Int J Legal Med (2015) 129:471–480
DOI 10.1007/s00414-014-1104-z

ORIGINAL ARTICLE

Regarding the fitness to ride a bicycle under the acute influence of alcohol

Benno Hartung · Nona Mindiashvili · Rüdiger Maatz · Holger Schwender · Eckhard H. Roth · Stefanie Ritz-Timme · Justin Moody · Axel Malczyk · Thomas Daldrup

Received: 8 August 2014 / Accepted: 30 October 2014 / Published online: 27 November 2014

Abstract To determine the threshold for the absolute inability to ride a bicycle, practical cycling tests and medical examinations at different blood alcohol concentrations were performed. Special attention was given to additional medical examinations, reaction tests and alcohol consumption under real-life conditions. Seventy-eight test subjects were included in the trials (37 females, 41 males). Five test subjects participated twice; thus, there were a total of 83 evaluable trials. Alcohol-related deficits were already identifiable at very low BACs. A significant increase in gross motoric disturbances compared to the soberness state did not regularly occur until a BAC of at least 0.8 g/kg was reached. At the BAC of 1.4 g/kg and above, no test subjects were able to achieve or surpass their sober driving results. Isolated highly alcoholised test subjects rode the bike in a manner that was not conspicuously different than the other sober test persons. Contrary to the assumptions of current German legal practise, it cannot be stated that all people are 'absolutely impaired' to the point of being incapable of riding bicycle at BACs of at least 1.6 g/kg.

B. Hartung (✉) · N. Mindiashvili · S. Ritz-Timme · J. Moody · T. Daldrup
Institute of Legal Medicine, University Hospital Duesseldorf, Duesseldorf, Germany
e-mail: benno.hartung@med.uni-duesseldorf.de

R. Maatz
Federal Court of Justice, Karlsruhe, Germany

H. Schwender
Institute of Mathematics, Heinrich-Heine-University, Duesseldorf, Germany

E. H. Roth
Augenzentrum Friedrichstadt, Duesseldorf, Germany

A. Malczyk
German Insurers Accident Research (UDV), German Insurance Association, Berlin, Germany

Keywords Alcohol · Bicycle · Impairment to drive · Driving performance · overall performance

Introduction

Compared to motor vehicle operators, cyclists are at a proportionally higher level of vulnerability in daily traffic, and this difference has led to frequent discussions about the needs and obligations of cyclists. National accident data from 20 European countries (i.e. Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden and the United Kingdom) revealed 1994 bicycle fatalities in 2010, which account for 6.8 % of the total number of fatal traffic accidents in these countries. In 2001, 3217 cyclist fatalities were reported by the police in these 20 countries. The deceased were counted as traffic fatalities when death occurred within 30 days of the accident. However, it can be assumed that bicycle accidents occur far more often than indicated in police records [1]. Although there have been stepwise decreases in cyclist fatalities in nearly all countries, Romania exhibited a significant increase from 145 in 2001 to 182 in 2010 for unclear reasons. While cyclist fatalities compose approximately 20 % of all fatal traffic accidents in the Netherlands (available data 2001–2009), they only contribute to approximately 2 % to all traffic fatalities in Spain (2001–2010). The typical victim is male and over the age of 60 years [2]. The majority of bicycle accidents (60–95 %) that require hospital care are caused by the cyclist themselves [3], which supports the theory that riding a bike is the most dangerous for the cyclists themselves.

In Germany, alcohol-associated bicycle crashes with injured cyclists comprised between 4.5 and 5.8 % of all bicycle-related injuries during the period of time from 1991 to 2012. A total of 3726 bicycle-related injuries were thought to be caused by the influence of alcohol [4].

Alcohol intoxication is one of the most essential risk factors for injury [5]. Craniocerebral injuries are the most common fatal injuries sustained by bicycle riders and are considered to account for approximately one-third of all bicycle-related injuries [6]. Although helmet use undoubtedly has protective effects for non-alcoholised cyclists, the effect for inebriated riders is confounding, as helmet use was associated with the degree of injury for this subgroup [7].

Alcohol affects the ability to operate a vehicle in several ways (e.g. lack of concentration, prolonged reaction time, motoric disturbances, lack of balance, blurred vision and tunnel vision) and the alcohol-triggered disappearance of psychic inhibitions regularly leads to increased risk-taking (e.g. [8–10]) that can result in injuries. Therefore, it can be logically assumed that fewer alcoholised drivers would lead to fewer injuries/fatalities in daily European traffic. It has even been shown that injury severity increases exponentially with the level of alcoholisation [11, 12].

In different European countries, several different blood alcohol concentration (BAC) limits for bicycle riders exist. While the Czech Republic and Slovakia have established a 'zero tolerance for alcohol in traffic' policy with BAC limits of 0.0 g/L and fines starting at 150€, Great Britain, Ireland, Finland and the Scandinavian countries have no fixed BAC limits for bicycle riders [13]. In German jurisdictions, there is a differentiation between relative and absolute impairment in the fitness to drive ('Fahrunsicherheit'). Both actions are punishable according to §316 of the German Criminal Code ('Strafgesetzbuch'). Additionally, an impaired cyclist can be punished according to §315 c if he endangers another person or an object of considerable value by the way of cycling. For a criminal conviction based on this chapter, there is no legal definition of when the jurisdiction has the ability to assume that a bicycle rider is impaired. In cases of 'relative' impairment of driving fitness, the bicycle rider has to commit an alcohol-related operational fault, and thus the exact BAC at the time of driving is of minor importance. In cases of 'absolute' impairments in driving fitness, the criminal conviction is determined only by the exact BAC. As the legislature has left vast space for interpretation of §316, the Federal Court of Justice ('Bundesgerichtshof') itself was forced to handle this question and concluded in 1986 that cyclists under the influence of alcohol with BACs of at least 1.7 g/kg[1] are unfit to ride a bicycle [14]. The BAC of 1.7 g/kg includes a safety margin of 0.2 g/kg, which was later reduced to 0.1 g/kg; thus, the relevant BAC is 1.6 g/kg. The jurisdictive requirements to define the threshold of 'absolute impairment' are very strict, as the specific BAC is required to be the level at which 'every single person' is unable to operate a bike 'beyond the shadow of a doubt'. This level should be determined according to the current scientific knowledge. The results of practical trials are given special attention, as they surpass theoretical considerations. The mentioned verdict [14] was based mainly on the results of the practical trials performed by Schewe et al. [15, 16], which intended to represent traffic situations, that cyclists have to take into account at every time (driving straight ahead on a narrowing track, driving while slaloming between poles spaced at 1.20 m, driving around caps spaced at distances that decreased from 4 m to 1.50 m, circling clockwise and anticlockwise). At BACs of around 1.5 g/kg, all test persons were considered to be impaired to ride a bicycle; as at these BACs, all test persons showed more distinctive features than in the state of soberness. However, the trials have been criticised methodologically in subsequent discussions (e.g. no considerations were given to the morning consumption of alcohol or courses without interactive challenges).

To answer the question whether a BAC of 1.6 g/kg might still be too high as a threshold for the absolute inability to drive, practical driving tests with medical examinations at different BACs were performed. Special attention was given to the accompanying medical examinations, reaction tests and alcohol consumption under real-life conditions, which means that there was no rigid drinking protocol. The trial was pre-approved by the ethics committee of the University of Duesseldorf.

Materials and methods

Test persons

Seventy-eight test subjects were included in the trials (37 females, 41 males). Five test persons participated twice; thus, there were a total of 83 evaluable trials. The median age was 25 years (range: 18–53 years, for details see Fig. 1). The test subjects were required to meet the following inclusion criteria:

- Age between 18 and 53 years.
- Ability to drive a bicycle.
- Certificate of health.
- Experience with the consumption of alcohol (no abstinent individuals were included).
- Declaration of informed consent.
- Negative urine screening for drugs. Test persons with positive results were allowed to participate conditionally if there were no signs of acute clinical disturbances. Blood samples were specifically examined for active agents. Only when the blood samples revealed no relevant concentrations of the drug this inclusion criterion was considered to be met.

The exclusion criteria were acute illnesses, a history of drug abuse, regular medication, disturbances in liver functioning and pregnancy.

[1] In Germany, forensic relevant blood alcohol concentrations are expressed in gram of alcohol per kilogram of blood.

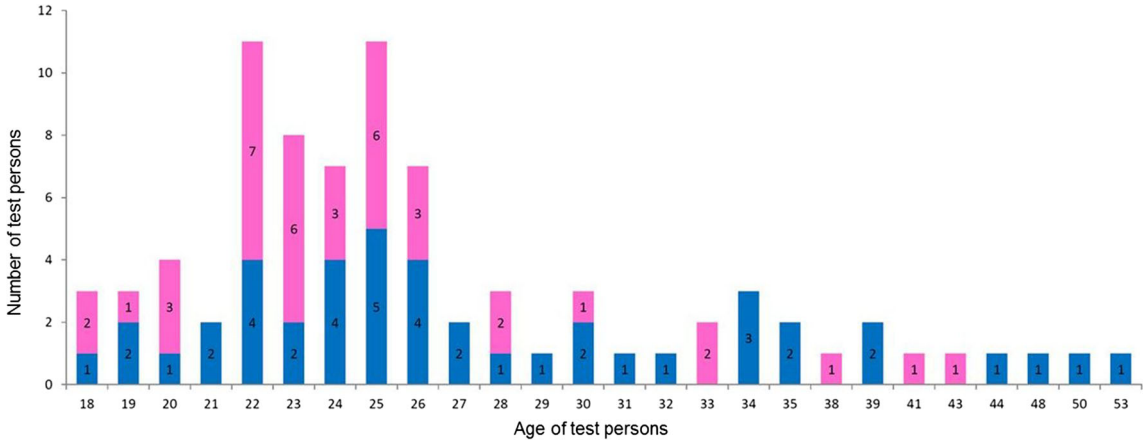


Fig. 1 Age distribution of the test persons (*red*: females; *blue*: males)

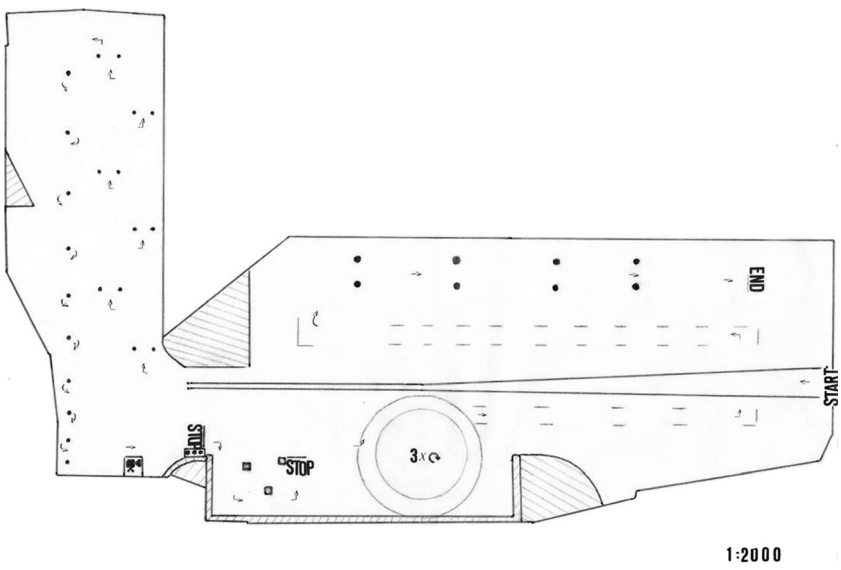
Course

Our course was based on the course described by Schewe et al. [15, 16]; however, several new elements were integrated (Fig. 2). The elements adopted included the following: driving straight ahead on a narrowing track of 45 m (metres) length ('START'), driving while slaloming between poles spaced at 1.20 m, driving around caps spaced at distances that decreased from 4 m to 1.50 m and circling clockwise. The new elements were the following: reaction tests at stop-lines and a manually adjustable traffic light, a memory test of a random word that was presented on a LED display while driving, handling a complex situation (e.g. a ball rolling in front of the bicycle, a blocked path, being subjected to the glare of a torch light and verbal disturbances; shown by the *dashed lines* in Fig. 2) and driving between moveable plastic barrels (spaced at a distance of 1.20 m).

Bicycles and test area

The trials took place in a non-public area on asphalt on six different days with different weather conditions that included rain and lasted up to 24 h. Special safety bicycles with cushioned handlebars and without crossbars were used. The bikes were equipped with two extra wheels on the rear bogie wheel. These stabilising wheels were fixed on outriggers and were located 6.7 in (17 cm) over the ground in a distance of 13.8 in (35 cm) from the bogie wheels. These wheels only contacted the ground in cases of excessive bicycle tilt when a fall was imminent. Riding the bikes was only allowed when the subjects were wearing a complete motorcycle protective suit with knee, elbow and spine protectors and a bicycle helmet. However, the protective gear allowed sufficient comfort and mobility for the test persons.

Fig. 2 Course



Cameras

All rides were video recorded with two different cameras. A mobile camera (Go Pro Hero 3) was fixed to the handle bars of the bicycles. A camera booth for a movie camera was installed at a central place in the course.

Basic experimental set-up

Driving test and medical examinations at different BACs (including sobriety) were performed. To minimise habituation effects, all test persons were initially advised to make themselves familiar with the test course and to the test bikes for at least three rides. After acclimating to the test, all participants were asked to perform their sober ride (0.0 g/kg). The medical tests included the examination report for suspicion of driving under the influence of alcohol before each ride and ophthalmological tests (e.g. amplitude of fusion, time required to read a 50-word text, a swinging-test involving ten touches of a moving fingertip) after each ride. After completing the sober test, the participants were allowed to drink alcohol according to their individual preference. Draeger 6510 Breathalyzers were used to approximately estimate the breath-alcohol concentrations (BrAC) while drinking. At each BrAC step of approximately 0.15 mg/l, the participants were asked to reliably check their exact BrAC with the Draeger 9510 DE Evidential, equipped with the software which is also used by German investigative authorities. If the assumed BrAC was confirmed by Draeger 9510 DE Evidential, a new test series started by drawing blood and the examination for suspicion of driving under the influence of alcohol. Afterwards, the test persons were asked to ride the bike. Finally, the ophthalmological examinations were carried out. After completion of the ophthalmological tests, the test persons were allowed to >carry on drinking alcohol. Partially, test persons skipped the intended steps of 0.15 mg/l. The participants were allowed to stop drinking at any time, and they were required to stop drinking when signs of alcohol intoxication occurred (e.g. vomiting or severe imbalance).

Alcohol

The most common local alcoholic beverages and mixed drinks with these beverages were available (Altbier, cordials, corn schnapps, pils, red wine, white wine, rum and vodka).

Insurance

No-fault insurance was contracted for all involved persons.

Ophthalmological examinations

The amplitude of fusion was measured in dioptres. The time needed to read the 50-word text and the time required to perform the tenfold touching of the moving fingertip of the investigator were measured in seconds.

Evaluation

To objectively evaluate the results of the *examination reports and the practical trials*, demerits were allocated for distinctive features. The more noticeable problems were considered to be caused by alcohol, the more demerits were allocated in the medical examinations. The distinctive features mentioned in the examination report were considered to be comparable regarding its explanatory power of alcoholisation and a maximum of 2 demerits was allocated for every single distinctive feature. As no test person reached the state of unconsciousness, 2 demerits were allocated for the state of confusion. For the evaluation of the bicycle rides, more demerits were allocated for distinctive features that seemed to be of greater abstract relevance to traffic. A maximum of 3 demerits could be gained for a single distinctive feature. The demerits were allocated in the following manner:

Demerits for the examination report

- Finger-finger-test, nose-finger-test, walking straight ahead, sudden turnarounds while walking: secure 0; borderline 1; insecure 2
- Speech: clear 0; borderline 0.5; slowed 1; slurred 2
- Consciousness: clear 0; dazed 1; confused 2
- Formal thought process: without pathologic findings 0; accelerated, decelerated, adhesive, hectic, repetitive 1; distracted 2
- Mood: balanced 0; talkative, upset, nervous, distanced, introverted 1; provocative, aggressive, offensive 2
- Subjective condition: normal 0; sweating, freezing, headache, tiredness, thirst 1; nausea, vertigo 2

Demerits for the bicycle rides

It was differentiated between three types of faults: coordinative faults (primarily based on motoric disturbances), concentrative faults (primarily based on cognitive impairments), and faults committed when a complex situation had to be handled.

(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 driving, 2

Skipping an obstacle, 2
Driving in severely meandering lines, 2
Driving in moderately meandering lines, 1
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 word on LED display, 1
Partial obliviousness to word on LED display, 0.5

(c) *Faults in complex situations*

It was differentiated only between adequate and inadequate reactions. Inadequate reactions were assigned 3 demerits.

Severe coordinative faults

Additionally, those coordinative faults that were considered to be imminently dangerous ('severe coordinative faults') in daily road traffic were evaluated separately from all coordinative faults. The following faults were chosen: leaving the track (circle or straight track) with both wheels; difficulties initiating cycling; and (severe or moderate) driving in meandering lines (demerits as stated above).

Relative driving performance

All driving faults as described above that were committed were accounted for in the evaluation of the relative driving performance. Here, the driving performance in the state of soberness was considered to be 100 % and served as the comparison for the subsequent rides. A doubling of the allocated faults committed while sober was considered to represent a relative driving performance of 50 %.

Results

Maximum achieved BACs

The maximum BACs are illustrated in Fig. 3. The trials were stopped early for nine test persons (test persons 8, 10, 29, 45, 49, 57, 59, 73, 74) either due to the objective effects of alcohol (e.g. vomiting and falling over) or due to subjective discomfort.

Drug screening

Three test persons exhibited positive urine screening tests for cannabis; however, there were no indications of acute influences of cannabis. Other illegal substances were not detected. The urine sample of one test person revealed the intake of metoprolol, and the urine sample of another subject revealed lamotrigine and quetiapine.

Ophthalmological examinations

The average time required to read the 50-word text linearly increased with BAC. The average time needed to touch the investigator's fingertip ten times remained constant and was between 10 and 11 s. However, the general amplitude of fusion linearly decreased with rising BAC (Fig. 4), and the range was wide. At BACs greater than 1.2 g/kg, the amplitudes of fusion were significantly lower than that during the sober examination (p=0.0020).

Examination reports for the suspicion of driving under the influence of alcohol

Figure 5 illustrates the cumulative values of all of the traffic-relevant distinctive features. All of the evaluated features can be observed in cooperative participant and are routine examinations of persons that are suspected of driving under the influence of alcohol. An exponential increase in the cumulative values was observed at BACs greater than 1.0 g/kg. Here, only one single test person did not show exhibit of these features above the BAC of 1.0 g/kg. The test persons with low BACs (up to 0.2 g/kg) already exhibited significantly more distinctive features than did the sober subjects (p= 0.047). No test person reached the state of unconsciousness.

Coordinative faults

As shown in Fig. 6, the sum of all coordinative faults committed during the sober rides varied widely. Nevertheless, under the influence of low BACs (up to 0.2 g/kg), nominally significantly more mistakes were committed (p=0.02) compared to the state of soberness. After a phase of minor increase with increasing BAC, the demerits increased rapidly at high BACs of around 1.4 g/kg and more. Figure 6 also shows some isolated test persons that collected far fewer demerits at high (1.0–1.6 g/kg) and very high (above 1.6 g/kg) BACs than did other subjects while not under the influence of alcohol.

Severe coordinative faults

Close examination of the coordinative faults that were considered to be imminently dangerous in road traffic (e.g. leaving the track with both wheels, difficulties initiating driving,

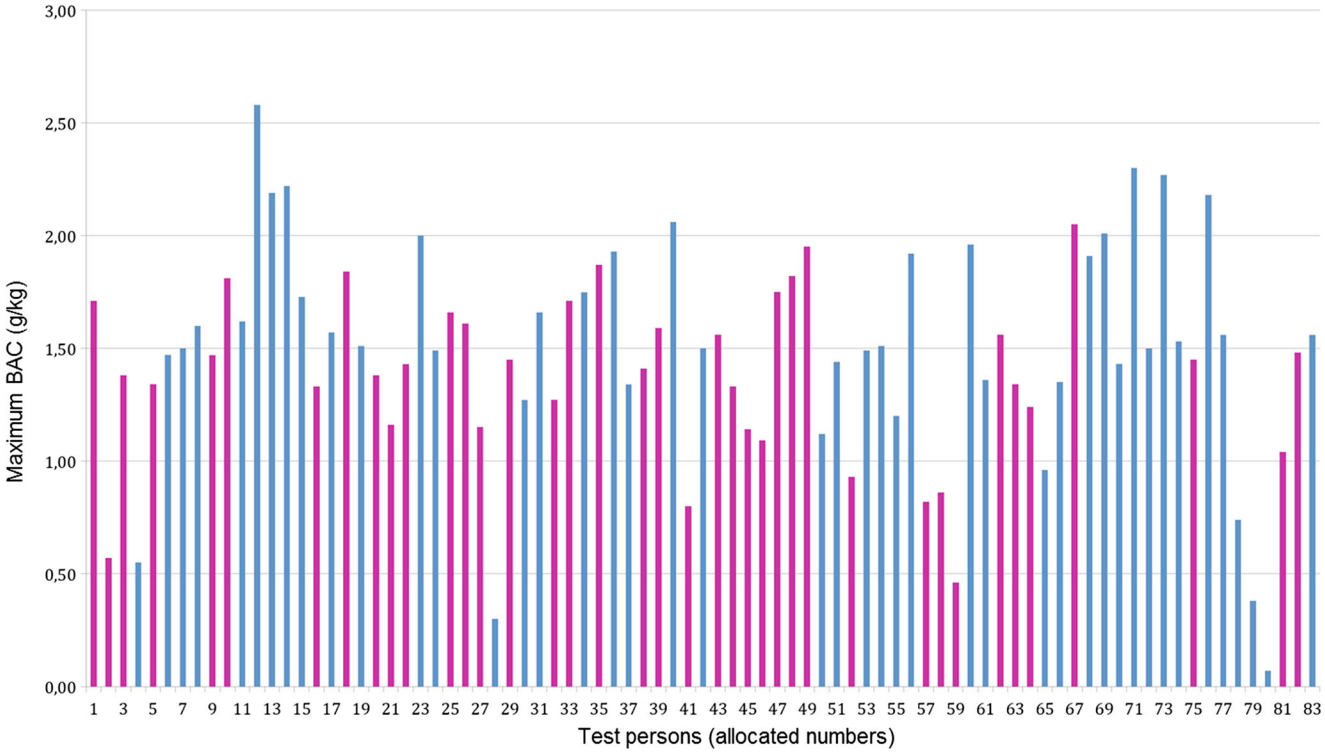


Fig. 3 Maximum BAC per test person (*red*: females; *blue*: males)

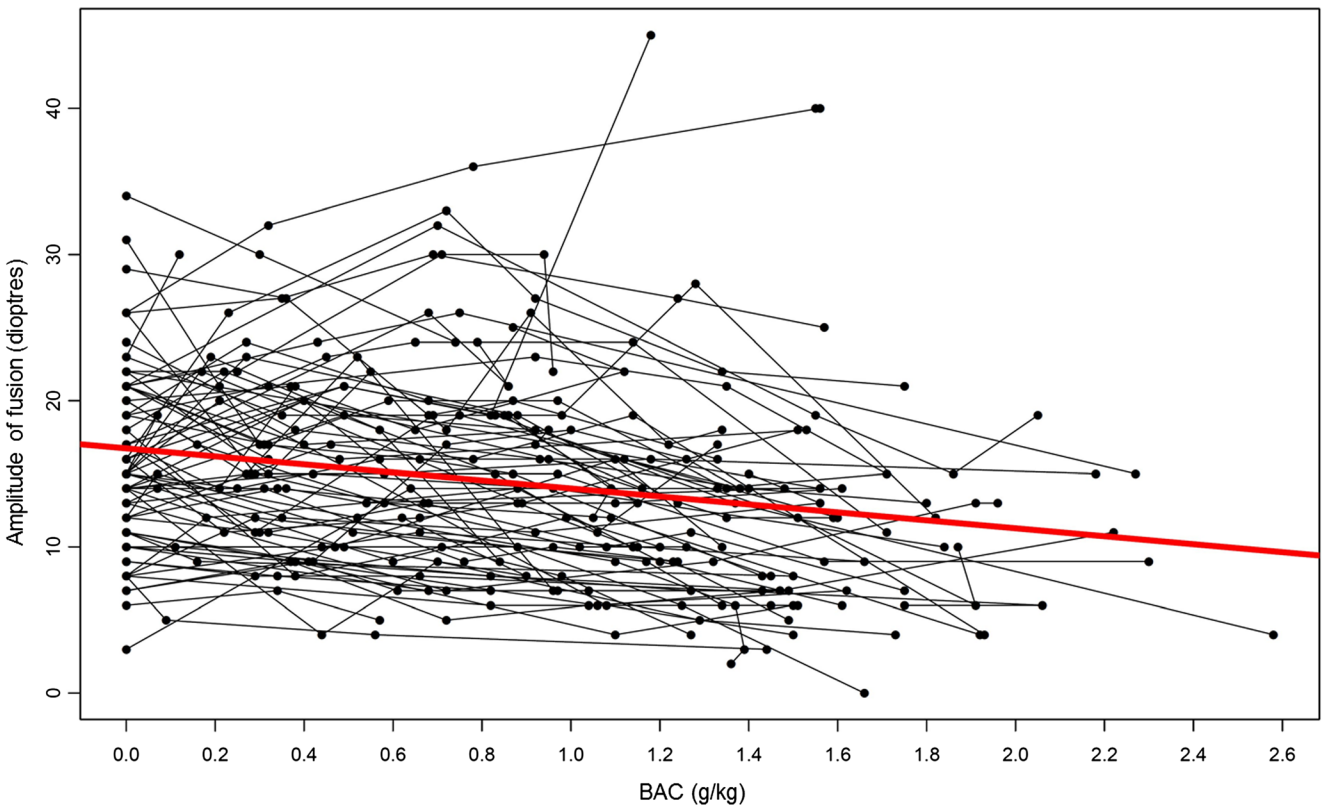


Fig. 4 Amplitude of fusion in relation to BAC (the *dots* indicate the examinations, and the *black lines* connect examinations of each single test person; regression analysis by Poisson regression)

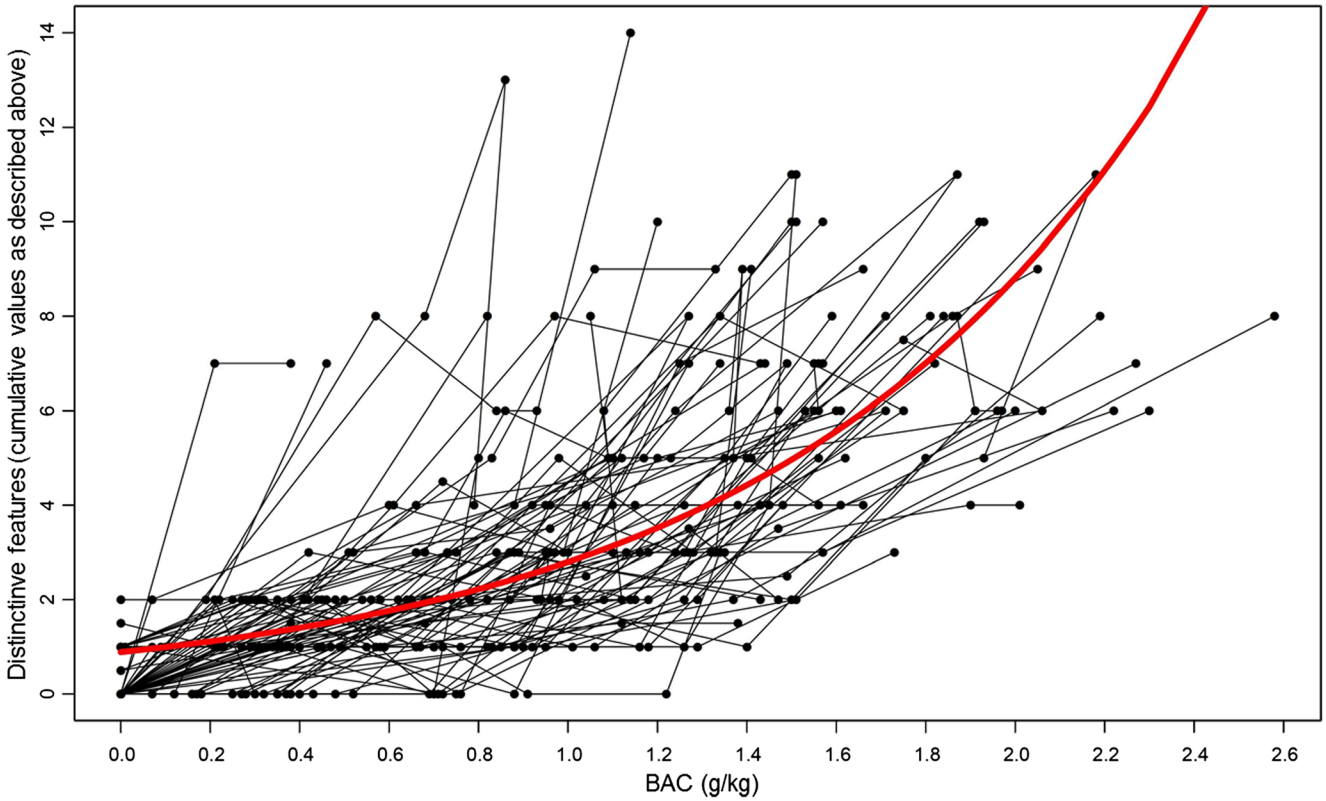


Fig. 5 Distinctive features from the medical examination reports in relation to BAC (the *dots* indicate driving trials, and the *black lines* connect the driving trials of each single test person; regression analysis by Poisson regression)

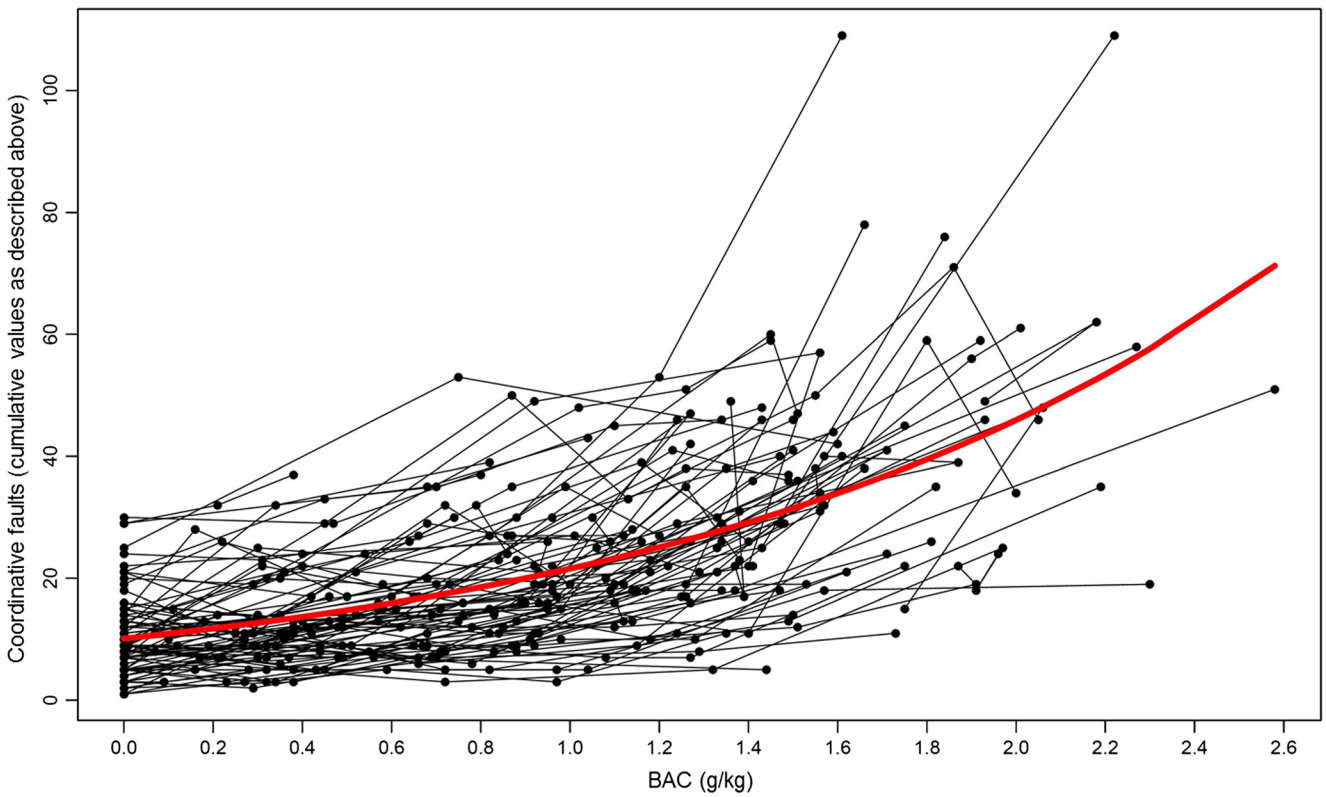


Fig. 6 Coordinative faults in relation to BAC (the *dots* indicate the driving trials, and the *black lines* connect the driving trials of each single test person; regression analysis by Poisson regression)

driving in meandering lines) were responsible for a significant increase in the number of demerits at BACs greater than 0.8 g/kg compared to the sober rides (p=0.0042). Notably, isolated test persons committed none of these faults even at very high BACs, e.g. above 1.6 g/kg (Fig. 7).

Relative driving performance

Each participant's driving performance in the state of soberness was taken as 100 % and served for comparison to the subsequent rides. As shown in Fig. 8, a considerable number of subjects improved their driving performances at low BACs (0.2 to 0.6 g/kg), although the median driving performance of all subjects significantly decreased beginning at very low BACs (up to 0.2 g/kg; p=0.02). At BACs between 0.4 and 1.2 g/kg, only a moderate decrease in driving performance could be observed. At BACs between 1.2 and 1.4 g/kg, only two test persons were able to improve their driving performance. At BACs of 1.4 g/kg and greater, none of the test persons were able to achieve or improve on their sober driving results.

Overall performance

In order to evaluate the individual alcohol-related effects at different BACs, we combined the demerits from the driving performance and the medical examination reports to the individual overall performance (Fig. 9). It is remarkable that at BACs of 1.0 g/kg and above, no test persons were able to surpass their sober overall performance. At BACs of at least 1.4 g/kg, no test persons were able to only achieve their sober overall performance. A significant reduction of the overall performance could already be seen at BACs below 0.20 g/kg.

Discussion

The described course contained several additional requirements compared to the trials performed by Schewe et al. [15, 16]. In accordance to Schewe et al., who stated that at BACs of around 1.5 g/kg all test persons showed more distinctive features than in the state of soberness, the conducted trials found that no test person was able to achieve or even surpass his sober driving results at BACs of 1.4 g/kg and above. At BACs of 1.0 g/kg and above, no test persons were able to surpass their sober overall performance. The crucial question is how to legally define an absolute impairment to ride a bicycle. Would it be the BAC where every person individually commits more distinctive features than in the state of soberness (analogue to Schewe et al. [15, 16]), the threshold would

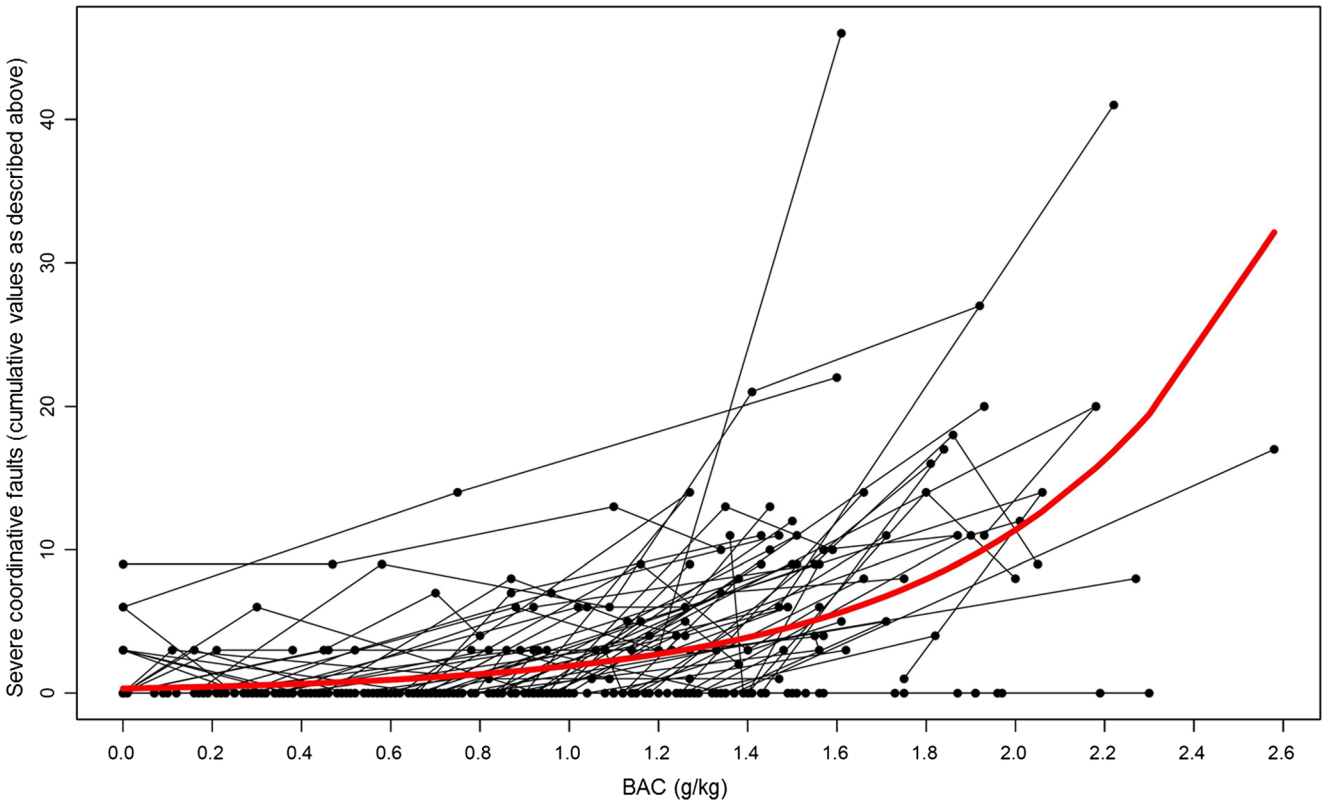


Fig. 7 Severe coordinative faults in relation to BAC (the *dots* indicate the driving trials, and the *black lines* connect the driving trials of each single test person; regression analysis by Poisson regression)

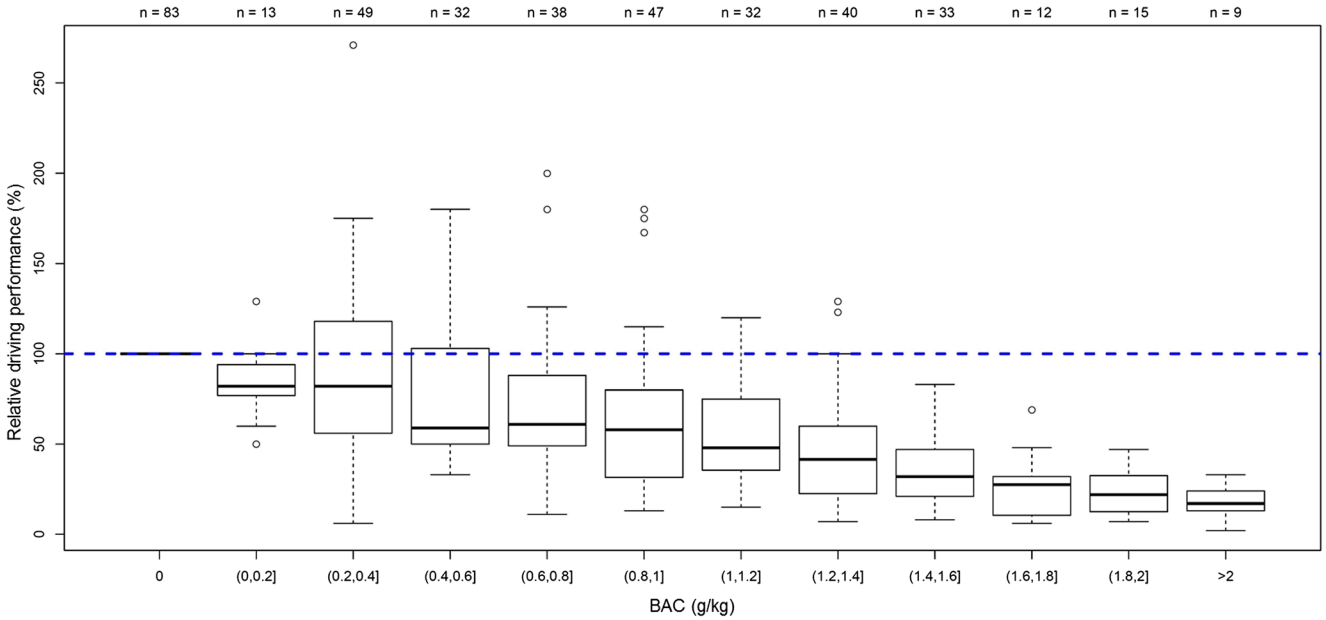


Fig. 8 Relative driving performance considering all driving faults in relation to BAC (the *boxes* contain 50 % of the tested persons, the *lines* indicate the median, the *satellites* indicate 25 % of the tested persons and the *circles* indicate outliers

have to be set at 1.4 g/kg. However, German jurisdiction does not compare certain distinct features of inebriated cyclists to their individual state of soberness rather than defines that state of impairment which makes every individual undoubtedly 'unable to drive safely' (§316 German Criminal Code). According to the present jurisdiction for driving a bicycle, this is supposed to be the fact at a BAC of 1.6 g/kg and above. According to the results of the conducted trials, it has to be underlined that there is no distinctive feature which can exclusively be seen at a certain BAC. Using this way of identifying alcohol-impaired cyclists, it has to be taken into account that some highly alcohol-intoxicated participants drove less conspicuously than did other sober test subjects.

Obviously, the manner in which alcohol is administered plays a crucial role in the outcome of drinking-driving trials.

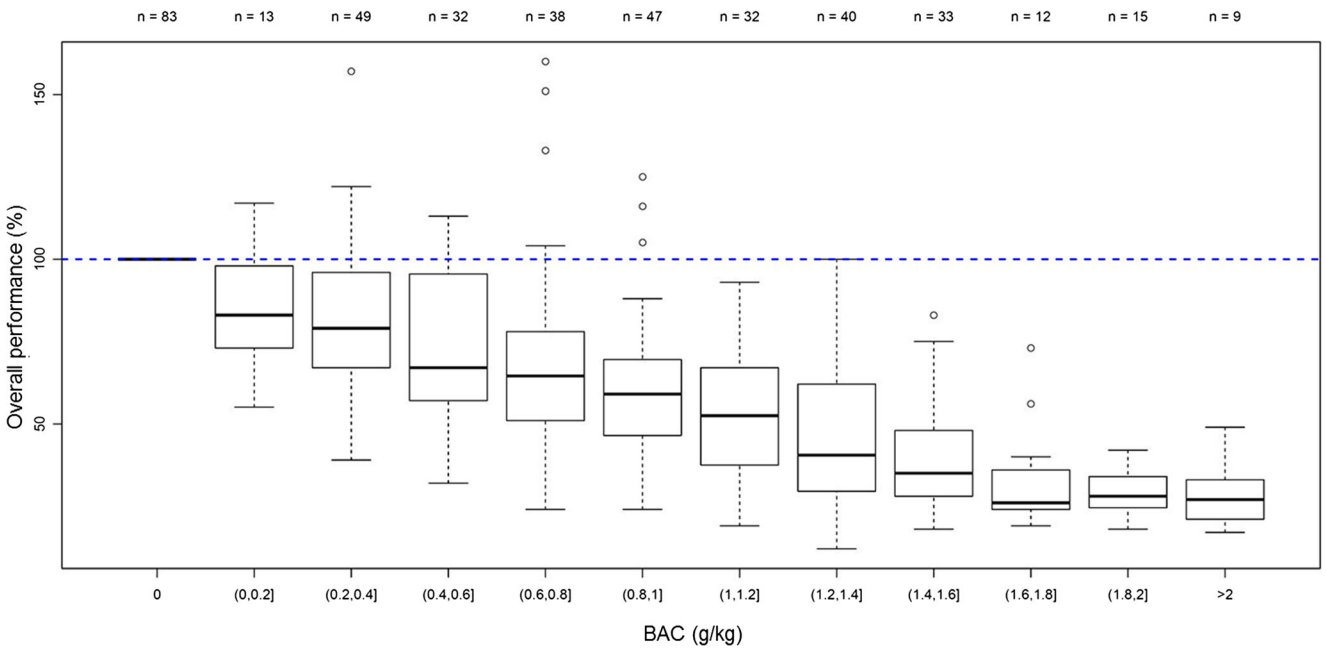


Fig. 9 Overall performance considering considering all driving faults and distinctive features from the examination report in relation to BAC (the *boxes* contain 50 % of the tested persons, the *lines* indicate the median, the *satellites* indicate 25 % of the tested persons and the *circles* indicate outliers

Participants who drink according to strict drinking protocols with high alcohol loads in short periods of time obviously generate more avoidable side effects than do test persons who drink according to their own preference and within their personal peer-group.

In summary, six main conclusions can be drawn from the trials:

- Alcohol-related deficits can already be seen at very low BACs (e.g. minor motoric disturbances), which is concordant with the available literature.
- Gross motoric disturbances can be compensated for by alcohol-experienced persons for a relatively long time. A significant increase in severe coordinative faults compared to the state of soberness does not regularly occur until BACs of at least 0.8 g/kg are reached. Obviously, once the compensatory mechanisms are exhausted, a rapid increase in the number of severe coordinative faults can be observed.
- The amplitude of fusion decreases with increasing BAC. It seems that no compensatory mechanism was available to offset this effect.
- At BACs of 1.4 g/kg and above, no test persons were able to achieve or surpass their sober driving results.
- At BACs of 1.0 g/kg and above, no test persons were able to surpass their overall performance.
- Isolated highly alcoholised test persons were able to drive less conspicuously than were other sober test persons. It cannot be stated that every single person is 'absolutely impaired' in their abilities to drive a bicycle at BACs of at least 1.6 g/kg.

These conclusions should be considered in light of the limitations that apply to every driving experiment. Because the examinations conducted were constrained by the ethical boundaries of scientific approaches to the investigation of the effects of alcohol, it is self-evident that imminent health-endangering traffic situations could not be included in the course. Additionally, it can be assumed that all test persons were highly motivated during the artificial situation of the tests; and in contrast to daily road traffic, all subjects knew about being evaluated in difficult traffic (-like) situations and were able to practise and prepare themselves accordingly. Also, the presented demerit system might be considered as a relevant limitation of this study because different weighing of certain distinctive features (e.g. according to a different national law) might lead to different results.

Acknowledgments The study was funded by the German Insurance Association/German Insurers Accident Research.

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