Alcohol and driving-related performance – A comprehensive meta-analysis focusing the significance of the non-significant

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ZUSAMMENFASSUNG

Die vorliegende Arbeit gibt einen umfassenden Überblick experimenteller Studien, die die akute Wirkung von Alkohol auf fahrrelevante Leistungen untersuchen. Hierzu wurde eine Metaanalyse durchgeführt, in der Studien von 1954 bis 2007 berücksichtigt wurden. Aus über 12.000 Referenzen wurden 450 Studien mit insgesamt 5.300 Befunden nach vorher festgelegten Ein- und Ausschlusskriterien ausgewählt. So umfasst die vorliegende Metaanalyse weit mehr Studien als die bisherigen veröffentlichten Literaturüberlicke.

In den ausgewählten Studien kamen verschiedene Leistungstests zur Anwendung, um die Effekte von Alkohol auf fahrrelevante Leistungen zu überprüfen. Diese Tests wurden in acht Kategorien klassifiziert: (1) visuelle Funktionen, (2) Aufmerksamkeit (einschließlich Vigilanz), (3) geteilte Aufmerksamkeit, (4) En-/ Dekodierung (einschließlich Informationsverarbeitung und Gedächtnis), (5) Reaktionszeit (einschließlich Einfachreaktionszeit und Wahlreaktionszeit), (6) psychomotorische Fähigkeiten, (7) Tracking und (8) Fahren. Neben den Leistungsaspekten berücksichtigt das in der vorliegenden Arbeit verwendete Klassifikationssystem auch andere für die Fahrleistung relevante Aspekte der beiden Bereiche subjektives Befinden und soziales Verhalten, wie beispielsweise Müdigkeit oder Aggressivität.

Gemäß der Vote-counting-Methode wurde die Anzahl der signifikanten und nicht-signifikanten Befunde für verschiedene Blutalkoholkonzentrationsgruppen zusammengezählt. Daraus ergab sich eine quantitative Schätzung der Effekte von Alkohol in Abhängigkeit der Blutalkoholkonzentration (BAK), die sogenannte Beeinträchtigungsfunktion. Diese stellt den Prozentsatz an signifikanten Befunden, die eine Beeinträchtigung berichteten, dar. Um einen allgemeinen Überblick über Alkohol und die Effekte auf die Fahrleistung zu geben, wurde eine globale Beeinträchtigungsfunktion aufgestellt, in die alle Leistungsbefunde eingegangen sind. Diese Funktion ist nahezu linear mit etwa 30% signifikanten Befunden bei einer BAK von 0,05% und 50% signifikanten Befunde bei einer BAK von 0,08%. Darüber hinaus wurden spezifische Beeinträchtigungsfunktionen berechnet, in denen die jeweiligen Befunde der einzelnen Kategorien berücksichtigt wurden.

Die Ergebnisse zeigten, dass die Beeinträchtigung nicht nur von der BAK abhängt, sondern auch von der geforderten Leistung. Tracking- und Fahrleistung waren dabei am stärksten betroffen. Hier zeigten sich bereits bei sehr geringen BAK von 0,02% Beeinträchtigungen. Auch psychomotorische Fähigkeiten wurden beträchtlich durch geringe BAK beeinträchtigt. Eine Beeinträchtigung der visuellen Funktionen und Informationsverarbeitung trat bei einer BAK von 0,04% auf und verstärkte sich deutlich mit höheren BAK. Eine Beeinträchtigung in Gedächtnistests konnte bei sehr geringen BAK von 0,02% gefunden werden, wobei diese in Abhängigkeit von der Art der Gedächtnistests variierte. Eine Abnahme der Leistung in Tests zu geteilter Aufmerksamkeit konnte in einigen Studien ebenfalls bei sehr geringen BAK gefunden werden. Eine Beeinträchtigung der Aufmerksamkeit trat bei einer BAK von 0,04% auf, aber erst bei höheren BAK kam es – wie bei Vigilanzaufgaben – zu erheblichen Beeinträchtigungen. Die Einfachreaktionszeit war zusammen mit der Flicker-Verschmelzungsfrequenz der am wenigsten sensitive Parameter für Alkoholeffekte.

Zusammenfassend lässt sich sagen, dass die meisten Fertigkeiten, die für das sichere Führen eines Fahrzeugs relevant sind, ab einer BAK von 0,05% deutlich beeinträchtigt sind. Die motorischen Fertigkeiten sind dabei stärker betroffen als die kognitiven Funktionen, und komplexe Aufgaben stärker als einfache Aufgaben. Generell lieferten die Ergebnisse keinen Hinweis für einen Schwelleneffekt von Alkohol. Das heißt es gab keine fahrrelevante Leistungskategorie, bei der bei einer bestimmten BAK-Stufe ein plötzlicher Übergang von unbeeinträchtigt zu beeinträchtigt auftrat.

Die Berechnung der Effektstärke lieferte keine zusätzliche Information bezüglich der allgemeinen Beeinträchtigung durch Alkohol. Da die Parameter, die für die Berechnung erforderlich waren, in den Studien oftmals nicht berichtet wurden, war die Anzahl der Effektstärken pro BAK-Gruppe eher gering. Die mittleren Effektstärken unterschieden sich nicht in Abhängigkeit von der BAK; vermutlich aufgrund der unterschiedlichen methodischen Bedingungen und der verschiedenen Leistungstests in den Studien. Zumindest stiegen die Effektstärken innerhalb von Studien, in denen der gleiche Leistungstest unter den gleichen methodischen Bedingungen durchgeführt wurde, mit höherer BAK an.

Im Allgemeinen ist die methodische Qualität in Studien zur Alkoholforschung relativ hoch. Allerdings werden in den veröffentlichten Studien oftmals relevante Informationen nicht berichtet und die Dokumentation von Statistiken ist häufig dürftig.

Um sicher zu gehen, dass die gezeigten Ergebnisse eine hohe Validität haben, wurden verschiedene Aspekte, die die Wirkung von Alkohol beeinflussen könnten, berücksichtigt und ihr Einfluss auf die Ergebnisse der Metaanalyse bewertet. Lediglich Aspekte der Alkoholgabe hatten einen geringen Einfluss auf die globale Beeinträchtigungsfunktion. Negative Effekte von Alkohol zeigten sich eher, wenn die Probanden eine hohe Alkoholdosis in kurzer Zeit trinken mussten, oder wenn die Tests nach 6 Uhr Abends oder während der Nacht stattfanden. Darüber hinaus wurden die Effekte von Alkohol nur geringfügig durch andere Faktoren wie Geschlecht oder Alter beeinflusst, wie Studien mit multifaktoriellem Design zeigten.

Zusätzlich wurde ein Vergleich zwischen der aktuellen Metaanalyse und den beiden Reviews von Moskowitz (Moskowitz & Fiorentino, 2000; Moskowitz & Robinson, 1988) durchgeführt. Moskowitz berichtete deutlich niedrigere BAK, die zu einer Leistungbeeinträchtigung führten. Die Gründe für diese Diskrepanz liegen in einer unterschiedlichen Art, wissenschaftliche Befunde zusammenzufassen. Moskowitz konzentrierte sich zum einen bei der Auswahl der Studien und Befunde für seine Reviews stark auf signifikante Befunde. Zum anderen ignorierte Moskowitz durch seine Auswertungsmethode nicht-signifikante Befunde, indem jede Studie nur einmal bei der geringsten BAK, bei der sich eine Beeinträchtigung erstmals zeigte, gezählt wurde. Die nicht-signifikanten Befunde sind jedoch genauso wichtig wie die signifikanten, um Schwellen für ein Auftreten der Beeinträchtigung zu bestimmen. Deshalb beschreibt die vorliegende Arbeit, im Gegensatz zu den Arbeiten von Moskowitz, die Effekte von Alkohol durch Funktionen, die auch die nicht-signifikanten Befunde berücksichtigen. Die Bedeutung der Nichtsignifikanz sowohl für das Auswahlverfahren der Studien als auch für die Auswertungsmethode wird durch die vorliegende Arbeit explizit hervorgehoben.

EXECUTIVE SUMMARY

The present work reviews the experimental literature on the acute effects of alcohol on human behaviour related to driving performance. A meta-analysis was conducted which includes studies published between 1954 and 2007 in order to provide a comprehensive knowledge of the substance alcohol. 450 studies reporting 5,300 findings were selected from over 12,000 references after applying certain in- and exclusion criteria. Thus, the present meta-analysis comprises far more studies than reviews on alcohol up to now.

In the selected studies, different performance tests were conducted which were relevant for driving. The classification system used in this work assigns these tests to eight categories. The main categories consist of several sub categories classifying the tasks more precisely. The main categories were: (1) visual functions, (2) attention (including vigilance), (3) divided attention, (4) en-/decoding (including information processing and memory), (5) reaction time (including simple reaction time and choice reaction time), (6) psychomotor skills, (7) tracking and (8) driving. In addition to the performance aspect, the classification system takes into account mood and social behaviour variables related to driving safety like tiredness or aggression.

Following the evaluation method of vote-counting, the number of significant findings and the number of non-significant findings were summarised per blood alcohol concentration (BAC) group. Thereby, a quantitative estimation of the effects of alcohol depending on the BAC was established, the so-called impairment function, which shows the percentage of significantly impaired findings. In order to provide a general overview of alcohol effects on driving-related performance, a global impairment function was established by aggregating all performance findings. The function is nearly linear with about 30% significant findings at a BAC of 0.05% and 50% significant findings at a BAC of 0.08%. In addition, more specific impairment functions considering only the findings of the single behavioural categories were calculated.

The results revealed that impairment depends not only on the BAC, but also clearly differs between most of the performance categories. Tracking and driving performance were most affected by alcohol with impairment beginning at very low BACs of 0.02%. Also psychomotor skills were considerably affected by rather low BACs. Impairment of visual functions and information processing occurred at BACs of 0.04% and increased substantially with higher BACs. Impairment in memory tests could be found with very low BACs of 0.02%, but varied depending on the kind of memory. Performance decrements in divided attention tests could also be found with very low BACs in some studies. Attention started to be impaired at 0.04% BAC, but – as in vigilance tasks – considerable impairment only occurred at higher BACs. Choice reaction time was affected at lower BACs than simple reaction time, which was – together with the critical flicker fusion frequency – the least sensitive parameter to the effects of alcohol.

To conclude, most skills which are relevant for the safe operation of a vehicle are clearly impaired by BACs of 0.05%, with motor functions being more affected than cognitive functions and complex tasks more than simple tasks. Generally, the results

provided no evidence of a threshold effect for alcohol. There was no driving-related performance category for which a sudden transition from unimpaired to impaired occurred at a particular BAC level.

The calculation of effect sizes provided no additional information concerning the general impairment by alcohol. Since the parameters which were required for the calculation were missing very often, the number of effect sizes per BAC group was small. The mean effect sizes did not clearly differ depending on the BAC, probably due to the different methodological conditions and examined performances in the studies. At least effect sizes increased with higher BACs when within a study the same performance test was conducted under the same methodological conditions with different BAC levels.

In general, the methodological quality of alcohol research is quite high. However, relevant information is often missing in the publications and the documentation of statistics is often poor.

In order to be sure that the presented results are valid, different aspects which might influence the effects of alcohol were considered and their impact on the results of the meta-analysis was evaluated. A small impact on the general impairment function were found for drinking conditions. Detrimental effects of alcohol became more apparent when subjects have to drink a high alcohol dose in a short time or when tests take place after 6 p.m. or during the night. Moreover, the effects of alcohol are not much influenced by other factors like gender or age, as studies with a multi-factorial design have shown.

In addition, a comparison was made between the present meta-analysis and the two reviews of Moskowitz (Moskowitz & Fiorentino, 2000; Moskowitz & Robinson, 1988). Moskowitz reported much lower BACs at which performance was impaired. The reasons for this discrepancy lies in a different way to review scientific findings. On the one hand, Moskowitz focused on significant findings when selecting studies and findings for his reviews. On the other hand, the evaluation method used by Moskowitz ignored non-significant findings and counted each study once at the lowest BAC for which impairment was found. Those non-significant findings are as important as the significant ones in order to determine thresholds of impairment. Therefore, in contrast to Moskowitz, the present work describes the effects of alcohol with functions considering also the non-significant findings. The significance of the non-significant is emphasized with respect to the selection procedure as well as to the evaluation method.

I THEORETICAL PART

1 INTRODUCTION

1.1 Background

Alcohol is probably the oldest drug to be used by human beings. It has long been known to possess psychoactive properties due to its ability to change the human consciousness. It is the most common sedative drug in the world (Summers, Trost, Zerkin, Prentice, Feeley & Carnage, 1975) and its pharmacology has been extensively examined and well described in the literature (see for example Pohorecky & Brick, 1988; Wallgren & Barry, 1970). The psychological effects of alcohol have been extensively studied for more than 80 years with an explosion of alcohol research literature beginning in the 1940s (Page, 1988). Since that time, many studies have demonstrated the detrimental effects of acute alcohol consumption on human performance (e.g. Klein & Jex, 1975; Moskowitz & Murray, 1976; Tiplady et al., 2001; etc.). It was shown that alcohol affected different aspects of performance, including those which are relevant to the safe operation of a motor vehicle like divided attention or visual functions. It is evident that this decrement in driving-related performance substantially increases the crash risk under the influence of alcohol. Many epidemiological studies have confirmed the correlation between the blood alcohol concentration (BAC) and driving impairment, with Borkenstein, Crowther, Shumate, Ziel and Zylman (1964) being the first who established a quantitative relationship between the BAC and the crash risk.

Since there are so many experimental and epidemiological studies about alcohol, literature reviews which subsume the relevant results of the previous research are more than helpful to get a comprehensive knowledge of the substance alcohol. Concerning the acute effects of alcohol on human performance and driving behaviour – which is the main interest of the present work – a lot of reviews have been published during the last 50 years (e.g. Carpenter, 1962; Jones & Joscelyn, 1978; Moskowitz & Fiorentino, 2000). Four of them (Holloway, 1995; Krüger, Kohnen, Diehl & Hüppe, 1990; Moskowitz & Fiorentino, 2000; Moskowitz & Robinson, 1988) can be termed as a meta-analysis following the definition from Glass (1976). According to him, a meta-analysis is “the statistical analysis of a large collection on analysis results from individual studies for the purpose of integrating the findings” (p. 3). Thus, in contrast to a review in which only qualitative evaluations are made, the use of statistical methods in a meta-analysis allows a quantitative estimation of the impairing effects of alcohol on performance.

The general advantages of meta-analyses are obvious. They deal with the high number of existing publications on a certain topic by subsuming scientific knowledge. Thus, a quick overview of the full range of evidence regarding the topic of interest is possible without looking through each single study. By the summarisation of independent studies, it is compensated for the singularity of experimental results and the validity is increased. The procedures range from a simple compilation of the

results to sophisticated statistical methods, by which even effect sizes can be estimated (Krüger & Vollrath, 2008).

All existing reviews have – generally speaking – come to the conclusion that the higher the dose of alcohol the larger is the impairment. Yet, the reviews concurred in the view that even with the same BAC, impairment differs according to the tasks which have to be performed in the studies. Thus, the effects of alcohol seem to be a combination of the substance concentration and the task sensitivity for alcohol. However, there are no consistent results concerning the height of the BAC leading to impairment and the performance areas which are particularly impaired. The literature on the effects of alcohol is so diverse that "for caution's sake one can only conclude that any demanding performance may be impaired after any amount of alcohol", as Finnigan and Hammersley (1992) stated (p. 73).

According to the literature review of Krüger et al. (1990), impairment was found in some studies at BACs as low as 0.03%, especially in driving tests. At BACs greater than 0.05%, clear effects on almost all driving-related skills were reported in many studies. Solely performance in reaction time or attention tests appeared more resistant to alcohol impairment and decreased with higher BACs around 0.08%. Generally, the authors concluded that the same BAC is the more hazardous the less a driver's action is automatic and the more it requires conscious control processes.

Moskowitz and Robinson (1988) came to the following conclusion in their review: "In assessing the minimum BACs required to produce performance decrements relevant to driving, it can be noted that for most of the performance areas discussed here impairment has been reported at BACs between 0.01 and 0.02%" (p. 67). At such low BACs, particularly performance in divided attention tasks was impaired. Performance in concentrated attention tests was least affected, with no study finding impairment below a BAC of 0.05%. Impairment of simple reaction time and psychomotor measures also began at higher BACs. Driving performance varied considerably depending on the driving task.

In accordance with his former review, Moskowitz concluded in his recent review (Moskowitz & Fiorentino, 2000) that impairment of some driving-related skills begins with any departure from zero BAC. Again, performance in divided attention or driving tests was particularly impaired, whereas reaction time tests were rather insensitive to the effects of alcohol. By BACs of 0.05%, the majority of studies found performance impairment, and by 0.08% impairment was found in almost every study.

The results of the three major meta-analyses provide evidence that driving tests in general are very sensitive to the impairing effects of alcohol, while performance in reaction time tests is – if at all – only impaired with high BACs. The sensitivity to alcohol of the remaining behavioural areas, in contrast, is not always consistent in research. Regarding the height of the BAC leading to impairment, many studies find impairment on most aspects of human performance related to driving at BACs as low as 0.05%. However, throughout all behavioural areas, there are studies which find significant impairment at lower BACs and also studies which find no effects at all, regardless of the BAC. Thus, the interpretation of the results regarding which BAC level affects performance is difficult.

In the above mentioned meta-analyses, different evaluation methods were used. When evaluating substance effects, the question arises which role non-significant findings play. As Krüger, Hüppe and Vollrath (1997) already noted, “we must know which functions at a given BAC are deteriorated and which are not. That is why a nonsignificant finding is quite as important as a significant one” (p. 3). According to this, Krüger et al. (1990) summarised the number of significant findings and also the number of non-significant findings per BAC group following the method of vote-counting. This leads to an impairment function showing the percentage of significantly impaired findings. In contrast, the method used by Moskowitz and Robinson (1988) and also by Moskowitz and Fiorentino (2000) disregarded non-significant findings. The authors counted each study once at the lowest BAC for which impairment was found in order to determine the onset of impairment. Thus, the reviews of Moskowitz and his colleagues emphasize impairment at very low BACs. “Extracting knowledge from accumulated studies is a complex and important methodological problem“, as Glass (1976) already stated (p. 8).

The present work is based on the publication of Krüger et al. (1990), who reviewed the literature on the effects of low dosages of alcohol, and can be seen as an update. However, the present focus of interest does not only lie on small concentrations of alcohol. The intention was to consider *all* experimental studies concerning the effects of alcohol on human behaviour related to driving performance and to conduct the most comprehensive meta-analysis by including studies from 1954 to 2007.

Since alcohol selectively affects different aspects of performance, performance tasks have to be classified in a senseful way in order to get specific information on the effects. The classification system used in this work has been developed by Krüger et al. (1990). Here, the tasks are classified according to the predominant psychological functions which are tested in the studies (e.g. attention or psychomotor functions). Besides performances, the system takes into account mood and social behaviour variables related to driving safety (e.g. drowsiness or aggression). The performance categories are very similar to the ones used by Moskowitz and Robinson (1988) or Moskowitz and Fiorentino (2000), so that the results can be easily compared.

1.2 Objectives

The aim of the present work is to provide a comprehensive knowledge of the acute effects of alcohol on driving-related performance. A huge body of experimental studies dealing with alcohol effects on human performance exists. Therefore, a meta-analysis is conducted in order to combine the results of different studies. The present meta-analysis covers scientific literature published between 1954 and 2007, thus it comprises far more studies than the reviews on alcohol up to now. By the high number of included studies (N = 450), a quantitative estimation of the effects of alcohol depending on the BAC is established, the so-called impairment function. The general impairment function is subdivided into different driving-related parameters (e.g. attention, psychomotor skills, visual functions) in order to specify the effects more precisely.

Besides, a number of aspects exists which might influence the effect of alcohol, for example the drinking time, the time of day or the phase of the blood alcohol curve (absorptive or eliminative). These aspects and their impact on the results when conducting a meta-analysis and summarising many studies are evaluated in order to be sure that the presented results are valid.

Furthermore, the dependency of the results from the selection procedure of the findings and from the evaluation method is discussed. In contrast to the two reviews of Moskowitz and Robinson (1988) and Moskowitz & Fiorentino (2000), the present review focuses not only on significant findings, but also on non-significant findings. The significance of the non-significant is emphasized concerning the selection procedure as well as the evaluation method.

As many variables are extracted from the studies, specifying for example the design or the procedure, a comprehensive description of the studies is possible. Thus, the material gathered for the meta-analysis can be used to review the methodological state of the art of alcohol research in order to draw conclusions for future investigations.

2 ALCOHOL AND THE HUMAN BODY

In this chapter, only the basic concepts about the nature of alcohol are presented. For more detailed information on the pharmacology of alcohol, see for example Feldman, Meyer and Quenzer (1997), Kalant (1971), Pohorecky and Brick (1988), Wallgren and Barry (1970) or Zakhari (2006).

2.1 Pharmacokinetics of alcohol

The active ingredient in alcoholic beverages is ethanol, a central nervous system depressant, which is also called ethyl alcohol or just alcohol. It belongs to the group of monohydric alcohols and is simpler in chemical composition than any of the other alcohols except methanol. Alcohol is soluble in water and is absorbed into the body through the simple process of diffusion. This means that after consumption it does not have to be digested before entering the blood from the stomach and small intestine. The speed of absorption into the venous blood depends on different factors, for example the type of beverage or the presence of food in the stomach. The alcohol is then circulated throughout the whole body and distributed among the organs and tissues in proportion to their fluid content. The molecules of alcohol easily pass through biological membranes, including the blood-brain barrier. The process of elimination begins before absorption is complete and takes much longer than absorption. The elimination rate depends partly on the amount of metabolizing enzymes in the liver and varies across individuals. It is almost completely linear until very low alcohol levels are reached. Typically, the elimination rate is about 0.015% per hour. In case of chronic alcohol consumption, it is higher. In Figure 1 the time course of the blood alcohol concentration and the three pharmacokinetic phases are outlined. The expression of blood alcohol as per cent (%), which is used in the following, indicates % w/v and follows the chemical usage of stating the *weight* of the quantity of alcohol contained in a given *volume* (e.g. a BAC of 0.05% means 0.05 g alcohol per 100 ml of blood).

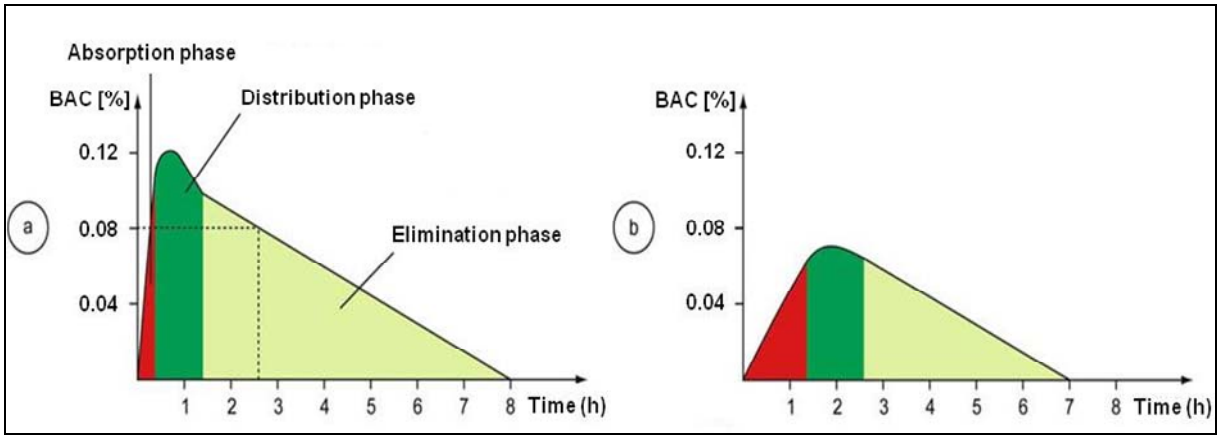


Figure 1: Time course of the BAC a) ideally and b) after a prolonged drinking time and an opulent meal (drawing adapted from Madea & Dettmeyer, 2007, p. 194).

Alcohol is eliminated from the body almost entirely through the process of oxidation and metabolized mostly in the liver. Only small amounts are eliminated from the body

through sweat, urine and expired air. The main part of hepatic alcohol oxidation is carried out by the enzyme alcohol dehydrogenase (ADH), which metabolized ethanol into acetaldehyde. Acetaldehyde is further converted in acetate by aldehyde dehydrogenase (ALDH). Finally, most of the acetate enters the blood stream and is metabolized extrahepatically in the citric acid cycle to carbon dioxide and water. For all these oxidation steps, the coenzyme nicotinamide adenine dinucleotide (NAD) which is converted to NADH is necessary. In order to be available again for oxidation, NADH has to be re-metabolized to NAD. This step is the reason for the speed limitation of the alcohol elimination. Metabolization may also take place via the microsomal ethanol oxidizing system (MEOS) or via the catalase system. However, these two systems play a minor role for the alcohol elimination in humans (Madea & Dettmeyer, 2007; National Highway Traffic Safety Administration, 1985; Transportation Research Board, 1987).

2.2 Pharmacodynamics of alcohol

Alcohol exerts its action in the body by penetrating the membrane of nerve cells in the brain. The structure and the functions of the cell membrane are influenced, for example the fluidity of the membrane is changed and the permeability increases. In addition, ion channels and various transmitter systems are affected:

- Alcohol binds to the $GABA_A$ receptor, a ligand-gated ion channel or ionotropic receptor for the inhibitory neurotransmitter gamma-aminobutyric acid (GABA). Since alcohol acts as an agonist to the GABA receptors, the inhibitory effects of GABA in different areas of the central nervous system (CNS) increase leading to sedation.
- The release of acetylcholine is inhibited by alcohol leading to the impairment of cognitive skills.
- N-methyl-D-aspartate (NMDA) receptors for glutamate are inhibited by alcohol leading to impairing effects on learning.
- Alcohol stimulates the synthesis and release of dopamine leading to euphoria.

Moreover, the alcohol-induced release of catecholamines leads to a dilatation of the peripheral vessels and consequently to a decrease of the blood pressure (Feldman et al., 1997; Hartmann, 1987; Julien, 1997).

The effects of alcohol are closely related to the alcohol concentration in the brain, which can be approximated by measuring the alcohol concentration in the blood. Alcohol depresses single functions and in particular complex performances of the central nervous system. Alcohol is known to have biphasic effects, this means paradoxical effects at different concentrations. At low doses, alcohol often acts like a stimulant and a general disinhibition occurs due to the suppression of inhibitory brain functions. A sense of euphoria is induced in many individuals, and sociability and talkativeness increase for example. Higher blood levels, in contrast, significantly impair cognitive ability and sensory-motor functioning in a dose-dependent fashion (see Chapter 3). Slurred speeches and a lack of coordination occur, while extremely high BACs around 0.4% may even cause coma and ultimately death due to severe

depression of respiratory function or other complications. The effects of alcohol highly depend on the drinking history and the alcohol tolerance of the person and vary between individuals. Some persons become aggressive after alcohol intake, whereas others become tired and lethargic. Besides, the effects of alcohol may also vary within individuals, depending on the form on the day for example (Madea & Dettmeyer, 2007; Pohorecky & Brick, 1988; Transportation Research Board, 1987).

3 EFFECTS OF ALCOHOL ON PERFORMANCE

3.1 The results of relevant reviews

3.1.1 Carpenter, 1962

The earliest review on the effects of alcohol which is taken into account was published about 50 years ago. Carpenter (1962) reviewed the literature on alcohol and driving-related skills. Only experiments with human subjects were included and strictly physiological studies have been omitted. In total, 77 studies were reviewed. The material has been organised into experiments on 1) reaction time (simple or choice reaction time), 2) motor skills, 3) nystagmus, 4) sensory processes, 5) intellectual functions (e. g. problem solving) and 6) driving skill (driving course or driving simulator).

Evidently, the quality of studies of that time was not as good as it is today. Many factors concerning the subjects like gender, age, driving and drinking experience have not received enough attention. In addition, the number of subjects in some studies was small (in 12 studies below 6) or even not reported. Sometimes, there was no information about the empirical BAC. However, it is striking that most investigated BACs were rather high. Quite often, the duration of drinking or the exact time of testing was not reported. Details concerning the performance tasks like stimulus or response characteristics were not available in many studies. Moreover, most results have not been evaluated statistically, and many studies probably contained significant practice effects.

There were little or no effects on **reaction time** at relatively low BACs around 0.05%. Increased reaction times only occured in studies which examined higher BACs. In contrast, **motor performance** might be impaired at moderate BACs. Positional **nystagmus**, which is associated with intoxicating doses of alcohol, occurred in each of the few studies investigating it. Alteration in **sensory phenomena** occurred as a result of alcohol administration, but none of the experiments represented profound excursions into sensory phenomena, as the author noted. The results of the experiments on **intellectual functions** did not confirm the assumption that higher processes are more affected by alcohol than lower ones. Intellectual functions were not impaired at a lower BAC than motor or sensory processes – on the contrary, they were more resistant to alcohol. Problem solving for example might even be facilitated by small doses of alcohol and impeded only by higher doses. Experiments on automobile **driving skills** showed that impairment occurred at low BACs, this means with less than 0.05%. Tracking error, time off the road and steering wheel movements were linearly related to the BAC, whereas speed was not.

The author pointed out that generalization from many of the experiments to driving must be done with care, because a relationship between laboratory experiments and driving is not always given. He came to the general conclusion that psychological functions might be impaired at relatively low BACs. Impairment on driving skills occurred at even lower BACs.

3.1.2 Wallgren & Barry, 1970

The review of Wallgren and Barry (1970) provides a comprehensive summary of scientific knowledge about alcohol effects on living organs and organisms. For the present work, the acute effects of alcohol on behavioural aspects are of special interest. The authors reviewed experiments on performance capabilities with regard to 1) perception of sensory stimuli, 2) sensori-motor coordination (e.g. reaction time, tracking, driving), 3) motor control (e.g nystagmus, standing steadiness), 4) intellectual functions (e. g. verbal performance or calculations) and on 5) self-perceived mood.

Studies of **sensory and perceptual capabilities** generally indicated that visual acuity is rather insensitive to the effects of alcohol. Some studies found impairment only at high dosages. There was some evidence that alcohol diminishes the sensitivity to colours. The ability to perceive rapid stimulus changes measured by the critical flicker fusion (CFF) was affected moderately by medium doses of alcohol around 0.07%, and strongly by higher doses. No reduction in the extent of the lateral visual field was found. Also auditory detection of faint sounds or pure tones was resistant to alcohol effects, whereas discrimination among different sounds was more susceptible.

The **sensori-motor performances** of monocular focusing and tracking and binocular coordination were greatly impaired even by low alcohol doses. The speed of response in reaction time tests was only slowed by high alcohol levels above 0.1%, whereas response accuracy (erroneous choices or responses prior to the signal) seemed to be more affected. Tests in which a sustained response to complex stimuli is required were also more sensitive to detrimental effects of alcohol. The same held true for auditory reaction time compared to visual reaction time. Tests with an emphasis on motor dexterity like the “pegboard test” appeared to be generally less sensitive to alcohol – only high doses had detrimental effects. In contrast, very low doses of alcohol were sufficient to impair the ability to track objects in motion. Substantially decreased performance was found in all studies with moderate alcohol doses. Again, accuracy (i.e. steering performance) was more impaired than the speed control. Steering errors also increased in simulated driving tests starting from a BAC of 0.03%. Regarding driving speed, it seemed that lower alcohol doses slightly decreased speed, whereas higher doses increased it. The variation in speed generally increased.

Motor functions with a minimum of sensory stimulation include the involuntary ocular motor response of nystagmus, which generally requires rather high doses around 0.08% to be elicited. Other predominantly motor functions like standing or hand steadiness were greatly impaired by medium alcohol doses.

Intellectual functions like verbal performance (e. g. word fluency or selecting an appropriate word) decreased substantially with medium BACs or even with low BACs in some experiments. With medium BACs, also the accuracy of arithmetical calculations decreased, while the speed was less affected, and also the performance in the digit symbol test was impaired. Complex problem-solving tasks were impaired with high alcohol doses. The detrimental effects of alcohol also became obvious in

memory tests. Medium doses impaired for example short-term memory in tests with complex verbal material or in which digits had to be recited backward.

Regarding **subjective measurements**, many subjects believed that their performance is normal or even better than usual in spite of objective impairment. However, they were found to estimate accurately their degree of intoxication. Subjective ratings of tiredness increased with medium alcohol doses.

3.1.3 Perrine, 1973

The question if alcohol effects on performance in laboratory tasks can be transferred to real world driving behaviour was specially considered in the review of Perrine (1973). He remarked that the behavioural aspects which have been examined experimentally in laboratory studies differ greatly in degree of assumed relevance for driving performance. His review was primarily concerned with three assumedly relevant behavioural categories: 1) neurophysiological aspects of behaviour, 2) neuromuscular aspects of behaviour and 3) sensory aspects of behaviour. Partly, he was taken into account the same studies like Wallgren & Barry (1970). Studies that were especially lacking in experimental rigor have been excluded.

According to Perrine, two **neurophysiological issues** seemed to be particularly relevant for understanding alcohol influences upon more complex behaviour such as driving performance: the actual site of alcohol effects in the nervous system and the basis for the apparent biphasic effects of alcohol. Regarding the first issue, lots of evidence has been reported that the reticular activating system (RAS) is the most important component of the central nervous system which is influenced by alcohol, even by low concentrations. The RAS plays a crucial role in the control of arousal and attention. Especially divided attention is largely mediated by the RAS. Regarding the second issue, numerous investigations have provided evidence for the so-called biphasic effects of alcohol on many levels of neural activity. Low alcohol concentrations decrease the excitation threshold and have a stimulating effect, whereas higher concentrations yield inhibitory or depressant effects.

For the examination of **neuromuscular aspects**, the Romberg standing steadiness test is most frequently used. Increased body sway seems to be symptomatic of acute alcohol intoxication. Perrine concluded from different studies that the threshold BAC at which swaying begins to increase appreciably lies around 0.06%. At BACs around 0.10%, all subjects showed a significant increase of body sway.

Since vision is the most important modality for driving, the paper of Perrine is primarily concerned with **sensory aspects** of vision. Different studies indicated that simple visual functions (e.g. visual acuity or visual field) were relatively insensitive to the influences of alcohol, whereas visual motility was disturbed by alcohol. Impaired static visual acuity, for example, was reported only at higher BACs above 0.08%. Impaired dynamic visual acuity, in contrast, started to occur at BACs as low as 0.03%. Regarding the lateral visual field, even high doses of alcohol did not cause any appreciable reduction. Regarding dark adaptation and brightness sensitivity, several studies reported significant detrimental effects of medium doses of alcohol (0.08%). There was no evidence that glare resistance is decreased by BACs up to

0.08%. By this BAC in contrast, the critical flicker fusion threshold, which is used as an index of the temporal resolution as well as an indicator of central nervous system function, is decreased according to the general agreement of the available studies.

3.1.4 Moskowitz, 1973

The review of Moskowitz (1973) is concerned with three essential driver performance areas: 1) visual functions, 2) tracking and 3) attention.

Studies examining peripheral **vision** in complex situations (which is more analogous to driving demands than isolated visual functions) reported extensive impairment by alcohol. For example, the detection of peripheral light signals decreased at a very low BAC when there was simultaneously a simple tracking task or a central blinking fixation light requiring information processing capacity. This suggested that the detection decreasement is an indirect result of the impairment by alcohol of the central processing system.

In compensatory **tracking tasks**, in which an index has to be maintained at a predetermined position, performance was found to be impaired at medium BACs when there was a subsidiary task. The tracking task alone was not very sensitive to alcohol and significant impairment only appeared at very high BACs. In contrast, most studies examining pursuit tracking, which requires a control index to be kept in alignment with an index that also is moving, found substantial impairment at a BAC of 0.05%. Similar to visual functions, data on tracking performance suggested impairment by alcohol when there are high information processing demands.

After looking at the two time-shared activities which are the basis for driving – visual perception and compensatory tracking – the author concluded that it is the time-sharing requirement itself which is most susceptible to alcohol influence in the driving situation. Neither of the two elements was particularly sensitive to alcohol when performed alone. However, in a combined task, performance could only be maintained in that activity to which the information processing capacity is allocated. In driving, the constant demands for **attention** by the ongoing tracking task overshadowed the intermittend demands of the peripheral search and recognition task. For example, a flying study found no significant decrement in tracking ability of experienced pilots even at high BACs, but procedural errors like flying without lights were committed at a BAC of 0.04%. Moreover, no alcohol effects were found in a variety of tests of concentrated attention and in vigilance tasks. However, medium levels of alcohol (and in some studies also low levels) impaired considerably performance in divided attention tasks, which required relatively complex operations on incoming information.

3.1.5 Levine, Kramer & Levine, 1975

41 studies reporting 165 findings and dealing with the effects of alcohol on cognitive, perceptual-sensory and psychomotor performance were reviewed. Several inclusion criteria were applied, for example an adequate task description, sufficient data and a control condition were obligatory.

Performance was represented by the relative measure of median percent difference. This was defined as the difference between the scores for the experimental and the control conditions divided by the control condition score and multiplied by 100%. Plotting this performance measure as a function of dosage and ability domain, data suggested that **psychomotor tasks** were least impaired by alcohol and **perceptual-sensory tasks** were most impaired. **Cognitive tasks** fell in between. However, the differences between these functions were fairly small. Overall, the amount of impairment increased with increased dosage up to 1 g/kg absolute alcohol.

3.1.6 Jones & Joscelyn, 1978

Jones and Joscelyn (1978) reviewed the effects of alcohol on human behaviour related to driving performance and divided such behaviours into three discrete parts: 1) Simple processes, 2) complex processes and 3) driving.

Simple processes involved tasks not requiring high degrees of motivation and understanding. As Wallgren and Barry (1970) already reported, there was evidence that **neuromuscular responses** like swaying may be impaired in some individuals at BACs as low as 0.04% and that many more individuals were affected at BACs around 0.08%. Basic **visual functions** were not substantially impaired by alcohol at BACs below 0.08%, but above 0.10% BAC vision became impaired in most persons. In contrast, dynamic visual acuity might be affected at very low BACs (0.03%). Concerning **tracking** performance and **attention**, the authors came to the same conclusion like Moskowitz (1973). There was no impairment in simple tracking or concentrated attention tasks at BACs of less than 0.10%, but the performance of complex tracking or divided attention tasks degraded in many individuals at BACs of 0.05%.

Complex processes involved tasks requiring **intellectual functions** like problem solving or memory. There were only few studies on risk taking indicating that the willingness to accept risks may be increased at moderate BACs. **Memory** experiments provided evidence that alcohol has detrimental effects on both short-term and long-term memory, with larger effects on long-term memory.

Simulator studies showed highly conflicting results, but seemed to indicate that moderate amounts of alcohol impaired performance of complex, concurrent tasks. Braking response was impaired by a medium BAC as well as the ability to perform parking maneuvers. **Closed course driving** performance was degraded by BACs as low as 0.05% (e.g. steering reversals, rough shifting).

The authors came to the conclusion that some driving-related behaviours are impaired by alcohol. Performance seemed to be consistently and significantly impaired in virtually all individuals as BACs approach 0.10%. However, in many persons impairment occurred at much lower BACs, particularly in light drinkers.

3.1.7 Mitchell, 1985

Mitchell[1] reviewed driving-related behavioural skills and found no evidence for impairment at BACs below 0.05%. At BACs above 0.05%, impairment began to be evident particularly in tasks requiring **cognitive functioning** and in **driving** tasks. In contrast, tasks requiring simple **perception** were least affected and also **divided attention** tasks were relatively little impaired.

3.1.8 Moskowitz & Robinson, 1988

The experimental literature from the 1950's through 1985 on alcohol effects on driving-related skills performance was reviewed in detail. 177 studies were selected after applying the following inclusion criteria: a driving-relevant behavioural area was tested, sufficient methodological detail was provided and the publication was available in English. The experimental tasks in the studies were assigned to nine behavioural categories: 1) reaction time, 2) tracking, 3) vigilance or concentrated attention, 4) divided attention, 5) information processing, 6) visual functions, 7) perceptions, 8) psychomotor skills and 9) driving. Particular attention was given to the BAC level at which impairment first appeared.

The authors calculated BACs for the time of starting behavioural testing, using the reported dosages and a 15 mg per cent per hour metabolism rate. Taking into account the subjects' gender and body weight, an estimated volume of distribution for alcohol was determined assuming the mean water body weight as 49% for females and 58% for males.

Of the 177 studies, 158 reported impairment of at least one behavioural skill at one or more BAC levels and 19 studies found no impairment. Overall, 20% of the studies (n = 35) reported performance impairment by 0.04% BAC and nearly all by 0.10%. The majority of studies found impairment below a BAC of 0.07%.

Regarding the behavioural categories, alcohol did not uniformly impair all aspects of performances and considerable differences existed in the BAC at which impairment first appeared. In studies of **reaction time**, impairment appeared at higher BACs than in other areas. Especially in simple reaction time tasks, impairment was found at higher BACs. However, choice reaction times could be affected by BACs as low as 0.04%, with tasks requiring accurate performance more likely to show impairment. The onset of impairment in **tracking** tasks occurred at very low BACs and a majority of studies demonstrated substantial impairment by BACs of 0.05% or less. No substantial differences between types of tracking tasks could be found. **Concentrated attention** or **vigilance** was the least sensitive area to the effects of alcohol. Only a small number of significant findings was found and no study reported impairment below a BAC of 0.05%. Decrements in attention or vigilance performance at BACs below 0.08% seemed to be unlikely. **Divided attention** was the most sensitive behavioural category. Most studies found impairment at or below 0.05% BAC. Also **information processing** skills appeared to be impaired at relatively low

[1] Unfortunately, the review of Mitchell was not available. Therefore, the summarisation of it by Jones and Lacey (2001) was used.

BACs. A majority of studies reported impairment by a BAC of 0.08% or less. Most **visual functions** such as visual acuity, glare recovery, peripheral vision and flicker fusion did not tend to show impairment at low or moderate BACs. In contrast, many visual oculomotor functions including eye movements were impaired at BACs as low as 0.05%. Regarding **perception**, relatively few findings of impairment existed below 0.08% BAC. **Psychomotor tasks** which required skilled motor performance and coordination tended to be impaired at BACs of 0.05%, in contrast to other psychomotor tasks which did not show impairment below a BAC of 0.07%. In **driving** tasks, results differed considerably depending on the demands. Performance might decrease at BACs of 0.05% or less, and BACs of 0.04% significantly impaired responses to unexpected, emergency situations, even in a simple driving situation. Moreover, there were lots of studies demonstrating alcohol impairment of **memory**, particularly of short-term memory, but rather by high BACs. Studies on **problem solving** indicated that performance decreased at BACs of 0.04% or more.

The authors concluded that performance impairment might occur at BACs as low as 0.02%. BACs of 0.05% or more impaired almost all driving-relevant behavioural categories except concentrated attention and visual functions. In general, it was emphasized that there was no threshold BAC below which impairment effects were absent. The shift toward the detection of impairment at lower BACs compared to former reviews was attributed to four factors: 1) the selection of more complex tasks, 2) the better instrumental capabilities, 3) an increasing sophistication in the measurement of alcohol treatment, 4) the examination of lower BACs.

All in all, it has to be criticized that the authors only focused on the significant findings within a study. Many studies examined more than one behavioural skill or BAC level and of course not all findings became significant. However, findings for which no impairment could be found were not considered or reported.

3.1.9 Krüger, Kohnen, Diehl & Hüppe, 1990

This review included 192 studies from 1950 to 1990 reporting 1,126 findings concerning the effects of alcohol on driving-related behaviour. The authors were interested in the effects of low BACs and considered BACs up to 0.84%. The empirical findings were classified into 12 behavioural categories: 1) reaction time, 2) attention (including vigilance), 3) divided attention, 4) psychomotor skills, 5) visual functions, 6) tracking, 7) en-/decoding (information processing and memory), 8) driving, 9) mood (including drowsiness), 10) aggressive behaviour, 11) sexual functions and 12) social behaviour.

Performance in **reaction time** tests appeared to be very resistant to alcohol impairment, even with high BACs around 0.08%. **Attention** tests as well were not very sensitive to the effects of alcohol. Performance in **divided attention** tests was impaired at BACs around 0.03% in some studies, but became more obvious at BACs above 0.05%. **Psychomotor skills** decreased at BACs around 0.07% in every second finding. Effects on **visual functions** differed according to the kind of function; particularly eye movements were impaired at BACs as low as 0.03%. Impairment in **tracking** tasks clearly occurred at BACs around 0.05%. The same held true for **memory** and **information processing** tasks. **Driving** performance was found to be

very sensitive to the effects of alcohol, with considerable impairment at BACs of 0.04%. Low BACs around 0.03% also clearly led to **drowsiness** and **aggressive behaviour** increased. The few findings concerning sexual functions and social behaviour are too heterogeneous to be reported here.

The authors concluded that almost all driving-related skills are affected by BACs above 0.05%, especially if not automatic but conscious control processes are required.

3.1.10 Finnigan & Hammersley, 1992

Finnigan and Hammersley (1992) reviewed 69 alcohol studies published from 1980 to 1991 which focused the acute effects on human performance and reported 78 findings in total. The performance tests were classified into the following categories: 1) tracking, 2) posture, 3) driving simulation, 4) perception, 5) critical flicker fusion), 6) memory, 7) vigilance, 8) simple reaction time, 9) choice reaction time, 10) decision-making (complex reaction) and 11) divided attention.

Six out of nine studies found impairment in **tracking** tasks, two of them with low alcohol doses. An increased **body sway** was found in eight out of ten studies, but only for one study the authors reported the BAC (0.07%). Unfortunately, the **driving** studies have not been well-designed, so that a useful conclusion could not been drawn from them, as the authors stated. Similarly, no conclusions were possible with respect to the effects of alcohol on **perception**, since there were too few studies. Several studies included the **critical flicker fusion** frequency task in their test battery, but only one of them found an alcohol effect. **Memory** and **vigilance** performance appeared to be reduced by alcohol (about three quarters of the findings were significant), but again details with respect to the BACs were missing in the review. In addition, even if the results for both **simple and choice reaction time** were inconsistent, there was some evidence that reaction time was slowed by high doses of alcohol. **Cognitive decision-making** seemed also to be slowed by alcohol with six out of eight findings being significant. Performance in **divided attention** tasks were always affected, without being told the BACs from the authors of the review. The authors concluded that alcohol slowed mental processing. Subjects might either perform more slowly or less accurately or neglect some other aspects of performance, for example a secondary task.

3.1.11 Ferrara, Zancaner & Giorgetti, 1994

The review aimed at examining the state-of the-art regarding low BACs and driving impairment. 38 studies between 1969 and 1991 reporting 113 findings concerning various psychomotor functions were included.

In spite of the lack of methodological homogeneity in experimental studies and the different degrees of sensitivity of the tests used, most studies agreed that low levels of alcohol could cause significant impairment in psychomotor functions. Though, to highlight the impairment of such functions, sufficiently complex psychometric tests were required. Below a BAC of 0.05%, especially performance in **vigilance**, **divided attention** and **driving** tests were impaired. **Attention**, **reaction time**, **memory** and

critical flicker fusion were affected at higher BACs. The authors concluded that all performance was susceptible to impairment at some level, although there were great differences between skills and the BACs at which significant impairment occurred.

3.1.12 Holloway, 1995

Holloway (1995) reviewed the literature examining alcohol effects on human behaviour, with the focus on low alcohol dose effects. He examined 155 empirical studies from 1985 to 1993 (reporting 346 findings), using the alcohol effect schema of Krüger (1993). This schema distinguished – besides subjective effects – between psychophysical functions (e.g. visual functions, vigilance, memory, posture) and performances. Performance tasks were further classified into automatic (e.g. easy tracking, reaction time, attention tests), controlled (e.g. difficult tracking, divided attention, information processing) and driving processes. For a quantitative evaluation of alcohol effects, the percentages of findings reporting significant impairment were presented for BAC ranges in 0.02%-steps.

The following general conclusions could be drawn: **Subjective intoxication** effects of alcohol were most obvious – 75% of the findings were significant at BACs between 0.02 and 0.04%. In contrast, only about 33% reported significant effects for **psychophysical functions**, with memory, vigilance or posture being more frequently impaired than CFF. Even less findings (about 25%) reported significant impairment in **automatic performance** tasks between BACs of 0.02 and 0.04%, with reaction time tasks being more frequently impaired than other automatic tasks. Sensitivity to performance impairment in **controlled performance** tasks was much greater – about 70% of the findings reporting significant effects. **Driving and flight simulator** studies (n = 6) indicated that performance could be impaired at or below a BAC of 0.04%. For example, tracking and collision avoidance errors occurred as well as departure, navigation, approach and landing errors in flight studies.

Besides, several task- (e.g. task complexity, multiple tasks), subject- (e.g. expectancy of alcohol, tolerance to alcohol) and environmental-characteristics (e.g. time of day, social context) were found to mediate the sensitivity to alcohol effects, especially at lower doses.

3.1.13 Koelega, 1995

Koelega (1995) analysed 28 studies (providing 38 alcohol-placebo comparisons with findings) from 1962 to 1993 testing the effects of alcohol on vigilance. Inclusion criteria were a placebo condition, no alcoholics as subjects and sufficient data. The aim of the review was to assess the sensitivity of vigilance tasks to the effects of alcohol.

In general, about half of the **vigilance** experiments reported an effect. The 50%-effect score increased to 67% when only studies with a larger-sized sample ($n \geq 15$) were considered, due to the higher power of those studies. The author stated that generalizations with respect to BACs were difficult to make – sometimes performance was impaired at 0.03% and sometimes performance was unimpaired at 0.10%, depending on the type of vigilance task. Sensitive to low doses of alcohol were

particularly those tasks requiring nonverbal, spatial information processing. In contrast, response latency to correct detections (reaction time) was as often impaired as was accuracy of performance (correct detections).

It was concluded that the sensitive types of vigilance tasks should be part of test batteries when evaluating the effects of alcohol on performance, whereas the usefulness of some other tasks (DSST, CFF, digit span memory, etc.) was questioned.

3.1.14 Kerr & Hindmarch, 1998

The review concentrates particularly on effects of low-to-moderate doses of alcohol on 1) reaction time and on 2) driving-related skills, both alone and in combination with other psychoactive substances.

The effects of small doses of alcohol on performance were very variable. This variability was due to differences in experimental methodology and methods employed by the researchers and to the large interindividual and interoccasional differences in the effects of alcohol. The authors came to the general conclusion that alcohol slowed down **reaction time**. Moderate doses of alcohol might impair performance, and the effect became stronger with increasing task complexity. Some studies demonstrated that the decrement was produced by perceptual and central cognitive mechanisms rather than peripheral or motor components. **Driving performance** as well was affected by moderate doses of alcohol, including for example brake reaction time, collision frequency, steering responsiveness and lane control.

3.1.15 Moskowitz & Fiorentino, 2000

The review included 112 studies published between 1981 and 1998, which met the following inclusion criteria: 1) driving-related skills were examined, 2) BACs at testing time were reported or calculable, 3) alcohol doses were not above 1 g/kg, 4) alcohol effects were not confounded with drug effects, 5) human subjects were studied, 6) the publication was available in English.

The behavioural categories to which the tasks were assigned are very similar to those used by Moskowitz and Robinson (1988). These are 1) simple reaction time, 2) choice reaction time, 3) vigilance, 4) divided attention, 5) psychomotor skills, 6) visual functions, 7) perception, 8) critical flicker fusion, 9) tracking, 10) cognitive tasks, 11) driving, 12) drowsiness, 13) aftereffects. In total there are 556 findings (= test results), since several studies reported tests of performance in different behavioural categories and at different BACs.

The authors mentioned two different approaches in reviewing the literature, but in fact there were three analyses. The first analysis determined the lowest BAC at which impairment was present in driving-related skills. The number of studies reporting impairment was counted, with each study counted once at the lowest BAC for which impairment was found (across all behavioural categories). Studies in which impairment was not found at any BAC were excluded from the analysis. Thus, the

analysis included 109 studies and findings, respectively. The methodological approach is explained more in detail in Chapter 8.4.3 and illustrated in Table 14 (left).

The second analysis is a slight modification of the first one. Here, the number of studies was counted, with each study counted several times at the lowest impairing BAC within each behavioural category which was examined (see Table 14, right, in Chapter 8.4.3). Thus, the analysis included 109 studies and 150 findings, respectively. The authors did not mention this analysis in the text, but they presented the results of it in a table in the appendix.

The third approach determined the thresholds of impairment for each of the behavioural categories. For this analysis, every finding – significant or not – was counted per BAC category for all the tasks examined. Thus, the analysis included all 556 findings from the overall 112 studies.

The results of the first analysis showed that 27% of the studies, in which impairment was found at any BAC, reported impairment by 0.039%, 47% by 0.049% and 92% by 0.079% BAC. The results of the second analysis are very similar. 27% of the studies counted manifold per examined behavioural category reported impairment by 0.039%, 46% by 0.049% and 90% by 0.079% BAC. Note that for both analyses non-significant findings were not considered.

The third analysis, which also took into account the non-significant findings, revealed that in general with a BAC higher than 0.040% the number of impaired findings is greater than the number not impaired. The percentage of significantly impaired findings is 50% between 0.030 and 0.039%, 70% between 0.040 and 0.049% and 63% between 0.070 and 0.079% BAC. Concerning impairment indicated by the single behavioural categories, Table 1 gives an overview.

Table 1: Overview of impairment indicated by the single behavioural categories according to the data of Moskowitz and Fiorentino (2000).

BAC [%]	By the lowest BAC at which impairment was found	By first BAC at which ≥50% of tests indicated impairment
0.001-0.009	Driving, divided attention	Driving, divided attention
0.010-0.019	Drowsiness, cognitive tasks, psychomotor skills, tracking	Drowsiness
0.020-0.029	Choice reaction time, visual functions	
0.030-0.039	Vigilance, perception	Vigilance, visual functions, psychomotor skills
0.040-0.049	Simple reaction time	Perception, simple reaction time, choice reaction time, cognitive tasks
0.050-0.059		Tracking
0.060-0.069		
0.070-0.079		
0.080-0.089		
≥0.090	Critical flicker fusion	Critical flicker fusion

The conclusion of the authors was that alcohol impaired some driving-related skills beginning with any departure from zero BAC. By BACs of 0.05%, the majority of studies reported significant impairment. By 0.08%, impairment was found in more than 94% of the studies. Thus, they expected all drivers to experience impairment in some driving-related skills by a BAC of 0.08% or less. It became evident that specific performance skills were differentially affected by alcohol. Some skills like driving itself or divided attention were significantly impaired by BACs of 0.01%, while others like cognitive tasks or choice reaction time did not show consistent impairment until BACs of 0.06%.

3.1.16 Jones & Lacey, 2001

This review updates the report of Jones & Joscelyn (1978), and it focuses on new experimental research on the impairing effects of alcohol at low BACs. Primarily, the authors referred to the report of Moskowitz and Fiorentino (2000) and also to the reviews of Ferrara et al. (1994) and Mitchell (1985). Based on their results, it was concluded that performance related to driving was impaired at lower BACs than was previously believed. At BACs in excess of 0.05%, performance was substantially impaired in many behavioural categories.

3.1.17 Ogden & Moskowitz, 2004

This report is not a comprehensive literature review, but gives an overview of the knowledge in the field of alcohol and performance. It mainly refers to the meta-analyses of Moskowitz and Robinson (1988) and Moskowitz and Fiorentino (2000). Therefore, the conclusions are only shortly summarised here.

The effects of alcohol clearly depended on the BAC and the performance required. The impairing effects of alcohol increased in a dose-related manner and some driving-related skills were impaired with any departure from zero BAC. The authors stated: “There is no evidence of a threshold effect for alcohol because some impairment of performance occurs at the lowest levels that can be measured; nor is there a level at which a sudden transition from unimpaired to impaired can be expected: whatever the level of BAC examined, at least some skills can be demonstrated to be significantly impaired” (Ogden & Moskowitz, 2004, p. 186).

By 0.05%, the majority of studies reported significant impairment of some relevant skills, especially performance in divided attention and driving tasks was substantially affected.

3.2 Summary

Reviews of the last 50 years were considered in order to evaluate the effects of alcohol on performance. Generally, the quality of studies was getting much better over the years, for example with respect to the number of subjects, to relevant information which was provided or to different effect-modifying factors (drinking experience, practice effects) which were considered. Moreover, in recent decades the investigated BACs were getting lower.

In each review, the tests used in the studies were classified in different performance categories. Evidently, some performances were more affected by alcohol than others. Table 2 gives an overview of the results of the different reviews by indicating the BAC group at which the majority of findings per performance category showed impairment. It is clear that not all tasks belonging to one performance category are of equal sensitivity to the effects of alcohol. As a consequence, results might differ remarkably within one category as it is the case for vigilance and divided attention. Thus, sometimes a generalization regarding the sensitivity of a performance category is difficult.

The results of **visual functions or perceptual** tasks could often not be summarised even within a review, because they were too heterogenous depending on which visual function was tested. Simple visual functions (e.g. visual acuity, glare recovery, dark adaptation, lateral visual field) were relatively insensitive to the influences of alcohol, or high doses were required to show impairment. In contrast, other visual functions like binocular coordination, dynamic visual acuity and eye movements might be affected by relatively low alcohol doses. In general, the majority of studies did not report sensory or perceptual impairment until BACs of 0.08%.

The ability to perceive rapid stimulus changes is measured by the critical flicker fusion test. High values of the frequency at which a flickering stimulus is perceived to be steady suggest greater perceptual accuracy. The **critical flicker fusion frequency** might be deteriorated by moderate BACs above 0.05%. By 0.08%, most reviews reported impairment according to the results of the majority of studies.

Only three reviews were concerned with **information processing** tests like visual backward masking tasks. Performance might significantly decrease at very low BACs around 0.03%, but the number of tests assessing such BACs was very low. Above a BAC of 0.05%, a clear majority of findings showed impairment of information processing.

Cognitive functions like problem solving performance might be impaired at relatively low BACs around 0.04%. However, most reviews showed that in the majority of findings cognitive functions including verbal performance and arithmetical calculations decreased substantially with medium BACs above 0.05%.

Regarding **vigilance**, the results of the reviews were not consistent. Some found that alcohol did not impair performance in vigilance tasks or that high BACs above 0.08% were required. In other reviews, it was evident that moderate or even low levels of alcohol impaired vigilance performance. Koelega (1995) came to the conclusion that impairment depended strongly on the type of vigilance task. Especially tasks requiring nonverbal, spatial information processing were sensitive to the effects of alcohol.

Performance in **divided attention** tests might be impaired at very low BACs (0.01%). However, most reviews reported that performance decreased in more than 50% of the findings with low or moderate BACs.

Both short- and long-term **memory** were affected by alcohol. In most studies, impairment of memory performance occurred at moderate BACs above 0.05%.

Results of reaction time tests were not always divided into **simple** and **choice reaction time**. If so, choice reaction time seemed to be more sensitive to the effects of alcohol than simple reaction time. Performance in reaction time tasks was affected by moderate BACs (0.05-0.08%), especially in more complex tasks. Increased simple reaction times in more than 50% of the findings occurred only at high BACs above 0.08% in three reviews. Generally, response accuracy was more likely to show impairment than speed of reaction.

According to the general agreement of the reviews, **(psycho-)motor skills** were impaired in the majority of findings by moderate BACs. Only Moskowitz & Fiorentino (2000) found impairment at lower BACs. Standing steadiness seemed to be one of the most sensitive behavioural indicators of alcohol intoxication and started to be impaired at BACs around 0.04%.

Tracking performance might be substantially affected by low BACs, particularly in complex tracking tasks. Overall, impairment occurred most frequently by moderate BACs above 0.05%.

Driving skills were in the majority of findings impaired at low BACs (<0.05%). Thus, it was the most sensitive performance category for the effects of alcohol. In more complex tasks or when responses to unexpected, emergency situations were required, driving performance might decrease substantially at BACs below 0.04%. The few studies on closed course driving and flight performance indicated that performance decrements occurred even at lower BACs than in simulator studies.

To conclude, the impairing effects of alcohol were dependent on the BAC and the performance tested. Performance clearly differed as a function of the ability requirements of the task. The decremental effects of alcohol became especially obvious in tasks with high information processing demands like driving or divided attention. Already in 1973, Moskowitz stated that there was an “(...) unanimous agreement that alcohol causes greater response impairment when the response requires complex information processing than when only simple motor reaction times are involved” (p. 194). Information processing tasks itselves as well as tracking, psychomotor and cognitive tasks were rather sensitive to the impairing effects of alcohol. In contrast, performance in tasks measuring choice and simple reaction time, memory, vigilance, visual functions or critical flicker fusion appeared to be least impaired. All in all, at BACs above 0.05%, the majority of studies reported significant impairment of most driving-relevant skills. Also subjective measurements like self-perceived intoxication or subjective performance and tiredness were affected by moderate doses of alcohol.

Table 2: Overview of alcohol concentrations leading to impairment in most studies reviewed regarding different performance categories ("very low": 0.001-0.029% BAC, "low": 0.030-0.049% BAC, "moderate": 0.050-0.079% BAC, "high": ≥0.080% BAC).[2]

Authors	Visual functions / perception	CFF	Information processing	Cognitive functions	Vigi-lance	Divided atten-tion	Memory	Simple RT	Choice RT	Psycho-motor skills	Trac-king	Driving
Carpenter, 1962	not clear*	mode-rate	-	mode-rate	-	-	-	mode-rate	mode-rate	mode-rate	-	low
Wallgren & Barry, 1970	high	high	-	mode-rate	-	-	mode-rate	high	high	mode-rate	low	low
Perrine, 1973	not clear*	high	-	-	-	-	-	-	-	mode-rate	-	-
Moskowitz, 1973	-	-	-	-	no effects	mode-rate	-	-	-	-	mode-rate	low
Jones & Joscelyn, 1978	high	-	-	-	no effects	mode-rate	unknown BAC	-	-	mode-rate	mode-rate	mode-rate
Mitchell, 1985	high	-	-	mode-rate	-	high	-	-	-	-	-	mode-rate
Moskowitz & Robinson, 1988	high	high	mode-rate	mode-rate	high	low	high	high	mode-rate	mode-rate	low	low
Krüger et al., 1990	mode-rate	no effects	low**	-	low**	mode-rate	mode-rate	no effects	high	mode-rate	low	low
Ferrara et al., 1994	-	mode-rate	-	-	low	low	mode-rate	mode-rate	mode-rate	mode-rate	mode-rate	low
Holloway, 1995[3]	not clear*	mode-rate	very low**	mode-rate	mode-rate	very low	mode-rate	mode-rate	mode-rate	mode-rate	mode-rate	low
Koelega, 1995	-	-	-	-	high***	-	-	-	-	-	-	-
Kerr & Hindmarch,	-	-	-	-	-	-	-	high****	mode-rate****	-	-	mode-rate
Moskowitz & Fiorentino, 2000	low	high	-	low	low	very low	-	low	low	low	mode-rate	very low

* results were too heterogenous (depending on which visual function was tested)
** very few studies
*** depends strongly on the type of vigilance task
**** only a rough estimation is possible, because the review did not report the BACs and the results of the single studies

[2] Not included in the table: Levine et al., 1975 (gave no information regarding significant impairment and BACs), Finnigan & Hammersley, 1992 (gave hardly an information regarding BACs), Jones & Lacey, 2001 and Ogden & Moskowitz, 2004 (referred to other reviews already included).
[3] The results for the single performance categories were presented individually in tables in Holloway, 1994.

4 THE METHODOLOGY OF META-ANALYSIS

The term “meta-analysis” was introduced by Glass (1976) who described it as an analysis of analyses. In contrast to a literature review, which provides a report of primary research using literary methods, a meta-analysis provides a report of primary research using statistical methodology and analysis. By using statistical techniques for combining findings of a number of data analyses, a meta-analysis forms a powerful integrative tool (Howitt & Cramer, 2005). Meta-analyses generally focus on the relationship between one explanatory and one response variable, this means on the effect of *X* on *Y* (DeCoster, 2004). For example, the effect of a *therapy* on *behaviour* is analysed, as Grawe, Donati and Bernauer (1994) did in their meta-analysis evaluating the efficacy of person-centered therapy. The authors aggregated studies which compared changes in an experimental group receiving a therapy versus changes in a control group receiving no therapy.

Evaluating the effects of alcohol on behaviour by a meta-analysis is a little bit more complex. On the one hand, there are not only the two levels of the independent variable *alcohol* “yes” or “no”, but there are many different BAC levels which are investigated in the different studies and on which the effects depend. On the other hand, the dependent variable *behaviour* consists of specific areas which are examined in the studies. For a detailed knowledge on the effects of alcohol, each behavioural area can be evaluated separately by the means of a meta-analysis.

For the validity of a meta-analysis, it is very important to check the quality of the different studies. Therefore, variables concerning the specifics of the study design, the methodology or the parameters have to be extracted. If the results of different types of studies are combined, it can be analysed which variable influences the global effect.

Generally, in a meta-analysis different methodological procedures can be used: The two main procedures are the method of vote-counting and the method of effect sizes. Vote-counting is particularly indicated if not much information is given in the studies or if information is missing in many studies. The method simply summarises the number of significant findings (positive vs. negative) as well as the number of non-significant findings over the different studies. This procedure permits merging the analyses of different studies and requires a minimal amount of statistical data (Hedges & Olkin, 1980).

However, this method using statistical significance does not give much information about the size of the effect, because statistical significance only indicates that the result is not due to chance. The method of effect sizes in contrast includes the difference between population mean values as well as the standard deviation. This means an effect size specifies the extent to which two populations are separated due to the experimental procedure, adjusted for the variability in the data (Aron, Aron & Coups, 2006; Howitt & Cramer, 2005).

There are different possibilities to measure the effect size. For example, the difference between the two conditions of a study (e.g. alcohol vs. placebo) can be calculated and then standardised by dividing by the combined standard deviation of

both conditions. This index is called Cohen's d (Rosenthal, 1991). Furthermore, the correlation coefficient r can be used as a measure of effect size. Howitt and Cramer (2005) point out that the correlation coefficient is a common statistical measure, which is familiar to most researchers. It estimates the size of the relationship between two variables and thus describes the size of the effect. Another often used measure of the effect size is η^2 (eta-squared). This coefficient of determination estimates the proportion of variance in the dependent variable which can be explained by the variation of the independent variable and ranges from 0 to 1 (Fricke & Treinies, 1985). The average effect size can be calculated by any of these measures.

II META-ANALYSIS

5 LITERATURE SELECTION

To conduct the meta-analysis all available publications that empirically answer the question of the influence of alcohol on (driving) performance and mood had to be collected. The enormous quantity of publications on alcohol and its effects demanded the definition of selection criteria for accepting or rejecting a paper from the literature pool. In this work “literature pool” means all papers which were collected as relevant or possibly relevant to the topic.

5.1 Selection criteria

The following presented inclusion and exclusion criteria were not applied just once. The stages of literature selection, acquisition and processing demanded a repeated checking of each paper for the postulated criteria.

5.1.1 Exclusion criteria

If a study met one or more of the following criteria, it was excluded from further consideration:

(1) The study is set up *non-experimentally*.

This means, only experimental laboratory or field studies remained as material. Analyses of accident statistics or epidemiological investigations were not considered. The effect of alcohol in these studies is not controlled for other influencing factors (e.g. fatigue).

(2) The study investigates only variables which are not connected to behavioural abilities needed to drive a vehicle safely.

This excluded papers which are mainly concerned with *physiological effects* of alcohol (e.g. cardiovascular functions or the functions of other organs) or metabolic processes.

(3) *Only animals* serve as subjects, not humans.

The results of animal tests were not considered, as the transferability to humans is doubtful, especially regarding behavioural variables, which are the main topic of the analysis.

(4) Alcohol is administered by *intravenous infusion*.

Only studies with oral alcohol administration were considered for the meta-analysis for reasons of comparability (e.g. absorption times are different) and for reasons of common practice (an oral intake is more usual).

(5) Less than *6 subjects* participated in the study.

For methodological issues, a minimum of 6 subjects was required since the power of the statistical tests is likely to be diminished with smaller samples.

(6) The investigated population is composed solely of *alcoholics*.

The classification of an investigated group as alcoholics was adopted by the authors of the publication. Because of unequal alcohol tolerance and different metabolism processes in alcoholics and non-alcoholics, it must be assumed that study results obtained with an extreme group are of limited significance for the driving safety of the general population.

5.1.2 Inclusion criteria

The following inclusion criteria were set for a study to be accepted for further processing:

(1) The study must use a *control group design*.

The effects of alcohol have to be tested by comparing the alcohol group with a placebo or non-alcohol condition. This ensures that no other influencing factor (e.g. testing time, test situation) is responsible for the observed result.

(2) At least one *alcohol-only treatment* must be applied.

This refers especially to studies whose primary interest is the investigation of drugs. To be included into the literature pool, not only the effect-modifying capacity of alcohol (i.e. alcohol-drug interaction) should be investigated, but also the pure effect of alcohol.

(3) *Own experimental data* have to be reported.

The minimal demands of a scientific report must be met, in particular referring to the data of the application of alcohol. Therefore, this meta-analysis relies only on studies which generated their own experimental data. If the same study was published more than once by an author or group of authors, it was included in the literature pool only once, namely in its most comprehensive version.

(4) *BAC must be reported* or be calculable from reported data.

If the empirical BAC was not measured or reported, its calculation with the Widmark formula must be possible. This needs information of the consumed quantity of alcohol and of the time between the end of alcohol intake and the beginning of measurement of the investigated variables. It was required that the alcohol dosage in grams of pure alcohol per kilogram of body weight was computable from the data given in the publication. Alcohol quantity was frequently already reported in g/kg in published work. The information of the volume of liquid sufficed if the alcohol concentration of the drink was also reported. In addition, the time after drinking, when measurement began, had to be reported or be calculable from other time information given in the description of the experiment.

(5) The study must be published in or after *1990.*

The review of literature on alcohol effects of Krüger et al. (1990) includes studies up to 1989 and these were integrated in the present analysis.

5.2 Literature search

5.2.1 Overview

The literature search was initiated to find as many studies as possible in the scientific literature, which reported experimentally determined results concerning the effects of different blood- or breath-alcohol concentrations (hereinafter summarised as BAC, because empirical breath concentrations were transformed into blood alcohol equivalents by the authors).

It soon became apparent that the effects of alcohol have been investigated in an enormous number of papers which are scattered widely over different research fields. Therefore, to fulfil the objective of the project without exceeding time and cost constraints, specialised search strategies were used (see next chapter). They were applied on different levels:

(1) Computer searches in relevant databases (Medline, PsychInfo).

(2) Tables of content and abstracts of relevant scientific journals.

(3) The publications of authors, of whom more than one study was included into the literature pool.

(4) Reference lists of the processed literature, reviews and non-experimental publications.

Even if the complete pool of publications on the subject of “effects of alcohol on (driving) performance, social behaviour and mood” could presumably not be acquired, one may assume that the present literature material comprises a representative and comprehensive overview of the available empirical work on the subject. The deadline to be included into this meta-analysis was November 2007.

5.2.2 Sources of literature

5.2.2.1 Bibliographical databases

The computer search was restricted to two databases, which were best suited to the object of investigation. To perform search runs, the databases Medline and PsychInfo were chosen. These bibliographic systems comprise a multitude of medical and psychological periodicals, in which the majority of the studies analysing the effects of alcohol is contained.

For both databases, the search took place in June 2005 and once again in November 2007, and it was run with the limitation that the publication year is ≥ 1990.

(1) Medline: The search for studies with “alcohol” in the so-called MESH field (major and minor descriptors) offered more than 33,000 publications since 1990. Therefore, the search was carried out with the combination “alcohol and performance” in MESH with respect to the general aim of the meta-analysis to include only behavioural effects. With this strategy, a narrowed number of 290 publications appeared.

(2) PsychInfo: In this database, the search for studies with “alcohol” in the so-called DE field (major and minor descriptors) resulted in more than 15,000 publications. To reduce the number, the search was then performed with the combination “alcohol” in DE and “23” as classification code (CC) for “human experimental psychology”. Thereby, 114 publications remained for analysing.

This rather strict search strategy was completed by three further levels of searching.

5.2.2.2 Relevant scientific journals

The tables of content and abstracts of 20 relevant periodicals (whose titles contain e.g. the words “alcohol”, “substance” or “addiction”) were analysed. The journals were all available via the databases Medline, PsychInfo or Psyndex. Search runs were performed with the name of the journal in SO (source) combined with “alcohol” in TI (title). All in all, 6,644 publications were found, of which 131 met the inclusion criteria and were not already included in the literature pool.

5.2.2.3 Papers of relevant authors

The search was supplemented by analysing the publications of experimental alcohol experts, this means of authors with more than one paper in the literature pool. This was the case for 106 authors. Each search was run with the author’s name in AU (author) linked with “alcohol” in TI (title) in Medline and PsychInfo together. A total of 1,542 papers were provided for reviewing. After applying the in- and exclusion criteria, 89 papers which were not already included in the literature pool remained for the meta-analysis.

5.2.2.4 Reviews and bibliographical references

Another 172 studies were identified as presumably relevant for the topic by checking the bibliographical references of the collected papers (including 14 reviews). After looking at approximately 4,000 references of more recent papers, it became obvious that almost every suitable publication had already entered the literature pool. This can be seen as an indicator for an exhaustive search strategy.

5.2.2.5 Unspecific search

Moreover, 12 papers were added to the literature pool without any specific search, this means they were already at hand.

5.3 Results of the literature search

The described search strategies led to an individual examination with respect to the above defined criteria of more than 12,000 bibliographical references. A first checking of the titles resulted in 808 publications possibly relevant to the topic. After reapplying the in- and exclusion criteria when reading the abstracts, 438 studies qualified for remaining in the literature pool. Of these, 24 papers were not available, this means they could not be found at university libraries in Germany or it would have been too expensive to obtain them. The copies of the remaining 400 papers were assembled as well as the copies of the 14 reviews. While processing the literature by reading the whole texts, the selection criteria were applied again and 79 publications were sorted out. Thus, 321 papers are left as database. These papers report on 329 experiments with a total of 4,078 findings of alcohol effects on (driving) performance, social behaviour or mood. Figure 2 summarises the output of the literature search.

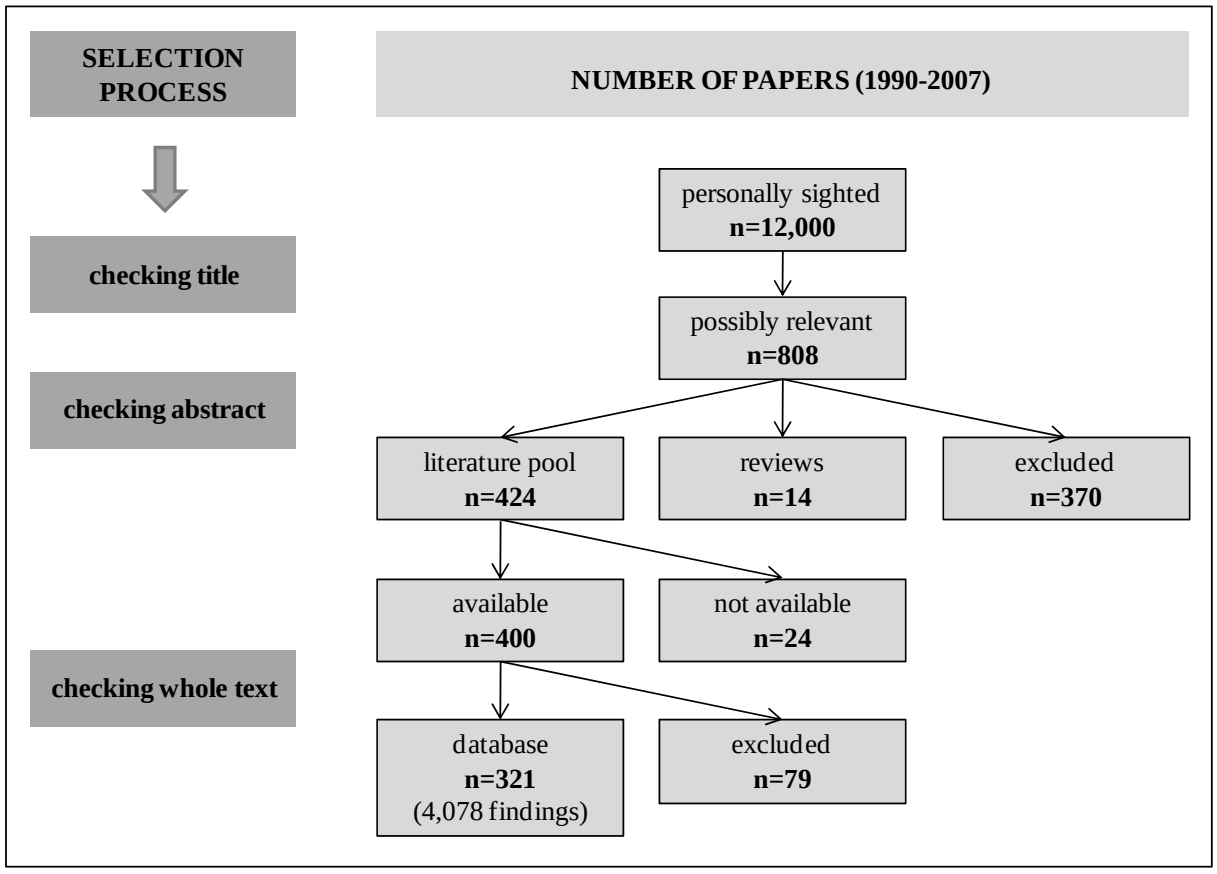


Figure 2: Results of the literature search and evaluation of the relevant papers.

Moreover, the references of the former meta-analysis of Krüger et al. (1990) were reviewed. Of these 202 studies, which investigated the effects of alcohol before 1990, 8 were not available and 11 were excluded because of methodological issues. Apart from this, 54 studies were not reviewed, because the findings only concerned subjective or physiological effects and no performance effects, which were primarily of interest to broaden the literature material. Thus, 129 studies from the years 1950 to 1990 were added, in which 142 experiments with 1,222 findings were described.

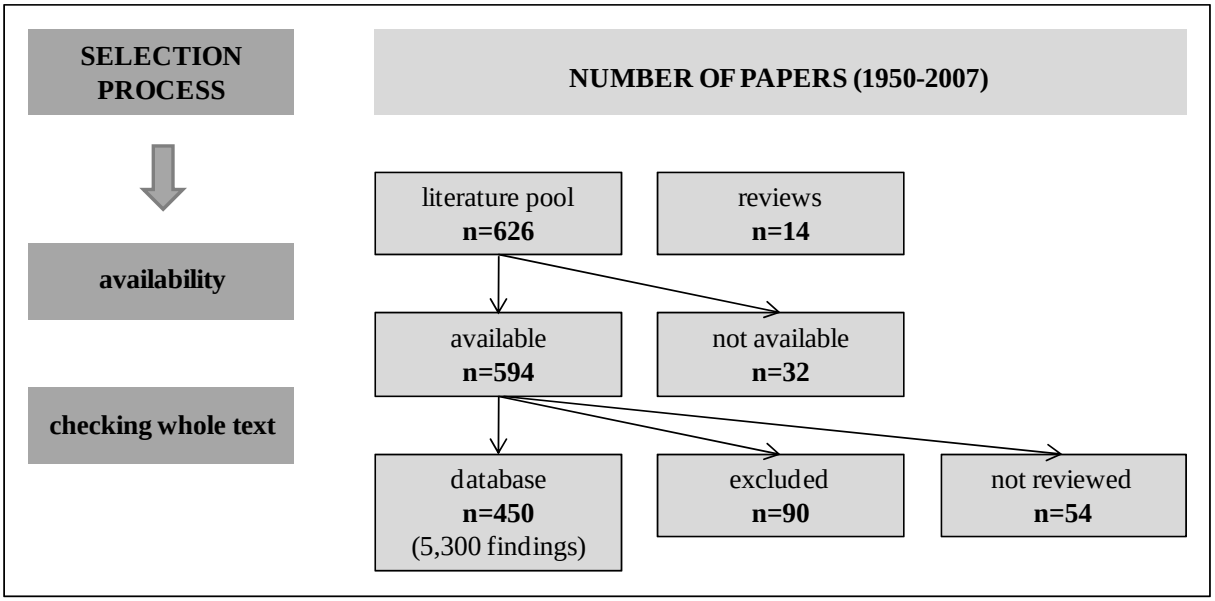


Figure 3: Overall result of the literature search and the evaluation of the relevant papers, after adding studies from the former meta-analysis.

As Figure 3 shows, the total number of papers which seem to be suitable for the meta-analysis is 626. Of the 594 available studies, 90 were excluded for different reasons after checking the whole text and 54 of the former meta-analysis were not revised for reasons mentioned above. Finally, 450 papers remained to form the literature material for the meta-analysis. In them, 471 experiments are described with a total of 5,300 findings of alcohol effects on (driving) performance, social behaviour or mood.

5.4 Publication bias

The fact that rather studies reporting significant results than non-significant results are published in scientific journals („publication bias“) is a well-known phenomenon. However, also a non-significant result is an important result and increases the knowledge of a specific issue. In a meta-analysis, publication bias may lead to the problem of representativeness of the studies included and to an overestimation of the effects (Rustenbach, 2003). Particularly regarding a substance like alcohol, from which it is known that its effects depend on the concentration level, it is essential not to neglect non-significant findings. Therefore, the existence of non-significant studies in the present meta-analysis is tested.

Overall, 77 of the 426 studies, which investigated the effects of alcohol on performance[4], report no significantly impaired finding. Regarding the year of publication, it seems that especially in the early stages of alcohol research only significant studies have been published. Up to the year 1970, all studies included in the meta-analysis report at least one significant finding (see Figure 4). Up to 1985, there are few studies without any significant result, but in more recent years the

[4] 24 studies, which solely investigated subjective effects of alcohol like the feeling of intoxication, have not been considered.

number of non-significant studies has increased. Since most studies in the present literature pool have been published during the last 20 years, the problem of publication bias seems to be negligible in the present meta-analysis.

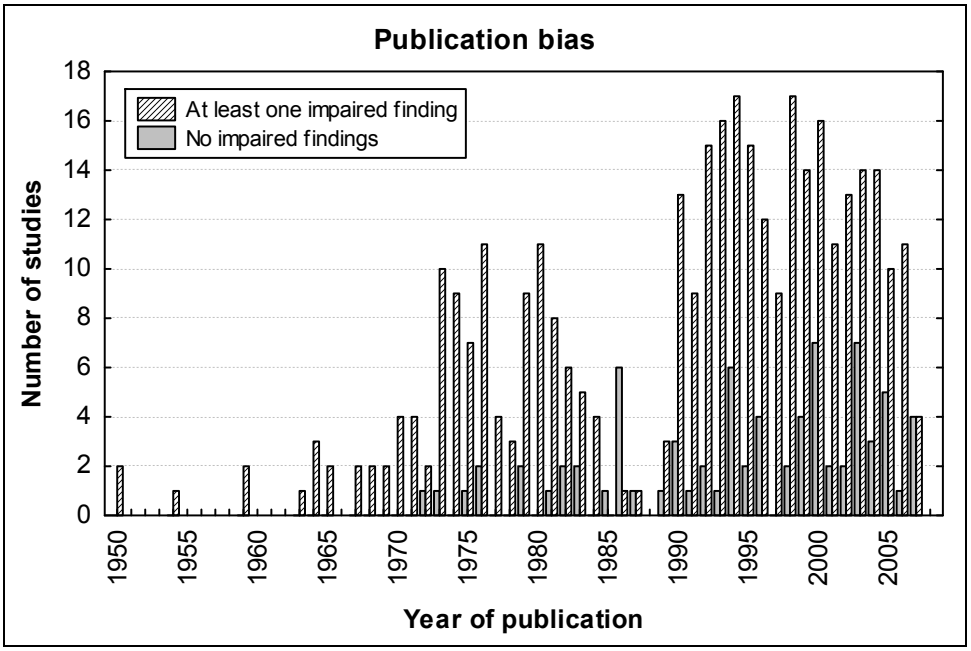


Figure 4: Number of studies reporting at least one impaired finding in a performance test vs. no impaired findings depending on the year of publication.

6 PROCESSING OF THE RELEVANT LITERATURE – THE DATABASE

6.1 Basic structure of the database

For the data input Microsoft™ Access was used. The basic structure of the database consists of two levels. The higher level ("publication level") contains all information about the publication and the basic methodology of the study which in most cases corresponds to one experiment (including one study design, one sample, etc.). If a publication contains more than one experiment, every experiment is inserted in the database as a separate publication. Each publication consists of one or more research findings. In this lower level ("finding level") all relevant information about the single findings is stored, which is for example the BAC level and the outcome for every examined parameter (significant increase or decrease or no significant change). The exact contents of the extracted information are described below[5].

6.1.1 The publications

The principle information describing a publication consists of the following topics which correspond to different entry forms in the database:

- the reference including information about the source (author, publication year, title, journal, volume, number of volume, pages, document type, etc., see Figure 5),
- the abstract,
- a **comment** on any unusual aspects of the study as well as a classification of the main question (e.g. "alcohol and drugs"),
- information about the **sample** (e.g. number and gender of the subjects),
- information about the **methodology** (e.g. the study design, single or double blind studies),
- **statistical** information of the study (e.g. kind of control group),
- information about the **processing** (e.g. date of processing, reasons for disqualification of the study).

[5] In the text only the basic structure of the database is explained. For a detailed description of all fields, categorisations and rules for the classifications see Chapter 10.1 in the appendix.

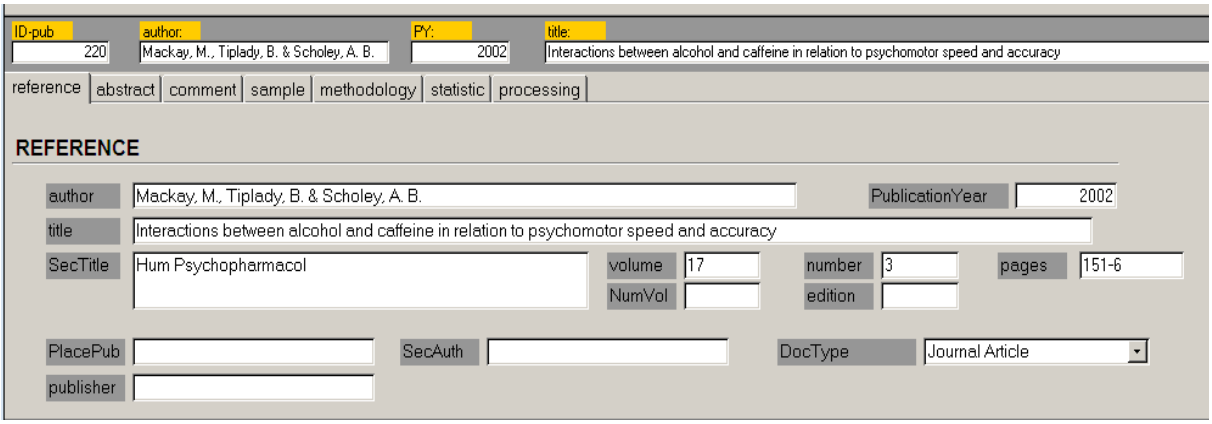


Figure 5: Screenshot of the input fields on the publication level.

6.1.2 The findings

The information describing a finding consists of the following topics corresponding to different entry masks in the database:

- information about the **BAC** (dose, BAC level, drinking time, etc., see Figure 6),
- information about the **task**, with which the parameter was measured,
- information about the **parameter** itself and the **result**,
- information about **other factors** and their interaction with the effect of alcohol (e.g. gender, other substances).

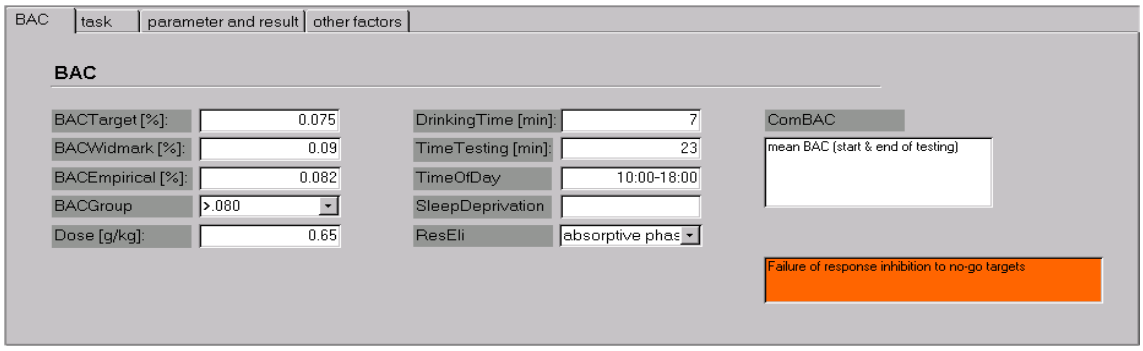


Figure 6: Screenshot of the input fields on the finding level.

Typically, the number of reported findings (i.e. the number of significant increase/decrease or non-significant results) corresponds to the number of tested BAC levels (without placebo) multiplied with the number of dependent variables (= parameters). So if only one dependent variable is tested in one alcohol condition versus placebo, there will be one entry in the database. If there are 8 dependent variables which are tested at three different BAC levels against placebo, there will be 8*3 = 24 entries in the database (see Figure 7). Different BAC levels might result either from different alcohol dosages for the subjects or from different points in time at which the same parameter is measured.

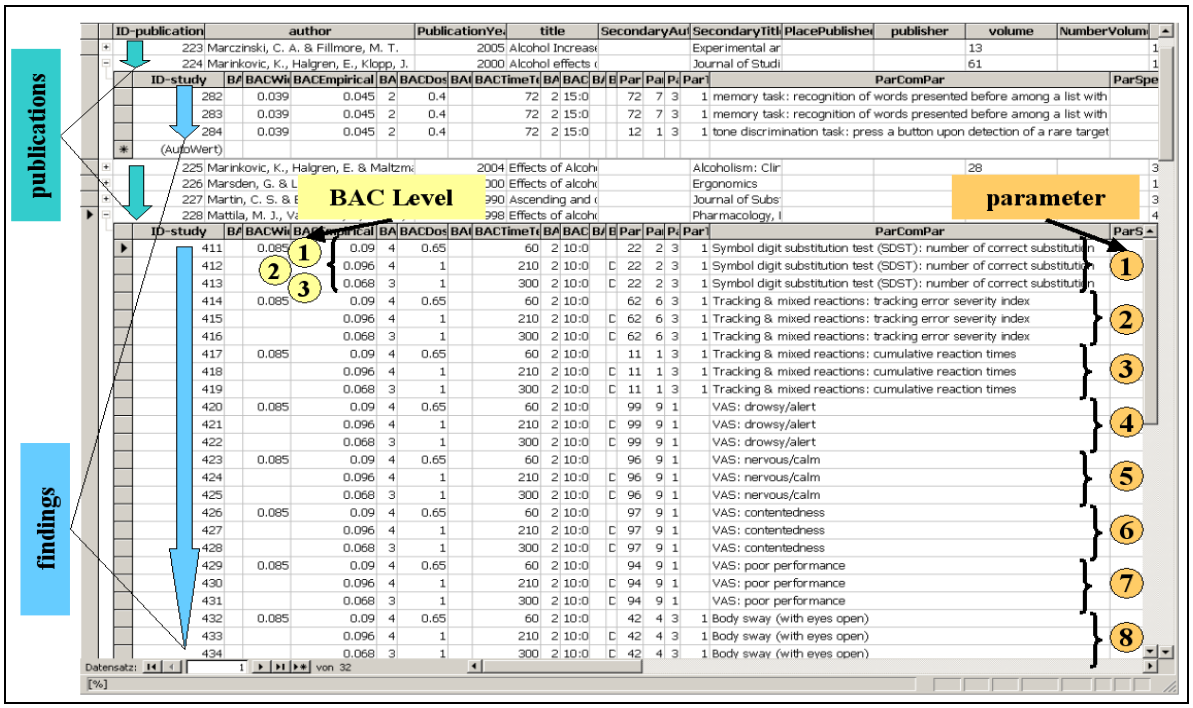


Figure 7: Structure of publications and findings in the database.

However, this rule needs not to fit all the time, for example, if there are multiple BAC levels but no post hoc tests. In this case, either the highest BAC is considered (if there is an effect) or the lowest (if there is no effect) in order to be conservative.

6.2 Description of the BAC

The main objective of the present work is to determine the effects of the different BACs on the indicators for traffic safety. In order to attribute the effects of alcohol to the respective BAC level, different ways of calculating the valid BAC must be introduced. For the determination of the BAC, different periods of time must be considered, namely the “drinking time”, the “time before testing”, and the “task duration” (see Figure 8).

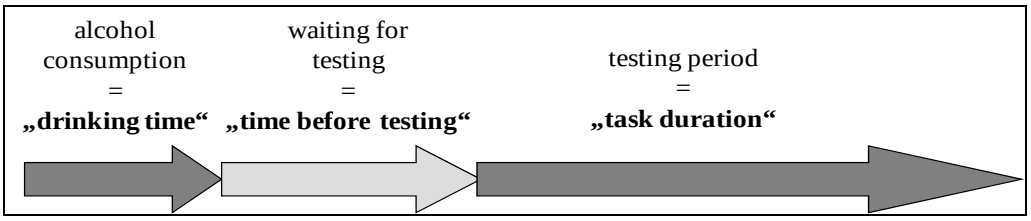


Figure 8: Illustration of the main chronological terms for calculating the BAC level.

In most publications these pieces of temporal information are given. However, sometimes there is a range given for the time periods, for example 10-20 minutes for drinking time. In this case the mean value is taken for further calculations.

6.2.1 Definition of the absorptive vs. eliminative phase

Due to the acute tolerance effect (Mellanby effect), meaning that there is greater impairment in the ascending than in the descending phase of the BAC curve (e.g. Hiltunen, 1997), these two phases have to be coded for further analysis.

If in the studies the BAC is measured empirically (by technical devices) before and after the test period and the empirical BAC after the test period is lower than before, an eliminative phase is coded. Conversely an absorptive phase is coded, if the empirically measured BAC after the test period is higher than before. If there are no BAC measurements, the criterion for differentiating between the two phases is set at 60 minutes after the end of alcohol intake, since the duration of the absorption phase is approximately between 30 and 90 minutes. The range might even be between a few minutes and two hours (Madea & Dettmeyer, 2007) and depends, for example, on the alcohol dosage, the drinking time or the content of the stomach. Getting only a low alcohol dose or drinking on an empty stomach leads to an earlier BAC peak. Therefore, it is assumable that the effects classified as "eliminative" do in fact lie with high probability in the elimination phase, while a part of the effects labelled as "absorptive" is probably eliminative.

If the duration of the task is given, this variable has to be considered as well for the coding of the two phases. Test periods which take place mainly within the first 60 minutes after the end of alcohol intake were classified as absorptive. If the main part of the task takes place after 60 minutes have passed since the end of alcohol intake, it is classified as eliminative. This means that to determine the crucial time phase, one half of the task duration is added to the time between consumption and start of the test [(task duration/2 + time before testing) < > 60 min][6].

6.2.2 BAC calculation by using the empirically measured BAC

In some studies the BAC is measured and reported at testing times, so that the empirical value can be taken. But there are lots of cases in which it is more complicated:

(1) The BAC before and after testing is given (especially if the task takes a long time):
⇨ the mean value is taken.

(2) Only the BAC before or after testing is given and the task takes more than 30 minutes:
⇨ the mean value during the task is calculated by estimating the alcohol concentration before or after the test, respectively, via the elimination function (elimination of 0.015% alcohol per hour is assumed, see Chapter 6.2.3). This calculation of course is only possible in the eliminative phase. In the absorptive phase there is no other possibility than taking the given value.

(3) The BAC is reported at a given time, but the test (or another test) takes place earlier or later:

[6] Example: time before testing = 10 min, task duration = 60 min ⇨ 60 min / 2 + 10 min = 40 ⇨ 40 min < 60 min ⇨ absorptive phase

⇨ the value is estimated via the elimination function as described above.

(4) More than one BAC is reported at given times, and the test takes place in-between:
⇨ the value is estimated via linear interpolation.

6.2.3 BAC calculation by using the Widmark formula

In some studies the BAC is not measured or reported. In order not to have to exclude these studies, the BAC is calculated via the Widmark formula (Widmark, 1932). It was used in the following modified form (Krüger et al., 1990):

$$BAC(g/100ml) = \frac{alcohol\ quantity\ g/kg}{10 * reduction\ factor} - alcohol\ elimination$$

The reduction factor in the Widmark formula (or distribution factor) represents the ratio of total body alcohol and blood alcohol concentration. Due to the close relationship between the alcohol content and the water content of organs, tissues and body fluids, r also corresponds to the ratio of total body water and blood water (Seidl, Jensen & Alt, 2000). In the forensic practice the usage of a reduction factor of 0.7 for men and 0.6 for women has become established (Huckenbeck & Bonte, 2003). If the study sample contains both sexes, a mean value of 0.65 is used.[7]

The calculated BAC by the first part of the formula must be seen as a virtual BAC maximum at the beginning of alcohol intake. From this maximum a time-dependent elimination is subtracted. The elimination of alcohol starts immediately after the intake. This elimination rate is estimated – conservatively – at 0.015 g/100 ml per hour (Madea & Dettmeyer, 2007).

The Widmark formula does not account for the so-called absorption deficit, which describes the absorption conditions of alcohol dependent on the physiological state of the body and on the fluid content of the drink. For example, the deficit is higher (i.e. the alcohol is absorbed more slowly) with a full stomach than with an empty one and higher for beer than for spirits, assuming the same quantity of alcohol (Kalant, 1971). The majority of the present papers does not give sufficient information to estimate this absorption deficit reliably.

Thus, the calculation of the BAC results in slightly exaggerated estimations compared to the empirically measured BAC. The consequences of this overestimation are conservative: alcohol-related decrements are demonstrated for comparatively higher BACs. "Conservative" is here seen from the statistical point of view, under which the null hypothesis must be protected as long as possible from being rejected.

[7] Methods determining the distribution factor more precisely by adjusting for age, weight or height (see e.g. Seidl et al., 2000), which improves the BAC estimation, cannot be used, because the studies rarely provide the subjects' height or weight.

For reasons of comparisons with the empirical BAC, two Widmark BACs are calculated before and after the test and the mean value is taken, if the test takes more than 30 minutes.

6.2.4 Calculation of the administered quantity of alcohol

Another difficulty in assembling alcohol studies is the fact that the administered alcohol dosages are not uniformly documented in the literature. The existing variants are:

- g/kg (pure alcohol per kilogram body weight),
- ml/kg (pure alcohol per kilogram body weight),
- ml/kg of a standard alcoholic beverage with indication of the alcohol level (e.g. 40% or 80-proof vodka),
- ml or ccm (1 ml = 1 ccm) not referring to kg,
- country-specific units of quantity (e.g. ounces [oz]).

In this work, the quantity of the consumed alcohol is expressed in grams of alcohol per kilogram of body weight, which is the internationally common unit. All quantities that were not expressed in g/kg had to be converted. The procedure in the cases of the above variants was as follows:

1. Quantity given in ml/kg (pure alcohol)

The given quantity of alcohol is converted into g/kg using the specific weight of alcohol (0.79 g/ml).

Example:

Quantity of alcohol administered: 0.7 ml/kg

Conversion: 0.7 ml/kg * 0.79 g/ml = 0.55 g/kg

2. Quantity given in ml/kg (standard alcoholic beverage)

The given quantity of alcohol is converted into g/kg using the specific weight of alcohol (0.79 g/ml) as well as the percentage by volume of the beverage. If the alcohol level is indicated by “proof”, it has to be converted into % by dividing it with 2.

Example:

Quantity of alcohol administered: 0.7 ml/kg

Alcohol level of the beverage: 40% (or 80-proof spirit)

Conversion: 0.7 ml/kg * 0.79 g/ml * 0.4 = 0.22 g/kg

3. Total quantity of the consumed alcohol is given

In few studies, the administered alcohol quantity is given as a whole, not referring to kilogram of body weight. The quantity of alcohol is converted using the reported average body weight of the subjects or (if not reported) an average weight of 70 kg for men and 60 kg for women.

4. Quantity given in ounces [oz]

The quantity of alcohol given in the unit ounce is converted into ml by multiplying it with 28.41 (British) or with 29.57 (American), respectively. Afterwards, it is converted into g/kg as described above.

Sometimes different dosages for men and women are used. In such a case, the average of the dosages was taken.

6.3 Classification of the tasks and parameters

A crucial point of every meta-analysis is the classification system within which the single studies are to be arranged. For evaluating substance effects, the one by Krüger et al. (1990) is used. It is based on functional behavioural categories relevant for traffic safety like “attention”, “visual functions” or “subjective intoxication”. The assignment of a study result to one of these driving-relevant categories depends on the investigated psychological function of the task.

6.3.1 The classification system

The classification system used in the present meta-analysis assigns the tasks to predominant psychological or psychophysiological functions. The same approach was chosen in different reviews about alcohol effects (see for example Moskowitz and Fiorentino, 2000).

Based on rather rough classifications by Moskowitz & Robinson (1987), Brückner, Peters & Sömen (1988) and Staak, Hobi & Berghaus (1988), Krüger et al. (1990) have developed this classification system for the meta-analysis of experimental alcohol studies. It was also used by Berghaus (1997) for classifying the effects of different medicines and by Berghaus, Schulz & Szegedi (1998) for classifying the effects of cannabis.

Within this method, the different performance tasks used in the studies are classified into one of the driving-relevant performance main categories (for an example see Figure 9). Each of them consists of several sub categories describing the paradigm more precisely, into which the tasks are classified as well. Besides the performance aspect, the domains of mood (containing subjective feelings like intoxication or tiredness) and social behaviour are integrated into the analysis. Due to the extensive subdivision, it is quite simple to assign the different findings of a study to the different main and sub categories.

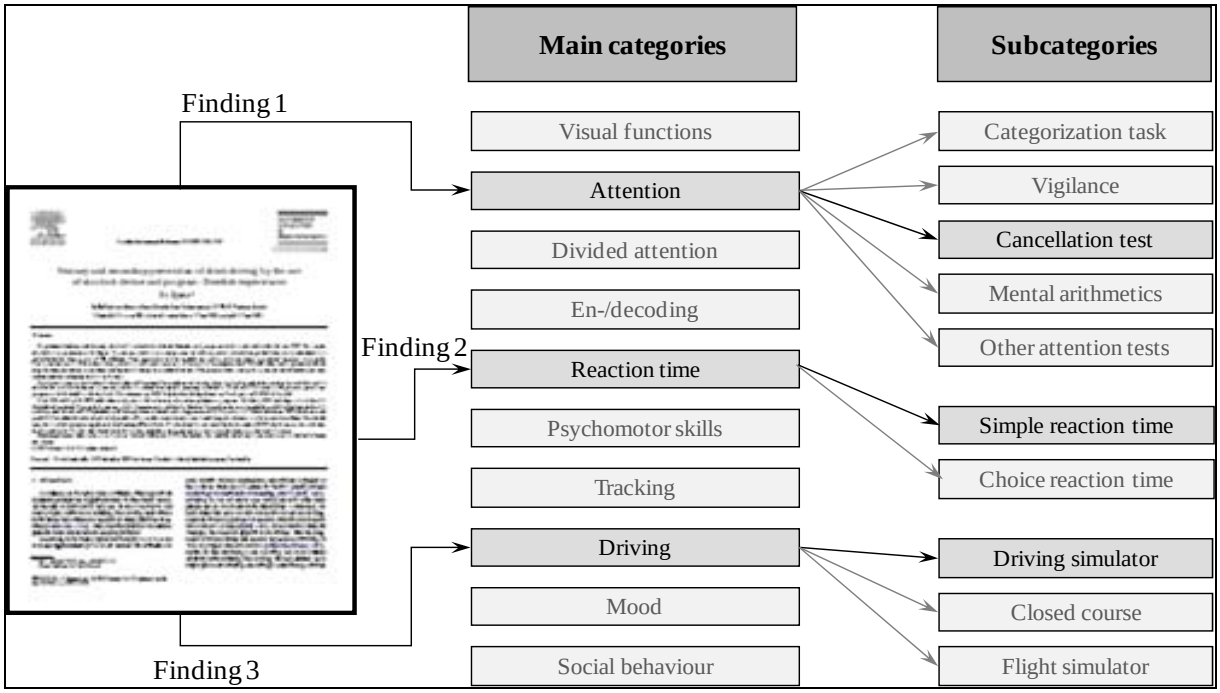


Figure 9: Example for the classification of findings into main and sub categories.

Using this approach the categories are not confounded, because all findings are classified only once into one category. In doing so the problem may arise that some of the sub categories will show small frequencies, so that in these cases only rough evaluations on the main category level are advisable. In advance of the results reported in Chapter 7, the frequencies of findings per category are presented in Table 3 together with the taxonomy and examples of tasks.

Table 3: Classification of parameters and frequencies of findings.

A. PERFORMANCE CATEGORIES			
Main and sub category	**Examples of tasks**	**N**	**%**
1) Visual functions[8]		475	14.6
- Physiology of the eye	- Visual acuity; critical flicker fusion frequency	181	5.6
- Eye movements	- Visual tracking; nystagmus	164	5.0
- Binocular vision	- Heterophoria; stereopsis; exophoria	65	2.0
- Complex perceptual functions	- Spatial orientation; time or length estimation	65	2.0
2) Attention		692	21.2
- Categorisation task	- Card sorting tasks; DSST; trail making test	202	6.2
- Vigilance	- Respond to rare target stimuli (Mackworth)	78	2.4
- Cancellation test	- Cross out target letters among distractors (D2)	44	1.4
- Mental arithmetics	- Pauli test (addition); Serial seven (subtraction)	47	1.4
- Other attention tests	- Go/NoGo tasks; Stroop test; logical reasoning	321	9.9
3) Divided attention		365	11.2
- Reactions to 2 stimuli	- Reaction to central & peripheral stimuli; auditory 2-channel signal detection task	182	5.6
- Reactions to 2 tasks	- Tracking or cancellation test & visual or auditory stimuli; many tasks simultaneously	183	5.6

[8] Some findings of this category were not used as “performance findings”, because they are physiological ones.

Main and sub category	Examples of tasks	N	%
4) En-/Decoding		455	14.0
- Information processing	- Cognitive speed: recognition of a tachistoscopically presented stimulus (letters or pictures)	170	5.2
- Memory	- Free recall, cued recall or recognition tasks	285	8.8
5) Reaction time		373	11.5
- Simple reaction time	- Visual/auditory stimuli: press a button as quickly as possible	183	5.6
- Choice reaction time	- Diverse visual or auditory stimuli: respond only to the target stimulus or with different keys to correspondent stimuli	190	5.8
6) Psychomotor skills		339	10.4
- Hand-eye-coordination	- Circular lights; hand steadiness; pin test	163	5.0
- Posture	- Standing steadiness (Romberg or balance test)	132	4.1
- Other motor functions	- Tapping test; tremor; proprioceptive coordination	44	1.4
7) Tracking		237	7.3
- Easy compensatory tracking	- Horizontal deviations have to be regulated with a steering wheel	33	1.0
- Difficult compensatory tracking	- Critical tracking: unstable system for which deviations between target & actual position have to be compensated	27	0.8
- Easy pursuit tracking	- Pursuit rotor: pursuit of a moving light; spiral maze	158	4.9
- Difficult pursuit tracking	- Stressalyzer (Tracometer): catch a target with a steering wheel	19	0.6
8) Driving		323	9.9
- Driving simulator	- Road tracking, car follow, hazard detection & reaction task	212	6.5
- Closed course	- Road tracking, car follow, hazard detection & reaction task	65	2.0
- Flight simulator	- Routine scenarios, communication, approaches	46	1.4
Total number		**3,259**[9]	**100**

B. MOOD CATEGORIES			
Main and sub category	**Examples**	**N**	**%**
9) Mood		1,953	97.3
- Experienced intoxication	- Feelings of drunkenness	394	20.2
- Unpleasant physical sensations	- Dizziness, nausea	236	12.1
- General well-being	- Global mood	12	0.6
- Subjective rating of performance	- Feelings of performance	87	4.5
- Physiological measurements	- Pulse, temperature, blood pressure	77	3.9
- Arousal/activity	- Stimulation, sedation, relaxation	365	18.7
- Pleasure	- Contentment, effect liking, depression	434	22.2
- Dominance	- Social mood, friendliness	38	2.0
- Tiredness	- Fatigue, drowsiness	202	10.3
- Aggressive feelings	- Subjective: hostility, anger	53	2.7

C. SOCIAL BEHAVIOUR CATEGORIES			
Main and sub category	**Examples**	**N**	**%**
10) Aggressive reactions		50	2.5
- Aggressive behaviour	- Objective: hostility	50	2.5
11) Social behaviour		5	0.3
- Behavioural measures of social activities	- Objective: social interactions	4	0.2
- Social feelings	- Subjective: social anxiety	1	0.1
Total number		**2,008**	**100**

N: absolute frequency

%: relative frequency (sum of performance categories = 100%; sum of mood and social behaviour categories = 100%)

[9] The exact number of “performance findings” after subtracting the physiological findings is 2,983.

In total, there are 5,267 findings of effects which can be assigned to the performance or mood or social behaviour categories. The remaining 33 findings which were entered into the database cannot be specified.

Among all findings mood variables occur most frequently, followed by attention, visual functions and en-/decoding variables, as it is visualised in Figure 10. Driving behaviour, tracking and variables in the social behaviour categories are relatively little investigated. These differences in frequencies are not surprising when considering the experimental designs: attention or visual functions tests are easy to conduct and it is easy to determine several parameters (each representing a finding in the meta-analysis) as it is the case with mood variables. In contrast, tracking and driving tests are more complex to conduct and especially for tracking tests usually only few parameters like errors or horizontal deviation are determined.

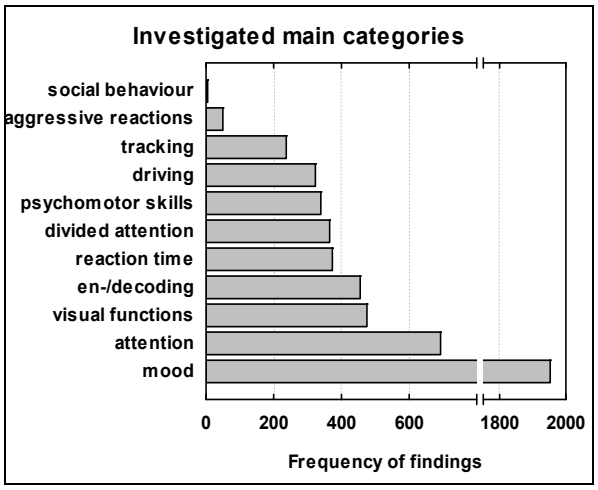


Figure 10: Frequency of findings per main category.

Additionally, it becomes obvious that the frequencies of findings in the different sub categories are extremely unequal (Figure 11). Some sub categories are hardly investigated, so that a meta-analytical evaluation of them will not make any sense. For example frequencies of complex performance tasks like difficult tracking, closed course, flight simulator or vigilance tasks are low, whereas frequencies of less elaborated performance tasks like reaction or memory tasks are high.

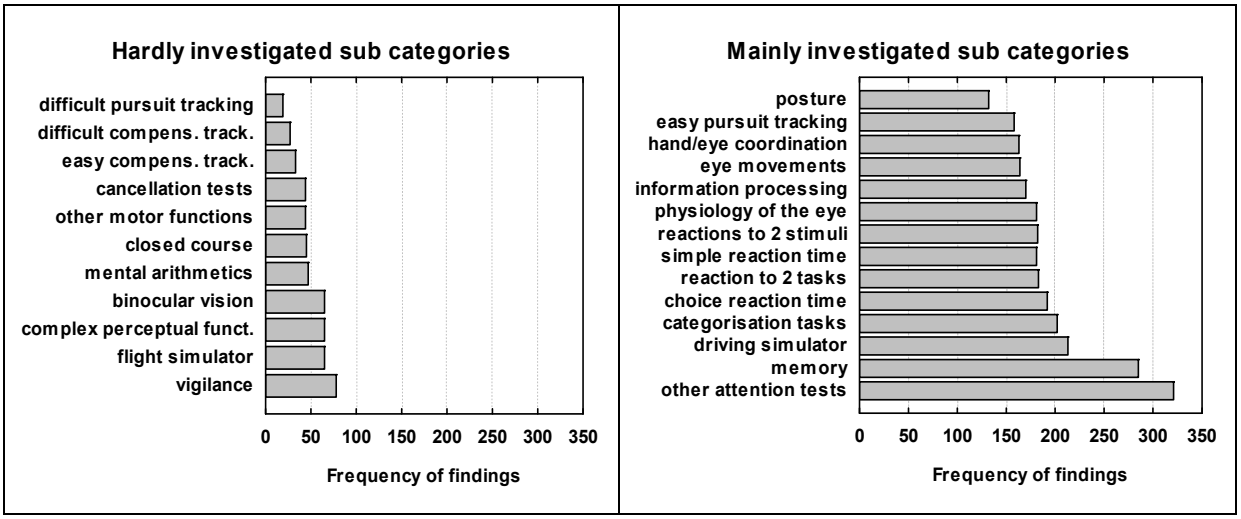


Figure 11: Frequency of findings per sub category – hardly investigated (left) vs. mainly investigated (right).

6.3.2 Additional input fields

Moreover, there are some variables that are specified for each finding as well. For example, the majority of performance tasks are evaluated in the studies in a twofold manner, under a *speed* perspective (reaction times) and under an *accuracy* perspective (error rates). Sometimes both of these perspectives are combined (e.g. number of correct responses in a given time), so that *speed & accuracy* is classified as "type of parameter"[10]. Of course, this distinction can only be made in performance findings.

Another variable is the training of the task before the experiment in order to avoid learning effects in a performance or driving test. When training is not mentioned, *no specification possible* is marked.

Moreover, a free text field is added for a better understanding of the task. There the name of the task is entered, as well as a short description of it and the measured parameter (e.g. "Tone discrimination task: press a button upon detection of a rare target tone; reaction time").

6.4 Classification of results

6.4.1 Statistical significance

The presence or absence of a significant alcohol effect is coded. Regarding the classification of results an important methodological requirement is to define what will be treated as a substance effect. This question is answered pragmatically according to the standard research convention:

[10] The variable "type of parameter" is not to be confounded with the dimension "kind of stress" which refers to the instruction.

A finding of effect exists if an alcohol-placebo comparison is done on a variable at a certain time point with a certain alcohol dosage in a study meeting all inclusion criteria and no exclusion criterion. If the statistical null hypothesis can be rejected on a significance level of α = 5%, a detrimental (-) or beneficial (+) effect of alcohol is recorded in the database. If the null hypothesis cannot be rejected, alcohol is in its effects not different from placebo (0). Detrimental effects on performance are coded as *decrease* in the field "EffectPerf" (Perf = performance), beneficial effect as *increase*. In order to have another coding of the effects regarding the semantic meaning of the description of the parameter, the effect is coded in the field "EffectPar" (Par = parameter) as well. So if alcohol leads to an increase of reaction time, the "EffectPar" is *increase*, but the "EffectPerf" is *decrease* (see Figure 12).

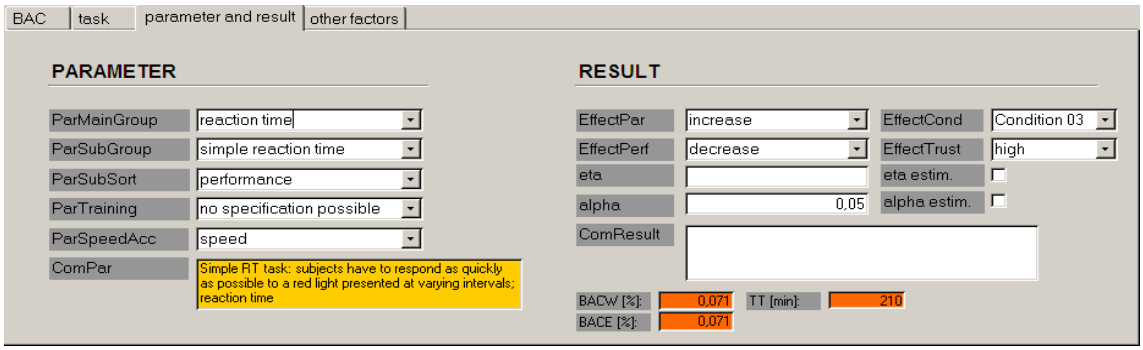


Figure 12: Example of a database entry reporting the parameter categories and the effects.

6.4.2 Effect sizes

In addition to the classification of the results into effect vs. no effect, the effect sizes have also tried to be determined. To estimate the strength of the alcohol effect, eta-squared (η^2) as a coefficient of determination is calculated which gives the proportion of explained variance to the total variance. There are different possibilities to calculate eta-squared depending on the information given in the studies. Table 4 shows the different formulas which are needed for the computations (Rosenthal, 1991, p. 66).

Table 4: Formulas to calculate eta-squared depending on the available information.

Case	Available information	Formula	Comment
ANOVA: 1 factor (1 paired sample or 2 samples)	F-value and degrees of freedom (df)	$\eta^2 = \frac{F*df_1}{df_2 + F*df_1}$	$F = F_{(effect)}$ $df_1 = df_{(effect)} = n_{(levels)}-1$ $df_2 = df_{(error)}$
ANOVA: >1 factor (1 paired sample or 2 samples)	only F-value of effect	$\eta^2 = \frac{F*df_1}{df_2 + F*df_1}$ actually (if all F-values and df are reported): $\eta^2 = \frac{F_{(A)}*df_{(A)}}{F_{(A)}*df_{(A)} + F_{(B)}*df_{(B)} + F_{(AB)}*df_{(AB)} + df_{(R)}}$	$F = F_{(effect)}$ $df_1 = df_{(effect)} = n_{(levels)}-1$ $df_2 = df_{(total)}-df_{(effect)}$ Assumption: F-values of other effects = 1
ANOVA: 1 factor (1 paired sample or 2 samples)	t-value and sample size n	$\eta^2 = \frac{t^2}{n-2+t^2}$	2 samples: $n = n_{(total)} = n_1+n_2$ 1 paired sample: $n = n_{(total)} = n_1+n_1$

The first formula is used to calculate eta-squared via the F-value. Even if there is more than one factor (see second row), this formula has to be used, since there is no study in which all F-values and df are reported. df_1 is the number of factor levels minus "1". Since the findings always refer to one BAC level, the F-value of the post hoc test has to be taken. Therefore df_1 is always "1", even if there are actually more levels of the factor alcohol. The last formula can be used, if the t-value is given.

In some of the studies, in which the F- or t-values are not available, means and standard deviations are reported. In these cases the following formulas (see Table 5) are used to calculate the t-value (Bortz, 2005, p. 262).

Table 5: Formulas to calculate the t-value depending on the available information.

Case	Available information	Formula	Comment
2 samples	n_1, n_2, m_1, m_2, s_1, s_2	$t = \frac{m_2 - m_1}{\sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2} * \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$	
	n_1, n_2, m_1, m_2, var_1, var_2	$t = \frac{m_2 - m_1}{\sqrt{\frac{n_1 \mathrm{var}_1 + n_2 \mathrm{var}_2}{n_1 + n_2 - 2} * \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$	with s = sqrt(var) ⇨ var = s^2
	n_1, n_2, m_1, m_2, SEM_1, SEM_2	$t = \frac{m_2 - m_1}{\sqrt{\frac{n_1^2 SEM_1^2 + n_2^2 SEM_2^2}{n_1 + n_2 - 2} * \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$	with s = SEM*sqrt(n) ⇨ SEM = s/sqrt(n) ⇨$s^2 = SEM^2*n$
1 paired sample		same formulas with $n_1 = n_2$	

The formulas for two samples can also be used for one paired sample by applying the same sample size (n) for n_1 and n_2. If eta-squared needs to be estimated by one of these formulas for a within-subject design, this is coded in the database in a boolean variable named “eta estimation”.

6.4.3 Consideration of multi-factorial designs

In many studies, there is not only the factor alcohol of interest, but also other factors which might influence the performance. If there is a multi-factorial design, the interesting interactions are reported in the following way: First, the factor is described in a free text field without categorisation. Thereby the levels of the factor are written down in such a way that the coding of the effect refers to that level which is named first. If, for example, there is a significant interaction of BAC and gender in such a way that the effect of alcohol on the proportion of errors in an attention test is stronger in women, the text should be: “female vs. male” in combination with *increase* in the field “F1EffectPar” and *decrease* in the field “F1EffectPerf” (see Figure 13). If there is no significant interaction, *no change* has to be selected in both fields. Moreover, the factor is assigned to one of the following categories: *gender*, *personality*, *motivation*, *beliefs*, *state/fatigue*, *signal quality*, *compatibility*, *stimulus timing*, *workload/difficulty*, *complexity/dimension*, *external stress, other substances* or *no specification possible*. A further free text field (“ComFac”) exists to give comments about the factor or the interaction. It is possible to enter up to three factors besides alcohol into the database.

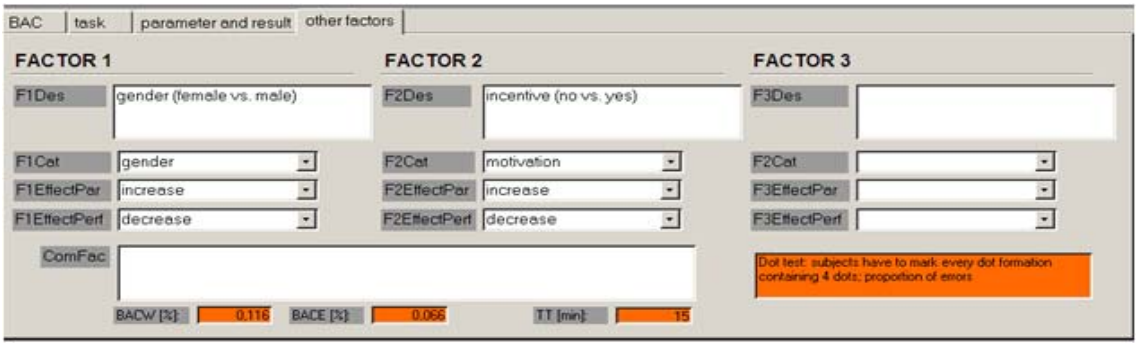


Figure 13: Example of a database entry reporting interactions or no interactions of alcohol with other factors.

6.4.4 Confidence rating of effects

Due to the different trustworthiness of the results in the publications, a system for rating the effects regarding their confidence level is introduced (see Figure 14). It distinguishes – in words of an analysis of variance – whether the main effect of alcohol is significant or not and whether there are interactions or not. If the main effect is significant, the level of confidence depends on the order of interactions (e.g. two-way or three-way interaction) and on the way of reporting them. However, this rating system needs only to be applied in a multi-factorial design. If there is just the factor alcohol, the confidence of the effect is always high.

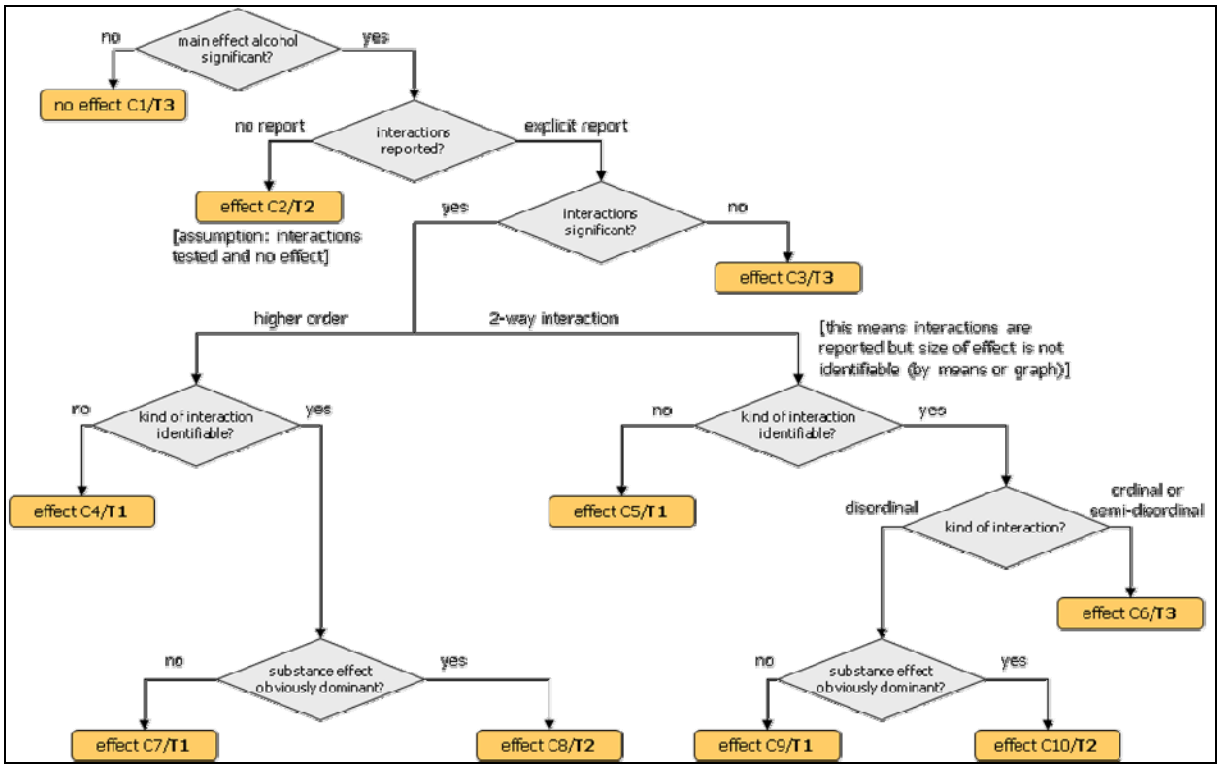


Figure 14: Decision tree in order to rate the confidence of the effect depending on the given information and kind of evaluation in the publication.

A high confidence (T3) is given

- if the main effect of alcohol is not significant (C1),
- if the main effect is significant and no interactions are significant (C3),
- if the main effect is significant, and significant interactions are well-reported and ordinal or semi-disordinal (C6).

A medium confidence (T2) is given

- if the main effect of alcohol is significant and interactions are not reported (C2),
- if the main effect is significant and significant interactions are reported, and these are disordinal or by a higher order (more than 2 factors, i.e. a three-way interaction), but the main effect of alcohol is obviously dominant (C8, C10).

A low confidence (T1) is given

- if the main effect of alcohol is significant and significant interactions are reported, but the kind of interaction cannot be identified because no means or graphs are reported (C4, C5),
- if the main effect is significant and significant interactions are reported, but they are disordinal, and the main effect of alcohol is not obviously dominant (C7, C9).

7 RESULTS

7.1 Evaluation

In order to evaluate the effects of alcohol, the method of vote-counting was applied (see Chapter 4). This method was also used by Moskowitz and Fiorentino (2000) in their review (see Chapter 3.1.15). Thereby, the number of significant and non-significant findings[11] was summarised for the same BAC groups as it is illustrated in Figure 15 with fictive data. The different BACs were summarised in 0.01%-steps. Thus, the lowest group comprises BACs from 0.001% to 0.009%, the next one from 0.010% to 0.019% and so on. By counting all findings, the *general* performance could be determined, whereas *more specific* performances could be determined by counting only the findings in the respective performance categories. In order to get reliable estimations of the alcohol effects, the minimum frequency of findings per BAC group was set at 10 for being presented in this work. The highest BAC group for which reliable information could be obtained was 0.110-0.119.

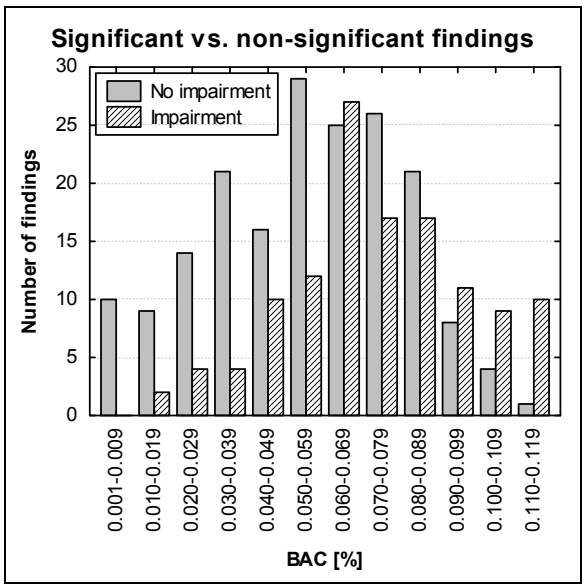


Figure 15: Example for the summarisation of significant and non-significant findings per BAC group (fictive data).

By this evaluation method, the percentages of significantly impaired findings per BAC group can be displayed, which is done in the following chapters. The resulting empirical function was interpreted as an “impairment function” by Berghaus et al. in 1998 when conducting a meta-analysis of cannabis.

[11] Significant beneficial findings were counted as non-significant.

7.2 Consistency of results

The effect of alcohol might differ depending on the kind of evaluation and on a number of other aspects. These aspects and their impact on the results are evaluated in the following subsections.

7.2.1 Vote counting vs. effect sizes

First of all, the method of vote counting is compared to the method of estimating effect sizes. In order to get a more precise estimation of the substance effect, eta-squared is calculated. Eta-squared is an estimator of the proportion of variance explained by the corresponding factors or independent variables.

The calculation of eta-squared requires some preconditions:

(1) The statistical comparison must be done between two groups.

(2) The necessary information must be given in the publication.

If eta-squared is calculated for a two-group comparison, it reflects mainly the difference of means in the treatment conditions. Assuming that the error component in the ANOVA model and the number of subjects are constant over the BAC groups, the probability of significance should rise with higher effect sizes[12]. Unfortunately in most publications the necessary information to calculate effect sizes is only given for significant results. As a consequence, the mean effect size for BAC groups with a low proportion of significant results will be overestimated, because the great number of non-significant results with low effect sizes is not included.

In the present analysis, effect sizes could be calculated in 602 cases of the overall 1951 significant impaired findings. Since there are only 375 eta values regarding performance findings, mean values for each BAC group are determined for the general performance and not for the single performance categories. Regarding the subjective sub category *experienced intoxication* there are at least 120 eta values. Therefore, the results of both methods concerning the general performance including driving and concerning the subjective feeling of intoxication are compared.

Regarding the performance results (Figure 16, left) the percentage of significant findings increases almost perfectly linearly with increasing BAC, whereas the effect sizes remain between 0.2 and 0.4 up to a BAC of 0.10%. This can be explained by the mentioned statistical artefact that in BAC groups with less than 50% significant findings the effect sizes are overestimated. The higher the proportion of significant findings the better the estimation of the real effect size is. Thus the effect sizes regarding the subjective feeling of intoxication (Figure 16, right) increase similarly to the percentage of significant findings, because almost all effect sizes (except η^2 at 0.02% BAC) are based on 80% significant results. The reason for the drop of the effect size at 0.11% BAC remains unclear as well as the abrupt rise of the effect size at that BAC level in performance tasks (data were checked for outliers).

[12] The error component must be postulated as constant. The number of subjects is checked and the median turns out to be rather invariant over the BAC groups.

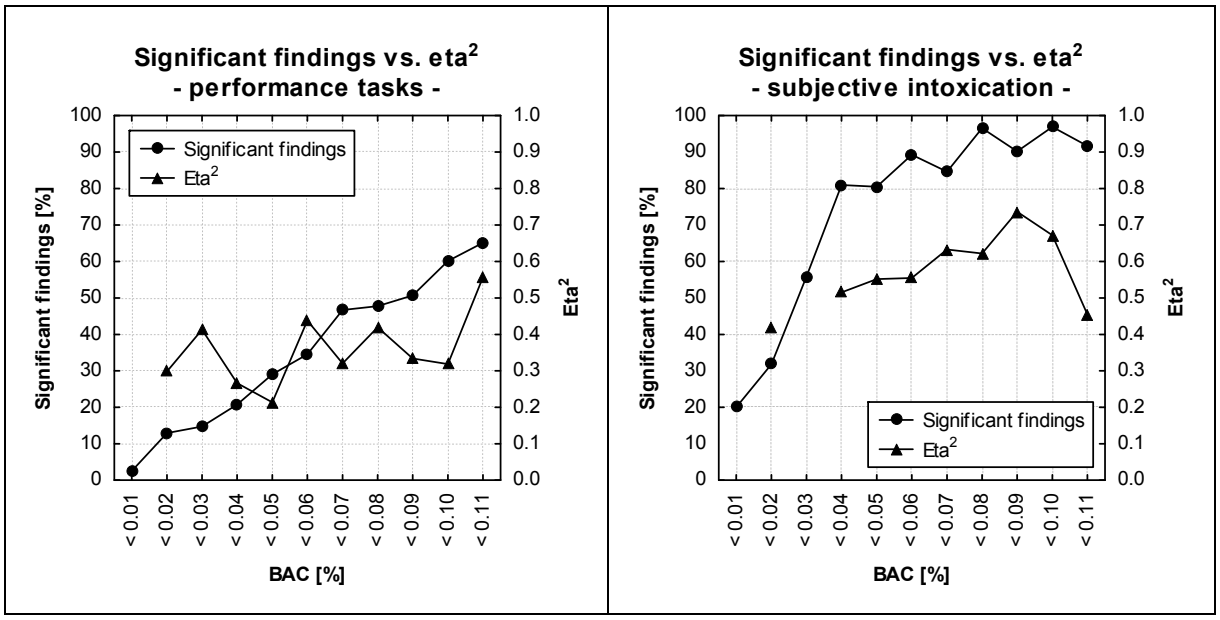


Figure 16: Comparison of the method of vote counting and the method of effect size estimation regarding the results of performance tasks (left) and subjective intoxication (right). The presented eta mean values per BAC group consist of at least three values.

Additionally it is tested if effect sizes increase with higher BACs when the same performance test is conducted under the same methodological conditions. Therefore, a closer look is taken at studies in which a performance test is conducted under different BAC levels and in which eta-squared can be calculated for each BAC level. As an example, Table 6 presents the corresponding driving studies together with the investigated BAC levels and the effect sizes. It becomes obvious that at least within the same study effect sizes increase with higher BACs. This also holds true for the majority of the other 22 studies conducting a total of 30 performance tests at different BACs.

Table 6: Effect sizes in studies conducting a driving test under different BAC levels.

Study reference	Sub category	BAC [%]	Eta²
Gengo, Gabos, Straley & Manning (1990)	Driving simulator	0.10	0.18
		0.11	0.29
		0.13	0.51
Rupp, Acebo, Seifer & Carskadon (2007)	Driving simulator	0.04	0.19
		0.05	0.25
Tornros & Laurell (1991)	Driving simulator	0.04	0.19
		0.16	0.62
Morrow, Yesavage, Leirer, Dolhert et al. (1993)	Flight simulator	0.07	0.21
		0.10	0.30
Ross, Yeazel & Chau (1992)	Flight simulator	0.03	0.37
		0.04	0.65
Arnedt, Wilde, Munt & Maclean (2000)	Driving simulator	0.05	0.43
		0.08	0.49

7.2.2 Multi-factorial designs

Moreover, it is of interest if other factors investigated in some studies have an influence on the effect of alcohol. More than every second study (56%) uses a multi-factorial design, and in two thirds (68%) of the findings of those studies the impact of other factors on the alcohol effect could be determined. Since there are up to three factors reported per finding, the total number of investigated interactions with alcohol is 2,066. Of these, 1,011 interactions refer to performance tests, on which the main interest lies. Most studies investigate the influence of other substances on the alcohol effect, followed by personality (including age and drinking habits) and gender (see Figure 17). Furthermore, the impact of the subjects' state (like fatigue), of their workload (e.g. task difficulty), beliefs (e.g. alcohol expectancy) and motivation (e.g. reward) is of interest. The figure also shows that most interactions are not significant (i.e. "no change"), which means the effects of alcohol are not much influenced by other factors.

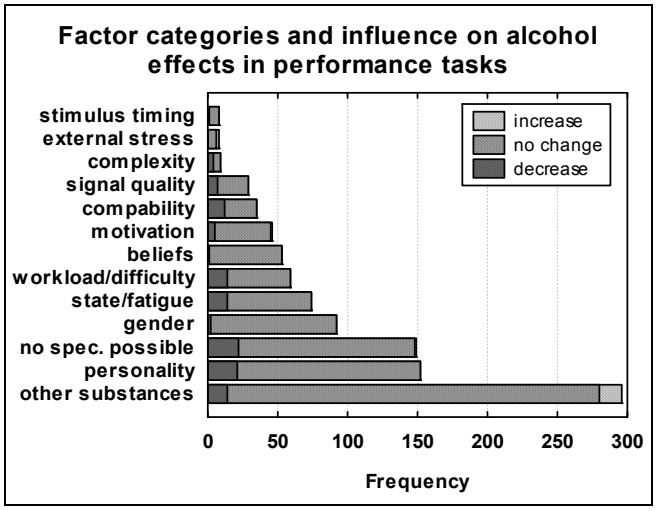


Figure 17: Categories and influence of other investigated factors than alcohol in performance tasks.

When looking more in detail at the most frequently investigated factor categories, it becomes obvious that the effects of alcohol in performance tasks are not influenced by the application of benzodiazepines (see Figure 18). In contrast, the administration of the anti-depressant befloxatone, MDMA or caffeine leads in some studies to a significant interaction in a way that the impairing effects of alcohol are reduced (coded as "increase" of performance in the figure). Regarding the gender of the subjects, a significant interaction is found only twice: once performance under alcohol decreases only in men (coded as "decrease 1") and the other time performance decreases only in women (coded as "decrease 2"). Regarding the subjects' age, 22% of the interactions become significant. In 9% impairment under the influence of alcohol is higher when older subjects perform the task, in 13% when young people are tested. If the subjects' habituation to alcohol is low, 10% of the interactions with the factor alcohol become significant. In contrast, the expectation of the subjects to get alcohol does not influence the effects of alcohol. Impairment under the influence of alcohol is higher in sleepy subjects or if performance testing takes place in the morning. Alcohol effects depend as well on the difficulty of the task. However,

impairment increases not only when the task is difficult and a high workload is demanded, but even when the task is easy a negative influence is possible.

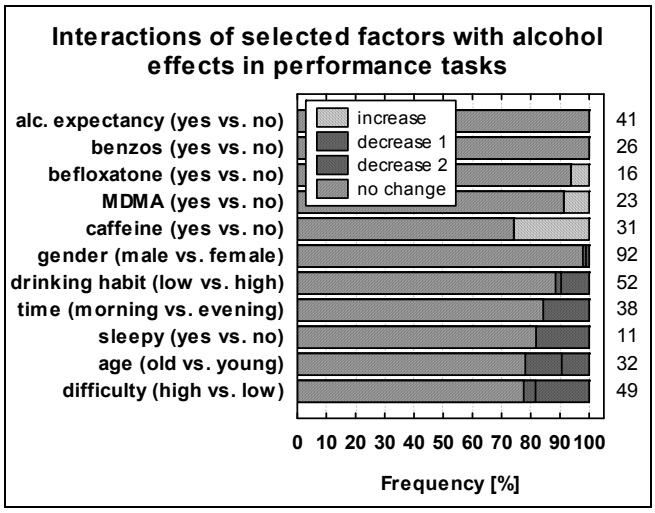


Figure 18: Interactions of selected factors with alcohol effects in performance tasks (on the right the number of interactions per factor is presented). "Decrease 1" means that the significant interaction refers to the first factor level defined in the brackets, "decrease 2" that it refers to the second factor level (explained in the text).

Regarding the feeling of intoxication the expectation to get alcohol does not influence the alcohol effect nor does the subjects' gender (see Figure 19). Subjects with a low habituation to alcohol feel more intoxicated in some studies when they get alcohol, whereas subjects feel less intoxicated in 22% of the investigated interactions with an additional cocaine application. Furthermore, there are significant interactions regarding aggressive behaviour under alcohol when subjects are provoked, are more irritable or are male. Lastly, the daytime influences the effect of alcohol on the subjective tiredness. In the morning subjects report a higher tiredness when drinking alcohol than in the evening.

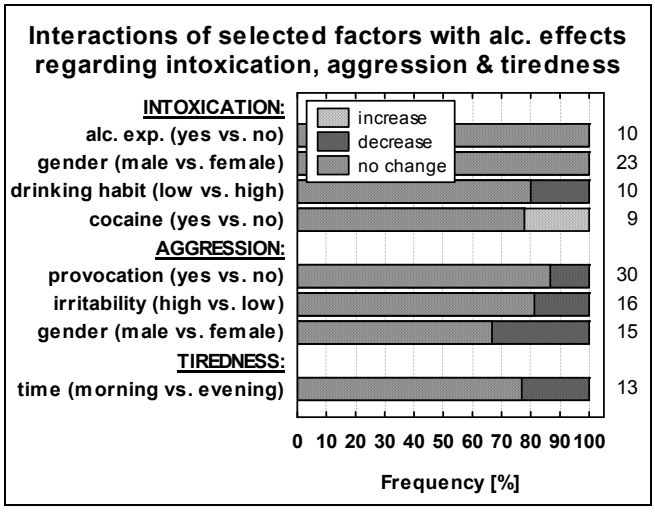


Figure 19: Interactions of selected factors with alcohol effects regarding subjective intoxication, aggression and tiredness (on the right the number of interactions per factor is presented).

7.2.3 Confidence of effects

When rating the confidence of the results according to the reported interactions in studies with a multi-factorial design (see Chapter 6.4.4), it becomes obvious that 99% of the findings are of a high confidence (see Table 7), which means that the result concerning the effect of alcohol is not biased by another factor. On the one hand, this high confidence level results from the fact that in 43% of the findings only the factor alcohol was tested and so there were no interactions to consider. Without possible interactions the confidence of the effect is always high. On the other hand, in many findings the main effect of alcohol is not significant, or the main effect of alcohol is significant, but not the interaction. Moreover, in some findings the significant interaction is ordinal or semi-disordinal. The frequencies of findings for the other conditions with a medium or low confidence level where interactions are not reported or disordinal or unidentifiable are negligible.

Table 7: Frequencies and percentages of findings per confidence level.

Confidence level	Frequency	Percent
High	5245	98.97
Medium	46	0.87
Low	9	0.16
In total	**5300**	**100.00**

7.2.4 Aspects of experimental procedure

Performance under alcohol might also be influenced by two variables concerning the experimental procedure in the studies.

7.2.4.1 Drinking time

The first one is the *drinking time*, this means the time available for drinking the alcoholic beverage. It could be determined in 86% of the findings and varied between 1 minute and 180 minutes with a median of 15 minutes (15^{th} percentile = 10 minutes; 85^{th} percentile = 30 minutes). By this feature, the influence of the speed of alcohol intake on the alcohol effects can be estimated in post-hoc analyses. For example, the consequences of drinking high alcohol quantities in a very short time can be analysed or of drinking alcohol more slowly, which is more relevant in everyday situations.

As Figure 20 (left) shows, there is only a small correlation between the alcohol dose and the drinking time ($r = 0.21$)[13], this means the subjects are not given more time for drinking high quantities. Thus, the drinking conditions in experimental studies differ from those in everyday life. Besides, when the drinking time is 15 minutes or less (= fast drinkers), the percentages of significantly impaired findings in performance tasks

[13] One outlier with an alcohol dose of 1.75 g/kg and a drinking time of 180 minutes is excluded. Otherwise the correlation would be 0.34.

are just slightly higher than for slow drinkers, mainly with a BAC between 0.05% and 0.08% (Figure 20, right).

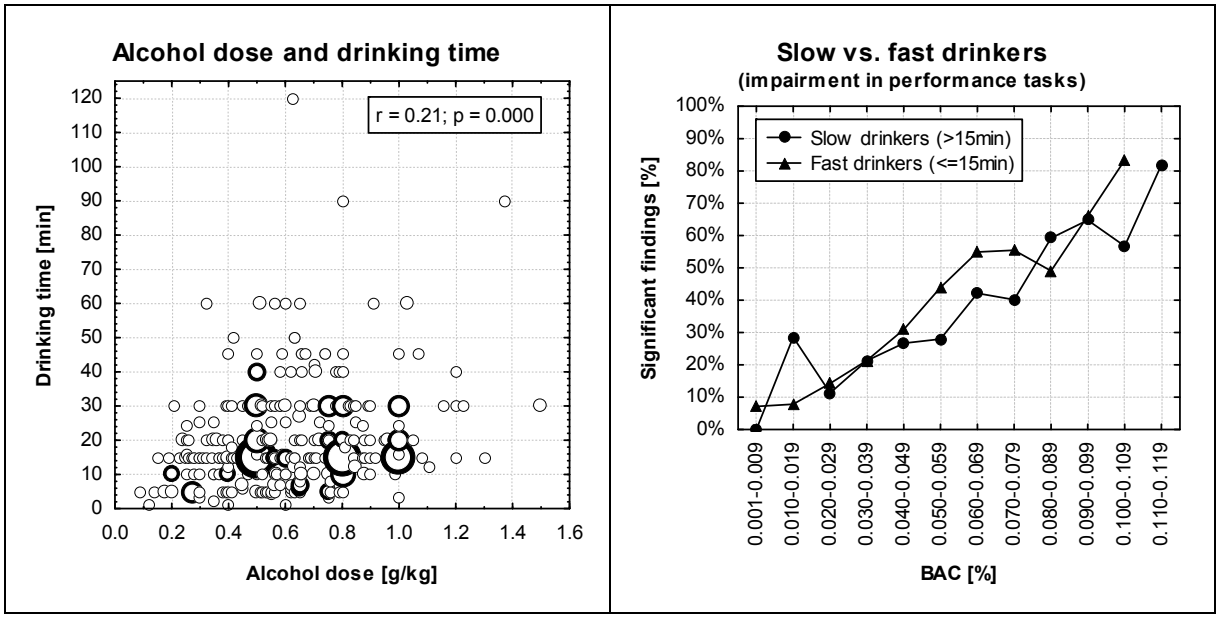


Figure 20: Correlation between alcohol dose and drinking time (left) – the size of the points symbolises the frequencies of findings; percentage of significantly impaired findings per BAC group depending on the drinking time (right).

The differences between slow and fast drinkers increase when considering the relation between the alcohol dose and the drinking time (as grams of alcohol per minute). If the subjects have to drink more than 0.0375 g/kg per minute (which is the median), more findings than in the low dose/min group become significant with a BAC above 0.05% (see Figure 21).

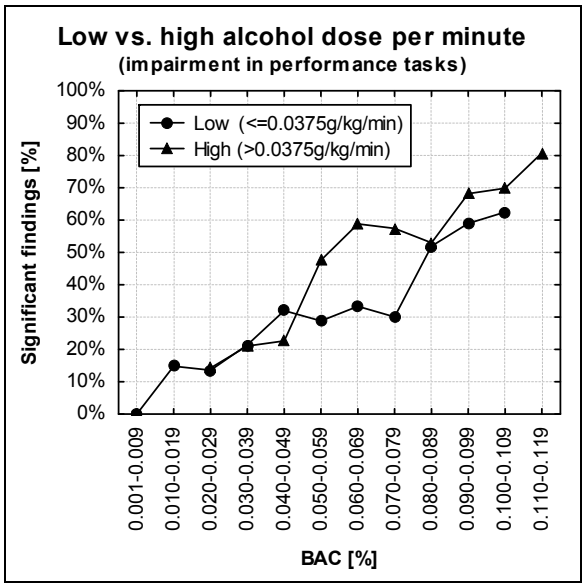


Figure 21: Percentage of significantly impaired findings per BAC group depending on the alcohol dose per minute.

7.2.4.2 Testing time

Another variable which might have an influence on performance under alcohol is the *testing time*, this means the time of day when performance testing takes place. In addition to the explicitly introduced time variable as a second factor in some studies where it is distinguished between morning and evening testing (see Chapter 7.2.2), the exact time of testing is recorded for every finding. This variable is reported in about half of the findings (51%). Performance tests were conducted at every time of the day except from 5 to 7 a.m. In some studies, a time span is reported, e.g. when a performance test battery is applied. In these cases, the mean value of the time span is taken for all tests in the study.

The percentages of significantly impaired findings in performance tasks are much higher when performance is tested after 6 p.m. or during the night (see Figure 22). Between testing in the morning (7 a.m. to 12 p.m.) and in the afternoon (12 to 6 p.m.) there is hardly a difference concerning significant findings. Therefore, during the day when subjects are normally not used to drinking alcohol, performance is best, whereas it is worst at a time of day when subjects are more likely to drink alcohol and might have to perform afterwards in some way (e.g. driving). Obviously, a late-night testing time impairs performance more than an unusual time for drinking, which indicates that fatigue is most probably interferring.

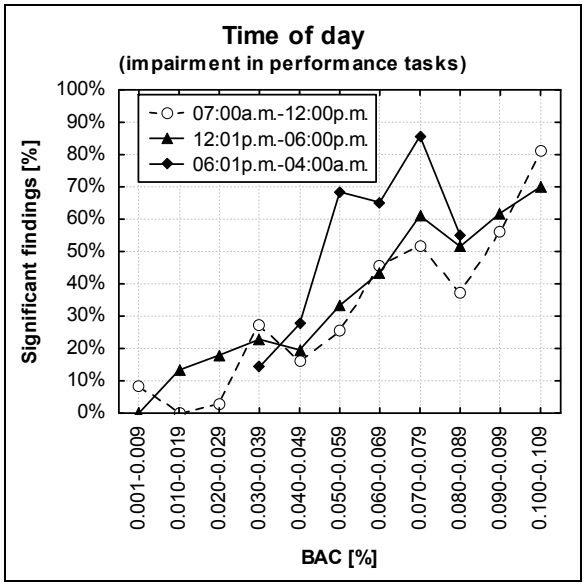


Figure 22: Percentage of significantly impaired findings per BAC group depending on the time of day of testing.

7.2.5 Aspects of the BAC

Besides the BAC level that has to be extracted from the studies as a clear effect-modifying factor, there are further important aspects concerning the BAC: firstly the distinction between the ascending and descending limb of the BAC curve and secondly, the kind of BAC estimation.

7.2.5.1 Absorptive vs. eliminative phase

In order to distinguish between the absorptive and the eliminative phase, the *time of test beginning* ("time before testing") has to be considered. This variable is defined as time between the end of the subject's alcohol intake and the beginning of measuring the study variables. These data are provided in 87% of the studies (and in 91% of the findings, respectively) and vary between 0 (which means an immediate beginning) and 900 minutes with a median of 60 minutes concerning all findings (15th percentile = 20 minutes; 85th percentile = 135 minutes). The assignment of a finding depending on the time of test beginning is explained in Chapter 6.2.1. Overall, 1,599 findings belong to the absorptive phase, 3,395 to the eliminative, and 306 could not be specified because of missing information.

Figure 23 (left) shows that there is no systematic difference between the absorptive and the eliminative phase concerning significantly impaired findings in performance. Only with very low BACs (0.01 and 0.03%) and with a BAC around 0.06% are absorptive findings slightly more often significant than eliminative findings.

To ensure that the absent difference between the two phases is not due to an incorrect definition, the time when testing takes place after the alcohol intake is inspected more in detail (Figure 23, right). The above defined absorptive phase is differentiated into below and above 20 minutes. Again it becomes obvious that there is hardly a difference, only with BACs between 0.03 and 0.06% are the percentages of significant absorptive findings higher.

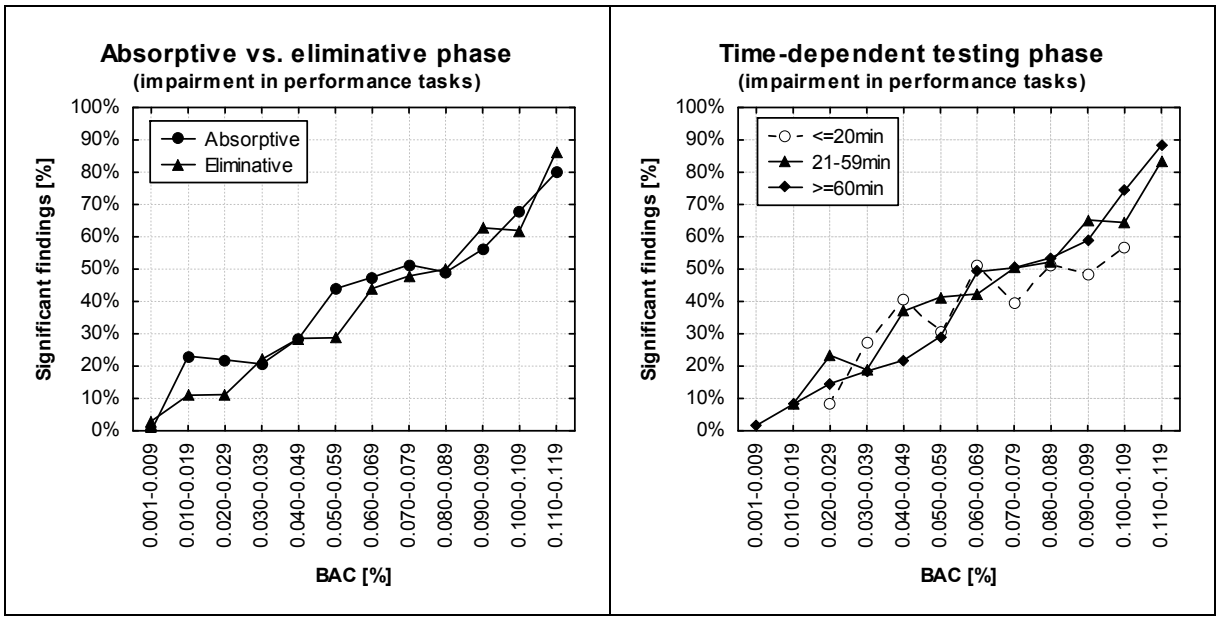


Figure 23: Percentage of significantly impaired findings per BAC group depending on the limb of the BAC curve (left) and more detailed depending on the time of testing after the alcohol intake (right).

7.2.5.2 Empirical BAC vs. Widmark estimation

In 82% of the findings the empirical BAC is determinable. It varies from 0.001 to 0.18% with a median of 0.06%. If it is not measured or reported, there are two other

possibilities for estimating the alcohol concentration, namely via the target BAC (if it is reported in the studies) or via the Widmark formula (if the alcohol dose is reported) as explained in Chapter 6.2.3. In general the correlation of the empirical BAC is higher with the target BAC than with the Widmark BAC (see Figure 24).

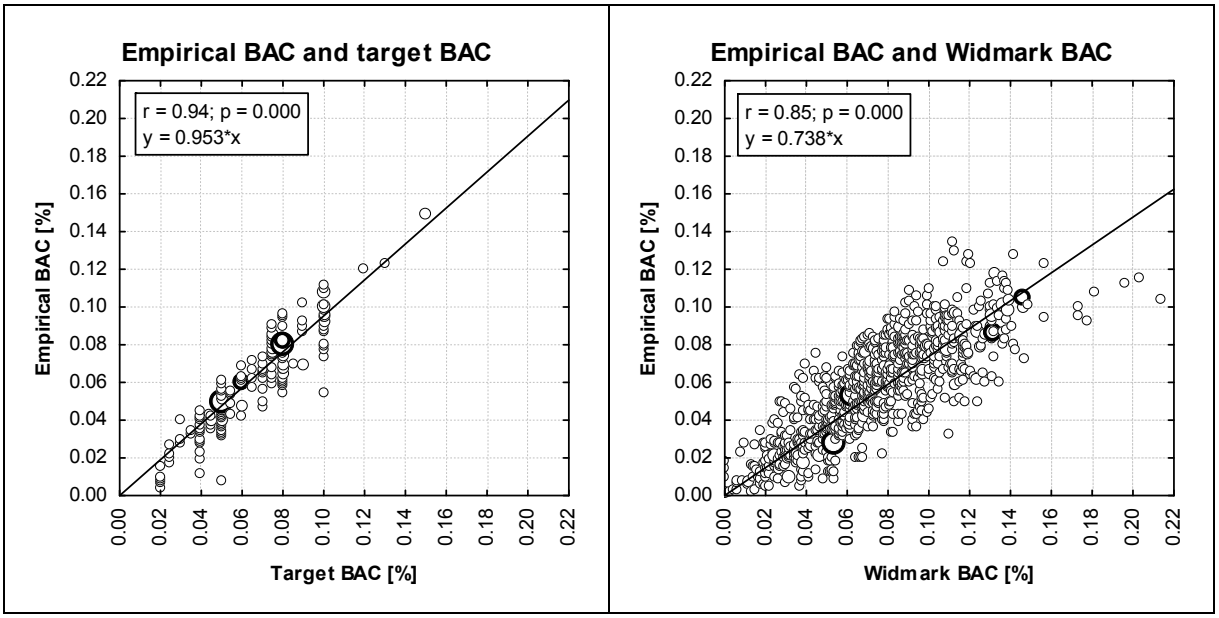


Figure 24: Correlation between the empirical BAC and the target BAC (left), and between the empirical BAC and the Widmark BAC (right) – the size of the points symbolises the frequencies.

Since the Widmark formula is intended for the case that the alcohol dose is consumed at once with an empty stomach, it has been known to overestimate the real BAC. The differences are sometimes very large, on average the Widmark BAC is 0.02% higher than the measured value (Figure 25, left). When the Widmark BAC is plotted against the difference to the empirical BAC (Figure 25, right), it can be seen that the Widmark BAC level correlates with the height of the difference (r = 0.64). The regression line reveals that the overestimation is about 33%.

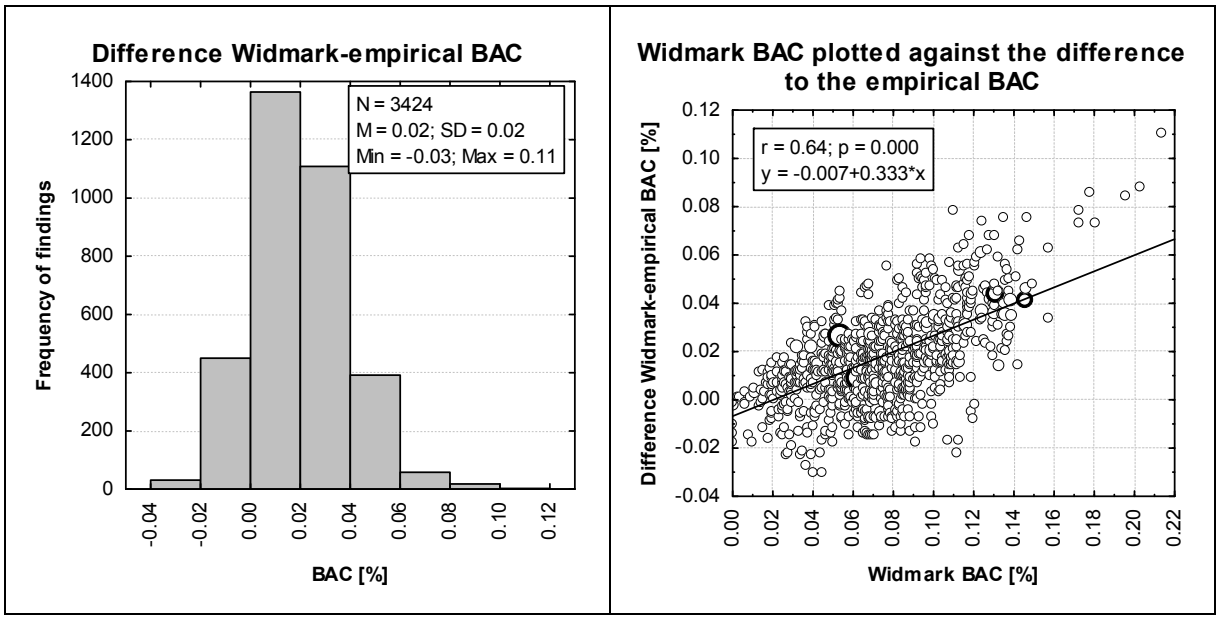


Figure 25: Difference between the Widmark and the empirical BAC (left), and Widmark BAC plotted against the difference to the empirical BAC (right) – the size of the points symbolises the frequencies.

The rather small correlation (r = 0.27)[14], which is shown in Figure 26 (left), indicates that the overestimation by Widmark does not depend on the drinking time, although it is significant. Even when subjects drink the alcoholic beverage within 10 minutes, the difference between the Widmark BAC and the measured values might be up to 0.06%. Such high overestimations only appear with a rather high alcohol dose (Figure 26, right), whereas with low doses the difference is much smaller (r = 0.57).

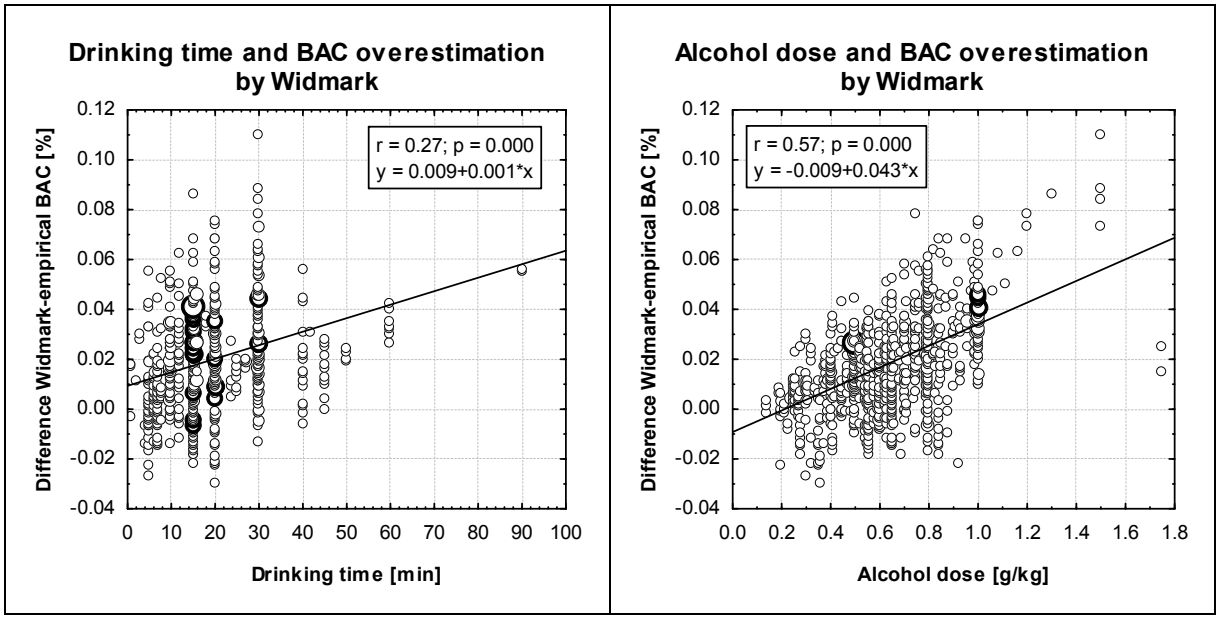


Figure 26: Correlation between the drinking time and the BAC overestimation by Widmark (left), and between the alcohol dose and the BAC overestimation (right) – the size of the points symbolises the frequencies.

[14] One outlier with a drinking time of 180 minutes is excluded. Otherwise the correlation would be even lower (r = 0.17).

As a consequence, when the empirical BAC is missing in the studies it was decided to take the target BAC, and only if this is not reported then the BAC calculated by Widmark is used. In 4% of the findings the target BAC is taken for the analysis, and in 14% the Widmark BAC.

Since, in general, the actual BAC is lower than the BAC calculated by Widmark (see above), the percentage of significant findings might be underestimated for the real BAC. If, for example, the BAC group 0.08% includes some BACs calculated by Widmark which are overestimated by 0.02% (so in fact the BAC is 0.06%), there might be fewer significant findings. The assumption that the percentage of significant findings is lower when including the Widmark BACs than when excluding them is confirmed, even though the difference is very small (see Figure 27).

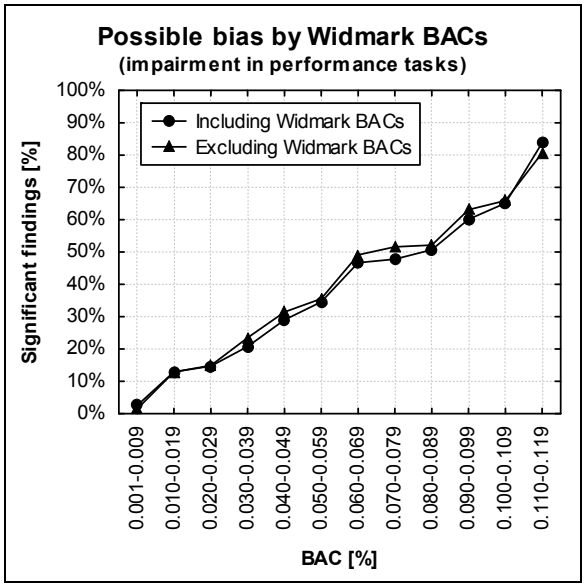


Figure 27: Percentage of significantly impaired findings per BAC group depending on the in- or exclusion of BACs calculated by Widmark.

7.2.6 Statistical aspects

In this chapter statistical aspects of the studies are considered in order to check their influence on the results regarding performance under alcohol by introducing a quality index according to the methodological standards of the studies.

7.2.6.1 Description of the analysed studies

Table 8 shows the statistical data concerning the experimental design of the 450 publications and the 471 studies reported in them. For variables which might differ within one study (like alcohol dosage, BAC value, testing time) the descriptive statistics refer to the 5,300 findings. Since every piece of information is not always reported, the statistics sometimes refer to fewer studies or findings. For interval-scaled variables the mean, standard deviation, median, range and number of studies or findings are presented. For nominal-scaled variables the absolute and relative frequencies are given. The variables are explained more in detail in the appendix (study variables in Chapter 10.1.1 and finding variables in Chapter 10.1.2).

Table 8: Statistical data for the variables of studies and findings, respectively.

A. INTERVAL-SCALED VARIABLES

Study variables	M	SD	Md	Range	N
Sample					
- Number of subjects	32.6	41.0	20.0	4-400	471
- Number of female subjects	8.1	17.4	0	0-166	451
- Number of male subjects	24.7	33.1	13.5	0-400	452
- Mean age	25.4	4.7	24.0	19-53	303
Number of findings	11.2	21.0	6.0	1-350	471
Finding variables	**M**	**SD**	**Md**	**Range**	**N**
BAC [%]					
- Target BAC	0.07	0.02	0.07	0-0.15	1,130
- Widmark BAC	0.07	0.03	0.07	0-0.21	4,323
- Empirical BAC	0.06	0.02	0.06	0-0.17	4,334
Alcohol dose [g/kg]	0.65	0.24	0.62	0.09-1.75	4,804
Drinking time [min]	20.3	18.1	15.0	1-180	4,544
Time till testing begins [min]	77.5	79.9	60.0	0-900	4,828
Task duration [min]	11.7	16.0	5.0	1-123	2,406

B. NOMINAL-SCALED VARIABLES

Study variables	N	%
Main question	*471*	*100*
- single alcohol effect	176	37.3
- alcohol and drugs	111	23.6
- different dosages of alcohol	61	13.0
- other	41	8.7
- different subjects groups	34	7.2
- different points in time	31	6.6
- alcohol and sleep deprivation	17	3.6
Gender	*471*	*100*
- only male	236	50.1
- mixed	206	43.7
- only female	17	3.6
- not specified	12	2.6
Drinking group	*471*	*100*
- social drinkers	381	80.9
- not specified	80	17.0
- heavy drinkers	9	1.9
- binge drinkers	1	0.2
Driver group (only for driving studies)	*76*	*100*
- amateur (from the general public)	56	73.7
- professional	14	18.4
- not specified	5	6.6
- novice	1	1.3
Selection processing	*471*	*100*
- on inquiry	181	38.4
- lab parameters	128	27.2
- not specified	88	18.7
- medical screening	63	13.4
- others	11	2.3
Methodological design (factors)	*471*	*100*
- >1 factor & interaction	251	53.3
- 1 factor	202	42.9
- >1 factor & no interaction	13	2.8
- others	5	1.0

Study variables	N	%
Methodological design (levels)	*471*	*100*
- >2 levels & post hoc	248	52.7
- 2 levels	181	38.4
- >2 levels & no post hoc	37	7.9
- others	5	1.0
Standardisation of meals	*471*	*100*
- instruction	250	53.1
- standardisation	111	23.6
- not specified	92	19.5
- no standardisation	18	3.8
Blinding	*471*	*100*
- single blind	184	39.1
- double blind	175	37.2
- no	108	22.9
- not specified	4	0.8
Control group	*471*	*100*
- placebo	359	76.2
- non-alcohol	65	13.8
- no	47	10.0
Variance test for homogeneity	*471*	*100*
- not specified	457	97.0
- yes	11	2.3
- no	3	0.7
Randomising	*471*	*100*
- without relevance	308	65.4
- yes	133	28.2
- not specified	23	4.9
- no	7	1.5
Multivariate testing	*471*	*100*
- no	432	91.7
- yes	39	8.3
Non parametric testing	*471*	*100*
- no	458	97.2
- yes	13	2.8
Repeated measures	*471*	*100*
- yes	375	79.6
- no	96	20.4
Alpha adjustment	*471*	*100*
- not specified	416	88.3
- yes	48	10.2
- no	7	1.5
Finding variables	**N**	**%**
BAC group	*5,300*	*100*
- 0.050-0.079	1,972	37.2
- ≥0.080	1,502	28.3
- 0.030-0.049	1,001	18.9
- 0.001-0.029	825	15.6
Type of parameter (only for performance tasks)	*2,967*	*100*
- speed	969	32.7
- accuracy	1,567	52.8
- speed & accuracy	369	12.4
- other	62	2.1
Training of the task (only for performance tasks)	*2,971*	*100*
- yes	2,271	76.4
- not specified	424	16.0
- no	232	7.6

The table shows that the total sample size is rather small with a median of 20, but about 80% of the studies use a repeated measurement design, which compensates for this deficit. The selection process, this means the checking whether the subjects fulfill the in- and exclusion criteria of the study, is mostly done on inquiry, only about one quarter of the studies uses lab parameters. The mean age of the subjects is 25 years (md = 24 years), and half of the studies give alcohol only to men, who are in the majority of cases social drinkers. The mean administered alcohol dose is 0.65 g/kg and it varies from 0.09 to 1.75 g/kg. This illustrates different investigative questions: extremely low quantities test whether and which alcohol effects are readily observable. In contrast, an extremely high dosage of alcohol tests which alcohol effects are still observable after a long period of alcohol elimination (up to 16 hours). Drinking time is rather brief with a median of 15 minutes. This means that a 75-kg-man has to drink on average 49 g pure alcohol in 15 minutes, which corresponds approximately to 1.25 liter beer or to 0.6 liter wine. The range of the BACs estimated by using the Widmark formula is higher (0-0.21%) than that of the empirically measured BACs (0-0.17%) and that of the target BACs (0-0.15%). In general, the empirical BAC is 0.01% lower than the BAC estimated with Widmark or the target BAC: the mean BAC values of all findings are 0.06 (empirically) or 0.07% (Widmark and target).

Time between the end of alcohol drinking and the beginning of measurement varies considerably from 0 to 900 minutes with a median of 60 minutes. This median value empirically supports the criterion for differentiating between the absorptive and eliminative phase which is set to 60 minutes. Thus, half of the studies investigate the effects of alcohol in the eliminative phase. The duration of tasks is on average 5 minutes (median), so only few studies investigate the effects of alcohol by long lasting tasks. In 76% of the performance findings the task is trained before testing in order to avoid learning effects. Regarding the type of the measured parameter more than half of the findings (53%) refer to accuracy in contrast to one third which refers to speed, this means the evaluation is rather error-related. Driving tests are mainly investigated with drivers from the general public (74%), and 77% of the studies standardised meals or gave an instruction what to eat before the test session. The main question refers mostly (37%) to the single effect of alcohol, and in 24% of the studies the combination of alcohol and other substances is of interest.

Referring to the methodological design, in 53% of the studies more than one factor is used and interactions are tested. In the same percentage of studies the factor has more than two levels and post hoc tests are conducted. For fully complete entries in the database post-hoc tests are essential in the case of more than two BAC levels (including placebo) or two testing time points. In 76% of the studies there is a placebo control group and the application of alcohol is single or double blind. Of the 35% studies in which a between-subject design is used, 80% assign the subjects randomly to the alcohol condition. A multivariate analysis is conducted in 8% of the studies and in 3% a non-parametric test. Only 3% specify whether they tested the homogeneity of variances and 90% performed no adjustment of the α-level for the

number of statistical tests, even the maximum of findings of effects is 350 in one study[15] and the mean number of findings per study is 11.

Moreover it has to be criticised that sometimes in the studies relevant data is missing (see Figure 28). Even though the studies are well selected, in 13% the administered alcohol dosage is not reported. The same holds true for the time between the administration of alcohol and the beginning of the test. In 14% of the studies the BAC is either not measured or at least not reported, and in 17% the drinking time is missing. 25% of the studies with performance findings do not report the duration of all tasks.

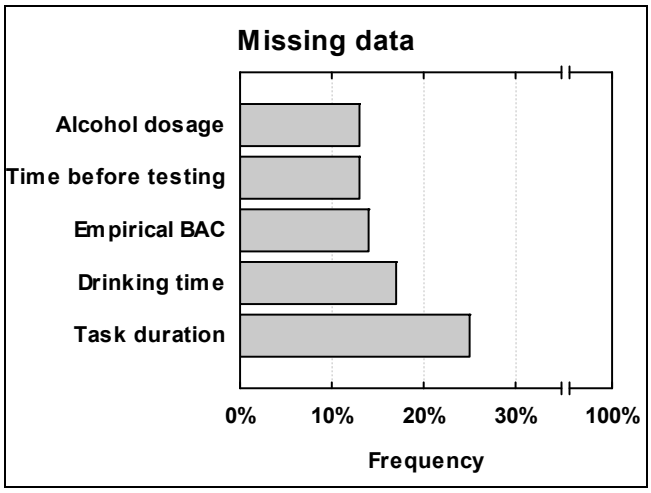


Figure 28: Frequencies of studies with missing data.

7.2.6.2 Quality index

The database contains a lot of variables which describe the methodological standard of the studies and their findings. Despite strong inclusion and exclusion criteria when selecting the studies for review (see Chapter 5.1), the remaining literature material is of varying quality. Table 9 gives a list of criteria to evaluate the methodological strength of a study. The first 12 criteria describe the quality of the study and the last 4 ones describe the quality of the reported finding. A rough estimate of the study and finding quality is given by the sum of bonus points.

15 At least in this study an alpha adjustment was performed. Moreover, 314 of the 350 findings refer to subjective parameters like e.g. “unpleasant physical sensations” or “pleasure”, so that there is no bias of the performance findings.

Table 9: Criteria for the quality of a study or finding.

		Criteria (variables of the database)[16]	Specifications[17]	Points
STUDY QUALITY	1	Number of subjects	N < 10	0
			10 ≥ N < 20	0.5
			N ≥ 20	1
	2	Selection processing	On inquiry	0.5
			Medical screening/others	1
			Lab parameters	1
	3	Drinking group	Social drinkers	1
			Heavy drinkers	0
			Binge drinkers	0
	4	Meals before alcohol intake	No standardisation	0
			Instruction	1
			Standardisation	1
	5	Control group	No (baseline comparison)	0
			Non alcohol	0.5
			Placebo	1
	6	Methodological design	No post hoc test	0
			Post hoc test	1
	7	Alpha adjustment	No	0
			Yes (Bonferroni/others)	1
	8	Randomising	No	0
			Yes	1
	9	Confounding time (with alcohol effects)	No	1
			Yes	0
	10	Alcohol dose	Reported	1
	11	Drinking time	Reported	1
	12	Testing time	Reported	1
FINDING QUALITY	1	Training of the task	No	0
			Yes/not necessary	1
	2	Confidence of effect (interactions)	Low	0
			Medium	0.5
			High	1
	3	Estimation of effect	No (effect clearly described)	1
	4	BAC	Widmark	0
			Target	0
			Empirical	1

Since after reading the selected literature, 12% of the studies were already excluded because of methodological issues, it can be assumed that the quality of the studies and their findings is rather high. This is confirmed by a left-skewed distribution of the quality indices (see Figure 29).

[16] The variables and their specifications are explained in detail in the appendix (see Chapter 10.1).
[17] If no specification is possible because of missing information in the study, zero points are given.

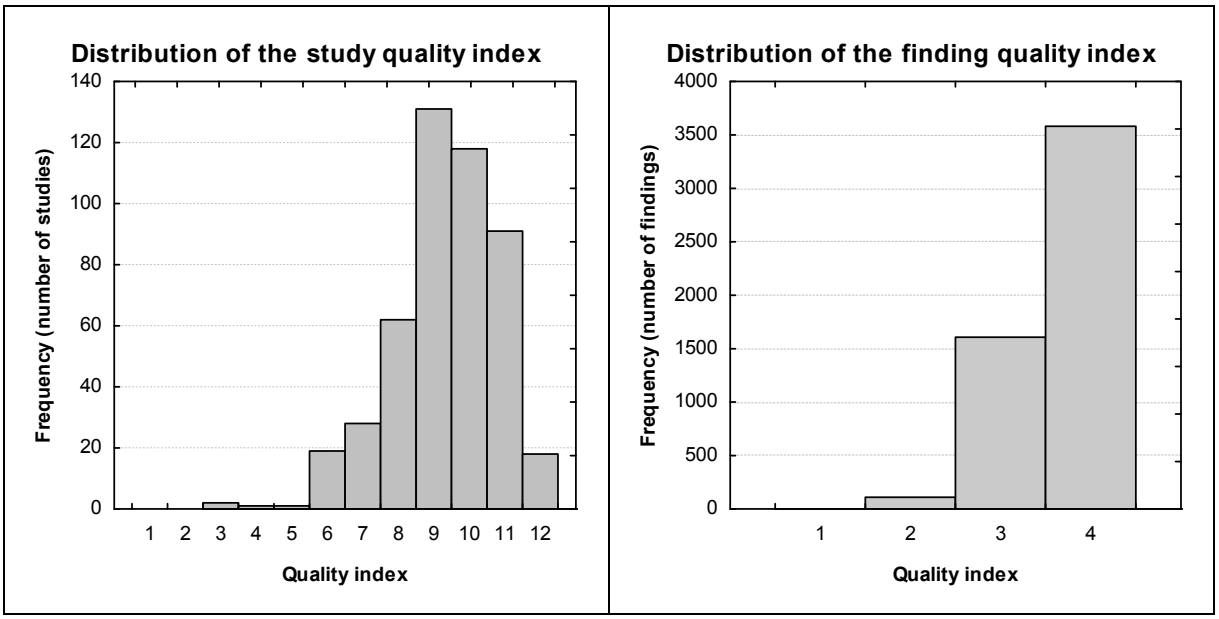


Figure 29: Distribution of the study quality index (left) and of the finding quality index (right).[18]

In a next step both indices are combined, and findings with a lower quality index than 3 or which belong to a study with a lower quality index than 8 are excluded. From the 2,983 findings concerning performance tests, 547 findings are sorted out according to these criteria. Figure 30 compares the impairment function for all findings with the function obtained for the 2,436 findings of high methodological quality. There are no obvious differences. Evidently, the selection criteria for being accepted for this meta-analysis have been so strong that only well controlled studies passed. This is supported by the fact that nearly all studies have a quality index of 6 or more points (see Figure 29, left).

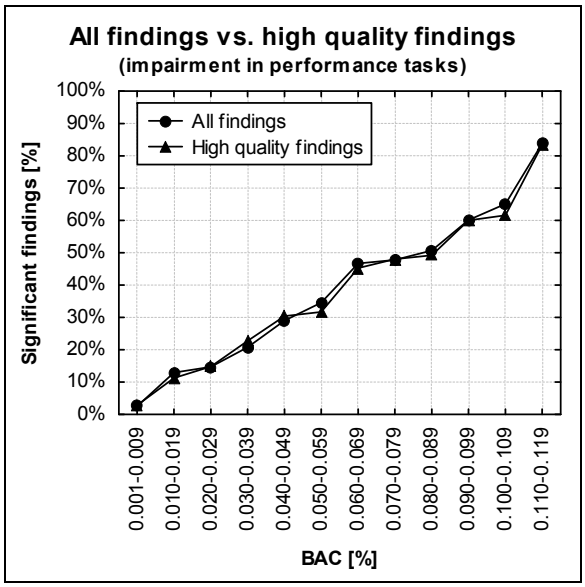


Figure 30: Percentage of significantly impaired findings per BAC group depending on the quality of studies and findings.

[18] Uneven index values are part of the next higher category, e.g. 7.5 is comprised in 8.

7.2.7 Consequences for further evaluation

This chapter checked whether the alcohol effects reported in the studies are affected by other variables or experimental conditions. As shown in the studies with a multi-factorial design, the effects of alcohol are not much influenced by other factors. An influence of drinking conditions was found, but is small enough to be neglected in the further evaluation. The same holds true for the kind of BAC estimation, although the real BAC is overestimated by the Widmark BAC. Despite the fact that alcohol is known to have different effects in the two phases of metabolism, no systematic difference could be identified, even if 20 minutes are taken as duration of the alcohol absorption. Apparently, the acute tolerance effect cannot be confirmed by means of a meta-analysis, as there are so many heterogenous studies combined with different individuals, alcohol dosages, drinking times and performance tasks, for example. Thus, this work does not introduce the phase distinction as a factor for describing the findings.

What also became apparent is that the calculation of effect sizes gives no additional information, since the results are not very clear. This might be due to the fact that very often the necessary parameters for calculating are missing, so that the number of effect sizes is small. Finally, the introduction of a quality index according to the methodological standards of the studies does not make any difference regarding the results. This is a consequence of the strict selection of the studies, which accounts for a generally high quality of the findings.

In summary, the methodological approach of a meta-analysis results in an impairment function which is only slightly moderated by additional variables. As a consequence, in the following analyses all gathered findings are included.

7.3 The effects of alcohol on driving-related performances

The raw data referring to the main and sub categories are presented in Table 16 in the appendix (see Chapter 10.2) where the frequencies of significant impairing effects per BAC group and category are listed. For the performance categories the main interest of the researchers lies in alcohol concentrations between 0.03% and 0.09%. For mood sub categories the frequencies of investigated BACs are nearly equally distributed within the range from 0.01 to 0.11% BAC. Generally, as expected, the number of impairing effects increases with increasing BAC. However, as former literature reviews have already demonstrated, the single performance categories are differently sensitive to the effects of alcohol (some show an effect very early, i.e. with low BACs, and some rather late).

7.3.1 Subjective impairment

The mood sub category *subjective intoxication* is the category with the greatest effect (Figure 31). The feeling of intoxication already increases at very low BACs, for example at a BAC of 0.04% 80% of the findings show a significant effect. With higher BACs subjects feel significantly more intoxicated than the control group without alcohol in almost every finding. Obviously the feeling of intoxication increases logarithmically with increasing BAC which may be explained by a ceiling effect.

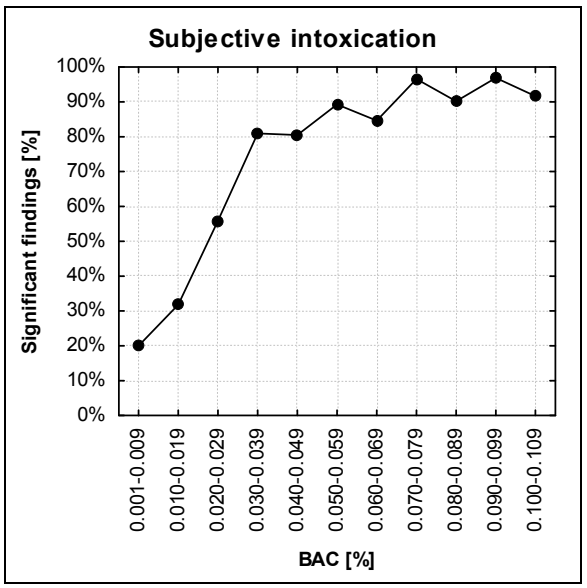


Figure 31: Subjective intoxication – percentage of significant findings per BAC group.

For the sub category *subjective fatigue* the percentage of significant findings increases nearly linearly (Figure 32). With increasing BAC more and more findings reveal a significant alcohol effect on fatigue – for example at a BAC of 0.08% every second finding. This means that the subjective feeling of fatigue rises more slowly with increasing BAC than the feeling of intoxication.

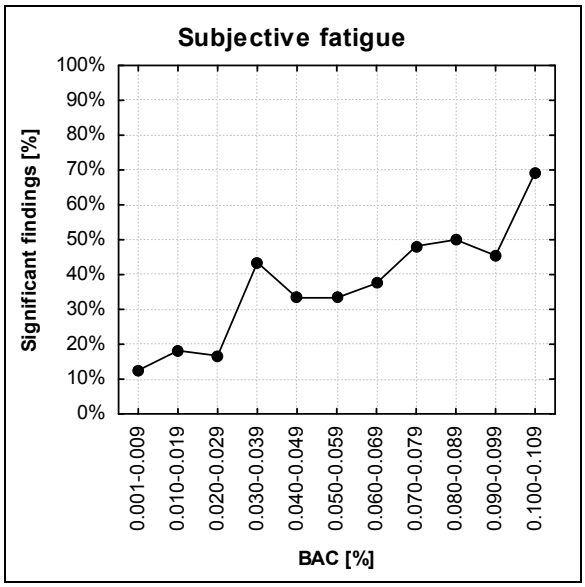


Figure 32: Subjective fatigue – percentage of significant findings per BAC group.

7.3.2 General objective impairment

In Figure 33 the percentage of significantly impaired findings for all performance categories is presented. Since this percentage increases to the same degree as the BAC, a linear function is fitted to the empirical values of the general performance data. The general impairment function comprises 2,914 performance findings. At a BAC of 0.05%, 30% of the findings are significant, while at a BAC of 0.08% about 50% of the findings are significant. With every BAC group the percentage of significant findings increases by 6.6%.

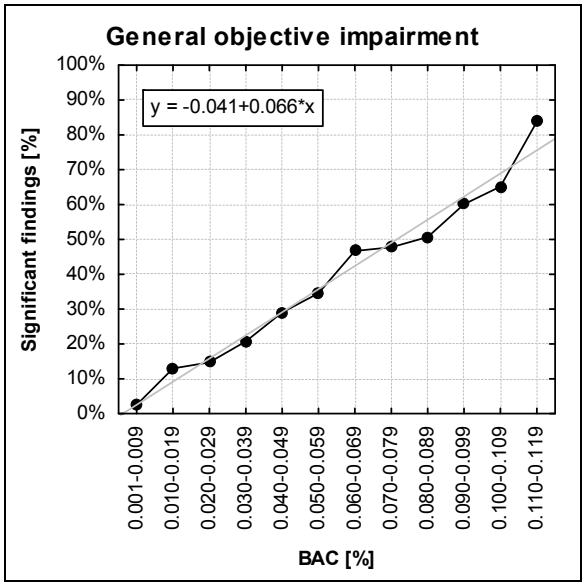


Figure 33: General objective impairment (including all performance categories) – percentage of significant findings per BAC group.

The substantial relevance of the general impairment function requires a closer look at its origination. If, for example, a performance category, which is already impaired by a low BAC, is overrepresented in low BAC groups, the general impairment will be overestimated. However, the distribution of the frequencies between the BAC groups is similar for all performance main categories (Figure 34). Most of them are mainly investigated with a BAC between 0.05% and 0.08%. This means that the general impairment function is not affected by category-specific frequency distributions.

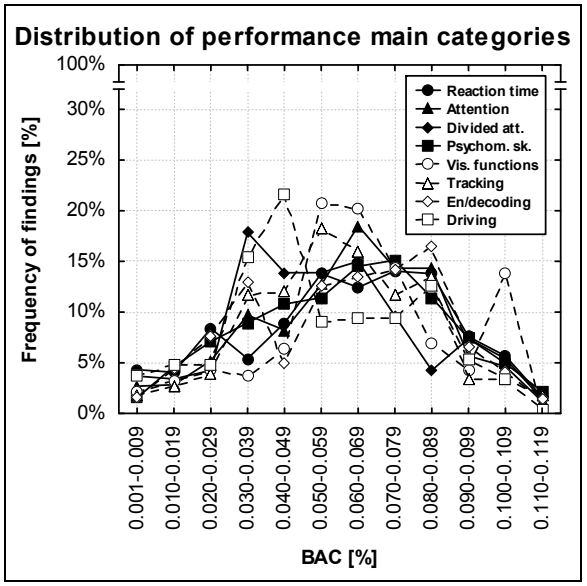
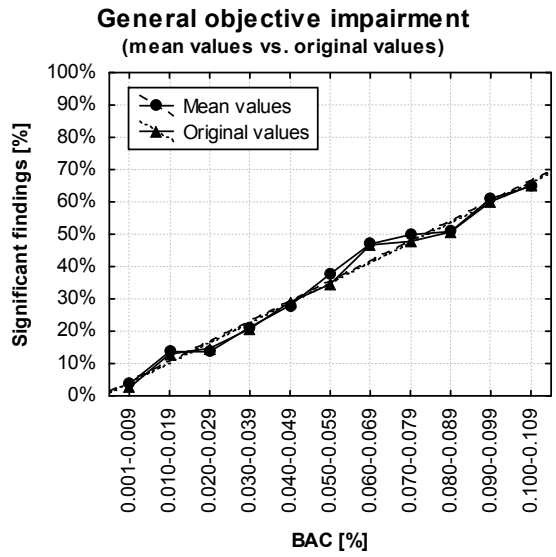


Figure 34: Distribution of performance main categories according to BAC group.

A second test regarding the representativeness of the general impairment function has to be conducted, since some performance categories are investigated more frequently than others, for example attention is studied more often than visual functions and tracking (see Chapter 6.3.1, Figure 10). It has to be determined whether this fact influences the result when aggregating the single performance categories into a general performance measure. To guarantee that each performance category is represented with the same weight in the aggregated general performance measure, the percentage of significant findings is calculated for each BAC group and for each main category (provided that the number of findings is beyond 10). This procedure eliminates the effect of unequal number of findings. Averaging those percentages per BAC group yields Figure 35, in which the results are compared with those of the unadjusted procedure of Figure 33.



BAC [%]	% sign. findings – mean values	% sign. findings – original values
0.01	3.65	2.53
0.02	13.65	12.96
0.03	13.68	14.71
0.04	21.28	20.75
0.05	28.01	29.04
0.06	37.72	34.54
0.07	47.00	46.70
0.08	49.83	47.76
0.09	50.85	50.70
0.10	61.06	60.11
0.11	64.81	65.13

Figure 35: General objective impairment – percentage of significant findings according to the mean values of performance main categories[19] in comparison to the original values.

Obviously, there is no substantial difference between the two types of analyses. However, some of the mean values of the single categories could not be considered because of their doubtful reliability (too low number of findings, see Table 16). Therefore, we recommend taking the original values for estimating the effects of alcohol on driving-related performance.

The next analysis refers generally to all performance findings. It considers the type of parameters that are evaluated in the studies. Apparently, parameters concerning *speed* like reaction time are less frequently impaired than *accuracy* parameters like errors (Figure 36). With high BACs parameters considering *speed and accuracy* (e.g. number of errors in a given time) are most frequently impaired.

[19] Regarding the main category “visual functions” only the performance sub categories “eye movements” and “complex perceptual functions” are considered, not the physiological ones.

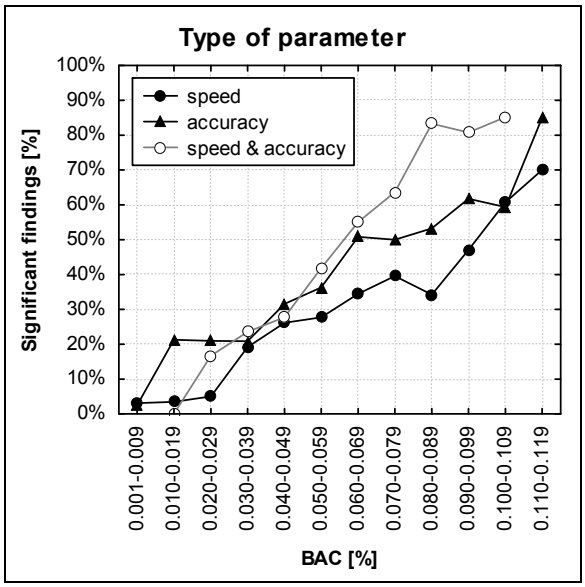


Figure 36: Percentage of significantly impaired findings per BAC group according to speed vs. accuracy parameters.

7.3.3 Psychological functions

In order to get a more global view, three combinations of main categories and/or sub categories are composed with the headings “motor vs. cognitive”, “simple vs. complex” and “automatic vs. controlled”. For the dimension **motor functions,** the main categories *reaction time*, *psychomotor skills*, *tracking* and *driving* requiring basically psychomotor skills are aggregated, for **cognitive functions** the main categories *attention*, *divided attention*, *visual functions* and *en-/decoding.* Psychomotor functions are earlier impaired than tasks with cognitive demands (Figure 37). With a BAC of 0.05% there are almost twice as many significant findings for psychomotor functions.

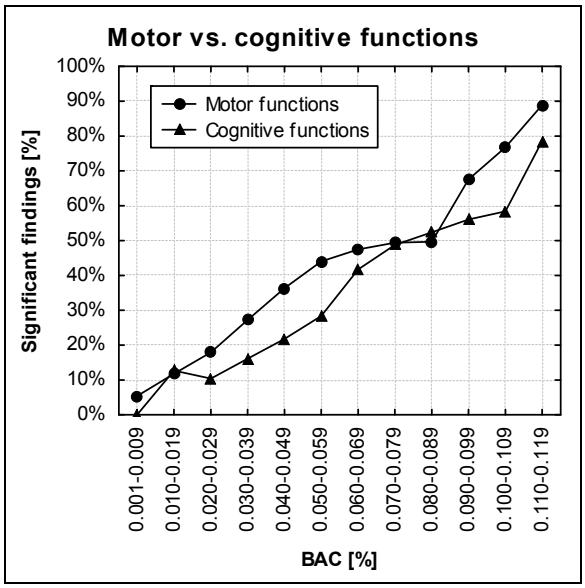


Figure 37: Impairment of motor vs. cognitive functions – percentage of significant findings per BAC group.

A second traffic-relevant distinction is whether the performance task is a **simple or a complex** one. Tasks in the sub categories *simple reaction time*, *other attention tests* and *posture* are regarded as simple. *Visual functions* and *memory* are omitted, because they do not exactly fit with the categories *simple* or *complex*. Tasks in all the other performance sub categories are classified as complex. Figure 38 reveals that impairing effects of alcohol appear very early in complex tasks compared to simple tasks. At higher BACs, however, the number of significant findings does not differ.

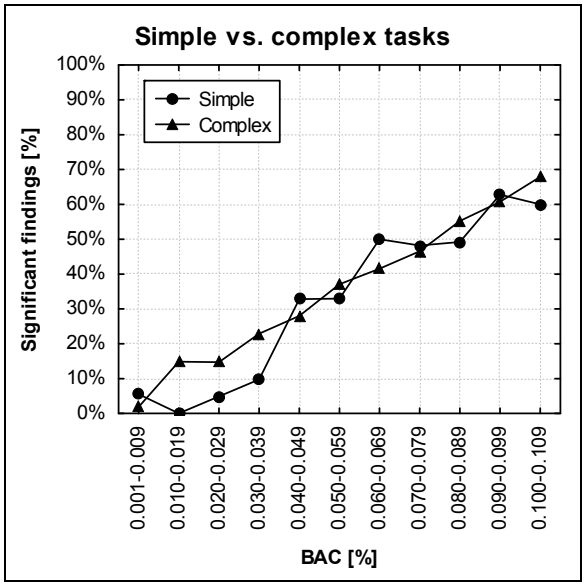


Figure 38: Impairment of simple vs. complex tasks – percentage of significant findings per BAC group.

As a last distinction, the assignment to **automatic and control processes** by Krüger (1993) is applied. He refers to Schneider, Dumais & Shiffrin (1984) who classified actions in analogy to the functioning of computer systems into automatic and control processing. Automatic actions are characterised by the fact that they take place at very low awareness, with little effort and without making use of central functions. Control processes, in contrast, are characterised by high awareness, subjective effort and using a lot of central capacity. It is assumed that tasks in the sub categories *simple* and *choice reaction time* are characterized by automatic processes as well as *categorisation*, *cancellation*, *mental arithmetic*, *other attention tests* and *easy tracking*. Control processes comprise *hand-eye coordination*, *divided attention*, *difficult tracking* and *information processing* tests. *Posture*, *visual functions*, *memory* and *driving tests* are excluded from the assignment to automatic and control processes. Unlike the result in Krüger (1993) where performance in automatic processes could be sustained even with higher BACs, there is no clear difference between the two groups here (Figure 39). At least, control processes are slightly more affected by alcohol than automatic processes between a BAC of 0.05 and 0.10% and at some lower BACs (0.02 and 0.04%).

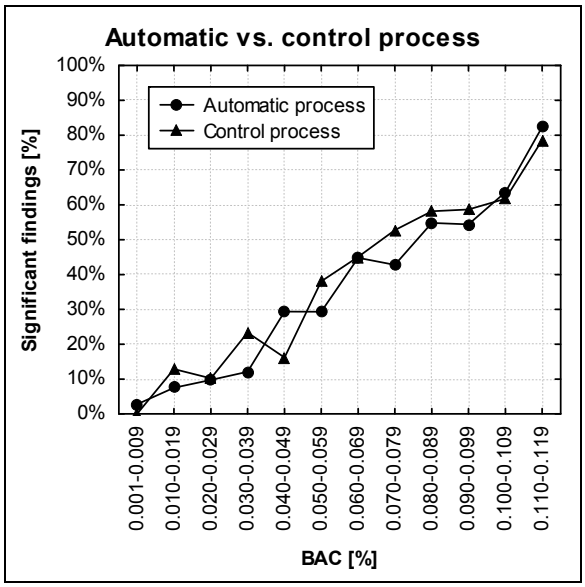


Figure 39: Impairment of automatic vs. control processes – percentage of significant findings per BAC group.

7.3.4 Single performance categories

In the following, the impairment functions of the performance main categories are shown. In addition – for reasons of comparison with former reviews – the impairment functions of some relevant sub categories are presented. Note that due to the lower frequencies of findings in the sub categories, the minimum number per BAC group for presenting the values is set at five (in contrast to ten in the main categories), thus the reliability is limited.

The impairment functions for the remainder of the sub categories (all listed in Figure 11) can be taken from Table 16 in the appendix (see Chapter 10.2).

7.3.4.1 Visual functions (including critical flicker fusion)

A variety of parameters of visual functions is important for safe driving. Impairment of visual functions begins at BACs of 0.04%, where about 30% of the findings show a significant impairment (see Figure 40, left). At higher BACs between 0.07% and 0.11%, the percentage of significant findings is twice as high with about 60%.

The ability to perceive rapid stimulus changes is measured by the critical flicker fusion test. This test was assigned to the sub category *physiology of the eye*, which belongs to the main category *visual functions*. As Figure 40 (right) shows, the critical flicker fusion frequency decreases only with high BACs beyond 0.07% in every third to fifth finding. The parameter is the least sensitive one to the effects of alcohol.

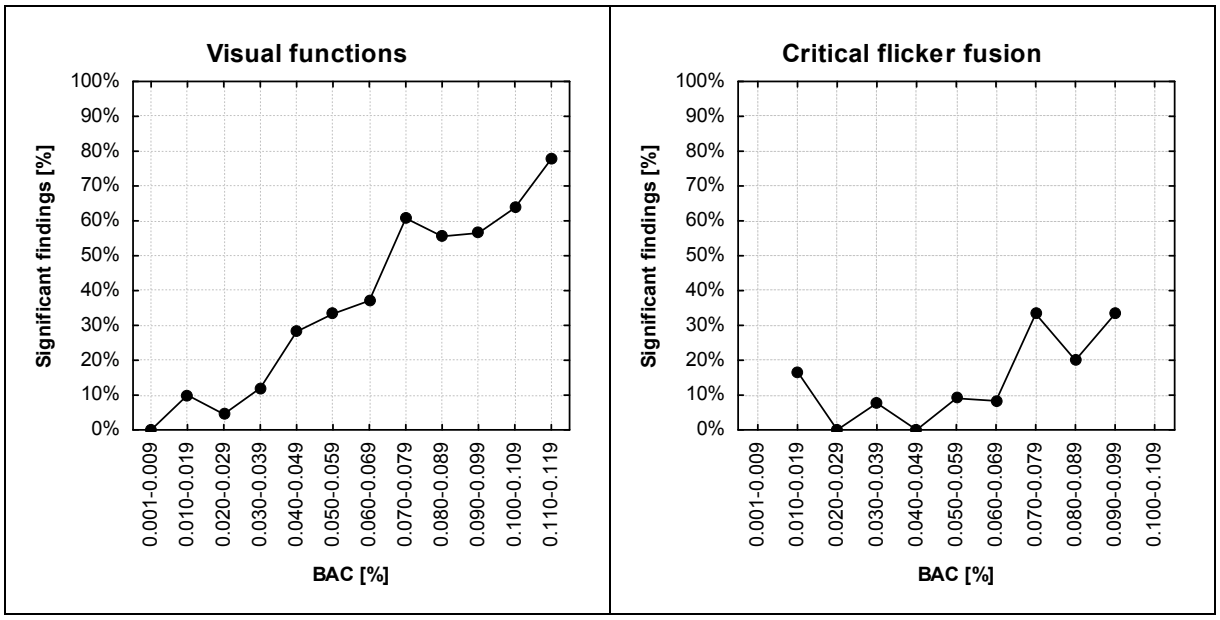


Figure 40: Impairment of visual functions (left) and critical flicker fusion frequency (right) – percentage of significant findings per BAC group (limited reliability due to low number of findings for critical flicker fusion).

7.3.4.2 Attention (including vigilance)

Up to a BAC of 0.04%, almost no study finds impairment in attention tests (Figure 41, left). At BACs above 0.04%, the percentage of significantly impaired findings increases up to 60% at a BAC of 0.08%.

The main category *attention* includes the sub category *vigilance*, into which tests measuring sustained attention with low stimulus frequency were assigned. Only few findings report significant impairment in vigilance tasks up to a BAC of 0.08% (Figure 41, right). Anyhow, with higher BACs the percentage of significant findigs increases substantially. The result that vigilance is only impaired at high BACs is quite surprising, as alcohol is known to be a sedative substance. It may be explained by the fact that the so-called vigilance tests conducted in the studies differ considerably regarding the instruction, the stimulus frequency or the duration of testing. If stimulus frequency is too high and test duration too short, the task rather resembles a simple reaction time task. As it is shown later, performance in simple reaction time tests is also impaired only at high BACs (see Figure 46).

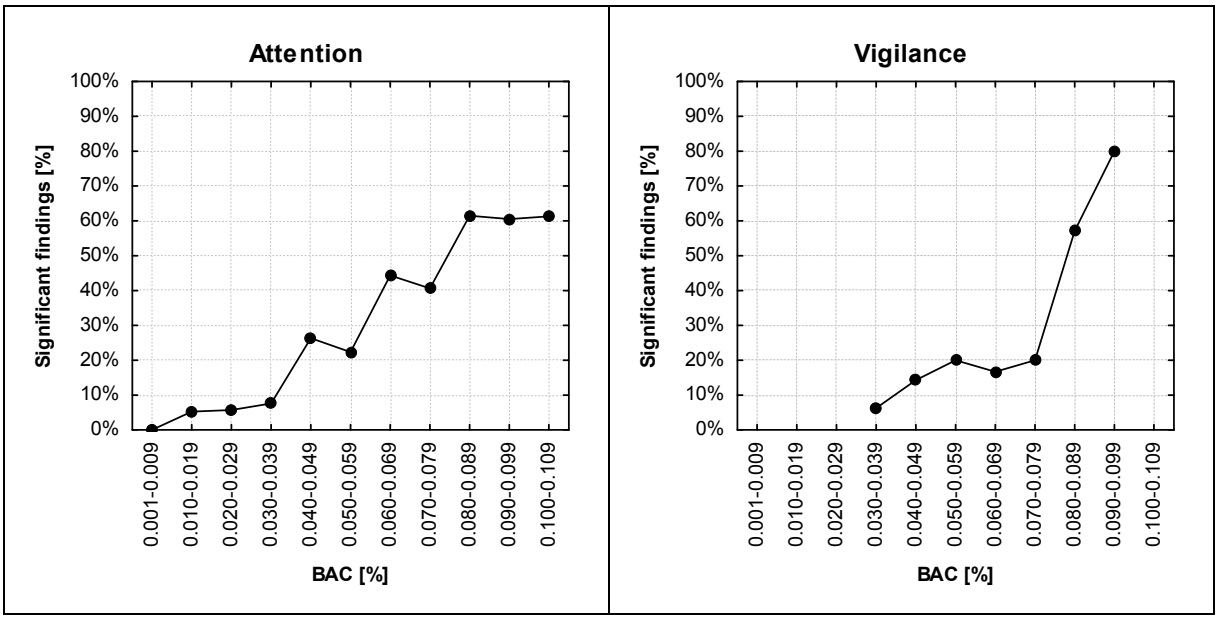


Figure 41: Impairment of attention (left) and vigilance (right) – percentage of significant findings per BAC group (limited reliability due to low number of findings for vigilance).

7.3.4.3 Divided attention

Impairment in divided attention tests occurs in every third finding at BACs between 0.01% and 0.019% (Figure 42). However, other BACs up to 0.07% lead to impairment in only few findings. For significant impairment in more than every second finding, BACs above 0.07% are necessary. When interpretating the figure, it has to be considered that there is not only one result for a divided attention task, but that each finding concerning the two simultaneous tasks enters the database. In most cases performance in at least one of the tasks can be sustained, thus the percentage of significant findings is unlikely to go beyond 50%.

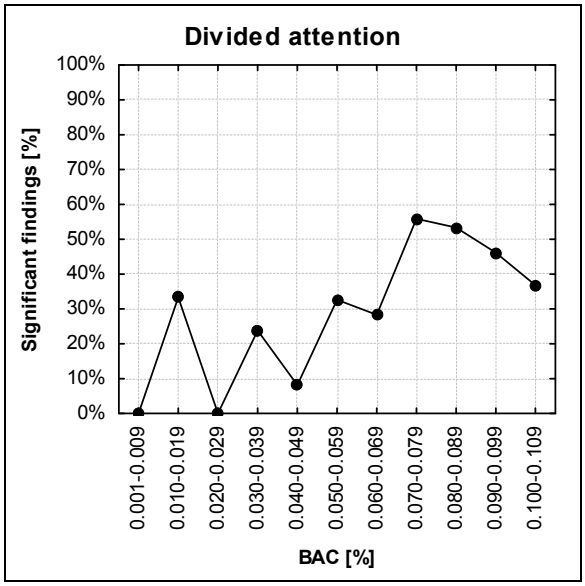


Figure 42: Impairment of divided attention – percentage of significant findings per BAC group.

7.3.4.4 En-/decoding (information processing and memory)

The main category *en-/decoding* consists of the two sub categories *information processing* and *memory*. Impairment of en-/decoding becomes obvious at very low BACs of 0.02% and the percentage of significant findings increases considerably at 0.06% BAC (Figure 43).

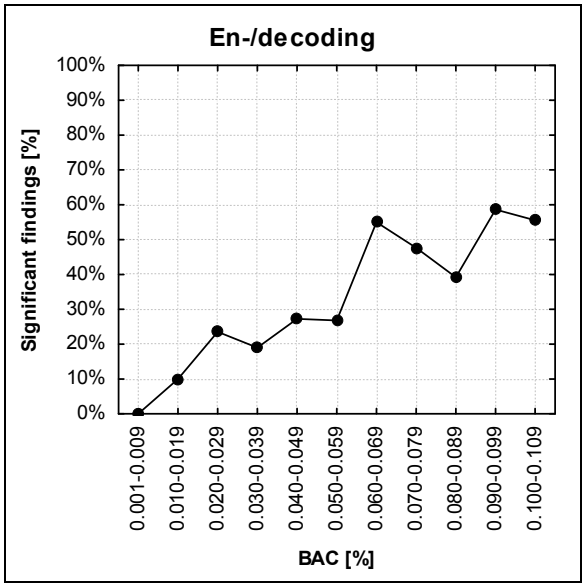


Figure 43: Impairment of en-/decoding – percentage of significant findings per BAC group.

Information processing and memory

With low BACs below 0.03%, memory is more frequently affected than information processing, whereas with high BACs above 0.05% the percentages of significantly impaired findings are higher in information processing tasks than in memory tasks (Figure 44). The great variation in memory impairment between the BAC groups may be due to the merging of short- and long-term memory tasks as well as recognition and free recall tasks in this category. Probably, these tasks differ in their sensitivity to the effects of alcohol.

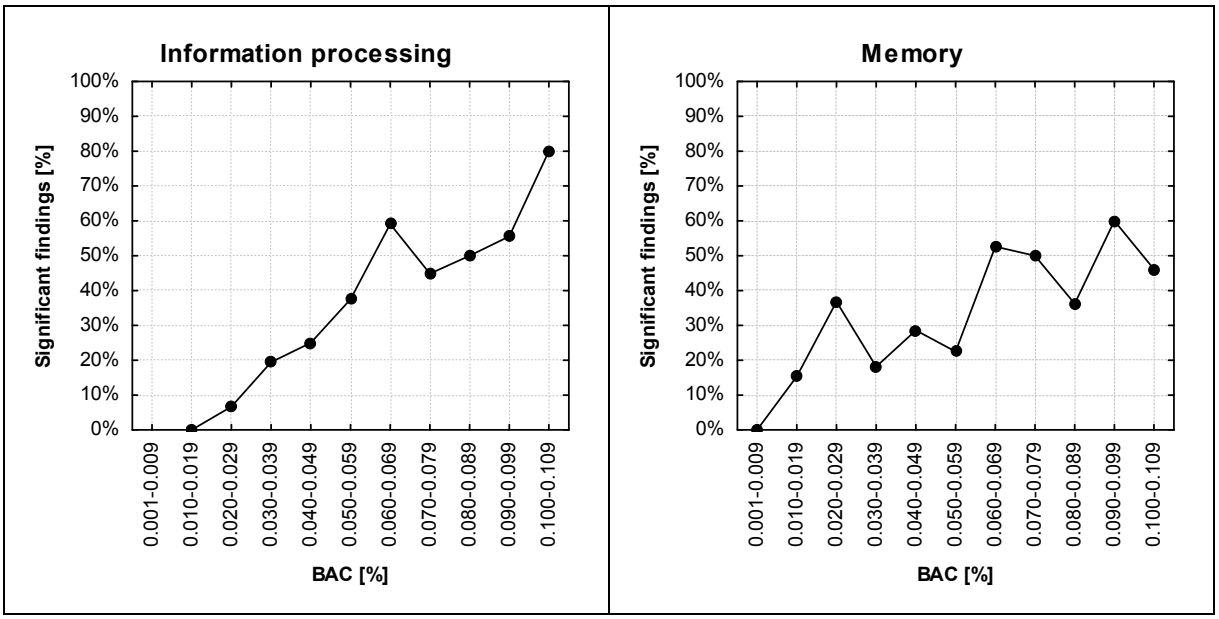


Figure 44: Impairment of information processing and memory – percentage of significant findings per BAC group (limited reliability due to low number of findings for information processing).

7.3.4.5 Reaction time (simple and choice reaction time)

As Figure 45 shows, performance in reaction time tasks is not affected up to a BAC of 0.04%. Clear impairment in three out of four findings occurs at very high BACs above 0.1%.

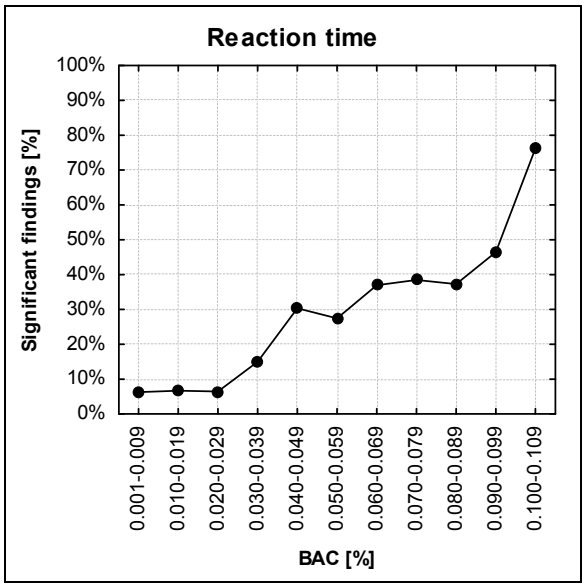


Figure 45: Impairment of reaction time – percentage of significant findings per BAC group.

Simple and choice reaction time

In Figure 46, the impairment function of reaction time is splitted up into simple and choice reaction time. It becomes obvious that performance in choice reaction time tests is impaired at slightly lower BACs than in simple reaction time tests.

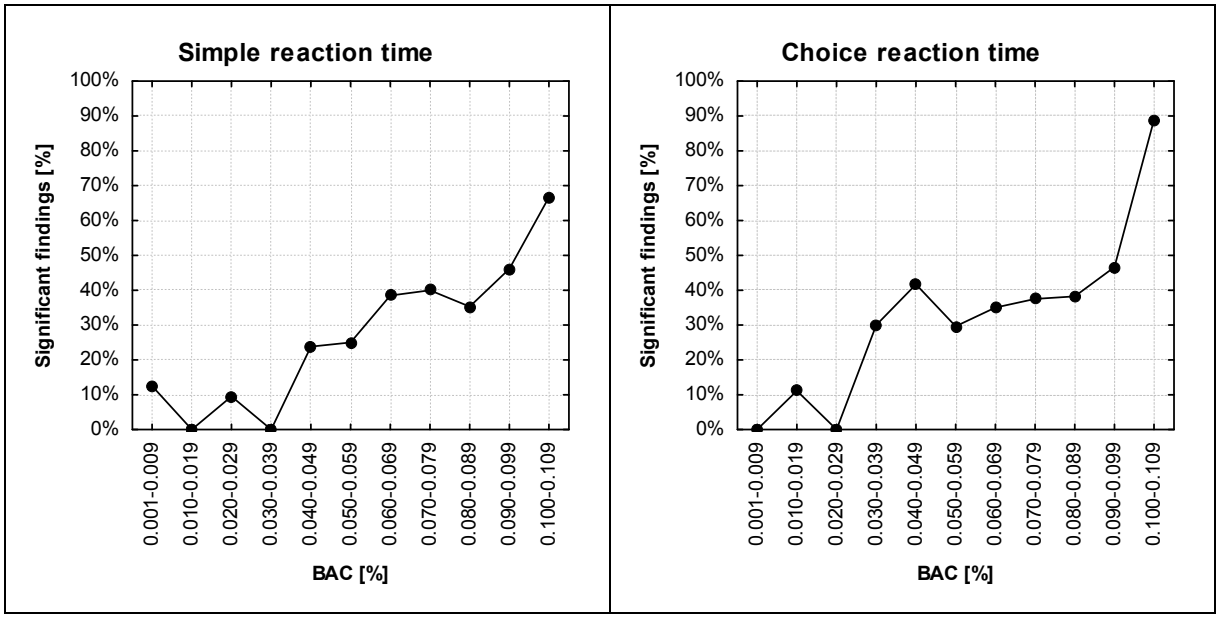


Figure 46: Impairment of simple (left) and choice (right) reaction time – percentage of significant findings per BAC group (limited reliability due to low number of findings).

7.3.4.6 Psychomotor skills

At a BAC of 0.04%, every third finding concerning psychomotor skills reveals significant impairment (Figure 47). With higher BACs, the percentage of significant findings increases considerably, until every finding is impaired at a BAC of 0.1%.

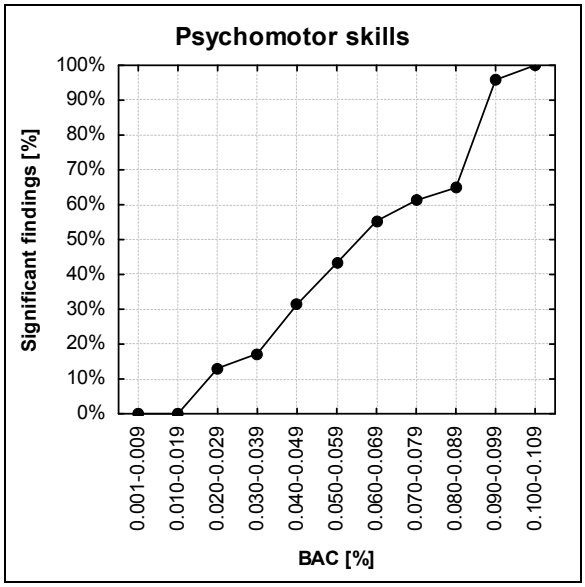


Figure 47: Impairment of psychomotor skills – percentage of significant findings per BAC group.

7.3.4.7 Tracking

Impairment of tracking performance begins at very low BACs of 0.02% (Figure 48). At a BAC of 0.05%, more than every second finding is significantly impaired. Thus, tracking tests are most sensitive to the effects of alcohol.

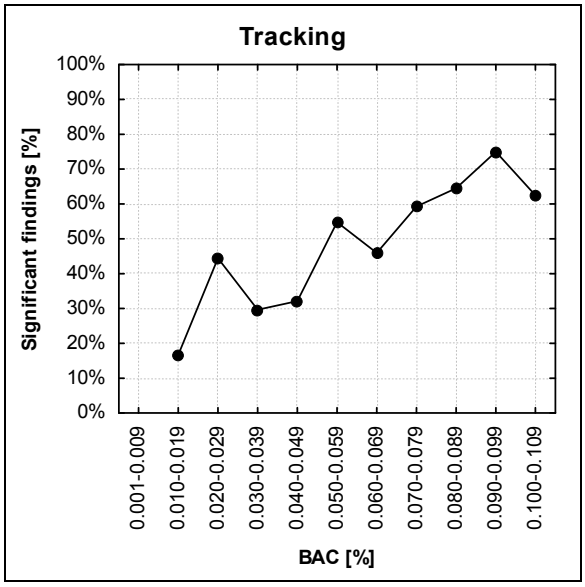


Figure 48: Impairment of tracking – percentage of significant findings per BAC group (limited reliability due to low number of findings).

7.3.4.8 Driving

As traffic behaviour is the main issue of the study, a closer look is taken at the main category *driving*, which comprises the assessment approaches driving simulator, flight simulator and closed course. In order not to confuse these approaches, only the findings of the sub category *driving simulator* are taken, which constitute two thirds of the main category (207 out of 317 findings up to a BAC of 0.11%). The impairment function of driving simulator tasks increases relatively logarithmically up to 50% significantly impaired findings at the maximum (Figure 49). Unfortunately, there are few studies available, especially with low and high BACs (just around 10 findings per BAC group). If findings of the more demanding flight simulator and closed course tasks were integrated (not shown in the figure), the percentage of significant findings would be slightly higher (up to 59%). The figure reveals that in contrast to the general impairment function, the percentage of significant findings in driving simulator tasks is higher with low BACs.

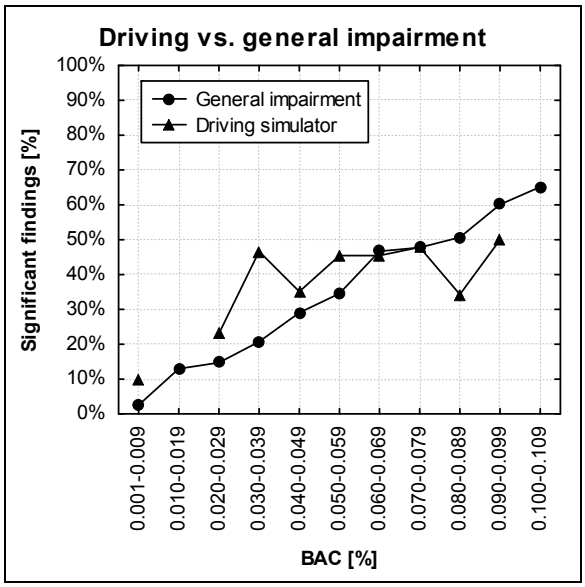


Figure 49: Impairment in driving simulator tasks vs. in general – percentage of significant findings per BAC group.

The underestimation of driving impairment by the general impairment function at low BACs is quite plausible, since a driving simulator task is more complex than most of the laboratory tasks. As it was demonstrated in Chapter 7.3.3, complex tasks are more affected by alcohol than simple tasks especially at low BACs. Moreover, the driving performance in simulator tasks is mainly represented by parameters measuring motor skills (e.g. the standard deviation of lateral position or reaction times), which are impaired sooner than cognitive skills (see also Chapter 7.3.3). In order to find an explanation for the only slight increase of 5% from a BAC of 0.06% to higher intoxications, the driving studies are looked at more precisely.

First, the simulator driving tasks are analysed regarding their complexity. If with increasing BAC the complexity of tasks decreases, the percentage of impaired findings might not increase. Four different types of driving tasks were identified in the studies:

- Road tracking: main parameters standard deviation of lateral position, off-road incidents, speed, speed variability
- Car following: main parameters headway, coherence, time-to-collision, collisions
- Complex driving tasks (e.g. complex scenarios, difficult conditions, secondary task or speed component): main parameters errors, time
- Hazard perception tasks: main parameters reaction time, brake latency

The first two types of driving tasks are classified as simple, the last two types as complex. Figure 50 reveals that low BACs up to 0.05% are mainly investigated with complex tasks, whereas at BACs between 0.06 and 0.08% simple tasks predominate. This result might contribute to the early increase of impaired driving findings and also to the constant percentage of impairment afterwards.

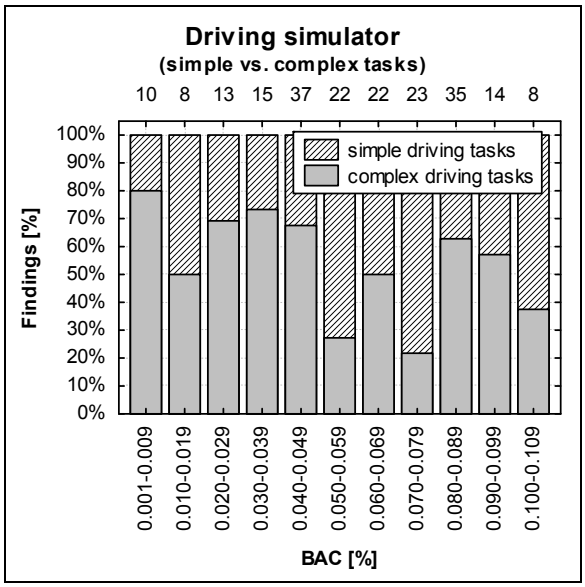


Figure 50: Percentage of simple vs. complex driving simulator tasks findings (on top the number of findings per BAC group is presented).

Second, the simulator driving tasks are analysed regarding the age of the subjects. Mayhew, Donelson, Beirness and Simpson (1986) stated in their review that young drivers have a greater risk of crash involvement than older drivers at all BACs. This finding is attributed in part to a lack of driving experience. Moreover, young drivers are inexperienced not only in driving, but also in drinking and in combining these two activities. When looking at the subjects' age, it is striking that at low BACs there are many more findings with young drivers, whereas at high BACs findings with drivers older than 24 years are in the majority (Figure 51). Subjects in the 0.09% BAC condition are on average 13 years older than subjects in the 0.06 BAC condition (36 vs. 23 years). Thus, it can be assumed that – besides the decreasing complexity of driving tasks – older drivers are responsible for the only slight increase of impairment at higher BACs.

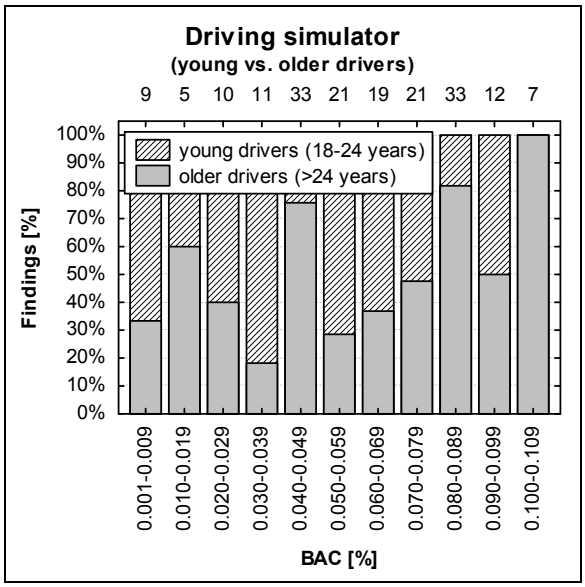


Figure 51: Percentage of young vs. older drivers in driving simulator tasks findings (on top the number of findings per BAC group is presented).

7.3.5 Short summary

Additionally, a short overview of the percentage of significantly impaired findings regarding all performance main categories is given for a BAC around 0.05% (Table 10). Without going into too much detail, but to cover at least this most interesting BAC area, BAC levels between 0.040 and 0.059% are considered.

Table 10: Percentage of significantly impaired findings with a BAC around 0.05% per main category.

Performance main categories	Percentage of sign. findings (0.040-0.059% BAC)
Driving[20]	48%
Tracking	46%
Psychomotor skills	38%
Visual functions	33%
Reaction time	29%
En-/decoding	27%
Attention	24%
Divided attention	20%
General objective impairment	**32%**

Also when analysing the single performance categories, impairment with a BAC around 0.05% is found more frequently in categories which comprise psychomotor or complex tasks rather than cognitive or simple tasks. For example, the percentage of significant findings is much higher in driving or tracking tasks than in attention tasks.

[20] The percentage of impaired findings for the sub category “driving simulator” at BACs between 0.040 and 0.059% is 39% (see also Figure 49).

8 DISCUSSION

This meta-analysis of the scientific literature on alcohol effects has four aims:

(1) to provide a scientific base for estimating the impairing effect of alcohol on driving safety,

(2) to evaluate the impact of different experimental aspects (like drinking time or time of day) on the results,

(3) to evaluate the dependency of the results from the evaluation method and to emphasize the relevance of non-significant findings (see Chapter 8.4),

(4) to review the methodological state of the art of alcohol research.

8.1 Methodological criticism of the analysed studies

In general, the methodological quality of alcohol research is quite high. Most studies use placebo control groups and are single or double blind. In the majority of cases the ingestion of food is standardized before the application of alcohol, which is randomised in between-subject designs. In most studies the tasks are practised. In addition to a global evaluation, most studies conduct post-hoc tests if there are more than two levels of the factor alcohol. However, the effects of alcohol are predominantly studied with rather small sample sizes consisting of young men who are social drinkers. Performance tests take place mainly in the eliminative phase and the task duration is quite short. Moreover, rather high quantities of alcohol have to be consumed at an unusual time of day in a short time, which does not correspond to normal drinking habits and conditions. Unfortunately, relevant information is often missing in the publications (e.g. the administered alcohol dosage, the time between the administration of alcohol and the beginning of the test, the duration of the test, the drinking time, the BAC, etc.). Additionally, the documentation of statistics like F-values, mean values or standard deviations is poor. The calculation of effect sizes was only possible for every third finding. In 68% of the findings of those studies which used a multi-factorial design, the impact of other factors on the alcohol effect could be determined. In the other one third of the findings interactions are not reported. Principally, the methodological requirements like placebo control groups or training of the task are in accordance with the guidelines for research on drugged driving developed by the International Council on Alcohol, Drugs and Traffic Safety's (ICADTS) working group (Walsh, Verstraete, Huestis & Morland, 2008). However, future investigations will have to pay more attention to the problem of missing information and should report the relevant information more carefully.

8.2 Summary of the results

In order to provide a general overview of alcohol effects on driving-related performance, a global impairment function has been established. For this purpose, all findings concerning performance were aggregated. Hence, this function is a collection of experimental studies using different tasks, dependent variables, instructions and test environments. Nonetheless, if nothing is known about the task and the person, this function (as an average) is the best estimate for alcohol-induced

impairment. The function includes 2,914 findings related to BACs between 0.001% and 0.119%. It is nearly linear with a slope of 6.6% (increment of significant findings) per 0.01% BAC, with about 30% significant findings at a BAC of 0.05% and 50% significant findings at a BAC of 0.08%. In addition to the global impairment function, impairment functions of single functions were calculated. In the case that more information about the characteristic of the task or the person is available, these more specific impairment functions should be used.

The meta-analytic procedure determines for each BAC group how often significant effects were reported. Therefore, the percentage of significant results is only a descriptive measure. Interpreting these percentages as degrees of impairment is an interpretation going beyond the information from the data base. Even though this interpretation has high face validity, one must be aware of this limitation when using this information for practical purposes.

A small impact on the general impairment function has been found for drinking conditions. The percentage of significant findings is higher per BAC group above 0.05% when subjects have to drink an alcohol dose higher than 0.0375 g/kg per minute. Detrimental effects of alcohol become also more apparent when tests take place after 6 p.m. or during the night.

In contrast, no systematic difference concerning the effects of alcohol in the two phases of metabolism could be found. Thus, by means of a meta-analysis, which combines many heterogenous studies with different alcohol dosages, drinking times or performance tasks, the acute tolerance effect cannot be confirmed. Moreover, the effects of alcohol are not much influenced by other factors like gender or age, as studies with a multi-factorial design show.

Unfortunately, the calculation of effect sizes provides no additional information concerning the general impairment by alcohol. The results are not very clear, probably due to the different performances which are examined in the studies. Since the necessary parameters for calculating are missing very often, the number of effect sizes per BAC group is small and a differentiation according to the performance categories is not possible. At least it could be shown that effect sizes increase with higher BACs when within a study the same performance test is conducted under the same methodological conditions with different BAC levels.

General impairment by alcohol across all performance tests differs for speed and/or accuracy parameters. Tasks in which reaction times and errors are considered simultaneously are most impaired, especially at BACs above 0.05%. The difference is up to 50% of significant findings compared to the single parameter of speed.

Regarding the subjective feeling of fatigue, the function looks very similar to the general impairment function with about 30% significant findings at 0.05% BAC as well. In contrast, the function for the subjective feeling of intoxication increases logarithmically with 80% significant findings at a BAC of 0.04%. At BAC levels where fatigue arises and performance starts to be impaired, subjects already feel considerably intoxicated (at least social drinkers, on which the study results are based). This means that subjective intoxication is an early indicator for impairment.

Moreover, the results reveal that motor functions are more impaired than cognitive functions. With low BACs, performance in simple tasks is less impaired than in complex tasks. It seems that subjects are able to compensate if the demands are low. However, with higher BACs the impairing effects do not differ depending on the complexity of the task.

Performance in automatic processes does not differ systematically from that in control processes. This does not support the result of Krüger (1993) who found that automatic processes are not as much affected as control processes even with high BACs. However, he only considered BACs up to 0.08%, and up to a BAC of 0.10% automatic processes are actually slightly less impaired (at least if a linear function is fitted). Also Maylor and Rabbitt (1988) did not find a difference between automatic and controlled processing, but reported identical effects of alcohol for the two types of processing.

Figure 52 gives an overview of the impairment in the single performance categories. For each driving-related skill, it is shown at which BAC the percentage of significant findings exceeds 30%, 50% or 70%.

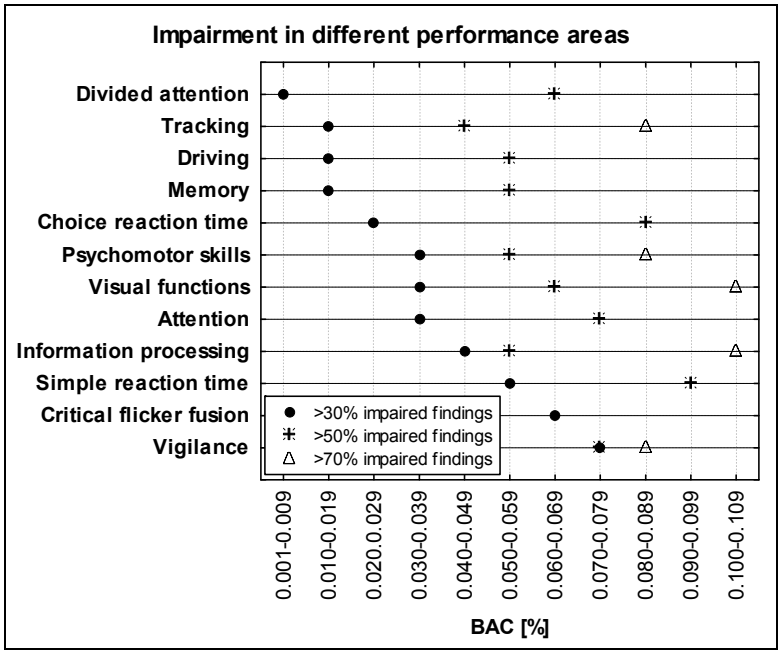


Figure 52: Impairment (>30%, >50% or >70% impaired findings) in different performance areas depending on the BAC.

Obviously, impairment under the influence of alcohol clearly differs between most of the driving-related performance categories. Tracking and driving performance are most affected by alcohol with impairment beginning at very low BACs of 0.02%. Also psychomotor skills are considerably affected from BACs of 0.04% on. It is the only performance category in which every finding is impaired at high BACs of 0.1%. Impairment of visual functions also starts at BACs of 0.04% and increases substantially with higher BACs. The same holds true for information processing. Impairment in memory tests can be found with very low BACs of 0.02%, but varies depending on the kind of memory which is tested. Impairment in divided attention

tests can also be found with very low BACs, but only BACs between 0.07% and 0.09% lead to significant impairment in more than 50% of the findings. Attention starts to be impaired at 0.04% BAC and above a BAC of 0.08% more than every second finding is impaired. For considerable impairment in vigilance tasks, also a BAC of 0.08% is necessary. Impairment in reaction time tests occurs at BACs of 0.04%, but remains rather stable up to a BAC of 0.1%. Choice reaction time is affected at lower BACs than simple reaction time. The parameter the least sensitive to the effects of alcohol is the critical flicker fusion frequency with only few significant findings even at high BACs.

The main category *driving* shows the highest impairment at BACs around 0.05% with 48% significant findings. Since this is much more than for all the other driving-relevant categories, driving tests are obviously essential for risk estimations concerning the effects of alcohol. Especially at low BACs, the general impairment function does not represent the driving performance. Impaired driving occurs much earlier than general impairment. This may be due to the fact that driving is a rather complex task with a predominance of those skills which are sensitive to alcohol.

Generally, the results provide no evidence of a threshold effect for alcohol. There is no driving-related performance category for which a sudden transition from unimpaired to impaired occurs at a particular BAC level, as Ogden and Moskowitz (2004) already stated in their review. The shape of the BAC-effect curve suggests a straight linear relationship for psychological functions or performances. Only for subjective intoxication, a threshold effect can be found, as it increases promptly already at low BACs. These results were found by Holloway (1995) as well.

8.3 Comparison of the findings with former reviews

As in the present work, the effects of alcohol differ as well in the former reviews depending on the performance category (see Chapter 3.2, Table 2). Table 11 shows the number of reviews reporting impairment in the majority of findings per BAC group and per performance category. For comparison, the BAC at which the majority of findings reported impairment in the present meta-analysis are shown (last column).

Table 11: Number of reviews reporting impairment in the majority of findings per BAC group ("very low": 0.001-0.029% BAC, "low": 0.030-0.049% BAC, "moderate": 0.050-0.079% BAC, "high": ≥0.080% BAC). The BAC group, to which the present results belong, is highlighted in bold and italic (exact BAC in the last column).

Performance category	Number of reviews per BAC group with >50% impaired findings					Present results
	Very low	Low	Moderate	High	No effect	(BAC)
Driving	1	7	***3***	-	-	0.05%
Tracking	-	3	***5***	-	-	0.05%
Psychomotor skills	-	1	***8***	-	-	0.06%
Information processing	1	1	***1***	-	-	0.06%
Memory	-	-	***4***	1	-	0.06%
Visual functions	-	1	***1***	4	-	0.07%
Divided attention	-	2	***3***	1	-	0.07%
Cognitive functions	-	1	5	***-***	-	0.08%
Vigilance	-	3	1	***2***	2	0.08%
Choice reaction time	-	1	5	***2***	-	0.1%
Simple reaction time	-	1	3	***3***	1	0.1%
Critical flicker fusion	-	-	3	***4***	1	0.1%[21]

As already mentioned in Chapter 3.2, the results of the former reviews differ remarkably in some performance categories. For example, **driving** is impaired in the majority of findings in one review at very low BACs, in seven reviews at low BACs and in three reviews at moderate BACs. Overall, it seems to be the category the most impaired, which is also suggested by the results of the present work. More than 50% of the findings are significantly impaired at a BAC of 0.05%. The same holds true for **tracking** performance in the present meta-analysis. This result is supported by the other reviews, which report impairment in 50% of the findings at low to moderate BACs.

Also for the categories **psychomotor skills**, **information processing** and **memory**, for which the majority of findings showed impairment at a BAC of 0.06%, the results are supported by most of the other reviews.

The results for visual functions or divided attention in the former reviews are very inconsistent. Impairment of **visual functions** even differs within the reviews, depending on which kind of visual function is tested. Most reviews report impairment at high BACs above 0.08%, and in the present meta-analysis impairment is found at moderate BACs of 0.07%. Impairment of **divided attention** ranges from very low to high BACs in the reviews. In the present meta-analysis, the majority of findings shows impairment at 0.07% BAC.

[21] Result bases on only three findings.

According to the results of the present work, **cognitive functions** (which is the category **attention** in this work) decrease significantly in the majority of findings at a BAC of 0.08%. Most reviews, in contrast, report impairment at moderate BACs or even at low BACs. It was also shown that **vigilance** is impaired at high BACs of 0.08%, whereas the results of the former reviews differ from low BACs to even no effect at all.

Both **simple** and **choice reaction time** are at high BACs of 0.1% affected in more than 50% of the findings in the present work, with choice reaction time being generally affected at slightly lower BACs. In former reviews, impairment of choice reaction time is mostly found with moderate BACs, while increased simple reaction times most frequently occur at moderate to high BACs. The result that response accuracy is more affected than speed of reaction is supported by the present work. In accordance with the results of former reviews, the least sensitive parameter to the effects of alcohol is the **critical flicker fusion** frequency, with impairment only at high BACs above 0.1%.

Generally, the present meta-analysis reveals that in the majority of findings BACs above 0.05% lead to significant impairment of driving-related skills, with some performances being impaired only at high BACs above 0.08%. Former reviews partly support these results, but often find impairment at much lower BACs.

8.4 Comparison with Moskowitz

Moskowitz and Robinson (1988)[22] and particular Moskowitz and Fiorentino (2000)[23] reported very low BACs at which performance in the different driving-relevant behavioural categories was impaired (see chapter 3.1.8 and 3.1.15). This cannot be supported by the present meta-analysis. The same discrepancy in results already occurred between the reviews of Krüger et al. (1990) and M. & R. (1988). Therefore, Krüger et al. (1997) compared the two reviews and came to the conclusion that the reasons for this discrepancy lies in a different way to review scientific findings. In the following, another comparison is made between the present meta-analysis[24] and the reviews of M. & R. (1988) and M. & F. (2000) focusing the proceeding and the results.

8.4.1 Selection of studies

First, the way of selecting the studies is compared (see Table 12). The review of M. & R. (1988) comprises the years 1950-1985, the one of M. & F. (2000) the years 1981-1998, and the present review the years 1950-2007. Some in- and exclusion criteria were the same in all three reports (e.g. driving-related behaviour was examined, human subjects were studied, BACs were reported or calculable), but in the present work additional methodological standards were required (e.g. a minimum of 6 subjects or a control group design; see Chapter 5.1). The two additional criteria applied by Moskowitz and colleagues were that the study was available in English

[22] In the following abbreviated as “M. & R. (1988)”.
[23] In the following abbreviated as “M. & F. (2000)”.
[24] In the following tables and figures named „Schnabel (2011)“.

(criteria in both reports) and that alcohol doses were not above 1 g/kg (criteria only in M. & F., 2000).

In total, 177 studies resulted in M. & R. (1988) of which 158 reported at least one significant finding, and 112 studies in M. & F. (2000) with 110 reporting at least one significant finding. Of the 471 studies in the present work, 404 were significant. 5,300 findings resulted (with 1,951 significant) in contrast to 556 findings (with 313 significant) in M. & F. (2000) and 398 (significant) findings in M. & R. (1988).

Table 12: Comparison between the two reviews of Moskowitz and the present review with respect to the selection of studies.

	M. & R. (1988)	**M. & F. (2000)**	**Schnabel (2011)**
Years included	1950-1985	1981-1998	1950-2007
Inclusion criteria	Experimental studies Driving-related behaviour Human subjects Sufficient information on dose and procedure Alcohol alone condition No alcoholics English	Experimental studies Driving-related behaviour Human subjects Sufficient information on dose and procedure Alcohol alone condition English Dose below 1 g/kg	Experimental studies Driving-related behaviour Human subjects Sufficient information on dose and procedure Alcohol alone condition No alcoholics At least 6 subjects Oral alcohol application Control group design
Number of studies (number significant)	177 (158)	112 (110)	471 (404)
Number of findings (number significant)	398 (398)	556 (313)	5,300 (1,951)

In the following, a comparison of the studies in common is made. As Figure 53 shows, the present review includes 127 studies between 1950 and 1985, but only 79 of them also appear in M. & R. (1988). 10 of the missing 48 studies do not appear in M. & R. (1988) because of the different inclusion criteria, but for the remaining 38 studies there is no clear reason for not being included by M. & R. (1988). Regarding the time period from 1981 to 1998, 211 studies are included in the present review, but no more than 61 studies[25] of them also appear in M. & F. (2000). 38 of the missing 150 studies were not included by M. & F. (2000) due to the different inclusion criteria. This means that the missing of 112 studies in the review of M. & F. (2000) cannot be explained by the inclusion criteria.

[25] Actually, there are 60 studies, but one study with two experiments (Pearson and Timney, 1998) was counted twice in the present review, thus this was done as well for the comparison with M. & F. (2000).

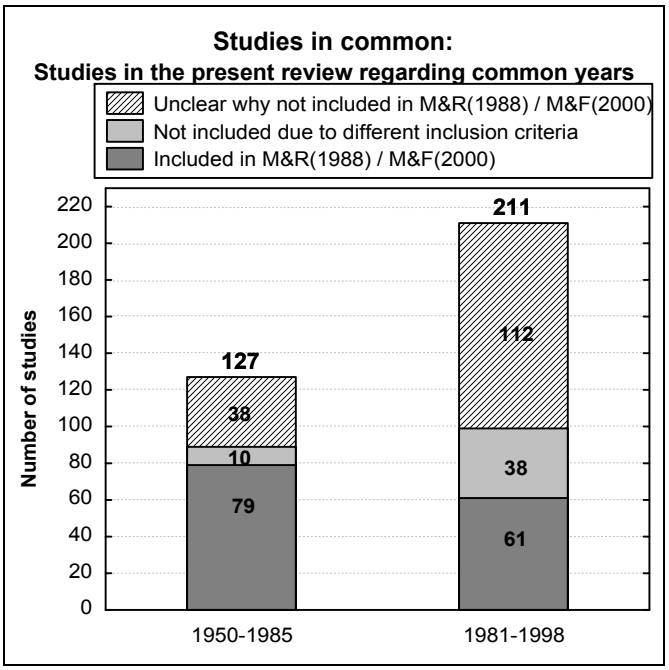


Figure 53: Studies selected in the present review and number of studies included or not in the reviews of M. & R. (1988) and M. & F. (2000) regarding the years in common.

8.4.2 Selection of findings

Next, the way of selecting the findings from the studies is compared (see Table 13). In the present meta-analysis findings from all behavioural categories were selected (including e.g. aggression and the feeling of intoxication), since all domains were considered as relevant to driving. Moskowitz and his colleagues in contrast selected only findings which are specifically related to driving-relevant skills, which included findings referring to performance tests (M. & R., 1988), and additionally findings referring to subjective drowsiness (M. & F., 2000). Moreover, M. & R. (1988) only selected the significant findings from a study and disregarded tests which did not find an effect of alcohol.

Another difference is that in most cases M. & R. (1988) and M. & F. (2000) only considered one point in time, namely the significant one, whereas in the present review all points in time at which testing took place were considered. In the study of Azcona, Barbanoj, Torrent and Jané (1995), for example, testing took place at five different points in time (1, 60, 120, 210 and 330 minutes after the end of drinking) leading to five different BACs (0.062, 0.088, 0.083, 0.071, 0.046%). A significant effect occurred at 210 minutes in the simple reaction time test. M. & F. (2000) solely selected this finding, although non-significant findings should be considered as well in this review.

A problem is that some studies with more than two levels of the factor alcohol did not conduct post hoc tests when a global effect was found. To be conservative, only the highest BAC level was considered as significant in the present review. In contrast, Moskowitz and his colleagues regarded all BACs at which tests were conducted as significant in their two reviews. This proceeding can be illustrated exemplarily by the

study of Horne and Gibbons (1991). A vigilance test was conducted with placebo, a low (0.034%) or a high (0.066%) BAC in the afternoon or in the evening. The authors reported significant main effects for dose and for time of day. It remained unclear, between which alcohol levels the difference in performance became significant (i.e. between high alcohol dose and placebo or also between low alcohol dose and placebo). M. & F. (2000), however, entered significant findings for both the high and the low dose into the database.

Another difference in the proceeding is that M. & R. (1988) and M. & F. (2000) generally subsumed different tests within one behavioural category to one finding. This was done when all tests have been significant (there is for example only one entry for Bird et al., 1980, who reported a significant simple reaction time test as well as a significant choice reaction time test) and also when only one test has been significant (see for example Lewis, Dustman & Beck, 1969, who reported a significant spiral after effect, but no significant effect for the critical flicker fusion threshold). Additionally, M. & F. (2000) applied this proceeding when all tests have been non-significant (see for example Hill & Toffolon, 1990, who conducted several visual tests with none of them becoming significant at 0.061% BAC). In this case, M. & F. (2000) entered only one non-significant finding in his database.

In many tests, more than one parameter was used, for example the authors looked at a speed and an accuracy component. Especially in driving tests, there were many parameters like lane position, SDLP, off-road incidents, speed variation, steering wheel reversals or time headway to the preceeding vehicle. All these cases implicated only one finding in the databases of M. & R. (1988) and M. & F. (2000). The finding was entered as significant if one of the parameters was significant. Taylor, Dolhert, Morrow, Friedman and Yesavage (1994) for example reported a significant effect for one out of seven pilot performance parameters with a BAC of 0.074%, namely the oil pressure detection. This was entered as one significant finding by M. & F. (2000), while the remaining six non-significant findings were ignored. The same held true for the study of Brookhuis and De Waard (1993), who reported significant effects for two out of five driving parameters (SDLP, delay in reaction time to varying speed of the leading vehicle).

Table 13: Comparison between the two reviews of Moskowitz and the present review with respect to various aspects concerning the selection of findings from the studies.

	M. & R. (1988)	M. & F. (2000)	Schnabel (2011)
Driving-relevant behavioural categories	Only performance categories	Performance categories and subjective drowsiness	All behavioural categories
Significance	Only significant findings within a study	Significant and non-significant findings	Significant and non-significant findings
Several testing times or BACs for one test	In most cases only 1 point in time with 1 BAC (the sign.)	In most cases only 1 point in time with 1 BAC (the sign.)	All points in time / all BACs
Effects without post hoc tests	All BACs are considered as significant	All BACs are considered as significant	Only highest BAC is considered as significant
Different tests within one behavioural category	Only 1 finding for different tests per category	Only 1 finding for different tests per category (non-significant tests)	All different tests
Test parameter	Only 1 test parameter	Only 1 test parameter (the sign.)	All test parameters

The above described proceeding of Moskowitz and his colleagues leads to much less findings, mainly because of ignoring all (M. & R., 1988) or many (M. & F., 2000) of the non-significant findings. In the review of 2000, M. & F. were supposed to consider also the non-significant findings, but in fact only few were considered due to the rules for selecting the findings (see above). Sometimes the non-significant findings were ignored without a rule, for example in the study of Millar, Duncan and Tiplady (1995). A test battery was conducted and significant impairment was found with a low and a high alcohol dose in a memory and in a letter cancellation test. The authors reported that no other test (two other attention tests and a sentence verification test) had shown significant effects. In M. & F. (2000), however, the non-significant tests were not considered. As a consequence, regarding the studies included in both the review of M. & F. (2000) and the present review, 325 findings resulted in the review of M. & F. (2000) of which 144 were non-significant (44%) in contrast to 678 findings in the present review with 454 being non-significant (67%).

Furthermore, the classification of tasks to the categories sometimes differ between the reviews. For example, a required buttonpush to the motion onset of highly visible dots (in the study of MacArthur & Sekuler, 1982) was classified as a simple reaction time task in the present review and not as a choice reaction time task (in M. & F., 2000) or as perception (in M. & R., 1988). The same holds true for the BAC, which is not always exactly the same. M. & R. (1988), for example, always estimated the BAC in the studies via the Widmark formula, even when the BAC was measured and reported by the authors. This leads to a slightly higher BAC. Besides, he calculated the BAC for the time when testing commenced and did not take the mean value for the test period if test duration was given. Thus, the BACs used by M. & R. (1988) are higher in case of testing on the descending limb of the blood alcohol curve, or lower in case of testing on the ascending limb (see for example the study of Cherry et al.,

1983). In 2000, M. & F. only estimated the BAC via the Widmark formula if there was no empirically measured BAC, which corresponds to the proceeding in the present review. Thus, when comparing the findings both reviews have in common, most BACs were similar.

The definition what a significant finding is, is different as well. M. & F (2000) entered a significant finding not only if the main effect of alcohol was significant (like in the present review), but also if the interaction with another factor was significant (without a significant main effect). In the study of Post, Lott, Maddock and Beede (1996), for example, none of the main effects achieved statistical significance, but the interaction of dose and display size was significant. This means that reaction times only increased under alcohol when subjects had to react on stimuli in the large display configuration. In the present review, this implied a non-significant finding, whereas in M. & F. (2000) it was entered as a significant finding into the database.

Finally, when comparing the findings in the studies the reviews have in common, it was stated that M. & R. (1988) entered some findings as significant by mistake. In the review there was, for example, a significant finding at a BAC of 0.09% for the digit-symbol substitution test referring to the study of Hollister and Gillespie (1970). Indeed, the authors reported that this test revealed a difference between substance treatments. However, it was added that this difference was on the one hand an *improvement* in performance and on the other hand attributable to the substance *dextroamphetamine*. With a BAC of 0.09%, actually no effect could be found. Similarly, M. & R. (1988) entered a significant effect at a BAC of 0.03% for the choice reaction time test in the study of Palva, Linnoila, Routledge and Seppälä (1982), although the authors clearly reported that no objective evidence was found for alcohol impairment.

8.4.3 Evaluation approaches

Apart from the differences in the selection of studies and findings in the reviews of M. & R. (1988), M. & F. (2000) and the present review, there were different approaches to evaluate the findings. Besides the method of vote-counting, which was the evaluation method in the present review (see Chapter 7.1), M. & F. (2000) used a method presenting the number of findings by the lowest BAC at which impairment was found (see Chapter 3.1.15). On the one hand, this method was used to determine the onset of *general* impairment by counting each study once at the lowest BAC for which impairment was found, regardless of the behavioural category (see Table 14, left, for an example). On the other hand, this evaluation method was used to determine the onset of impairment in the *single behavioural* categories by counting each study at the respective lowest impairing BAC per behavioural category which was examined in the study (see Table 14, right). This was also done by M. & R. (1988) in their review (see Chapter 3.1.8).

The approach is illustrated in the following table. Three studies are exemplarily presented with 16 findings, of which only those highlighted in bold and italic font were considered for the analysis (in contrast, in the method of vote-counting, *all* findings would be considered). The BAC group “5” represents BACs between 0.040 and 0.049% and so on.

Table 14: Example for the evaluation method of Moskowitz for determining the onset of general impairment (left) and the onset of impairment in the single performance categories (right). Only the highlighted findings were counted per study.

Study reference	Behavioural category	BAC group	Impair-ment
Barnes, Crombie, Adge, 1985	Visual functions	***5***	***Yes***
		8	Yes
Azcona, Barbanoj, Torrent & Jané, 1995	CFF	8	No
	Simple RT	***8***	***Yes***
	Psychom. skills	8	No
Cohen, Hamilton & Peck, 1987	Psychomotor skills	***2***	***Yes***
		5	No
		5	Yes
	Simple RT	2	No
		5	Yes
		5	Yes
	Tracking	2	Yes
		5	No
		5	Yes
	Visual functions	2	No
		5	Yes

Study reference	Behavioural category	BAC group	Impair-ment
Barnes, Crombie, Adge, 1985	Visual functions	***5***	***Yes***
		8	Yes
Azcona, Barbanoj, Torrent & Jané, 1995	CFF	8	No
	Simple RT	***8***	***Yes***
	Psychom. skills	8	No
Cohen, Hamilton & Peck, 1987	Psychomotor skills	***2***	***Yes***
		5	No
		5	Yes
	Simple RT	2	No
		5	***Yes***
		5	Yes
	Tracking	***2***	***Yes***
		5	No
		5	Yes
	Visual functions	2	No
		5	***Yes***

Additionally, the cumulative percentages of significant studies per BAC group with reference to the total number of significant studies could be presented. This was done by M. & F. (2000) in a table in their review for both the data of 1988 and 2000.

In Table 15, the different evaluation approaches are presented in summary with respect to the review in which they were used.

Table 15: Evaluation approaches in the two reviews of Moskowitz and the present review.

	M. & R. (1988)	M. & F. (2000)	Schnabel (2011)
Onset of impairment in general		Only significant findings: the lowest BAC at which impairment was found per study	
Onset of impairment by behavioural category	Only significant findings: the lowest BAC at which impairment was found per behavioural category	Only significant findings: the lowest BAC at which impairment was found per behavioural category	
Vote-counting		Significant and non-significant findings: numbers per BAC	Significant and non-significant findings: percentages of sign. findings per BAC
(Additionally)	(Cumulative percentages of significant studies)		

8.4.4 Comparison of results according to the different evaluation approaches

In the following section, the results of M. & R. (1988), M. & F. (2000) and the present review are compared for each of the above described evaluation approach. For this comparison, findings according to the behavioural categories of M. & F. (2000) have been selected from the present review (resulting in n = 3,468). Moreover, findings with a BAC of 0.09% or more have been summarised into a residual category (>=0.09%) according to M. & F. (2000).

8.4.4.1 The onset of impairment in general

As described above, this evaluation method of M & F. (2000) only considers significant findings and determines the lowest BAC at which impairment was found per study.

In total, the present review comprises much more studies than the review of M. & F. (2000), but in both reviews the onset of impairment is approximately normally distributed across the BAC groups (see Figure 54, left). However, in M. & F. (2000), most studies first found impairment at a BAC between 0.040 and 0.049%, whereas in the present review most studies first found impairment at a BAC between 0.060 and 0.069%. Generally, in M. & F. (2000) driving-relevant impairment occurred earlier – this means at lower BACs – than in the present review. About half of the studies which found impairment reported it by a BAC of 0.05% in M. & F. (2000), whereas in the present review this was only the case by a BAC of 0.06% (see Figure 54, right). Overall, a difference of a BAC of about 0.01% between the two reviews can be stated for finding impairment.

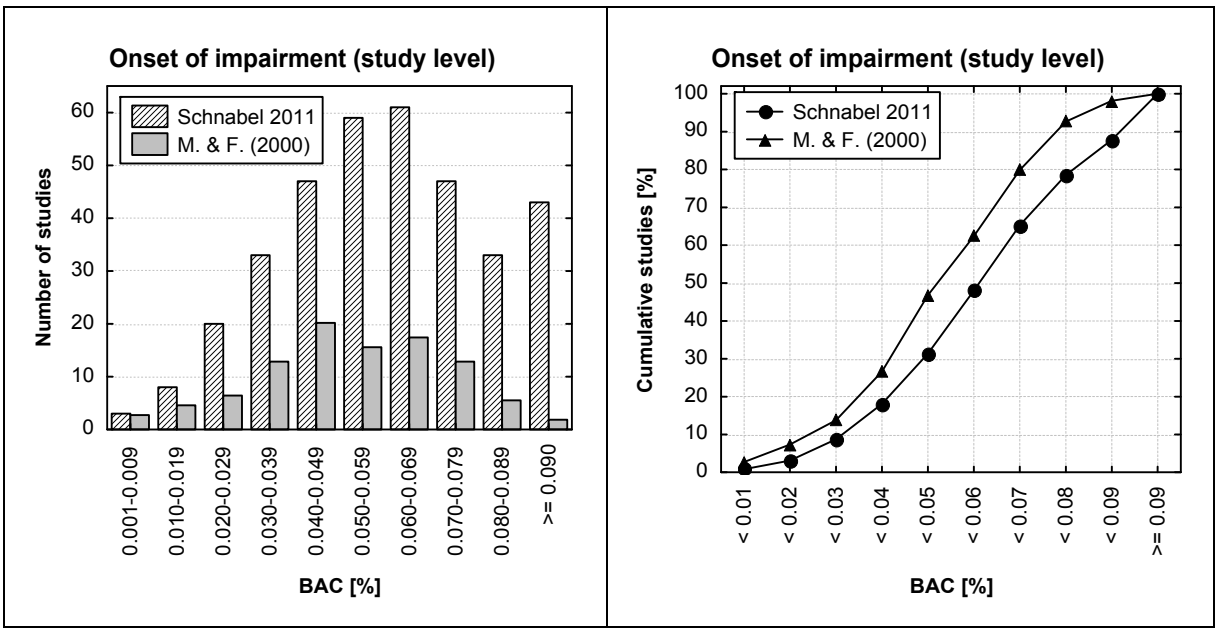


Figure 54: Number of studies reporting impairment by the lowest BAC at which impairment was found per study (left) and cumulative percentages (right) for Moskowitz & Fiorentino (2000) (n = 109) and the present review (n = 354).

The difference in impairment might be due to the fact that – in studies which conducted no post hoc tests after a global effect had been found – M. & F. (2000) considered *all* examined BAC levels as significant instead of taking conservatively only the highest BAC level. Another reason for the difference might be that M. & F. (2000) also registered a significant finding if only the interaction with another factor than alcohol was significant, without a significant main effect of alcohol.

When interpreting the results of this evaluation method, it has to be kept in mind that non-significant findings within a study have not been considered. Thus, the method solely determines the BAC at which most of the *significant* studies start to find the impairment.

8.4.4.2 The onset of impairment by behavioural category

This evaluation method, which is very similar to the above one, was used by Moskowitz and his colleagues in both reviews. Again, only significant findings were considered, but the lowest impairing BAC was determined per behavioural category and not per study. This means that each behavioural category which was examined in a study (and in which a test has become significant) was considered.

Due to the higher number of studies in the present review compared to the two reviews of M. & R. (1988) and M. & F. (2000), there were also much more behavioural tests showing impairment under the influence of alcohol in the present review (see Figure 55, left). In most of the significant tests, the onset of impairment occurred at a BAC of 0.090% or higher, which was also the case in M. & R. (1988). In contrast, in M. & F. (2000) most tests first found impairment at a BAC between 0.040 and 0.049%. Generally, in M. & F. (2000) impairment was found more frequently at lower BACs than in M. & R. (1988), with the present review lying in-between (see Figure 55, right). Up to a BAC of 0.05%, 47% of the significant studies in M. & F. (2000) reported performance impairment in contrast to only 26% in the present review and 20% in M. & R. (1988).

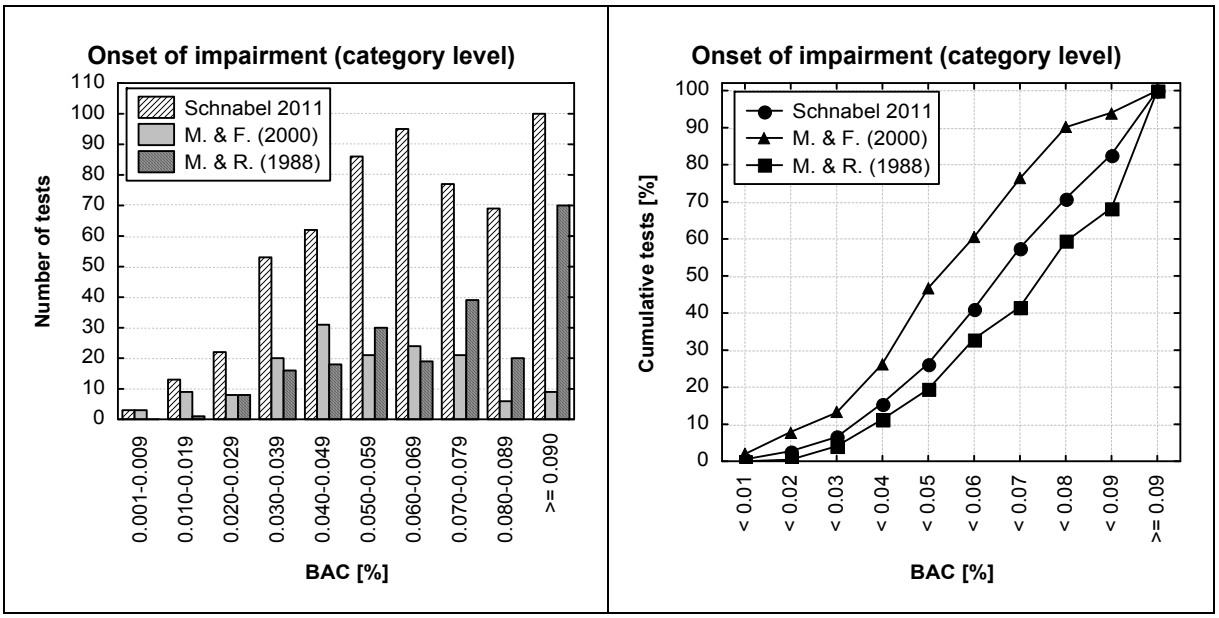


Figure 55: Number of tests reporting impairment by the lowest BAC at which impairment was found per behavioural category (left) and cumulative percentages (right) for Moskowitz and Robinson (1988) (n = 221), Moskowitz and Fiorentino (2000) (n = 152) and the present review (n = 580).

The higher percentages of impairment (up to 21% per BAC level) in M. & F. (2000) might be due to the same facts as mentioned above for the first evaluation method. The rather low percentages of impairment in M. & R. (1988), on the contrary, might be attributed to the fact that experiments at that time included less frequently low doses of alcohol. Thus, the onset of impairment could be found more probably at higher doses. Another reason might be that M. & R. calculated in 1988 each BAC via the Widmark formula and for the time when testing commenced, which resulted in a higher BAC. Nevertheless, M. & R. (1988) concluded in their review that performance impairment might occur at BACs as low as 0.02% and that there was no threshold BAC below which impairment effects were absent. It has to be emphasized that this conclusion was made because of just one significant finding at a BAC of 0.02%.

8.4.4.3 Vote-counting

This evaluation method of the present review was also used by M. & F. (2000). The number of significant and non-significant findings were counted and summarised per BAC group.

In the following, the results are presented across all behavioural categories for the present review and for M. & F. (2000). In the present review, findings reporting no significant impairment clearly dominated findings reporting significant impairment up to a BAC of 0.079% (Figure 56, left). In M. & F. (2000), in contrast, the number of impaired findings was greater than the number not impaired by the time subjects reached BACs of 0.040% (Figure 56, right).

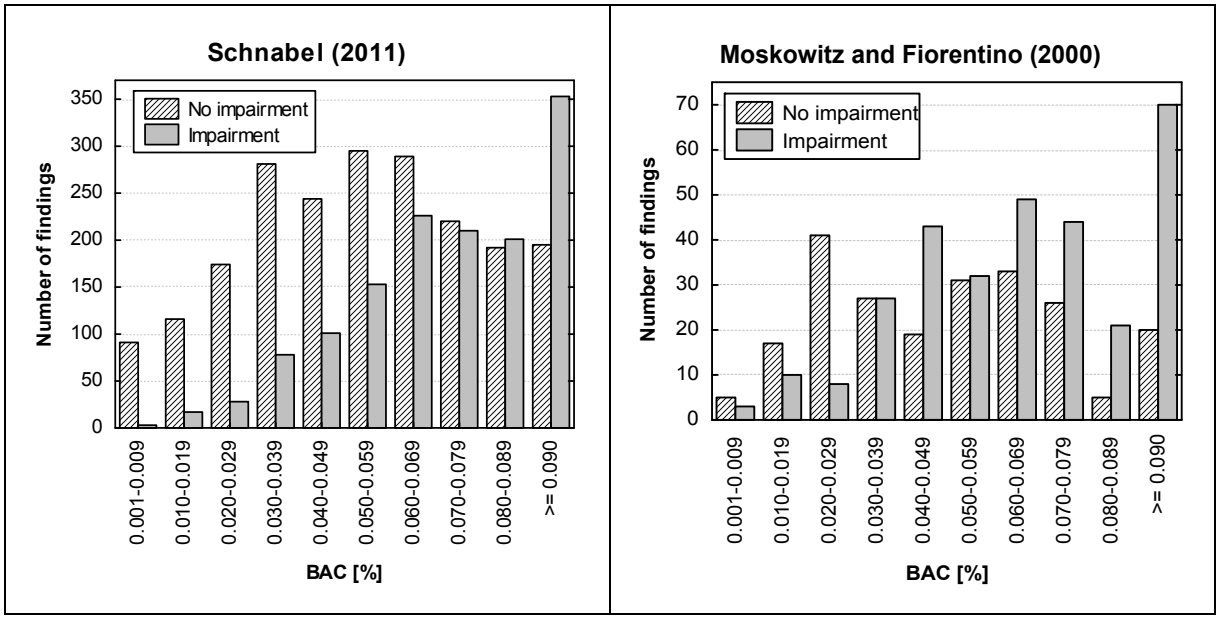


Figure 56: Number of findings reporting impairment vs. no impairment in the present review (n = 3,467) (left) and in Moskowitz and Fiorentino (2000) (n = 531) (right).

The percentages of significantly impaired findings were higher in M. & F. (2000) than in the present review in each BAC group, particular with very low or with medium BACs around 0.04% (see Figure 57, left). With medium BACs (0.03-0.049%), for example, 50 to 70% of the findings were significant in contrast to 20 to 30%. The cumulative percentages of significant findings in M. & F. (2000) were about twice as high than in the present review. Up to a BAC of 0.06%, for example, 23% of all findings were significant in contrast to 11% (see Figure 57, right). It has to be emphasized that the cumulative percentages were determined in relation to *all* findings, not only to the significant ones, which leads to rather flat curves.

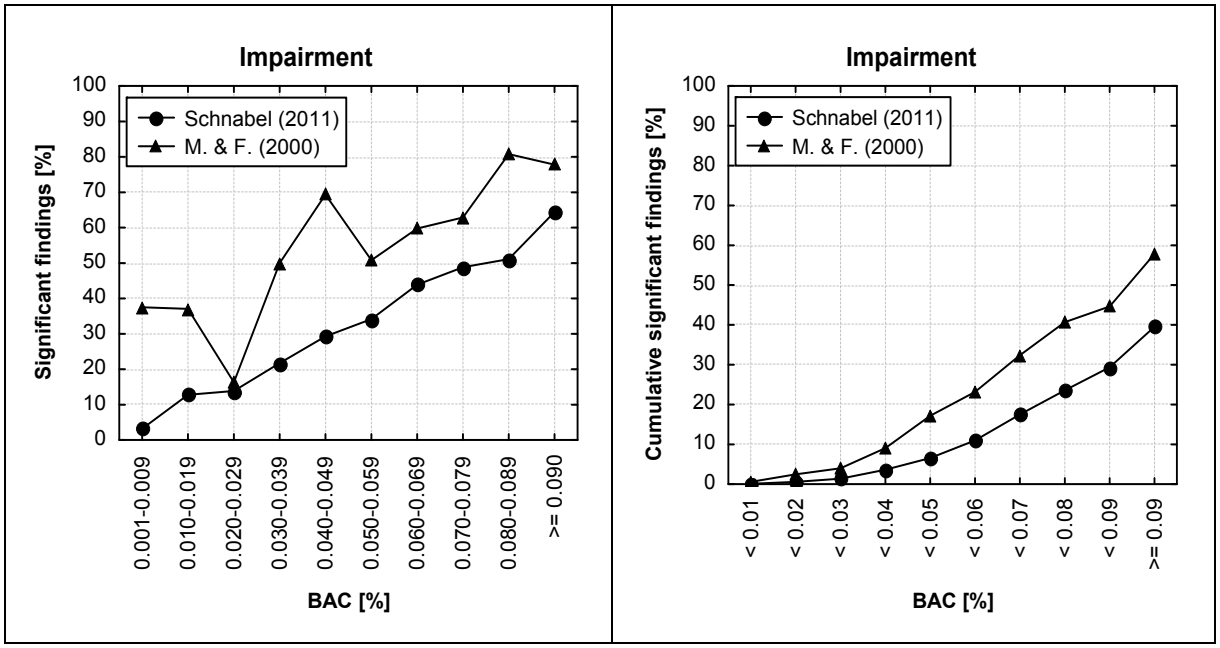


Figure 57: Percentage of significantly impaired findings per BAC group (left) and cumulative percentages (right) for Moskowitz and Fiorentino (2000) and the present review.

Again, M. & F. (2000) reported driving-relevant impairment at very low BACs. The percentage of significant findings in relation to the non-significant findings was much higher than in the present review. However, there were not more significant findings in M. & F. (2000), but much less non-significant findings due to the different way of selecting findings for the review. For example, M. & F. (2000) subsumed different tests within one behavioural category to one significant finding when one of the test has been significant and to one non-significant finding when all tests have been non-significant. Moreover, M. & F. (2000) only entered one finding (the significant one) in the database when more than one parameter (especially in driving tests) or point in time at which testing took place existed in a test.

8.4.4.4 Conclusions

The different way of M. & R. (1988), M. & F. (2000) and the present work to review scientific findings leads to different results as shown in the previous chapters. The results differ not only between the reviews of M. & R. (1988), M. & F. (2000) and the present review, but also between the different evaluation approaches. The frequency of impairment found in the studies seems to be much higher in the two evaluation approaches of M. & R. (1988) and M. & F. (2000), in which the non-significant findings were not included at all. Almost 50% of the studies, which found impairment, reported it by a BAC of 0.05% in M. & F. (2000) and around 30% in the present review. With the evaluation method used in the present review, which considered also the non-significant findings, the cumulative frequencies of significantly impaired findings were much lower. 17% of the findings were impaired in M. & F. (2000) and 7% in the present review by a BAC of 0.05%.

Thus, besides the way of selecting studies and findings for a meta-analysis, the evaluation method is crucial concerning the results. The approaches of M. & R. (1988) and M. & F. (2000), which focus on significant findings, lead to an overestimation of the effects of alcohol, for example when considering only the three significant findings at 0.01% BAC and not the five non-significant ones. Especially when assuming that studies or measures of performance which completely fail to show significant effects of alcohol are underreported in scientific literature, it is extremely important to consider non-significant findings.

The method of Moskowitz and his colleagues is only useful to find out the lowest BAC at which one author reports a significant impairment, as Krüger et al. (1997) already stated. This may be helpful for an experimenter in search of the right dosage. However, Krüger et al. (1997) criticized that it makes no sense to add up these extreme findings along the BAC groups and to interprete this cumulation as the course of alcohol action. The effects of alcohol must be described with functions considering also the non-significant findings. Those findings are as important as the significant ones in order to determine thresholds of impairment, which are defined as a point at which more than a predefined ratio of significant findings exceeds the respective ratio of non-significant findings. However, a threshold at which impairment suddenly occurs at a particular BAC level has not been found, as the impairment function appears to be linear.

8.5 Final remarks

Driving is a complex task, requiring cognitive and motor skills, and there is no doubt that alcohol impairs driving-related performance. The principal question is, which functions that are needed to drive a vehicle safely are impaired and at which BAC impairment occurs.

The effects of alcohol on the single relevant functions can be tested in a laboratory setting. The results of those studies have been summarised in the present work. However, the question how the results of laboratory tasks like sorting playing cards applies to the tasks that must be performed in driving an automobile is not clarified, as Jones and Joscelyn (1978) already pointed out. Even the results of driving studies are limited with respect to their validity. Driving tests often last for relatively short time periods and require only the use of simple skills. Nevertheless, driving was found to be the most sensitive performance category for the effects of alcohol. Especially in more complex tasks, driving performance decreased substantially at very low BACs.

Besides, the picture is more complex than just “effect” or “no effect”. Many studies examined more than one behavioural skill or tested several times and of course not all findings became significant. Sometimes an effect is noted only with one dose and not with other doses, or only one parameter of the test is affected and not the other one. Such studies are usually written up as a demonstration of the adverse effects of alcohol, but with equal justification they might be reported as evidence that alcohol is relatively benign.

Furthermore, the impairment function is not a risk function. There is no direct way from an impairment level to an accident risk. The risk is constituted by an interaction of impairment with the demands of the driving situation and the individual abilities to compensate for the detrimental effects of alcohol. In experiments, impairment generally occurs at rather low BACs, whereas in reality an accident occurs rarely and rather at high BACs. It is clear that experiments are designed to find an effect and that significant results are reported rather than non-significant.

The question may arise why the risk function is exponential whereas the impairment function is strictly linear. Two reasons are conceivable. First, driving is a very special combination of subtasks, each with another impairment function. Therefore, the exponential shape of the risk function may be the result of a weighted aggregation of task-specific impairment functions. Second, driving under the influence of alcohol has severe legal consequences. Therefore, all drivers will try to compensate for the effects. This compensation may be successful at least for lower BACs, resulting in a slow increase of the risk, but breaks down with higher BACs. A more detailed answer requires a better understanding of the task profile of safe driving.

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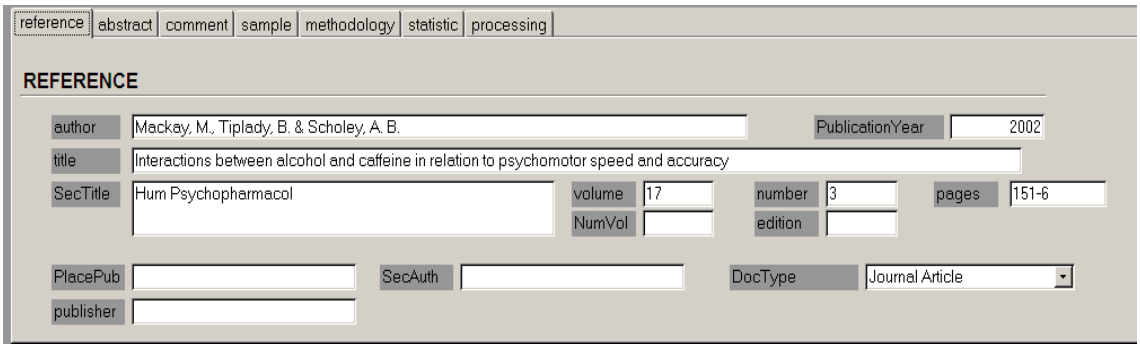
10 APPENDIX

10.1 Detailed description of the database

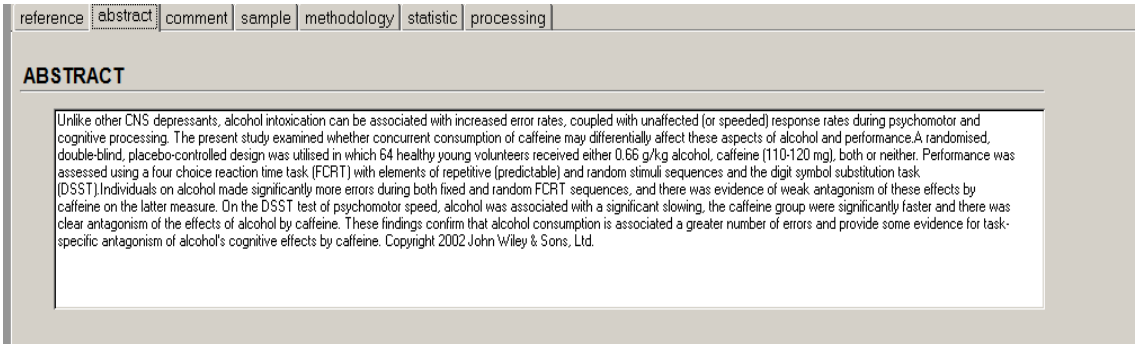
10.1.1 Publication level

10.1.1.1 Reference



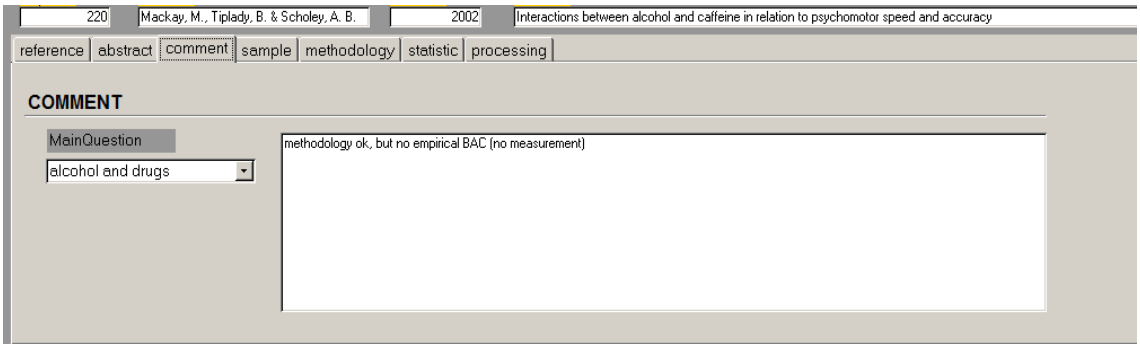
- Bibliographical data of the publication

10.1.1.2 Abstract



- Short summary of the publication

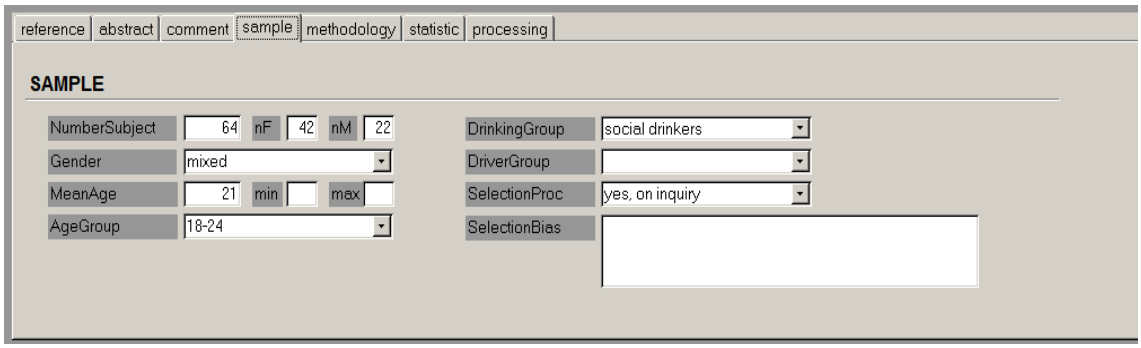
10.1.1.3 Comment



- Free input field: remarks referring to the whole study
- Main Question: main interest of the study

Main Question	Definition
1) single alcohol effect	only the effect of alcohol is of interest
2) different dosage of alcohol	at least two different dosages of alcohol are given to the subjects and differences in effects are of interest
3) different points in time	time of day, absorptive vs. eliminative
4) alcohol and drugs	if combination of alcohol and other substances is of interest (also caffeine, sucrose, acamprosate, nicotine…)
5) different subject groups	e.g. gender, age, aggressive/anxiety dispositions, drinking behaviour, family history of alcoholism, driving/cognitive performance
6) alcohol and sleep deprivation	comparison of alcohol effects with sleep deprivation/prolonged wakefulness or combination of alcohol with sleepiness
7) other	e.g. alcohol tolerance, genetic factors, social/environmental condition, drug expectancy, food intake, reward, feedback

10.1.1.4 Sample



- Number Subject (nF, nM): sample size (number of females, number of males)
- Gender: only female, only male, mixed
- Mean Age (min, max): mean age of the sample (minimum, maximum age)
- Age Group: the chosen category refers to the mean age of the sample
- Drinking Group: alcohol experience of the subjects

Drinking Group	Definition
1) anti-alcoholics	never drink alcohol
2) social drinkers	drink occasionally or regularly in moderation
3) heavy drinkers	drink regularly and heavily (men >7 units/day, women >5 units/day)
4) binge drinkers	drink irregularly and heavily (>5 units on one occasion)
5) alcoholics	alcoholics

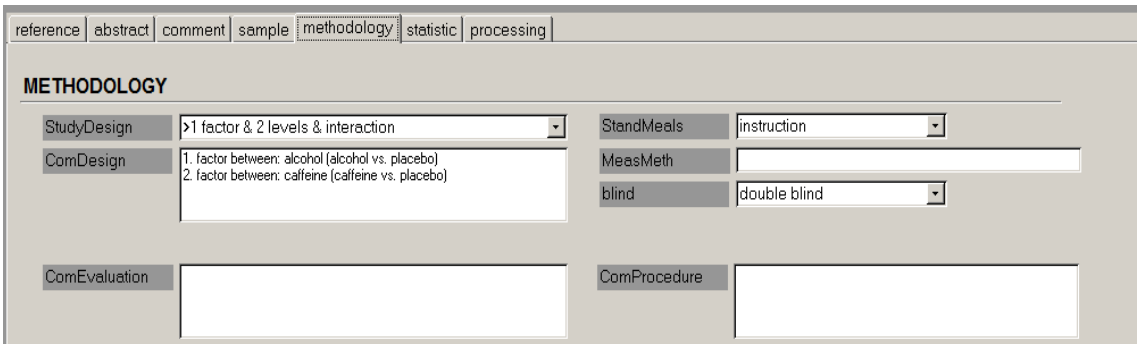
- Driver Group: driving experience of the subjects (for driving studies only)

Driver Group	Definition
1) novice	drivers or pilots with a licence for less than 2 years
2) amateur	for drivers from the general public or if nothing is mentioned
3) professional	professional drivers or pilots

- Selection Proc: checking of in- and exclusion criteria regarding the subjects

Selection Proc	Definition
1) yes, on inquiry	if in- and exclusion criteria are checked only by asking the subjects
2) yes, medical screening	if subjects are medically screened
3) yes, lab parameters	if lab parameters are taken like urine or blood
4) others	if subjects are checked e.g.for normal visual acuity

10.1.1.5 Methodology



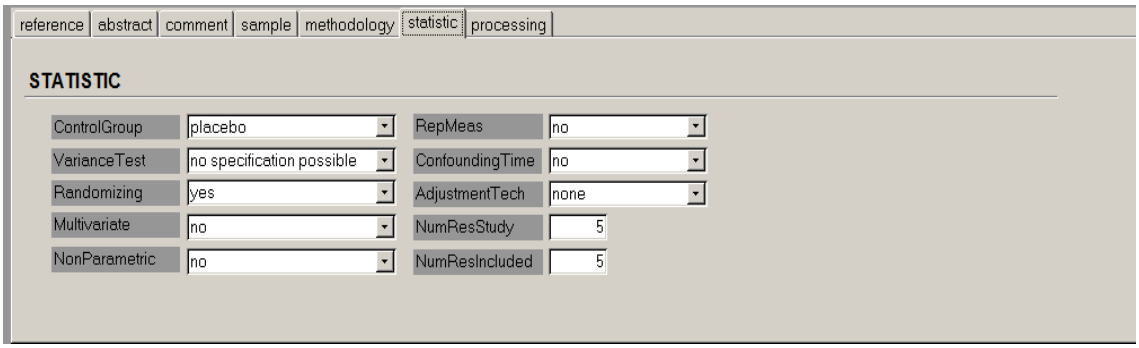
- Study Design: number of factors and levels, and if there are interactions and post hoc tests
- Com Design: description of the factors and the design (within- or between-subject)
- Stand Meals: refers to the standardisation of meals before the alcohol intake

Stand Meals	Definition
1) no standardisation	if it is mentioned that there was no standardisation of meals
2) instruction	subjects were instructed what to eat or not to eat before testing
3) standardisation	observed intake of a standard meal before the alcohol intake

- Meas Meth: Measurement method for testing breath alcohol
- Blinding: refers to the alcohol administration

Blinding	Definition
1) no	the subject and the experimenter know the content of the beverage; if there is no placebo-condition but a non-alcohol-condition
2) single blind	the subject does not know the content of the beverage; if nothing is mentioned, but there is a placebo-condition
3) double blind	neither the subject nor the experimenter know the content of the beverage

10.1.1.6 Statistic



- Control Group: group which receives no alcohol

Control Group	Definition
1) no	no control group for all time points (e.g. only baseline)
2) placebo	placebo control group for all time points
3) non-alcohol	non-alcohol control group for all time points

- Variance Test: testing for variance homogeneity

Variance Test	Definition
1) no	if test is made, but variances are heterogeneous
2) yes	test is made and variances are homogeneous

- Randomising: refers to the assignment of the subjects to the alcohol conditions

Randomising	Definition
1) no	subjects are not randomly assigned to the alcohol condition
2) yes	subjects are randomly assigned to the alcohol condition
3) without relevance	if there is a within-subject design and no assignment is necessary

- Multivariate: refers to the analysis of variance for testing the effect of alcohol

Multivariate	Definition
1) no	if no multivariate analysis of variance is conducted
2) yes	if a multivariate analysis of variance is conducted

- Non-Parametric: refers to the statistical test

Non-Parametric	Definition
1) no	if a parametric test is used
2) yes	if a non-parametric test is used for at least one variable

- Rep Meas: refers to the methodological design (repeated measures)

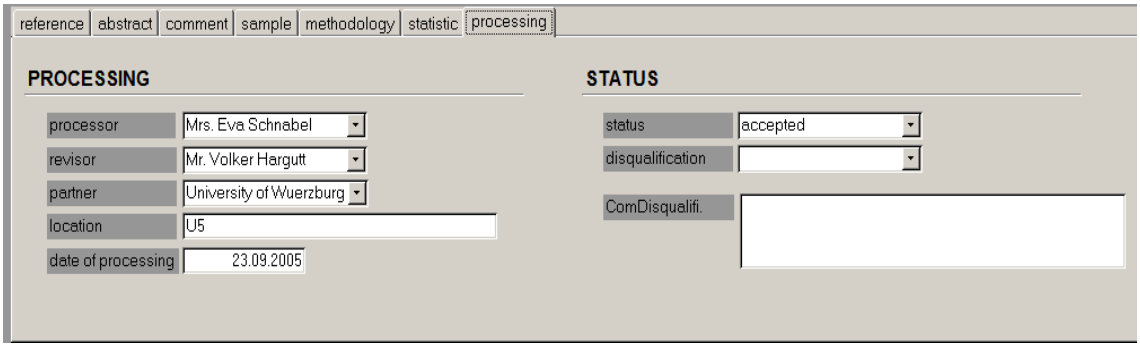
Rep Meas	Definition
1) no	between-subject design and only one testing time point
2) yes	within-subject design or between-subject design with several testing time points

- Adj Tech: refers to the adjustment of the alpha-level

Adj Tech	Definition
1) none	if authors say they did not make an adjustment
2) Bonferroni	Bonferroni adjustment technique
3) Bonferroni Holm	Bonferroni Holm adjustment technique
4) others	e.g. Dunn's technique

- Num Res Study: number of findings concerning alcohol reported in the study
- Num Res Included: number of findings of the study included into the database

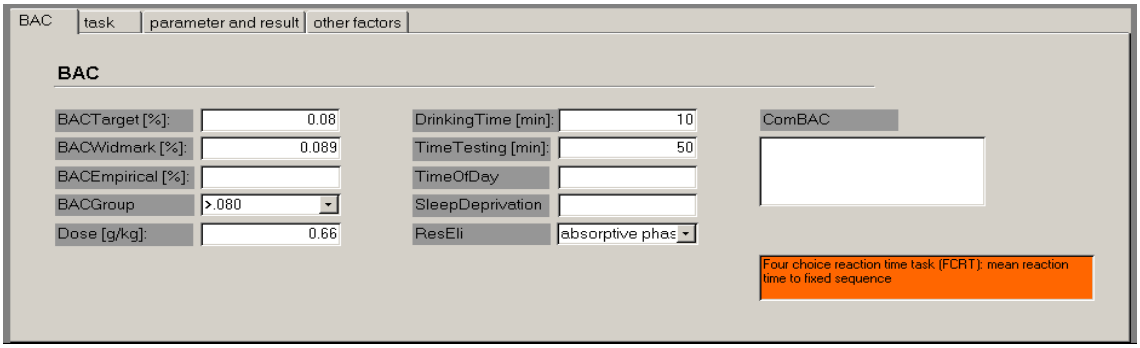
10.1.1.7 Processing



- Processing: information about the processor and date of processing
- Status: if study is accepted or excluded and reasons for disqualification

10.1.2 Findings Level

10.1.2.1 BAC

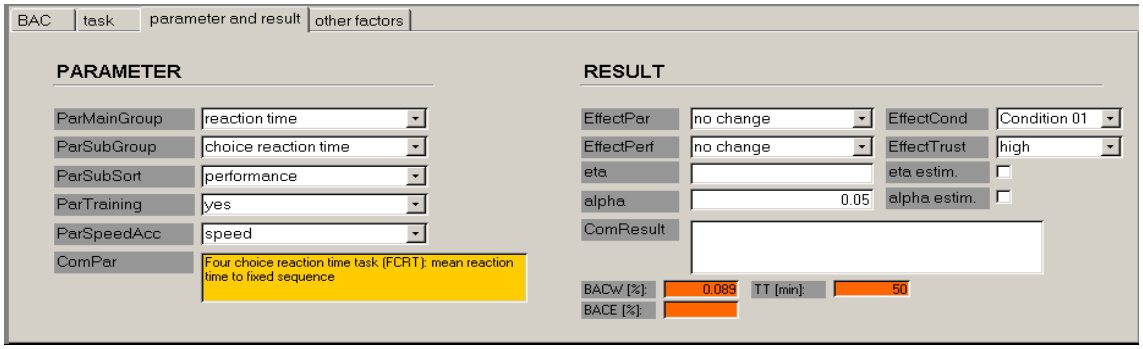


- BAC Group: crude classification referring to the BAC Empirical if reported or to the BAC Target if reported or to the BAC Widmark
- Drinking Time: time subjects are allowed to drink the administered alcohol (if a range is given, mean drinking time is taken)
- Time Testing: time between end of drinking and starting of the test
- Time Of Day: time when testing session takes place

- Sleep Deprivation: “yes”, if sleep duration of all subjects is restricted or if they are awake longer than about 16 hours
- Res Eli: limb of the blood alcohol curve

Res Eli	Definition
1) absorptive phase	<60 min since end of drinking, or if main part of test takes place in this phase, or if BAC after the test is higher than before (even if test is performed within defined eliminative phase)
2) eliminative phase	≥60 min since end of drinking, or if main part of test takes place in this phase, or if test takes place symmetrically in both phases, or if BAC after the test is lower than before (even if test is performed within defined absorptive phase)

10.1.2.2 Parameter and result



- Par Main Group: function-oriented classification into main groups
- Par Sub Group: function-oriented classification into sub groups
- Par Sub Sort: umbrella term for the parameters in the main groups (subjective feeling, behaviour, performance, driving, physiological)
- Par Training: refers to the training of the task before testing (for performance tasks only)
- Par Speed Acc: refers to the parameter, not to the instruction

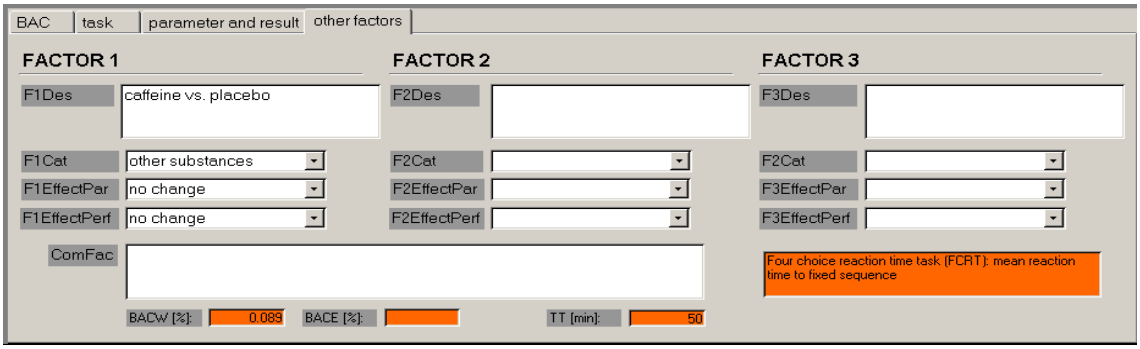
Par Speed Acc	Definition
1) speed	if reaction time is measured or total performance time needed for a task
2) accuracy	if number of errors is measured
3) speed & accuracy	if number of errors or a total score in a given time are measured

- Com Par: name and short description of the task
- Effect Par: direction of effect referring to the parameter
- Effect Perf: direction of effect referring to the performance
- Eta: if there is an effect, η^2 is calculated (if enough information is given)
- Alpha: the chosen significance level in the studies, commonly $\alpha = 0.05\%$

- Effect Cond: classification according to the decision tree in Chapter 6.4
- Effect Trust: trustworthiness of the effect depending on interactions
- Eta estim.: check mark if η^2 is estimated by m and s (via t-value) for a within-subject design
- Alpha estim.: check mark if effect is estimated by t-value and df with a two-tailed test (when there is no post hoc test or no information concerning significance)

  The red fields are not for entering data, but are just repetitions of important study information for a better overview for the processor.

10.1.2.3 Other factors



- F1 Des: description of the other factor(s) besides alcohol
- F1 Cat: labelling of the other factor(s) regarding its content
- F1 Effect Par: direction of the interaction effect referring to the parameter
- F1 Effect Perf: direction of the interaction effect referring to the performance

10.2 Raw data of the main and sub categories

Table 16: Frequencies of significant impairing effects and no effects[26] per BAC group[27] and category.

A. PERFORMANCE CATEGORIES												
BAC (%)	**<0.01**	**<0.02**	**<0.03**	**<0.04**	**<0.05**	**<0.06**	**<0.07**	**<0.08**	**<0.09**	**<0.10**	**<0.11**	**Total**
1) Visual functions												
no effect	11	18	21	22	28	52	56	20	12	10	25	275
decrease	0	2	1	3	11	26	33	31	15	13	44	179
total	11	20	22	25	39	78	89	51	27	23	69	454
1.1) Physiology of the eye (including critical flicker fusion)												
no effect	3	9	8	13	14	23	35	6	4	6	13	134
decrease	0	1	0	1	2	3	6	5	3	3	16	40
total	3	10	8	14	16	26	41	11	7	9	29	174
1.2) Eye movements												
no effect	4	7	3	5	5	18	6	2	1	0	9	60
decrease	0	1	1	2	6	16	19	19	6	7	19	96
total	4	8	4	7	11	34	25	21	7	7	28	156
1.3) Binocular vision												
no effect	2	2	5	3	1	4	4	2	1	1	3	28
decrease	0	0	0	0	2	6	5	5	4	2	7	31
total	2	2	5	3	3	10	9	7	5	3	10	59
1.4) Complex perceptual functions												
no effect	2	0	5	1	8	7	11	10	6	3	0	53
decrease	0	0	0	0	1	1	3	2	2	1	2	12
total	2	0	5	1	9	8	14	12	8	4	2	65
2) Attention												
no effect	19	18	33	61	42	66	69	57	37	15	12	429
decrease	0	1	2	5	15	19	55	39	59	23	19	237
total	19	19	35	66	57	85	124	96	96	38	31	666
2.1) Categorisation tasks												
no effect	6	9	14	18	10	13	9	12	11	4	1	107
decrease	0	0	1	1	3	3	11	17	32	8	14	90
total	6	9	15	19	13	16	20	29	43	12	15	197
2.2) Vigilance												
no effect	3	0	0	15	6	8	15	8	3	1	0	59
decrease	0	0	0	1	1	2	3	2	4	4	2	19
total	3	0	0	16	7	10	18	10	7	5	2	78
2.3) Cancellation test												
no effect	1	2	1	5	6	6	3	3	0	1	2	30
decrease	0	1	1	1	1	2	2	2	2	1	1	14
total	1	3	2	6	7	8	5	5	2	2	3	44
2.4) Mental arithmetics												
no effect	0	1	4	2	4	5	7	6	2	0	1	32
decrease	0	0	0	0	0	0	2	1	4	2	1	10
total	0	1	4	2	4	5	9	7	6	2	2	42
2.5) Other attention test												
no effect	9	6	14	21	16	34	35	28	21	9	8	201
decrease	0	0	0	2	10	12	37	17	17	8	1	104
total	9	6	14	23	26	46	72	45	38	17	9	305

[26] The lines “no effect” also include beneficial effects.

[27] The BAC groups are only presented up to 0.11% in order to clearly represent the raw data and since 96% (n = 5107) of all findings refer to a BAC below 0.12%.

3) Divided attention												
no effect	13	8	15	48	45	33	38	15	7	14	12	248
decrease	0	4	0	15	4	16	15	19	8	12	7	100
total	13	12	15	63	49	49	53	34	15	26	19	348
3.1) Reactions to 2 stimuli												
no effect	0	5	0	30	31	12	28	7	6	12	7	138
decrease	0	1	0	2	1	3	8	4	2	10	2	33
total	0	6	0	32	32	15	36	11	8	22	9	171
3.2) Reactions to 2 tasks												
no effect	13	3	15	18	14	21	10	8	1	2	5	110
decrease	0	3	0	13	3	13	7	15	6	2	5	67
total	13	6	15	31	17	34	17	23	7	4	10	177
4) En-/Decoding												
no effect	7	18	26	47	16	41	27	33	45	12	8	280
decrease	0	2	8	11	6	15	33	30	29	17	10	161
total	7	20	34	58	22	56	60	63	74	29	18	441
4.1) Information processing												
no effect	2	7	14	29	6	10	9	16	8	4	1	106
decrease	0	0	1	7	2	6	13	13	8	5	4	59
total	2	7	15	36	8	16	22	29	16	9	5	165
4.2) Memory												
no effect	5	11	12	18	10	31	18	17	37	8	7	174
decrease	0	2	7	4	4	9	20	17	21	12	6	102
total	5	13	19	22	14	40	38	34	58	20	13	276
5) Reaction time												
no effect	15	14	29	17	23	37	29	32	32	15	5	248
decrease	1	1	2	3	10	14	17	20	19	13	16	116
total	16	15	31	20	33	51	46	52	51	28	21	364
5.1) Simple reaction time												
no effect	7	6	18	10	16	18	16	12	11	7	4	126
decrease	1	0	2	0	5	6	10	8	6	6	8	52
total	8	6	21	10	21	24	26	20	17	13	12	178
5.2) Choice reaction time												
no effect	8	8	10	7	7	19	13	20	21	8	1	122
decrease	0	1	0	3	5	8	7	12	13	7	8	64
total	8	9	10	10	12	27	20	32	34	15	9	186
6) Psychomotor skills												
no effect	5	15	20	24	24	21	21	19	13	1	0	163
decrease	0	0	3	5	11	16	26	30	24	23	16	154
total	5	15	23	29	35	37	47	49	37	24	16	317
6.1) Hand-eye-coordination												
no effect	4	12	13	13	10	11	7	11	6	1	0	88
decrease	0	0	3	2	5	5	14	11	13	9	7	69
total	4	12	16	15	15	16	21	22	19	10	7	157
6.2) Posture												
no effect	1	3	6	6	9	7	7	4	2	0	0	45
decrease	0	0	0	2	5	11	11	16	10	13	9	77
total	1	3	6	8	14	18	18	20	12	13	9	122
6.3) Other motor functions												
no effect	0	0	1	5	5	3	7	4	5	0	0	30
decrease	0	0	0	1	1	0	1	3	1	1	0	8
total	0	0	1	6	6	3	8	7	6	1	0	38

7) Tracking												
no effect	4	5	5	19	19	19	20	11	11	2	3	118
decrease	0	1	4	8	9	23	17	16	20	6	5	109
total	4	6	9	27	28	42	37	27	31	8	8	227
7.1) Easy compensatory tracking												
no effect	2	1	3	0	2	2	1	3	0	0	2	16
decrease	0	0	1	0	2	2	2	4	3	0	1	15
total	2	1	4	0	4	4	3	7	3	0	3	31
7.2) Difficult compensatory tracking												
no effect	0	0	2	2	1	1	2	0	0	0	0	8
decrease	0	0	0	4	1	3	3	1	0	1	3	16
total	0	0	2	6	2	4	5	1	0	1	3	24
7.3) Easy pursuit tracking												
no effect	2	4	0	17	16	14	17	7	9	2	1	89
decrease	0	1	2	4	6	13	11	7	14	5	1	64
total	2	5	2	21	22	27	28	14	23	7	2	153
BAC (%)	**<0.01**	**<0.02**	**<0.03**	**<0.04**	**<0.05**	**<0.06**	**<0.07**	**<0.08**	**<0.09**	**<0.10**	**<0.11**	**Total**
7.4) Difficult pursuit tracking												
no effect	0	0	0	0	0	2	0	1	2	0	0	5
decrease	0	0	1	0	0	5	1	4	3	0	0	14
total	0	0	1	0	0	7	1	5	5	0	0	19
8) Driving												
no effect	11	11	10	31	39	12	14	18	24	7	5	182
decrease	1	4	5	18	30	17	16	12	16	10	6	135
total	12	15	15	49	69	29	30	30	40	17	11	317
8.1) Driving simulator												
no effect	9	5	10	8	24	12	12	12	23	7	4	126
decrease	1	3	3	7	13	10	10	11	12	7	4	81
total	10	8	13	15	37	22	22	23	35	14	8	207
8.2) Closed course												
no effect	0	1	0	4	12	0	1	0	0	0	0	18
decrease	0	0	0	8	16	2	1	0	0	0	0	27
total	0	1	0	12	28	2	2	0	0	0	0	45
8.3) Flight simulator												
no effect	2	5	0	19	3	0	1	6	1	0	1	38
decrease	0	1	2	3	1	5	5	1	4	3	2	27
total	2	6	2	22	4	5	6	7	5	3	3	65
SUM	**87**	**122**	**184**	**337**	**332**	**427**	**486**	**402**	**371**	**193**	**193**	**3134**

B. MOOD CATEGORIES

BAC (%)	<0.01	<0.02	<0.03	<0.04	<0.05	<0.06	<0.07	<0.08	<0.09	<0.10	<0.11	Total
9) Mood												
no effect	76	110	198	132	83	122	119	129	137	66	78	1250
decrease	4	10	28	47	58	75	74	103	84	55	71	609
total	80	120	226	179	141	197	193	232	221	121	149	1859
9.1) Experienced intoxication												
no effect	8	15	15	4	8	6	4	2	5	1	3	71
decrease	2	7	19	17	33	50	22	56	46	31	33	316
total	10	22	34	21	41	56	26	58	51	32	36	387
9.2) Unpleasant physical sensations												
no effect	8	23	36	13	12	14	4	15	21	17	11	174
decrease	0	0	1	5	8	6	7	10	5	4	12	58
total	8	23	37	18	20	20	11	25	26	21	23	232
9.3) General well-being												
no effect	0	0	1	1	1	2	0	1	0	0	2	8
decrease	0	1	0	0	0	0	2	0	1	0	0	4
total	0	1	1	1	1	2	2	1	1	0	2	12
9.4) Subjective rating of performance												
no effect	2	2	9	10	6	3	8	2	3	2	0	47
decrease	1	0	0	4	2	3	7	4	5	6	5	37
total	3	2	9	14	8	6	15	6	8	8	5	84
9.5) Physiological measurements												
no effect	1	0	6	3	0	8	7	7	8	1	0	41
decrease	0	0	0	0	0	0	0	0	2	0	0	2
total	1	0	6	3	0	8	7	7	10	1	0	43
9.6) Arousal/activity												
no effect	18	20	45	30	15	29	25	38	25	12	24	281
decrease	0	0	5	8	6	7	15	11	8	6	4	70
total	18	20	50	38	21	36	40	49	33	18	28	351
9.7) Pleasure												
no effect	24	29	54	39	25	35	43	39	50	20	31	389
decrease	0	0	0	2	4	0	7	2	2	3	4	24
total	24	29	54	41	29	35	50	41	52	23	35	413
9.8) Dominance												
no effect	4	3	6	5	1	4	4	3	4	2	0	36
decrease	0	0	0	0	0	0	1	0	0	0	0	1
total	4	3	6	5	1	4	5	3	4	2	0	37
9.9) Tiredness												
no effect	7	9	15	13	10	14	15	14	11	6	4	118
decrease	1	2	3	10	5	7	9	13	11	5	9	75
total	8	11	18	23	15	21	24	27	22	11	13	193
9.10) Aggressive feelings												
no effect	4	3	5	8	2	5	6	4	3	1	0	41
decrease	0	0	0	0	0	2	2	4	2	0	1	11
total	4	3	5	8	2	7	8	8	5	1	1	52

C. SOCIAL BEHAVIOUR CATEGORIES

10) Aggressive behaviour												
no effect	0	0	1	2	0	1	0	2	9	0	6	21
decrease	0	0	0	0	0	1	1	3	3	8	11	27
total	0	0	1	2	0	2	1	5	12	8	17	48
SUM	**80**	**120**	**227**	**181**	**141**	**199**	**194**	**237**	**233**	**129**	**166**	**1907**

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