	0	–
8.2 (*)	44	5.1	31	>30	31
8.3 (*)	47	7.0	52	>30	140
8.4 (*)	32	10	70	>30	285
8.5	5.8	3.3	54	17	395
9.1	3.1	1,3	106	4	–
9.2 (*)	96	15	145	>30	26
9.3 (*)	48	9,1	146	>30	205
9.4	8.0	2,7	118	9	360
10.1	0.5	0,6	58	0	–
10.2 (*)	35	16	103	>30	31
10.3 (*)	25	15	112	>30	227
10.4	3.6	4.0	88	9	367
11.1	5.1	1.3	79	8	–
11.2 (*)	53	7.6	96	>30	28
11.3 (*)	30	6.8	120	>30	140
11.4 (*)	32	6.4	124	>30	220
11.5	11	3.6	76	21	325
12.1	7.2	2.4	103	10	–
12.2 (*)	79	12	98	>30	31
12.3 (*)	102	18	120	>30	140
12.4 (*)	113	20	117	>30	216
12.5	12	6.8	111	19	335
13.1	9.4	7.8	279	6	–
13.2 (*)	52	20	287	27	27
13.3 (*)	59	25	256	>30	135
13.4 (*)	42	24	259	27	250
13.5	11	10	234	10	365
14.1	0.3	0.3	5.4	0	–
14.2 (*)	8.2	2.2	11	>30	30
14.3 (*)	5.1	2.1	12	>30	197
14.4	0.9	0.6	7.8	22	316

- Touching a pole, cap or barrel = 1.
- Putting one or both feet on the ground without cause = 1.

(b) Concentrative faults

- Running a red light = 3.
- Running a yellow light = 2.
- (Inadequate) waiting at a green light = 1.
- Running a STOP line = 2.
- For each round that differed from the requested number of rounds ($N = 3$) in the circle = 1.
- Obliviousness to the word on LED display = 1.
- Partial obliviousness to the word on LED display = 0.5.

(c) Faults in complex situations

This distinction was based on adequate and inadequate reactions. Inadequate reactions were assigned three demerits.

In the medical examination report, the demerits were allocated in the same way as in the evaluation of cycling under the influence of alcohol [12, 16, 17].

Relative driving performance

The relative driving performance represents all of the described driving faults. The state of soberness was considered to be each individual's status of 100 % and served as the comparison for the following rides (e.g., a doubling of the allocated demerits would result in a relative driving performance of 50 %).

Statistical analyses

All results were evaluated both for three different groups of THC concentrations (<5, 5–15, >15 ng/ml) and for three different CIF groups (<10, 10–30, >30). Because two test persons had to be considered as acutely under the influence of amphetamines and MDMA (test persons 1 and 2, Table 2), all evaluations were carried out including and excluding the results of these two test persons. The presented figures declare the results of these two test persons separately (red crosses). p values were calculated for the three groups of different THC concentrations both including and excluding these two test persons. The presented p values are not adjusted for multiple testing.

Results

Serum concentration of THC, 11-OH-THC, and THC-COOH

The test persons' initial THC concentrations in serum (before smoking cannabis) varied between <LOD and 9.4 ng/ml. The initial THC-COOH concentrations ranged from 3.6 to 279 ng/ml. After the consumption of the joints, THC concentrations of up to 117 ng/ml were measured. Several test persons arrived with THC concentrations that indicated an acute or subacute influence of cannabis, e.g., test persons 1, 12 and 13. Immediately after smoking the cannabis cigarettes, the CIF regularly rose above 30 (Table 1).

Drug screening

Despite negative urine screening tests during the initial examinations, the follow-up examinations revealed the intake of amphetamines and/or MDMA of four test subjects. The test subjects did not show signs of an acute influence of these substances at the beginning of the trials. Test persons 3 and 9 had amphetamine concentrations that were considered to be no longer effective. The results of test persons 1 and 2 are indicated separately in the figures (red crosses).

Ophthalmological examinations

The average time required to read the 50-word text linearly did not significantly differ before and after the consumption of cannabis, and the median time remained constant between 16 and 17 s. The median time needed to touch the investigator's fingertip 10 times also remained constant and was between 10 and 11 s. The median amplitude of fusion decreased immediately after cannabis consumption (Fig. 2a, b) and increased again with falling THC concentration resp. CIF. No statistical significances were observed. It seems that the simultaneous influence of amphetamine/MDMA hinders the decrease in the amplitude of fusion.

Medical examination reports

Figure 3a, b illustrate the cumulative values of the distinctive features from the medical examination report for the different groups of THC concentrations (Fig. 3a) resp. the different CIF groups (Fig. 3b). Each of the evaluated features can be documented if the test person is cooperative. As shown in the figures, most test subjects presented some distinctive features after having smoked cannabis. However, several test subjects were unaffected after having smoked cannabis even under the influence of high THC concentrations and resp. high CIF values (black columns). If all test subjects are included in the evaluation of the unadjusted p value, a significant result is found ($p < 0.01$; adjusted $p = 0.01$). This significance diminishes when test persons 1 and 2 (MDMA and amphetamines) are excluded (unadjusted $p = 0.06$).

Driving faults

When the demerits allocated to any driving fault are taken into account (Fig. 4a, b), it can be seen that, on average, there is no increase in the number of demerits after the cannabis consumption. While the median demerits in the CIF groups below 10 and above 30 is 8 (Fig. 4b), the median demerits decreased from 9 to 8 only when the THC concentrations serve as a basis. There were no significant differences between the THC groups ($p = 0.81$).

Severe coordinative faults

Severe coordinative faults represent those coordinative faults that were considered to be imminently dangerous in road traffic (e.g., leaving the track). No severe coordinative faults were observed at THC concentrations

Table 2 Serum concentrations of amphetamine and MDMA of the positive test subjects (calibration ranges amphetamine: 0–750 ng/ml, MDMA 0–750 ng/ml)

Test person	Amphetamine	MDMA
1.1	13	48
1.5	11	24
2.1	148	29
2.5	91	16
3.1	3	<LOD
9.1	9	<LOD

below 5 ng/ml or at a CIF below 10 (Fig. 5a, b). Single severe faults were observed after smoking cannabis, especially when a few hours had passed after the last cannabis consumption (columns in the middle).

Relative driving performance

The demerits of each participant's driving performance in the state before cannabis consumption started were taken

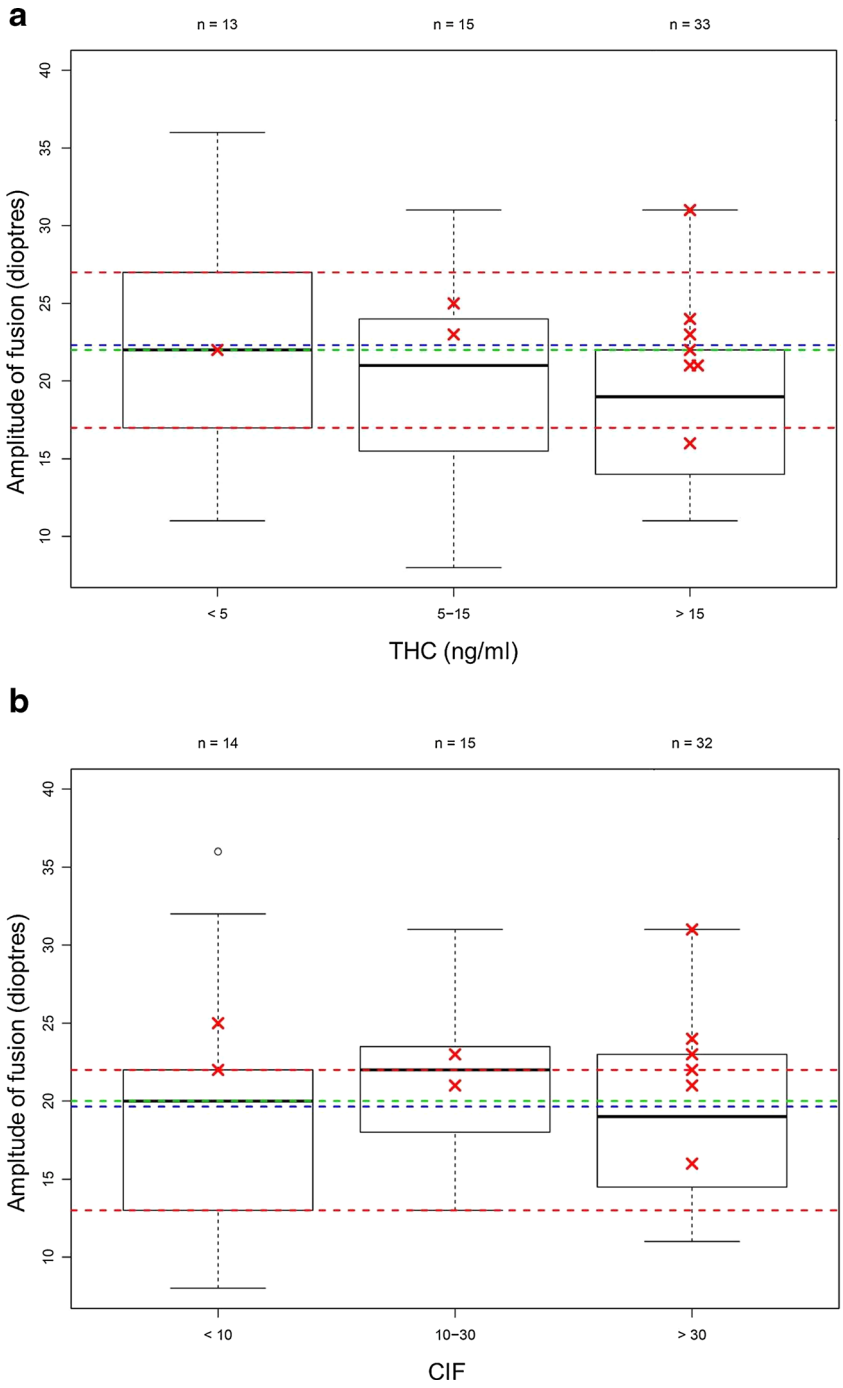

Fig. 2 **a** Amplitude of fusion (in dioptres) in relation to the different groups of THC concentrations (the *boxes* contain 50 % of the examinations, the *black lines* indicate the median, the satellites indicate 25 % of the examination, the *crosses* indicate the examinations of the test persons 1 and 2 who were under the influence of amphetamine and MDMA). **b** Amplitude of fusion (in dioptres) in relation to the different CIF groups (the *boxes* contain 50 % of the examinations, the *black lines* indicate the median, the satellites indicate 25 % of the examination, the *crosses* indicate the examinations of the test persons 1 and 2 who were under the influence of amphetamine and MDMA)

as the 100 % performance value. This performance value served as a comparison for the subsequent rides. As shown in Fig. 6a, b, the relative driving performance remained almost constant. Test persons 1 and 2 (influence of MDMA and amphetamines) showed worsening results with ongoing trials. The spike in the columns of the middle of both Fig. 6a, b (700 %) can be explained by a very uneventful last ride of one test person. Only one demerit was allocated during this last ride, while seven demerits were allocated for the initial ride.

Discussion

The presented data contribute to the poor understanding of the effects of cannabis in regular cannabis consumers when

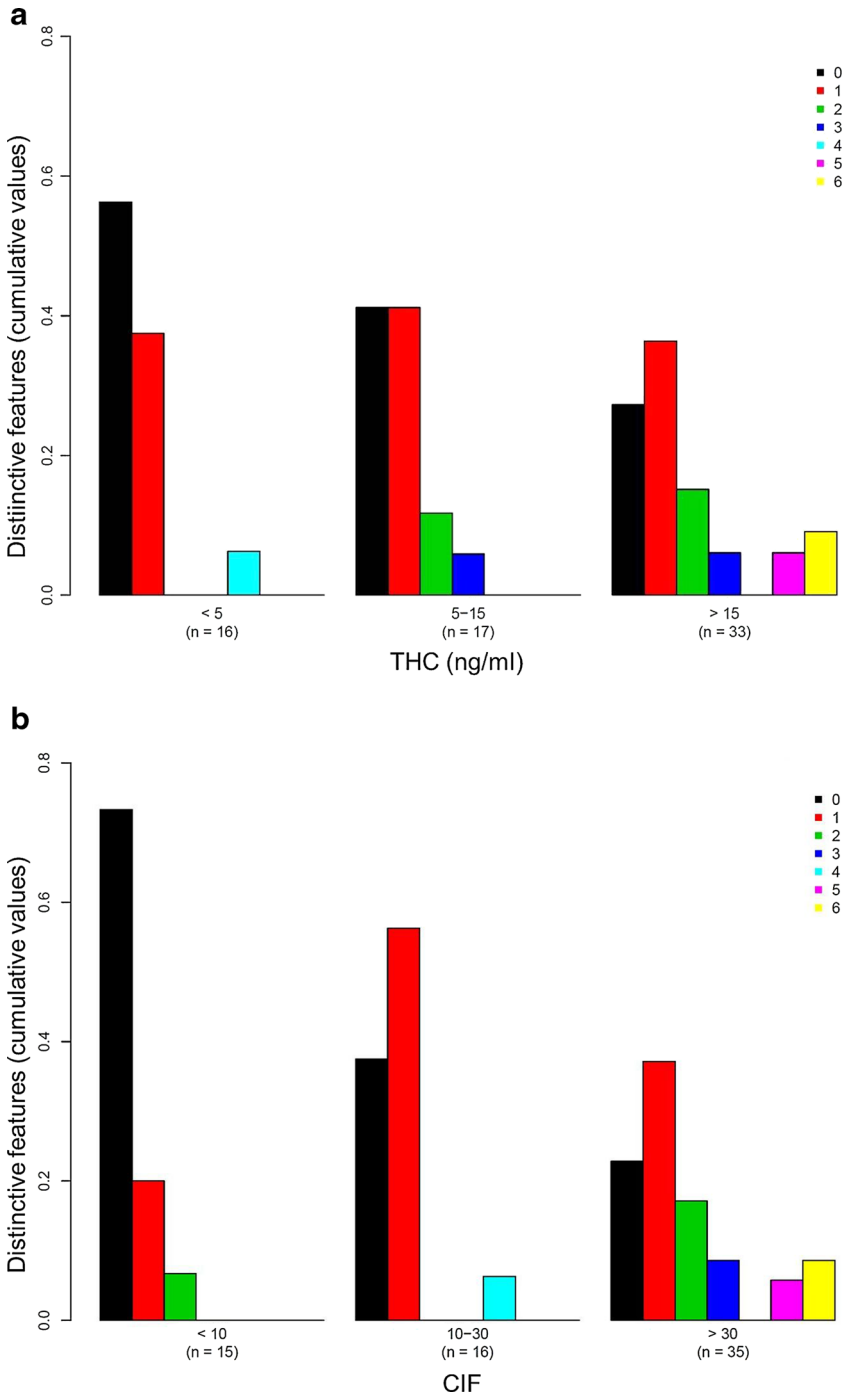

Fig. 3 **a** Cumulative values of the distinctive features from the medical examination report in relation to the different groups of THC concentrations (column colors: *black* none, *red* one, *green* two, *blue* 3, *light blue* 4, *pink* 5, *yellow* 6). **b** Cumulative values of the distinctive features from the medical examination report in relation to the different CIF groups (column colors: *black* none, *red* one, *green* two, *blue* 3, *light blue* 4, *pink* 5, *yellow* 6)

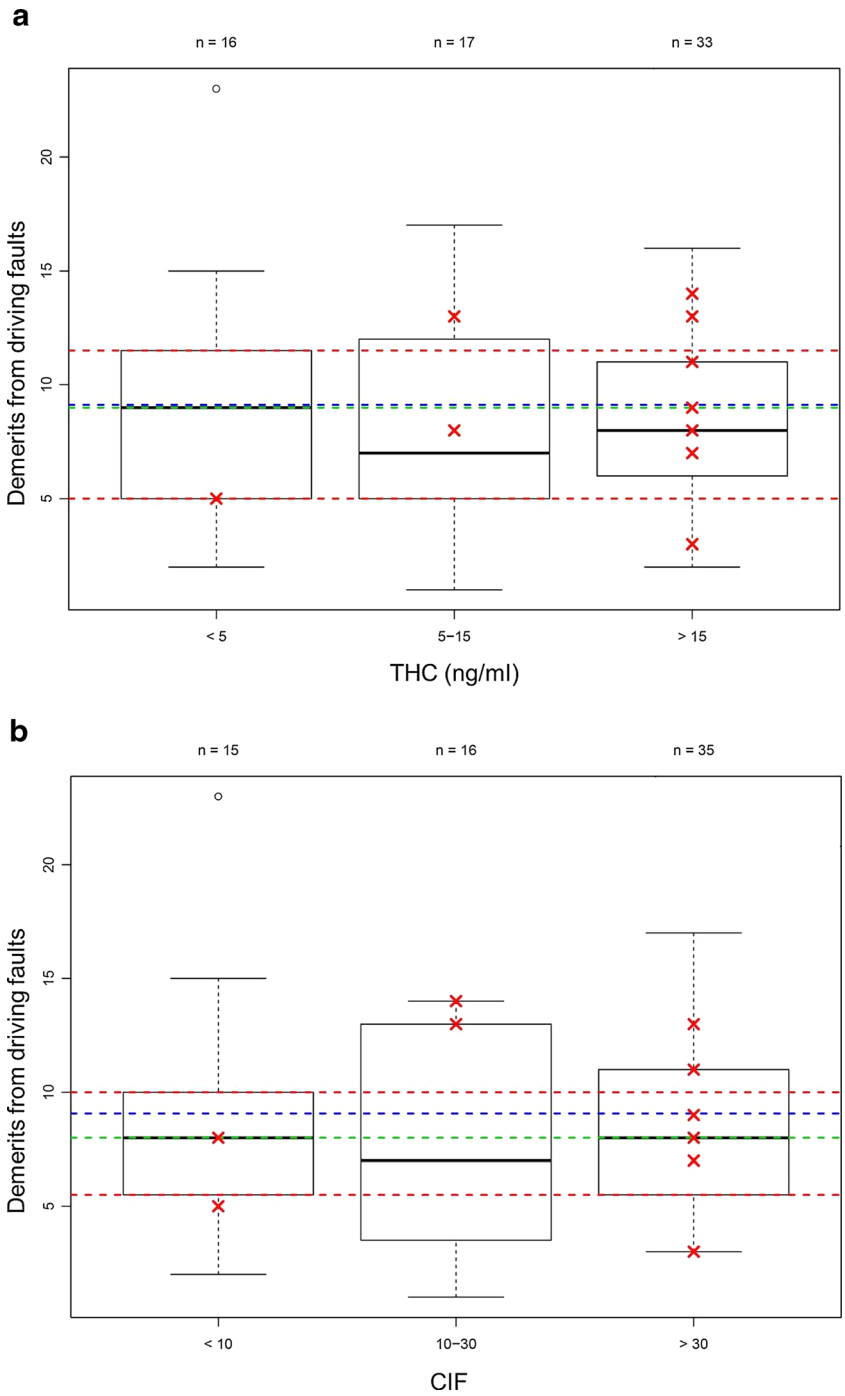

Fig. 4 **a** Demerits from any driving fault in relation to the different groups of THC concentrations (the *boxes* contain 50 % of the examinations, the *black lines* indicate the median, the *satellites* indicate 25 % of the examination, the *crosses* indicate the examinations of test persons 1 and 2 who were under the influence of amphetamines and MDMA). **b** Demerits from any driving fault in relation to the different CIF groups (the *boxes* contain 50 % of the examinations, the *black lines* indicate the median, the *satellites* indicate 25 % of the examination, the crosses indicate the examinations of the test persons 1 and 2 who were under the influence of amphetamines and MDMA)

cycling in road traffic. The study is limited by the small, male-dominated test group, by the fact that four test persons showed positive results for amphetamine/MDMA, and by the fact that only one test person showed a THC concentration below the limit of detection when the study began. However, the age and gender of the test persons are representative of the group of persons who are regularly found driving under the influence of cannabis products [1].

Hardly any coordinative disturbances could be detected under the influence of high or very high THC concentrations. No significant changes under the influence of cannabis were observed when the two test persons who were under the influence of amphetamines and/or MDMA were excluded from the analyses. The three described THC groups and the three CIF groups showed comparable results. These results are in accordance with the conclusion of Robbe [18] that a causal

relationship between cannabis smoking and impaired driving or the risk of accident involvement has not been convincingly demonstrated yet.

Cannabis consumers are more likely to be detected by distinctive features presented during medical examinations than by driving faults. Some of these distinctive features can become relevant in traffic situations, e.g., dilated pupils or an indifferent mood. The lowest amplitudes of fusion were observed immediately after the cannabis consumption, which indicates an increased risk of diplopic images during the acute phase. It seems that the simultaneous influence of amphetamine/MDMA hinders the decrease in the amplitude of fusion.

A cannabis influence factor above 30 was regularly observed shortly after the inhalative cannabis consumption was finished and can be considered a sign of an acute intoxication. A defined THC concentration or a CIF that leads to an impairment to ride a bicycle cannot be suggested. Some test persons with THC concentrations above 100 ng/ml partially rode their bicycles in a way that was not more suspicious than the way the test persons rode their bicycles during the initial rides (test

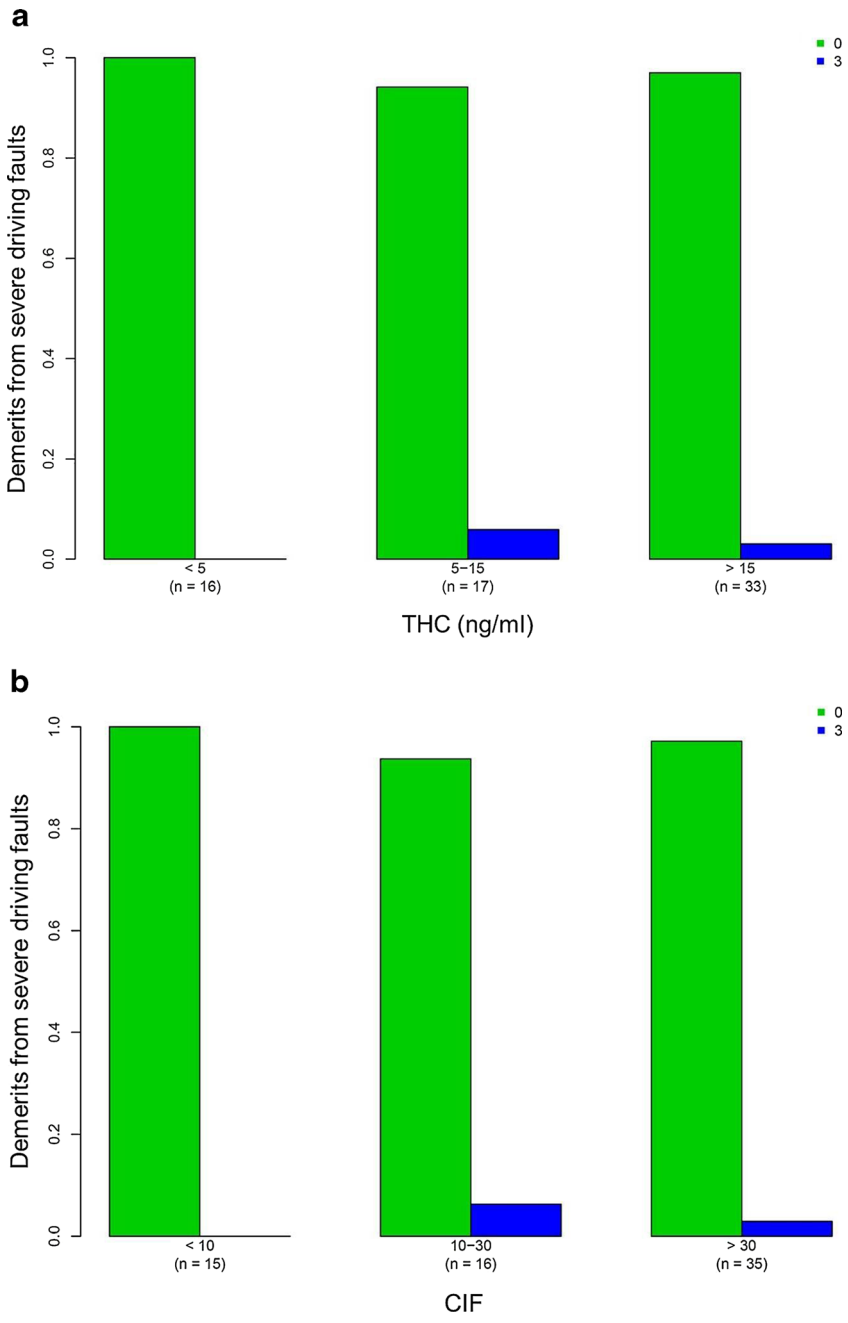

Fig. 5 **a** Demerits from severe driving faults in relation to the different groups of THC concentrations (column colors: *green* none, *blue* three). **b** Demerits from severe driving faults in relation to the different CIF groups (column colors: *green* none, *blue* three)

persons 1 and 12) or in comparison to the initial (sober) rides of other test subjects.

Additionally, no comparison can be drawn between the effect of a body weight-adapted joint (300 μg THC per kg body weight) and the effect of a certain BAC [10, 11] on cyclists' performances. THC concentrations and BAC are hard to compare due to the completely different ways they are metabolized and eliminated from the body. Additionally, hardly any driving faults occurred under the influence of cannabis. However, the demerits from any driving faults between the group of cannabis consumers with THC concentrations below 5 ng/ml (median: nine demerits) and the sober alcohol test persons [12, 16, 17] are comparable. Individual assessments will be necessary unless larger trials with larger numbers of test persons reveal a contradictory result.

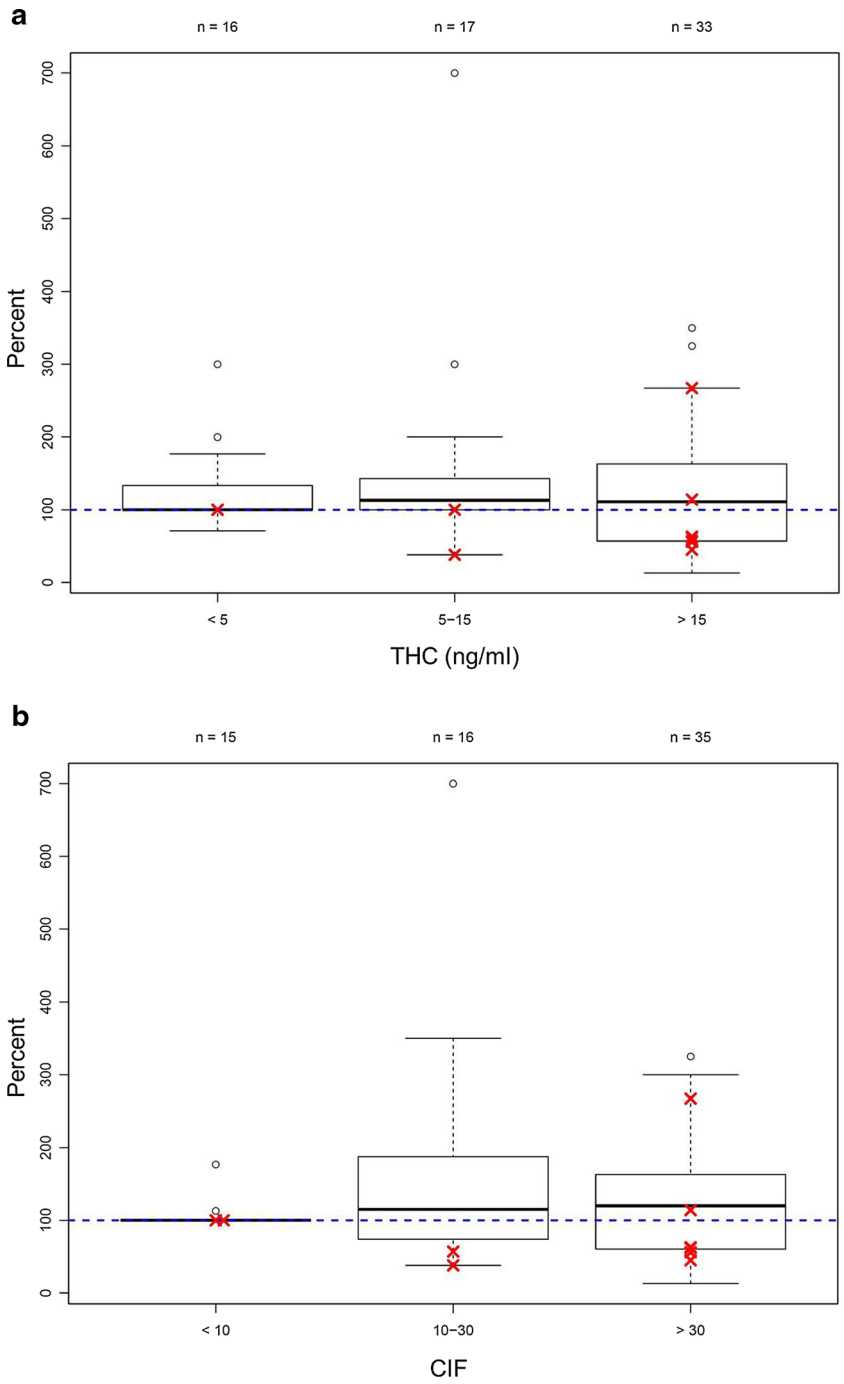

Fig. 6 **a** Relative driving performance considering all driving faults in relation to the different groups of THC concentrations (the boxes contain 50 % of the examinations, the *black lines* indicate the median, the *satellites* indicate 25 % of the examination, the *crosses* indicate the examinations of test persons 1 and 2 who were under the influence of amphetamine and MDMA). **b** Relative driving performance considering all driving faults in relation to the different CIF groups (the *boxes* contain 50 % of the examinations, the *black lines* indicate the median, the *satellites* indicate 25 % of the examination, the *crosses* indicate the examinations of test persons 1 and 2 who were under the influence of amphetamine and MDMA)

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Compliance with ethical standards

Ethical standards The experiments of this study comply with the current German laws. The study protocol was pre-approved by the ethics committee of the University Hospital Düsseldorf.

Conflict of interest The authors declare that they have no competing interests.

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