Effects of benzodiazepines, antidepressants and opioids on
driving: a systematic review of epidemiological and experimental
evidence

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ABSTRACT

Background: Many individuals in the community are prescribed psychoactive drugs with sedative effects. These drugs may affect their daily functions, of which automobile driving is a major component.

Objective: The aim of this systematic review was to examine the association of 3 classes of commonly used psychoactive drugs (viz. benzodiazepines and newer non-benzodiazepine hypnotics, antidepressants and opioids) with 1) the risk of traffic accidents (as indexed by epidemiological indicators of risk) and 2) driving performance (as indexed by experimental measures of driving performance).

Methods: A literature search for material published in English between January 1966 and January 2010 in PUBMED and EMBASE databases was combined with a search for other relevant material referenced in the retrieved articles. Retrieved articles were systematically reviewed, carrying out meta-analyses where possible. Twenty one epidemiological studies (13 case-control and 8 cohort studies) fulfilled the inclusion criteria by estimating the accident risk associated with drug exposure (ascertained by blood/urine analysis or prescription records). Sixty nine experimental studies fulfilled the inclusion criteria by testing actual or simulated driving performance after administering a single dose or multiple doses.

Results: Two meta-analyses showed that benzodiazepines are associated with a 60% (for case-control studies: pooled odds ratio [OR]: 1.59, 95%CI: 1.10–2.31) to 80 % (for cohort studies: Pooled incidence rate ratio: 1.81, 95%CI: 1.35–2.43) increase in the risk of traffic accidents and a 40% (pooled OR: 1.41, 95%CI: 1.03–1.94) increase in ‘accident-responsibility’. Co-ingestion of benzodiazepines and alcohol was associated with 7.7-fold increase in the accident risk (Pooled OR: 7.69, 95%CI: 4.33–13.65). Subgroup analysis of case-control studies showed a lower benzodiazepine-associated accident risk in elderly (>65 years) drivers (pooled OR: 1.13, 95% CI: 0.97 – 1.31) than in younger (pooled OR: 2.21,
95% CI: 1.31–3.73), a result consistent with age-stratified risk differences reported in cohort studies. Anxiolytics, taken in single or multiple doses during daytime, impaired driving performance independent of their half-lives. As for hypnotics, converging evidence from experimental and epidemiological studies indicates that diazepam, flurazepam, flunitrazepam, nitrazepam and short-half-life non-benzodiazepine hypnotic zopiclone significantly impair driving at least during the first 2-4 weeks of treatment. The accident risk was higher in the elderly (> 60 years) who use tricyclic antidepressants (TCAs), however the evidence for an association of antidepressants with accident risk in younger drivers was equivocal. Sedative but not non-sedative antidepressants were found to cause acute impairment of several measures of driving performance. Limited epidemiological research reported that opioids may be associated with increased accident risk in the first few weeks of treatment.

**Conclusions:** Benzodiazepine use was associated with a significant increase in the risk of traffic accidents and responsibility of drivers for accidents. The association was more pronounced in the young drivers. The accident risk was markedly increased by co-ingestion of alcohol. Driving impairment was generally related to plasma half-lives of hypnotics, but with notable exceptions. Anxiolytics, with daytime dosing, impaired driving independent of their half-lives. TCAs appeared to be associated with increased accident risk at least in the elderly, and caused acute impairment in driving performance. Opioid users seemed to be at a higher risk of traffic accidents; however experimental evidence is scarce on their effects on driving. The clinical and medico-legal implications of these findings are also discussed.
1. **BACKGROUND**

Many individuals in the community are prescribed psychoactive drugs with sedative effects such as benzodiazepines, tricyclic antidepressants (TCAs) and opioids. The vast majority of those who are treated with these drugs are outpatients and expected to carry out their daily activities in a similar manner to healthy individuals. However, these drugs can adversely affect the cognitive and psychomotor functions underlying daily activities, and some of those functions (e.g. reaction time, attention, visuospatial skills) are considered important in automobile driving. [see 1, 2 for reviews, 3]

The effects of drugs on driving safety have been previously examined using epidemiological and experimental study designs. The epidemiological studies examine this relationship in terms of traffic safety by measuring the association between use of sedative psychotropic drugs and the risk of traffic accidents, while experimental studies approach the question by examining whether administration of drugs is likely to impair driving performance. The focus of the present review is to explore the role of three classes of psychoactive drugs (viz. benzodiazepines and newer non-benzodiazepine hypnotics, antidepressants and opioids) in traffic safety by combining the evidence from epidemiological and experimental studies, because each type of study in isolation, fails to establish drugs as a causative factor in traffic accidents.

The outcome of interest in epidemiological studies is traffic accidents (in most instances injurious or fatal accidents) which are a major outcome of immediate practical significance. Being observational studies, they fall short of establishing a cause and effect relationship between drug use and traffic accidents, i.e., detection of a drug in a driver who met with an accident does not necessarily mean that the drug was a cause for the accident. [4] Accident responsibility studies attempt to overcome this limitation by establishing that the drug in question is more prevalent in drivers responsible for accidents than in those who are
not responsible for accidents. Therefore the present review also focuses on accident responsibility studies.

The aim of experimental studies is to determine the causative role of single or a few doses of drugs on driving performance as tested in different actual driving tests \([\text{e.g.} 5, 6, 7]\) or driving simulator tests. \([\text{e.g.} 8, 9, 10]\) Experimental studies can eliminate many of the limitations of epidemiological studies, but mostly at the cost of compromising the ecological validity. Driving performance is almost always tested in a highly controlled environment where only certain components of driving behaviour are examined through specific driving tasks. Certain driving tests however have achieved a greater ecological validity within a controlled environment and had been also validated against surrogate markers of traffic safety. For example, in a standardised driving test developed by O’Hanlon and colleagues in early 1980s, the primary outcome measure is the driver’s ability to maintain the lateral position of the vehicle in the driving lane. Cognitive models of driving define such processes as ‘operational’ processes of driving which are necessary for stable driving. \([11-13]\) The degree of weaving of the vehicle (termed standard deviation of lateral position: SDLP) was calibrated against different blood levels of alcohol which is a known risk factor for traffic accidents. \([5]\) Several recent reviews have comprehensively analysed the effects of different doses of commonly used benzodiazepine and non-benzodiazepine hypnotics \([14, 15]\) and antidepressants \([16]\) on this measure of lateral position control in highway-driving. While impaired performance in the above driving test suggests the participant is unfit for highway driving, unimpaired driving performance does not necessarily mean that one is able to drive safely, particularly in complex driving environments where the driver has to interact with other vehicles, pedestrians, traffic signs and other roadside objects. According to cognitive models of driving, more complex processes necessary to interact with the external environment and make higher level decisions in driving are categorised as ‘tactical’ and ‘strategic’ level.
processes. Different actual and simulated driving tests have attempted to tap these higher level aspects of driving and are reviewed in the present paper.

Many recent epidemiological studies and reviews of experimental studies emphasize the differences in the effects of individual drugs (even if they are in the same class of drugs). Accordingly, the present review also will focus down onto the level of individual drugs. In addition, we also focus on different subject factors (patients vs. healthy volunteers, young vs. old) that are likely to modify drug effects on driving and traffic accidents.

Objectives:

The broad objective of the present study was to systematically review the literature to find out whether three classes of commonly used psychoactive drugs (benzodiazepines and newer non-benzodiazepine hypnotics, antidepressants and opioids) are associated with increased risk of traffic accidents and impaired driving. More specifically we aimed to examine;

1) whether use of each of these drugs are associated with increased risk of traffic accidents (as indexed by risk estimates measured in analytical epidemiological studies) and

2) whether experimental administration of these drugs causes impairment in driving performance (as indexed by quantitative measures of driving performance in a real vehicle or a driving simulator).

2. METHODOLOGY

2.1. Literature search strategy
We conducted a literature search on the PUBMED and EMBASE databases for material published between January 1966 and 31 January 2010. The search was limited to human studies published in English. Two sets of search terms were used. The first set consisted of the EMTREE / MeSH terms ‘benzodiazepine derivative’, ‘zaleplon’, ‘zopiclone’, ‘zolpidem’, ‘zolpidem tartrate’, ‘eszopiclone’, ‘antidepressant agent’ and ‘opiate agonist’. The second set included the EMTREE / MeSH terms ‘traffic accidents’, ‘traffic safety’ and ‘car driving’ and general search term ‘driving’. By selecting the ‘explosion’ option, the search also incorporated the terms that are subtopics (e.g. individual drugs in a particular class of drugs) of each of the above EMTREE / MeSH terms. The articles that contained at least one term from each of the above sets of search terms were extracted for consideration for inclusion in the review. The reference lists of the eligible articles were searched for any other relevant literature.

2.2. Inclusion criteria

Inclusion criteria for epidemiological studies were; a) cohort or case-control study design or variants such as case-crossover studies (survey designs and other descriptive studies were excluded) and b) explicitly stated exposure ascertainment (e.g. detection of drugs in body fluids, records of drug prescription) and outcome ascertainment (i.e. traffic accidents or subcategories such as ‘traffic accidents required hospitalisation’ or ‘fatal traffic accidents’). The research methods of epidemiological studies were assessed based on the appropriate fields outlined in STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statements for case-control studies and cohort studies.

The inclusion criteria for experimental studies were; a) administration of a single dose or multiple doses of a relevant drug to at least one of the study groups and b) implementation of an actual driving test or a test in a driving simulator (studies that examined cognitive /
psychomotor functions related to driving by laboratory tests were excluded). The
methodology of the experimental studies was evaluated under 4 categories: experimental
design, selection of study samples, pharmacological manipulation and outcome measures.

The initial search retrieved 1271 articles. Exclusion of the papers which did not meet
the inclusion criteria are summarised in Figure 1. This initial literature search retrieved 15
epidemiological studies and 54 articles on experimental studies. A review of the reference
lists produced an additional 6 epidemiological studies and 9 experimental studies. Thus in
total, 21 epidemiological studies and 69 experimental studies (in 62 papers) met the
aforementioned inclusion criteria. Of the 21 epidemiological studies 13 were case-control
studies (Table 1) and 8 were cohort studies (Table 2). Nineteen epidemiological studies
investigated exposure to benzodiazepines, 6 to antidepressants and 7 to opioids. Of the 69
experimental studies, benzodiazepines and/or ‘z drugs’ were tested in 48 studies
(Supplementary Table 1), antidepressants in 20 (Supplementary Table 2) and opioids in 3
(Supplementary Table 3).

2.3. Meta-analysis

The retrieved epidemiological studies were pooled for meta-analyses in the instances
where adequate numbers of studies with required data were available. A random-effects
model analysis (DerSimonian-Laird method) was employed to calculate the pooled estimates
as it does not assume that each component study of the meta-analysis is derived from the
same population, and hence allowed pooling statistically heterogeneous studies without
compromising the statistical validity of the results. However, random effects modelling
generated wider confidence-intervals for the pooled estimate than fixed-effects modelling
would do, thus compromising the precision of the pooled estimate. Subgroup analyses were
planned in the instances where there was a severe statistical heterogeneity. However, this could be carried out only for the case-control studies on benzodiazepines (based on age), because there were too few studies in the other meta-analyses.

3. RESULTS

3.1. EPIDEMIOLOGICAL STUDIES: RISK OF TRAFFIC ACCIDENTS AND USE OF BENZODIAZEPINES, ANTIDEPRESSANTS AND OPIOIDS

The methodology and results of 13 case-control studies and 8 cohort-studies are summarised with the limitations specific to individual studies noted in Tables 1 and 2, respectively.

Two distinct sampling methods can be observed in epidemiological studies. Seven case-control studies ‘recruited’ cases from drivers that were hospitalised\(^4,20-23\) or died\(^24,25\) after traffic accidents whereas controls were recruited either from the victims of traffic accidents or randomly from the roadside\(^20,22\). Drug exposure was ascertained by analysing the blood or urine samples. The main advantage of this method is availability of confirmatory evidence for occurrence of the drug under question at the time of accident.

In other case-control studies (except one, where exposure was ascertained through an interview\(^26\)) and all cohort studies, both exposure and outcome ascertainment was registry-based. Accident involvement was ascertained from entries in hospital admission or general practice databases or road accident registries, and drug exposure was ascertained by means of prescription entries in drug prescription databases. Outcome ascertainment was based on motor registry data or medical records. The number of days for which the drugs are prescribed was usually considered the ‘exposed period’. Linkage of the two databases
showed whether the patient was prescribed (and hence likely to be taking) the drugs at the

However this registry-based approach has also introduced certain biases common to

Firstly, it introduces an exposure ascertainment bias. It

Secondly, only a certain percentage of the outcomes (i.e. traffic accidents) are recorded in the databases. Particularly less serious accidents, which is likely to represent a significant proportion of all accidents, might have not been entered. For example, studies that recruited accident victims from hospitals\(^4\,20-23\) only includes injurious traffic accidents where the injuries were serious enough to seek medical assistance. Thirdly, data on some important confounders may have not recorded in the registries. Many studies did adjust the analyses or matched the samples for demographic variables (e.g. age, gender) but missed some other important confounders such as underlying illnesses for which the drugs are prescribed (e.g. depression), which can also affect driving. Inevitably, this may have had left a certain degree of residual confounding. Other limitations and potential biases specific to individual epidemiological studies are noted in Tables 1 and 2.

3.1.1. Benzodiazepine and ‘z drugs’

Of the three classes of drugs, benzodiazepines were the most extensively studied. Benzodiazepines have been studied in 12 case-control studies and 6 cohort studies. Of these, 1 case control study\(^{27}\) and 2 cohort studies\(^{18,28}\) have also examined the traffic accident risk
of ‘z’ drugs. Based on these studies we conducted three separate meta-analyses for case-control studies, cohort studies and accident responsibility studies.

1) Case-control studies on benzodiazepine exposure and traffic accident risk (Figure 2): Of the 12 case control studies, 8 examined whether exposure to benzodiazepines is associated with increased odds of traffic accidents. Two studies\cite{22,27} did not report the exposure data and numbers of traffic accidents in exposed and unexposed periods so that those two studies could not be included in the meta-analysis. However both these studies showed a significant association between benzodiazepine exposure and traffic accidents. The first was a case cross-over study where, in a group of drivers involved in traffic accidents, the proportion exposed to benzodiazepines on the day of accident (i.e. the case period) was compared with the proportion exposed on a within-subject control period (i.e. same day of the week in up to 18 weeks prior to accident date).\cite{27} The adjusted OR for all benzodiazepines in this study was 1.62 (95% CI 1.24 - 2.12) suggesting higher accident risk associated with benzodiazepines use. The second study reported benzodiazepine exposure was associated with a 5-fold increase in the risk (adjusted OR: 5.05, 95% CI 1.82 – 14.04) of injurious traffic accidents.\cite{22}

The other six publications contained adequate data for analysis and were included in the meta-analysis (see Figure 2). The studies showed a marked statistical heterogeneity (Cochran Q = 16.20, p = 0.006. $\Gamma^2 = 69.1\%$). Nonetheless, the overall association between benzodiazepine exposure and traffic accident risk was significant (p=0.014), showing that benzodiazepines are associated with a 59% increase in traffic accident risk (pooled OR =1.59, 95% CI: 1.10 – 2.31). A previous meta-analysis by Rapoport et al. 2009 used the same set of studies. However, the authors included subject counts only for long-acting benzodiazepines in the Hemmelgarn et al. 1997 study in their analysis.\cite{29} We included the subject counts for all benzodiazepines in Hemmelgarn et al. study because long / short-half-
life distinction has not been made in the other studies included in the current meta-analysis.

Indeed some other studies in the meta-analysis also included subjects predominantly exposed to short acting benzodiazepines (e.g. the majority of the subjects of the Leveille et al. 1994 study were exposed to triazolam).

2) **Cohort studies on benzodiazepine exposure and traffic accident risk** (Figure 3): Of the 6 cohort studies, two\cite{18, 19} included the same data-sources used in a previous study\cite{30} and thus those two articles were excluded. One other article was also excluded as it did not have enough information to calculate risk.\cite{28} However, this study showed a significantly high incidence rate ratio (IRR) suggesting benzodiazepines are associated with increased traffic accident risk. The remaining three studies\cite{30-32} were included in the meta-analysis (see Figure 3). Similar to case-control studies, there was a significant heterogeneity among individual study results (Cochran Q = 6.65, p = 0.036. I^2 = 70%). Nonetheless, the overall effect of exposure on traffic accident risk was highly significant (p<0.0001), with an 81% increase of accident rates in benzodiazepines users (pooled IRR: 1.81, 95% confidence intervals: 1.35 – 2.43).

3) **Case-control studies on benzodiazepine exposure and traffic accident responsibility** (Figure 4): Six case-control studies determined whether benzodiazepines are more commonly detected in the blood of drivers responsible for accidents than in the victims (i.e. drivers who were involved but not responsible for the accident or passengers). One of the studies was excluded due to inadequate data\cite{27}; however this study showed a significant association between accident responsibility and benzodiazepine exposure. The other 5 studies were included in the meta-analysis. In the selected studies, driver responsibility was ascertained using evidence of ‘unsafe driving actions’ at the time of accident\cite{25}, information from police / researcher investigation findings\cite{21} and comprehensive scoring systems based on drivers’ attempts to mitigate an accident\cite{4, 33} as well as subjective recall.\cite{26} The last study
was the smallest and had the widest confidence intervals. There was a marginally significant heterogeneity among the studies (Cochran Q = 9.30, p=0.054, $I^2 = 57\%$). The overall effect (p=0.034) showed benzodiazepines were significantly associated with a 41% increase in accident responsibility (Pooled OR: 1.41, 95% CI: 1.03 – 1.94).

These 3 meta-analyses clearly confirm benzodiazepines, as a group, are associated with increased accident risk for drivers. However, different subgroup analyses in individual studies suggest several other drug and driver factors can modify this association. These confounding factors include age of drivers, therapeutic use (i.e. day-time use as anxiolytics and night time use as hypnotics), half-life of the drug, drug dose, duration of benzodiazepine use and co-ingestion of other psychoactive substances. We conducted subgroup meta-analyses based on age and co-ingestion of alcohol but not for each of the above factors because the numbers of studies were limited.

Age:

Two independent sets of evidence suggest benzodiazepine associated traffic accident risk is lower in the elderly. Firstly, we estimated the pooled ORs of the 3 case-control studies that only involved old (>65 years) drivers and 3 case control studies that comprised drivers over a wider age range starting from 18 years. There was no significant statistical heterogeneity among the studies once the studies were sub-grouped according to age (Older group: Cochran Q = 2.15, p = 0.34, $I^2 = 6.9\%$. Younger group: Cochran Q = 3.19, p = 0.20, $I^2 = 37.3\%$). The pooled OR of the older subgroup (OR: 1.13, 95% CI: 0.97 – 1.31) was less than that of the younger subgroup (pooled OR: 2.21, 95% CI: 1.31 – 3.73). Secondly, of the epidemiological studies that had participants across a wider age range, four have reported the age stratified risk estimates for traffic accidents. Of these, three report lower risk in older groups than in younger groups while one reported similar ORs in the young (<60 years) and the old (>60 years). One accident responsibility study
also report age-stratified risks, and found higher responsibility in young benzodiazepine users but not in their older counterparts.\cite{25}

*Therapeutic use and dosing regimen:*

Anxiolytics are taken usually in single or multiple doses in daytime and thus it is possible that they increase accident risk irrespective of their short half-lives. Two cohort studies and one case-control study have categorised benzodiazepines as anxiolytics or hypnotics. All 3 showed increased risk with anxiolytics.\cite{27, 30, 32} Two cohort studies showed an increased risk in the groups using hypnotics\cite{30, 32} while the case control study showed that as a group, hypnotics did not significantly increase traffic accident risk.\cite{27} Hypnotics are taken at bedtime and the following-day adverse effects may depend on the duration of action of the individual drugs.

*Half-life of drugs:*

Two studies have examined the effect of elimination half-life of benzodiazepines, one on the risk of traffic accidents on older (>65 years) adults\cite{34} and the other on accident responsibility.\cite{25} The first study categorised benzodiazepines into short (\(\leq 24\) hours) and long elimination half-life (>24 hours) drugs.\cite{34} Long-half-life drugs but not short-half-life drugs were associated with increased accident risk in the elderly. The second categorised benzodiazepines into short (<6 hours, mainly midazolam), intermediate (6-12 hours) and long elimination half-life (>24 hours) drugs.\cite{25} New users of long-half-life and intermediate-half-life benzodiazepines were at a significantly higher risk of accident responsibility whilst those exposed to short-half-life benzodiazepines showed no increased risk compared to controls.

Where individual drugs have been analysed, the accident risk is increased with the use of diazepam\cite{19, 28, 32} even after 2-4 weeks into treatment, but not with oxazepam.\cite{32} Alprazolam was also more commonly detected in drivers responsible for accident than in
those who were not responsible.\textsuperscript{[25]} Although therapeutic use of each drug was not specified in the studies, these drugs are more often prescribed as anxiolytics.

Five studies report accident risks associated with several different benzodiazepine and non-benzodiazepine hypnotics. Long-acting benzodiazepines flunitrazepam,\textsuperscript{[18]} flurazepam\textsuperscript{[32]} and nitrazepam\textsuperscript{[18, 28]} appear to increase the risk of traffic accidents. However, medium-half-life benzodiazepine hypnotics lorazepam\textsuperscript{[32]} and temazepam\textsuperscript{[28]} and short-acting benzodiazepines triazolam\textsuperscript{[32]} were also found to increase the accident risk. No significant effect was observed with very-short acting hypnotic midazolam.\textsuperscript{[25]} The short acting non-benzodiazepine hypnotic zopiclone was examined in 3 studies. One case-control study shows a 4-fold increase in accident risk\textsuperscript{[27]} while a large scale cohort study reports a 2-fold increase in accident risk.\textsuperscript{[18]} The other study did not show a significant change in the accident risk with zopiclone.\textsuperscript{[28]} For the short-acting hypnotic zolpidem, the large-scale study reports a two-fold increase in risk\textsuperscript{[18]} while the other report no significant effect.\textsuperscript{[28]}

\textit{Duration of use:}

Five cohort studies have examined the traffic accident risk of benzodiazepines during the first 1-4 weeks after prescription and all found increased risk of traffic accidents.\textsuperscript{[18, 28, 30, 32, 38]} Two studies reported that the risk remained high with continuing use.\textsuperscript{[28, 34]}

\textit{Drug dose:}

Three epidemiological studies examined the dose-response relationship between benzodiazepines and traffic accidents. They showed that higher benzodiazepine doses are associated with greater accident risk\textsuperscript{[27, 31]} and higher benzodiazepine concentrations in blood are associated with accident responsibility of drivers.\textsuperscript{[4]} The last study reported higher accident responsibility associated with therapeutic and supratherapeutic benzodiazepine concentrations but not with subtherapeutic concentrations.
3.1.2. Antidepressants

Antidepressants were examined in 3 case-control studies and 3 cohort studies. One study, where all antidepressants were considered as a single group did not show a significant increase in traffic accident risk,\textsuperscript{[32]} or accident responsibility.\textsuperscript{[26]} There were too few studies in each category with necessary data to perform a meta-analysis.

There is no clear distinction between sedative and non-sedative antidepressants in their association with traffic accidents in patient groups investigated in epidemiological studies. In younger populations, two studies show no significant increase in accident risk either with tricyclic antidepressants (TCAs) or selective serotonin reuptake inhibitors (SSRIs)\textsuperscript{[27, 28]} while one reports an increased risk with both sedative and non-sedative antidepressants.\textsuperscript{[38]} However, in the elderly, the sedating antidepressants do appear to increase the traffic accident risk. Two epidemiological studies have studied antidepressants and accident risk in older drivers (\textgreater{} 60 years). Both show that TCA use increased the risk,\textsuperscript{[31, 35]} with one study demonstrating that the risk increases with dose.\textsuperscript{[31]} However, these studies have not examined the effects of non-sedating antidepressants and thus there is insufficient data to make any evaluation of newer antidepressants.

3.1.3. Opioids

Risk of traffic accidents associated with prescription use of opioids has been examined in 4 cohort studies and one case control study. Of the 4 cohort studies, 2 had overlap of data sources\textsuperscript{[17, 30]} and one did not have adequate information to calculate risk.\textsuperscript{[28]} Therefore a meta-analysis was not performed on epidemiological studies of opioids.

Therapeutic use of opioids (as a group) was associated with a higher risk of traffic accidents in young drivers.\textsuperscript{[28, 30]} The effect on accidents in elderly drivers (\textgreater{} 65 years) is
inconsistent. Limited evidence suggests that codeine, dihydrocodeine and tramadol may be associated with increased accident risk at least during the first 4 weeks of use. In contrast to prescription-based studies, the detection of opioids in blood in drivers was associated neither with the accident risk nor accident culpability.

3.1.4. Drug–alcohol interactions and drug interactions

Drug–alcohol interactions are reported in 3 case-control studies. Benzodiazepine-alcohol combinations always showed a greater risk of traffic accidents and accident culpability. All three studies consisted of adult drivers over a wide age range and determined benzodiazepine and alcohol exposure with blood/urine sample analysis. In each study, the reported OR for benzodiazepine-alcohol combination was higher than that observed with either benzodiazepines or alcohol alone (Table 1). The three case control studies were combined in a random-effects model meta-analysis (Figure 5). The results show that benzodiazepines can increase the odds of traffic accidents by 7.7 times (Pooled OR: 7.69, 95% CI: 4.33 – 13.65), suggesting a marked synergistic effect of alcohol-benzodiazepine combination on risk of traffic accidents. These studies do not specify the blood alcohol levels but all 3 have included some participants with blood alcohol levels below the legal limits for driving.

One case-control study and one cohort study report combined effects of psychoactive drugs on traffic accidents, both in elderly drivers. In the case-control study, use of one drug was associated with 30% increase in the accident risk, which further increased to 100% with the use of two or more drugs. Similarly, the cohort study showed 110% increase in traffic accident risk if the driver is on both benzodiazepines and TCAs.
3.2. EXPERIMENTAL STUDIES: EFFECTS OF BENZODIAZEPINES, ANTIDEPRESSANTS AND OPIOIDS ON DRIVING PERFORMANCE

3.2.1. Appraisal of the methodology:

Any methodological concerns specific to each study are noted against the respective studies in Supplementary Tables 1-3. Table 3 summarises the different methodological approaches of the 69 experimental studies.

3.2.1.1. Experimental design

Of the 69 studies, 63 were double-blind placebo-controlled studies whereas 6 were of other designs. Of the 63 double-blind placebo-controlled studies, 57 were within-subject crossover studies (where the same group of subjects were tested under different treatment conditions) thus ensuring maximum control over individual variations of driving performance. In many studies, attempts had been made to minimise systematic changes in performance across treatment conditions by providing adequate practice to participants and by randomising treatment order. The participants were assigned into separate treatment or placebo groups in the other 6 double-blind placebo-controlled studies (3 randomized, 3 not specified).

Of the 6 experimental studies with other designs, the participants were patients in 4 studies. [39-42] Single groups of patients were tested before and after treatment in two of these studies, whereas a control group treated with an active drug were included in the other two. The remaining two studies where healthy volunteers were tested, one was a randomised double-blind study in which lorazepam served as an ‘active-control’ drug [7] whilst the other one was a non-blind study. [43]
3.2.1.2. Study samples

The participants in the majority of the studies were healthy volunteers. Although healthy-volunteer studies examine the effect of a particular dose of a specific drug on driving performance, they cannot examine the interactive effects of the drugs and the conditions for which these sedative drugs are commonly prescribed (e.g. depression, insomnia, anxiety disorder, chronic pain) on driving. However, this ‘confounding by indication’ is accounted for in experimental studies that use patient groups suffering from insomnia, [5, 44–49] anxiety, [50–52] depression [39, 42] and chronic pain. [41, 53]

Participants of almost all experimental studies were relatively young. Of the 69 studies, only four [54–57] had elderly participants.

3.2.1.3. Pharmacological manipulation

Driving performance was tested after one or few doses of drugs to examine the acute effects and/or after several days of administration to find out subacute/subchronic effects. All drugs were orally administered (except one study where fentanyl was administered transdermally) in therapeutic doses. Adequate wash-out periods were ensured between treatment conditions in all crossover studies.

The driving impairment observed in drug naïve individuals with fixed, single/short-term dosing regimes of experimental studies does not portray the full spectrum of impairment that can occur in real-life situations. For instance, the effects of supratherapeutic doses (that might occur with deliberate self-poisoning) on driving may be much greater, whereas patients on long-term medication (especially benzodiazepines and opioids) show varying degrees of tolerance so that may not exhibit the same degree of impairment observed in drug naïve subjects in experimental studies.
3.2.1.4. Driving task and outcome measures

Forty nine studies have carried out actual driving tests while 21 have used driving manoeuvres performed in a driving simulator.

Actual car-driving tests have a better ecological validity, but safety concerns in pharmacological experiments preclude testing actual driving in traffic. A standardised highway driving test developed by a research group in The Netherlands had been used in 31 experimental studies retrieved in the current review.\[5 for technical details\] The primary aim of the driving task is to maintain a constant lateral position and constant speed of 95km/h. The main outcome measure, ‘standard deviation of lateral position (SDLP)’ indicates the degree of weaving of vehicle from the intended path and in turn depends on steering control. A secondary outcome, ‘standard deviation of speed (SDS)’ is a measure of variability of speed and depends on accelerator control. The driver sometimes has to interact with normal traffic (e.g. overtaking a slow vehicle); however, these segments are not included in calculating SDLP and SDS. Thus, the outcome measures do not directly reflect driving ability in normal traffic. Rather, the test examines the driver’s ability to operate the basic controls of the vehicle for stable highway driving at a constant speed.

Eight other actual driving experiments focus on more complex driving manoeuvres albeit on a closed-course. These tasks include manoeuvring around bollards (slalom task), gap estimation, reversal and parking.\[6, 50, 58-61\] Brake reaction time was an outcome measure in 7 studies on actual driving.\[58, 62-66\] One limitation of these studies is that being closed-course tests, subjects may not have had the same safety concerns as in open-road driving.

Driving simulator tests offer a safe alternative to on-the-road driving. Some simulator studies have measured mean variance of lateral position and mean variance of speed which are comparable with SDLP and SDS, respectively. However there are two main limitations in predicting actual driving performance based on simulated driving. Firstly, the artificial
quality of the driver-vehicle-environment interaction compromises the ecological validity of the tests. Although participants used at least some driving controls found in a real vehicle (i.e. steering, brake) in the tests, there is a wide variation of the nature of the driving scenes and the perceptual feedback generated by the vehicle. For instance, in the simplest simulators tests, subjects had to perform a continuous tracking task (with steering) and a secondary reaction time task (using a foot pedal) in response to relatively abstract visual stimuli, whereas the most complex simulator tests employed more life-like driving scenarios and emulated the forces acting upon an actual moving vehicle. Secondly, subjects performing simulated driving tests may not consider the safety factor as much as those who undergo real driving tests, so that the driving errors in simulated driving tests may exaggerate the actual risk of driving errors in real-life driving.

Pooled estimates of SDLP for different doses of short and long-acting benzodiazepines have been calculated in a recent meta-analysis. The authors report nightly doses equivalent to \( \leq 5 \)mg of diazepam significantly increase SDLP the following morning but not in the following afternoon. Doses equivalent to 10mg or more of diazepam caused a larger increase in SDLP. However, the strength of the experimental studies is the ability to assess the different doses of specific drugs on driving performance at different time intervals after dosing, whereas calculating pooled estimates across clinically heterogeneous studies may lead to loss of valuable information. In this respect, the patterns of impairment of SDLP observed with different benzodiazepine and non-benzodiazepine hypnotics and antidepressants have been reviewed recently by the original research group, comparing the impairment observed with drugs with what is observed with different blood alcohol levels (0.05, 0.08 and 0.1g/dl). However, these reviews do not comprehensively review the effects of drugs on more complex driving skills which are tested in other actual and simulated
driving studies. Thus the present review on experimental studies evaluates the effects of individual drugs on both actual and simulated driving tests.

3.2.2. Benzodiazepines and ‘z’ drugs

All 49 studies that we retrieved administered benzodiazepines orally in therapeutic doses. The doses were generally equivalent to 10-20mg of diazepam in almost all studies. Lower doses have been used in a few studies: diazepam 5mg-7mg in two, nitrazepam 5mg in one, and lorazepam 0.5mg in one. Two different dosing regimens which correspond to their therapeutic use have been applied by researchers in testing anxiolytics and hypnotics. The common design for anxiolytics was to test driving performance half-an-hour to about 5 hours after dosing. Hypnotics were always administered at night (replicating their therapeutic use) and driving was tested in the following morning (9-10 hours after dosing) or afternoon (16-17 hours after dosing).

3.2.2.1. Benzodiazepine anxiolytics

The results obtained in our search include 5 anxiolytics viz. diazepam, lorazepam, alprazolam, clobazam and medazepam. The latter two drugs are not widely used at present.

* Diazepam: * Diazepam was tested in 11 studies. Driving performance was assessed at different times post-dose, ranging from 30 minutes to 5 hours. Acute increase in SDLP and brake reaction time has been observed after a 10mg dose in on-the-road driving tests. A single 5mg dose did not cause a significant increase in SDLP in healthy volunteers, but did increase with thrice daily dosing. The impairing effect of the latter dosing regimen was observed up to 7 days in healthy volunteers and up to 3 weeks in patients with anxiety. These observations suggest that even administered in low doses, repeated administration of long-acting benzodiazepine like diazepam may cause significant
improvement. In driving simulator tests, 10-15 mg doses caused increased collisions,[9] increased tracking errors and reaction times[67, 69] and impairments in composite measures of overall driving performance.[54, 73] In the last study, driving impairment persisted even after 1 week of treatment. One driving simulator study did not show a significant effect after diazepam 0.11mg/kg body weight (~7mg) or 0.22mg/kg body weight (~15mg).[43] This is the only non-blind study (healthy volunteers knew what drug they had taken) included in this review. The authors argue that those who take sedative drugs in real-life know that the drugs may affect their driving performance and thus might take extra effort to compensate. However, there was a wide inter-subject variability in driving performance in this study probably attributable to the complex driving task and relatively short practice session and these factors may also account for the lack of significant effects of diazepam. In summary, the experimental studies indicate that diazepam can impair a wide range of task processes in driving, and the impairment appears to be significant even after 3 week of continuing treatment. These findings are consistent with the epidemiological evidence that showed increased accident risk in diazepam users.[19, 28, 32]

**Lorazepam:** Lorazepam was tested in 5 studies. SDLP was the outcome measure in 3 experiments and all showed a significant increase with lorazepam even after 1 week of treatment.[52, 74] Of these, one study was on a group of patients with anxiety and the experimenters continued treatment for 2 weeks and found a significant impairment even at the end of this period.[52] Two closed-course studies show that the drug can cause increased brake reaction time and impairment of more complex driving manoeuvres including parking, turning and avoiding obstacles.[7, 58]

**Alprazolam:** The 2 studies on alprazolam showed a 1mg dose can severely impair highway driving performance as indexed by SDLP.[75, 76] Sustained-release preparation of the drug caused less impairment but was still significant.[76]
Clobazam: No significant acute impairment was detected in different driving manoeuvres after 3 days of treatment with 10mg t.i.d.\textsuperscript{[62]} or after 20mg morning.\textsuperscript{[58]} One other study detected impairment after 6 days of treatment.\textsuperscript{[6]}

Medazepam: The long-acting anxiolytic medazepam caused driving impairment in patients even after 3 weeks of treatment.\textsuperscript{[50]}

3.2.2.2. Benzodiazepine and newer hypnotics

The effect of nocturnal doses of hypnotics on driving in the following morning generally depends on the half-life; however, there are some exceptions. The long-half-life (> 24 hours) hypnotics include flurazepam, flunitrazepam and nitrazepam.

Flurazepam (half-life of active metabolite: 40-250 hours): Flurazepam was tested in 6 driving performance studies and all report impairment with the drug. One to 2 days of treatment caused a significant increase in SDLP and SDS that lasts up to 10-11 hours after dosing in healthy volunteers with 30mg, and up to 16-17 hours in patients with insomnia after 15-30mg.\textsuperscript{[5, 46]} One study on patients showed the following morning’s impairment was persistent even after 1 week of continuing treatment.\textsuperscript{[46]} Another actual driving experiment found impaired manoeuvring skills in a slalom task 12 hours after a 15mg dose.\textsuperscript{[61]} Driving simulator tests showed increased tracking error and brake reaction time and reduced speed of driving.\textsuperscript{[10, 77]} These findings are consistent with the Neutal et al. 1995 study where flurazepam was associated with a 5-fold increase in the risk of injurious traffic accidents.\textsuperscript{[32]}

Flunitrazepam (half-life: 18-26 hours. Active metabolite: 36-200 hours): A single 2mg dose of flunitrazepam did not affect the SDLP after 10 hours in a group of young patients with sleep disturbances in one study,\textsuperscript{[47]} but did cause a significant increase which lasted 16-17 hours after 2 doses in another.\textsuperscript{[5]} This may be due to accumulation of this long-half-life benzodiazepine. In line with these findings, another on-the-road driving study
showed impaired steering control which lasted after 7 days of treatment in a group of patients with insomnia.\textsuperscript{[45]} Of the three driving simulator studies, one also reports increased lateral deviation and speed variation 10 hours after 1mg dose.\textsuperscript{[78]} These experimental findings corroborate a 3 to 4-fold increase in injurious traffic accident risk observed in a recent large-scale epidemiological study.\textsuperscript{[18]}

\textit{Nitrazepam (half-life: 15-38 hours):} Nitrazepam was tested in 2 studies. A 10mg dose increased SDLP which was observed 16-17 hours after a nocturnal dose in a group of young women with insomnia.\textsuperscript{[44]} This impairment persisted even after 8 days of continuing treatment. This evidence supports the epidemiological findings where nitrazepam was associated with 170\% increase in traffic accidents in the first week of use.\textsuperscript{[18]} A lower dose (5mg) caused increased brake reaction time in a driving simulator 9 hours after intake, but did not cause a significant increase in the number of errors in avoidance manoeuvres in a closed-course driving test.\textsuperscript{[59]}

Three other hypnotics (temazepam, loprazolam, lormetazepam) extracted in this review have intermediate plasma half-lives (8-24 hours).

\textit{Temazepam (8-22 hours):} All 5 studies that tested the effects of temazepam used 20mg nightly doses. SDLP was not significantly affected either in healthy elderly volunteers after a single dose\textsuperscript{[79]} or in young women with insomnia who received 3 consecutive doses\textsuperscript{[44]} the following morning (i.e. 10 hours after dosing). Two other driving studies reported that the drug did not impair manoeuvring ability in healthy volunteers\textsuperscript{[61]} or steering control in young insomniacs\textsuperscript{[45]} 10-12 hours after a single or multiple doses. Interestingly, temazepam also did not affect lateral position, speed deviation or reaction time in a group of elderly volunteers, even if they were tested only 5.5 hours after a 2am dose.\textsuperscript{[48]} However one cohort study shows that temazepam is associated with increased traffic accident risk during the first four weeks of use and to a lesser extent, during an extended period of use.\textsuperscript{[28]}
Loprazolam (6-12 hours): The only study on loprazolam (1mg and 2 mg) shows impairment in highway-driving (as measured by SDLP) even 16-17 hours after 2 nightly doses in young patients with sleep disturbances.\textsuperscript{[5]} This study also showed strong correlation between driving impairment and plasma drug concentration. This long-lasting impairment more-closely resembles the pattern observed with long-half-life hypnotics (e.g. flurazepam and flunitrazepam) rather than that observed with other intermediate-half-life hypnotics (e.g. temazepam).

Lormetazepam (half-life: 10-12 hours): Effects of lormetazepam on driving was tested in 5 experimental studies. Lorazepam 1mg or 2mg administered at night did not have significant acute or subchronic effects in the morning on SDLP in patients with insomnia.\textsuperscript{[46]} Healthy volunteers showed a significant impairment 10 hours after the first two days of administration but not 16 hours after the second dose.\textsuperscript{[68]} In driving simulation experiments lorazepam 2mg increased tracking errors and reaction time when tested 1-5 hours,\textsuperscript{[67]} but did not have significant acute\textsuperscript{[10, 68, 80]} or subchronic\textsuperscript{[10]} effects when tested in the morning following a nightly dose.

Short-acting hypnotics which have been tested for the effects on driving include triazolam, midazolam, zopiclone, zolpidem, zaleplon and eszopiclone.

Triazolam (half-life: 2-3 hours): One driving simulator study showed increased tracking errors up to 4.5 hours and delayed brake reaction time up to 1.5 hours after triazolam 0.25mg,\textsuperscript{[69]} but no significant effects were observed on simulated driving when tested in the morning following a 0.25mg or 0.5mg nightly doses.\textsuperscript{[59, 77]} However, given that there is some evidence that triazolam may be associated with increased accident risk,\textsuperscript{[32]} it is worth investigating drug effects also with on-the-road driving tests.

Midazolam (half-life: ~ 2 hours): The only study on midazolam did not show a significant impairment in brake reaction time 10 hours after midazolam 15mg.\textsuperscript{[63]}
Zopiclone (half-life: 5-6 hours): Effects of zopiclone have been tested in 4 standardised on-the-road driving studies and 5 driving simulator experiments. All studies used the standard treatment dose of 7.5mg. Despite the short-half life of the drug, there is consistent evidence that SDLP increases 5 hours\(^{[81]}\) and 10 hours after a bedtime dose in healthy young volunteers\(^{[79, 81, 82]}\) and 10 hours post-dose in the elderly individuals.\(^{[56]}\) One driving simulator study also reported increased lateral position deviation 10 hours after dosing but not after 12 hours.\(^{[78]}\) Other driving simulator studies reported increased collisions after 9-11 hours,\(^{[49]}\) increased tracking errors after 1.5 hours\(^{[69, 83]}\) and delayed brake reaction time after 1.5 and 4.5 hours.\(^{[69]}\) These findings parallel the markedly high traffic accident risk associated with zopiclone in epidemiological studies.\(^{[18, 27]}\) This is an unexpected trend given the short plasma half-life of zopiclone.

Zolpidem (half-life: ~ 2 hours): Two actual driving study and 1 simulator study examined the effects of zolpidem 10mg around 4-5.5 hours after middle-of the night dosing. This dose increased SDLP and SDS in healthy volunteers in both actual driving studies\(^{[79, 84]}\) and increased the variance of lateral position in patients with insomnia in the simulator study.\(^{[48]}\) Similarly, increased poor lateral position and speed control were reported at 2 hours, but not 13 hours after a 10mg dose in another driving simulator study.\(^{[85]}\) One actual driving study and 2 simulator studies showed that zolpidem 10mg does not impair SDLP in young insomniacs,\(^{[47]}\) or mean lateral position variance in healthy elderly\(^{[78]}\) or young insomnia patients,\(^{[49]}\) when tested in the following morning (i.e. 9-10 hours post-dose). The experimental evidence indicates that a 10mg bedtime dose of zolpidem does not affect the basic control processes of driving in the following morning but does impair if taken in the middle of the night. The largest cohort study conducted so far reports a two-fold increase in traffic accident risk in young zolpidem users during first 4 weeks of use,\(^{[18]}\) while another did not find a significant increase in the risk.\(^{[28]}\) However, the exposure was based on
prescription records, so that neither of the two studies is able to provide information on actual
time of administration of the hypnotic. There is also a theoretical possibility that even if the
basic control processes of driving are intact in the morning following a bedtime dose (as has
been observed in the experimental studies), more complex driving skills required for accident
avoidance may still be impaired.

Zaleplon (half-life: 1 hour): Effects of zaleplon had been examined only in 3 on-the-road driving studies. They showed that SDLP or SDS in healthy young individuals are not affected by 10 or 20 mg dose when tested 10 hours (i.e. morning after a bedtime dose)\(^{[82, 84]}\) or 4-5 hours (i.e. middle of the night dose).\(^{[81, 84]}\)

Eszopiclone (half-life: 6 hours): According to the 2 driving experiments conducted so far, eszopiclone 3mg did not affect the brake reaction time in either healthy young or elderly individuals, when tested 9-19.5 hours post-dose.\(^{[66]}\)

3.2.3. Antidepressants

Antidepressants have been used in therapeutic doses in almost all studies. Driving performance has been tested 1-5 hours after dosing, except in 5 studies\(^{[42, 86-89]}\) where drugs were given at night and driving was tested on the following morning.

The effect of antidepressants on automobile driving seems to be mainly determined by the sedative effect profile, and probably by the anticholinergic effects of the drugs.

3.2.3.1. Sedating antidepressants

Amitriptyline: Effects of amitriptyline have been examined in 4 actual driving experiments and 4 simulated driving tests. Three showed acute increase in SDLP after 25mg\(^{[5, 88]}\) and 75mg.\(^{[90]}\) A comparable driving simulator experiment found increased SDLP and headway variability 4 hours after amitriptyline 25mg,\(^{[91]}\) with a moderate positive
correlation between plasma amitriptyline concentration and SDLP.\textsuperscript{[8]} Only one study tested driving on the following morning after nocturnal dose.\textsuperscript{[88]} The investigators found increased SDLP even 13 hours after a 25mg nocturnal dose in patients with neuropathic pain. The other 4 studies report impaired tracking / steering control\textsuperscript{[69, 92, 93]} and brake reaction time\textsuperscript{[69, 94]} 2-5 hours after a 50mg dose.

\textit{Other tricyclic and related antidepressants:} All studies where healthy adult volunteers were administered sedative antidepressants in multiple daily doses reported increased SDLP. Acute (1-4 hours post-dose) impairment of SDLP has been reported with imipramine 50mg b.i.d.,\textsuperscript{[95]} doxepin 25mg t.i.d.,\textsuperscript{[5, 96]} mianserin 10mg t.i.d.\textsuperscript{[5, 96, 97]} Three studies on the effects of nocturnal doses showed that SDLP was increased in the following day (13-17 hours post-dose) with mirtazapine 15mg\textsuperscript{[89]} and 30mg,\textsuperscript{[87]} but not after dothiepin 75mg\textsuperscript{[86]} or mianserin 30mg.\textsuperscript{[89]} The only experimental study on elderly participants show no acute effects (2 hours post-dose) of imipramine 50mg on SDLP, although a significant increase was observed in their younger counterparts.\textsuperscript{[55]}

\textit{Effects of continuing treatment:} Post-dose impairment in SDLP remained significant even after 1-2 weeks of treatment with mianserin,\textsuperscript{[96, 97]} but not with imipramine,\textsuperscript{[95]} doxepin,\textsuperscript{[96]} mirtazapine\textsuperscript{[87]} or amitriptyline.\textsuperscript{[88, 90]} Only 3 studies examined the subchronic effects of sedative antidepressants on driving in patient groups. One study of chronic pain patients showed that the impairing effects (as indexed by increased SDLP) of amitriptyline disappear after 15 days of continuing treatment.\textsuperscript{[53]} The other two driving simulator studies on depressed patients showed improvement of performance after two to four weeks of treatment with mirtazapine.\textsuperscript{[39, 98]} The latter study also found that performance did not improve in an untreated control group.\textsuperscript{[98]}

3.2.3.2. Non-sedating antidepressants
In contrast to tricyclic and other sedating antidepressants, newer non-sedating antidepressants do not appear to have acute or subacute effects on driving when tested with standardised highway driving tests or driving simulation tests. Absence of any significant acute or subchronic effects on SDLP or speed variability in healthy volunteers has been demonstrated with SSRIs paroxetine (10mg), fluoxetine (20mg) and escitalopram (10-20mg), serotonin-noradrenaline reuptake inhibitor venlafaxine (37.5-75mg b.i.d.) and monoamine oxidase inhibitor moclobemide (200mg b.i.d.). The only study on depressed patients reports that driving performance (as tested on a simulator) improves after a two-week treatment with non-sedating antidepressant reboxetine as well as with sedative antidepressants mianserin.

3.2.4. Opioids

Only 3 experimental studies examined the effects of opioids on driving (Supplementary Table 3). One study on healthy volunteers showed increased collisions in a driving simulator task after a single 50mg dose of codeine while the other showed no significant acute effects of oxycodone-paracetamol combined preparation (5mg/325mg and 10mg/650mg) on SDLP or SDS. However, in the latter study, a dose response relationship was observed and subjective reporting indicated that the participants had to apply more effort in driving compared to control conditions. The only study on patients with chronic pain was a pre-test post-test design where driving performance was tested before and 2 months after initiation of a transdermal fentanyl treatment. There was no significant change in performance as assessed with a driving simulator test.

3.2.5. Drug-alcohol interactions and drug-drug interactions
A limited number of experimental studies compared the effects of drugs alone with drug-alcohol combinations on driving skills. The addition of alcohol was found to worsen the acute impairment caused by lormetazepam,\textsuperscript{67} flurazepam,\textsuperscript{77} triazolam\textsuperscript{69} and amitriptyline.\textsuperscript{93} One study reports the interactive effects of diazepam with amitriptyline and with mirtazapine. Severity of tracking error was greater with diazepam-antidepressant combinations than with any of the drugs alone.\textsuperscript{69}

4. DISCUSSION

The present paper reviewed the research evidence on the effects of three different classes of sedative drugs (benzodiazepines, antidepressants and opioids) on driving performance, and their association with traffic accidents, taking into account different drug and patient factors that modify these effects in a practical context.

Our meta-analyses of case-control and cohort studies indicate that benzodiazepines, as a group, are associated with 60-80\% increase the risk of traffic accidents. Meta-analysis of case-control studies on accident culpability shows that drivers responsible for traffic accidents are 40\% more likely to be positive for benzodiazepines than those who are not responsible, suggesting that benzodiazepines actually may play a causative role in traffic accidents.

Deleterious effects of benzodiazepines are potentiated by co-ingestion of other sedative substances. The present review shows that presence of alcohol and benzodiazepines was associated with 7.7-fold increase in the risk of traffic accident. Evidence from experimental studies supports this assertion. Benzodiazepines also interact with sedative antidepressants to impair driving skills and increase the risk of accidents. Although drug warning labels and consumer sites generally warn about the increased sedative effects of
drug-alcohol combinations, they do not specify the effects on driving. We believe that drug
information sheets / warning labels should specify this interactive effect on driving, and
prescribers should warn patients that the benzodiazepine-alcohol combination may markedly
increase the risk of accidents even if the blood alcohol levels are below the legal limit
(generally 0.5-0.8g/dL in most countries).

Epidemiological studies also suggest that benzodiazepine-associated traffic accident
risk is less in elderly drivers than in younger adults. Low benzodiazepine-associated accident
risk in elderly drivers may occur for a variety reasons. Elderly individuals tend to be
prescribed with lower doses of benzodiazepines compared to their younger counterparts.
Perhaps elderly drivers on benzodiazepines may appreciate the potential deleterious effects
of drugs more and resort to safer driving patterns or limit driving while they are on drugs.
Epidemiological studies however, do not provide information of drug doses or driving
patterns and thus fail to support or refute any of the above speculations. Only a few driving
experiments have been carried out in elderly\cite{54, 56, 57} and they do not make a clear distinction
between drug effects on young and the elderly. Although driving experiments in elderly
drivers after sedative drugs may have safety and ethical concerns, further research on this
group is necessary because increased life-expectancy and independence has increased the
proportion of elderly drivers in the community, and many elderly patients take
benzodiazepine hypnotics.

General patterns emerging from epidemiological and experimental studies also
indicate that anxiolytics, taken in single or multiple doses during daytime tend to impair
driving somewhat independently of their half-lives. As for hypnotics, the accident risk and
the possibility of daytime driving impairment tend to be related to their plasma half-lives, but
with exceptions.
The results of the experimental studies suggest that diazepam, flurazepam, flunitrazepam, nitrazepam and the short-half-life non-benzodiazepine hypnotic zopiclone may cause significant driving impairment and the findings of epidemiological studies show that use of these same drugs are associated with a significant increase in traffic accident risk. The accident risk remains elevated at least during the first 2-4 weeks after commencement of treatment, and nocturnal doses cause impaired driving performance at least up to the following afternoon in case of benzodiazepine hypnotics and the following morning in the case of zopiclone. Diazepam is the most extensively studied benzodiazepine. Even though widely prescribed, there is strong evidence that diazepam worsens driving performance and is associated with increased accident risk, at least for the first 3-4 weeks after commencement of anxiolytic treatment. Impairing effects of the above sedative drugs raise important, but controversial legal implications. The 2-3 fold increase in accident risk associated with these long acting benzodiazepines and zopiclone is equivalent to what has been observed with a blood alcohol concentration of 0.05-0.08g/dL,\textsuperscript{[101, 102]} which is above legal limits for driving in most countries. A series of on-the-road driving studies also illustrate that SDLP observed with therapeutic doses of the hypnotics is above these legal limits for alcohol.\textsuperscript{[14]} For hypnotic medication, an option for prescribers is to avoid these hypnotics (flurazepam, flunitrazepam, nitrazepam and zopiclone) if patients are engaged in driving. Relatively safer alternatives would be shorter acting hypnotics such as triazolam, temazepam, zolpidem and zaleplon which were not found to cause driving impairment at least in experimental studies (although there is evidence that some of the drugs are associated with increased accident risk). Still, patients should be cautioned against possible effects on driving and the course of hypnotic treatment should be continued only for the minimum required period. We believe in the present clinical context, patients with anxiety prescribed diazepam should be strongly encouraged not to drive at least during the first four weeks of treatment. However, unlike
with hypnotics, the research evidence does not readily offer safer alternatives for prescribers: all other anxiolytics, with daytime dosing, were found to impair driving, at least in healthy volunteers. Large scale epidemiological studies and experimental studies on patient groups are imperative to examine the safety of other anxiolytics.

There is no clear distinction between sedative and non-sedative antidepressants in their association with traffic accidents in epidemiological studies, particularly in young patients using antidepressants.\cite{27,28,38} Presumably one major source of confounding in patient studies is the condition to which the drugs are prescribed (i.e. depression). Antidepressants interact differently with depression at different stages of treatment to influence driving ability. To begin with, cognitive and psychomotor deficits of depression itself may limit driving capacity of an individual. As the antidepressants do not bring therapeutic effects immediately after commencement of treatment, patients may show driving impairment irrespective of the sedative properties of the antidepressants during the first 1-2 weeks of treatment. Patients on sedative antidepressants may be affected more than those on non-sedating antidepressants during this initial stage due to acute sedative effects of the drugs, as has been observed in healthy volunteers in experimental studies. Continuing treatment beyond 3-4 weeks tends to improve depression and patients tend to become tolerant to sedative effects, depression begins to be alleviated and patients may develop tolerance to sedative effects of sedating antidepressants. This notion is supported by limited experimental evidence which showed that young patient groups treated with sedative or non-sedative antidepressants improved their driving skills after a few weeks\cite{39, 88, 98} while untreated patients did not.\cite{98} In general epidemiological studies have failed to eliminate residual confounding effects of depression, because they have basically compared those who use antidepressants (i.e. depressed patients) with those who did not (most likely non-depressed individuals). Case-crossover\cite{27} and self-controlled case-series\cite{28} studies have attempted to
overcome this methodological constraint by employing with-in subject designs thus controlling for depression at least to some extent.

Limited evidence suggests that TCAs may be associated with an increased traffic accident risk in the elderly. Experimental evidence is very scarce on this group and hence it is impossible to confirm whether this is due to differential effects of antidepressants, depression or a complex interaction between the two.

Few epidemiological studies conducted so far suggests that opioid users (at least in young drivers) may be at a greater risk of traffic accidents in the first few weeks of treatment. However, scarce experimental data do not provide conclusive evidence on whether opioids impair driving in patients under treatment. Similar to antidepressants, the interactive effect of opioids and underlying conditions such as chronic pain on driving performance is also not clear.

Apart from the biases and limitations of the individual studies, there are certain limitations of the present review. We could not include certain epidemiological studies\textsuperscript{[22,27,28]} in the meta-analyses as they did not contain the necessary information required to calculate risk estimates which are compatible with the majority of the studies. However, only the magnitudes of the risk estimates of these studies were different from the pooled estimates; the direction of association was the same. It has to be also admitted that, even the best efforts of combining epidemiological and experimental evidence failed to establish a complete causative pathway between psychoactive drugs and traffic accidents. In other words, epidemiological studies showed that some these drugs are associated with (but not necessarily cause) an increased risk of traffic accidents. Driving performance studies showed that those drugs caused an impairment of driving, but this does not necessarily mean that the impairment is practically significant enough to increase the risk of accidents. As a compromise, some researchers have calibrated driving performance measures (e.g. degree of
weaving of vehicle as indexed by SDLP) against different levels of exposure to substances already known to increase accident risk (e.g. different blood levels of alcohol). Future research can further narrow this gap in the path of causation by correlating the performance measures (e.g. SDLP) directly with the risk of accidents of the same subjects (e.g. number of traffic accidents the test subjects encounter during a certain fixed time period before and after SDLP measurement). In fact, a similar approach had been used recently to validate trail-making test B performance (which is a neuropsychological measure of visual scanning, visuomotor coordination, divided attention and executive functions) as a predictor of motor vehicle crash risk.\[103\]

5. CONCLUSIONS

Although there are inherent limitations in pharmacoepidemiological and experimental study designs in detecting the effects of sedative drugs on driving and traffic safety, a clearer picture emerges in combining the findings of the two different types of studies. The results show that benzodiazepine use is associated with a significant increase in the risk of traffic accidents and accident responsibility of drivers. The accident risk is markedly increased by co-ingestion of alcohol. Driving impairment was generally related to plasma half-lives of hypnotics, but with notable exceptions. Anxiolytics, with daytime dosing, impaired driving independent of their half-lives. We believe that these findings will help in formulating more specific clinical guidelines and precautions in use of benzodiazepines.

Limited epidemiological evidence suggests that TCAs may be associated with increased accident risk at least in the elderly. Experimental studies also indicate that sedative, but not non-sedative antidepressants impair driving performance at the initiation of treatment. However, long-term experimental studies with regular follow-up are necessary to elucidate how antidepressants and their complex interaction with depression affect driving
performance over the course of treatment in depressed patients. Opioid users seem to be at a higher risk of traffic accidents; however experimental evidence is scarce on their effects on driving.

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zolpidem, and their combination on psychomotor functions, memory recall, and driving skills
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subchronic effects of dothiepin, fluoxetine and placebo on psychomotor and actual driving
function in healthy subjects after acute and subchronic treatment with escitalopram,
of amitriptyline on processing capacity in neuropathic pain patients using visual event-related
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on actual driving, psychomotor performance and subjective assessments in healthy
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paroxetine, amitriptyline, and placebo on driving performance and cognitive function in
healthy Japanese subjects: A double-blind crossover trial. Hum Psychopharmacol
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lofempramine, nomifensine, amitriptyline and placebo on aspects of memory and psychomotor


<table>
<thead>
<tr>
<th>Study, Country</th>
<th>Design, period</th>
<th>Study population from which the sample selected</th>
<th>Cases</th>
<th>Controls</th>
<th>Drug exposure ascertainment</th>
<th>Adjustment / stratification / controlled / variables</th>
<th>Subgroups / studied drug groups</th>
<th>Results: risk measure (95% CI)</th>
<th>Comments / Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagier et al., 1993</td>
<td>Case-control</td>
<td>Patients admitted to hospital after TA injury</td>
<td>Drivers responsible for accident</td>
<td>Drivers not responsible for accidents and pedestrians</td>
<td>Blood analysis for benzodiazepines</td>
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<tr>
<td>Puget Sound, US</td>
<td>July 1990</td>
<td>234 drivers &gt;65yrs old, sought treatment for</td>
<td>447 Drivers &gt;65yrs old matched for age, sex, county of residence, but not met with MVC during the</td>
<td>Prescription records: Current exposure; prescription within 60 days Past exposure: prescription 60 days−6 months</td>
<td>Race marital status, education miles driven, insulin or oral hypoglycaemic use for</td>
<td>Blood alcohol &lt;0.2g/l Blood alcohol &gt;0.2g/l Blood alcohol 0.2−0.8g/l with no benzodiazepines Benzodiazepines: Current exposure Past exposure</td>
<td>OR = 0.96 (0.8−1.2)</td>
<td>Benzodiazepine-alcohol combination increases risk compared to alcohol / benzodiazepine alone.</td>
<td></td>
</tr>
<tr>
<td>Honkanen et al., 1980</td>
<td>Case-control</td>
<td>Patients (15-64y) discharged from a Group Health</td>
<td>Group 1: 63 passengers Group 2: 85, driver-status undetermined (45), not-at-fault drivers (13), drivers fault status unknown</td>
<td>Prescription records: At least one prescription for sedative drug (major or minor tranquilliser, antihistamines or narcotic analgesic) within 3 months of accident.</td>
<td>Sex At-fault drivers vs. passengers (for use of any drug group)</td>
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<tr>
<td>Helsinki, Finland</td>
<td>Apr, May, Sept.</td>
<td>93 drivers ‘at fault’ of the accident, as recorded in clinical notes</td>
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<tr>
<td>Skegg et al., 1979</td>
<td>Matched case-control, Mar 1974 – Feb 1976</td>
<td>43,117 people registered with 16 general practitioners</td>
<td>57 drivers died or hospitalised due to injuries from TA</td>
<td>1425 randomly selected people from GP registers</td>
<td>Prescription records: Prescribed and dispensed with a tranquilliser during weeks before TA</td>
<td>matched for sex, general practice enrolled, year of birth</td>
<td>All tranquillisers Minor tranquillisers Major tranquillisers</td>
<td>RR=5.2 (2.2 − 12.6) RR=4.9 (1.8 − 13.0) RR=6.9</td>
<td>No confidence interval given for major tranquillisers as there were too few subjects</td>
</tr>
<tr>
<td>Jick et al., 1981</td>
<td>Case control, Jan 1977 – Dec 1978</td>
<td>Patients (15-64y) discharged from a Group Health</td>
<td>201 drivers arrived at emergency department within 6h after TA</td>
<td>325 car drivers selected randomly at petrol stations</td>
<td>Serum analysis for benzodiazepines</td>
<td>matched for weekday, hour of day and location of accident</td>
<td>Benzodiazepines (Mainly diazepam)</td>
<td>More commonly detected in cases than in controls (p&lt;0.03)</td>
<td>May have introduced a bias as the duration of holding the licence was shorter and blood alcohol levels higher in cases than controls</td>
</tr>
<tr>
<td>Leveille et al., 1994</td>
<td>Matched case-control, 1987-1988</td>
<td>Enrolees of Group Health Corporate, Puget Sound</td>
<td>234 drivers &gt;65yrs old, sought treatment for MVC within 7 days of accident</td>
<td>447 Drivers &gt;65yrs old matched for age, sex, county of residence, but not met with MVC during the</td>
<td>Prescription records: Prescribed and dispensed with a tranquilliser during weeks before TA</td>
<td>matched for sex, general practice enrolled, year of birth</td>
<td>All tranquillisers Minor tranquillisers Major tranquillisers</td>
<td>RR=4.9 (1.8 − 13.0) RR=6.9</td>
<td>No confidence interval given for major tranquillisers as there were too few subjects</td>
</tr>
</tbody>
</table>

**Table 1: Case control studies (OR: Odds ratio, RR: Relative risk, SIR: Standardised incidence ratio, TA: Traffic accident)**
### Hemmelgarn et al., 1997

**Nested case-control, Tayside, UK**

- **Cases:** 67 – 84 year old subjects who possessed a valid driving licence and resided in Tayside for at least 2 years
- **Controls:** 55,790 drivers (10 per one case) who were at risk of, but did not meet with accidents during the index date

**Main Findings:**
- Prescription records: exposed if index date included the period of prescription, not exposed if no benzodiazepine use within 365 days preceding index date
- Sex, Age
- Benzodiazepines: Long half-life
  - Current use
  - 1st week of use
- Benzodiazepines: Short half-life
  - Current use
  - 1st week of use

### Barbone et al., 1998

**Case-crossover, Tayside, UK**

- **Cases:** 410,306 residents in Tayside Region, UK, who had been registered with a Tayside general practitioner
- **Controls:** 19,386 persons >= 18y of age, who experienced an TA

**Main Findings:**
- Control period: The day of TA
- Intake of the drug on the day based on dispensed prescription records.
- Benzodiazepines: All
  - OR = 1.45 (1.04 – 1.96)
- Benzodiazepines: Short half-life
  - OR = 2.03 (1.45 – 2.85)
- Benzodiazepines: Long half-life
  - OR = 1.45 (1.04 – 1.96)

### Longo et al., 2000

**Case-control, Australia**

- **Cases:** 2500 injured drivers from South Australia
- **Controls:** Drivers not culpable for TA

**Main Findings:**
- Detention of drugs in blood samples
- Benzodiazepines: All
  - OR = 2.0 (p < 0.05)
- Benzodiazepines: Subtherapeutic
  - OR = 1.3 (p > 0.05)
- Benzodiazepines: Therapeutic
  - OR = 3.3 (p < 0.05)
- Benzodiazepines: Supratherapeutic
  - OR = 3.6 (p < 0.05)
- Benzodiazepines + alcohol
  - OR = 13.4 (p < 0.05)

---

**Note:**
- Other classes of drug, benzodiazepines may be more likely to be responsible for TAs. OR for benzodiazepines decrease with age. Anxiolytics: alprazolam, lorazepam, clorazepate, oxazepam. Hypnotics: flurazepam, flurazepam, loprazolam, oxazepam, temazepam, triazolam. Drivers on benzodiazepines are more likely to be responsible for TAs. OR for benzodiazepines decrease with age. Anxiolytics: alprazolam, bromazepam, diazepam, lorazepam, clorazepate, oxazepam. Hypnotics: flurazepam, flurazepam, loprazolam, oxazepam, temazepam, triazolam. Benzodiazepines alone: All levels
  - OR = 2.0 (p < 0.05)
- Benzodiazepines: Subtherapeutic
  - OR = 1.3 (p > 0.05)
- Benzodiazepines: Therapeutic
  - OR = 3.3 (p < 0.05)
- Benzodiazepines: Supratherapeutic
  - OR = 3.6 (p < 0.05)
- Benzodiazepines + alcohol
  - OR = 13.4 (p < 0.05)

Confidence intervals for odds ratios are not given. These findings are also presented in Longo et al., 2001 with emphasis on benzodiazepines. The results are similar.
<table>
<thead>
<tr>
<th>Study</th>
<th>Study Location</th>
<th>Design</th>
<th>Sample Size</th>
<th>Year</th>
<th>Methods</th>
<th>Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>McGwin et al., 2000</td>
<td>Alabama, US</td>
<td>Case-control</td>
<td>&gt;65y who had a driver license</td>
<td>2000</td>
<td>244 drivers involved in TAs from 1 Jan 1996 to 31 Dec 1996</td>
<td>Self-reporting of medication use in a telephone interview</td>
</tr>
<tr>
<td>Mura et al., 2003</td>
<td>France</td>
<td>Case-control</td>
<td>Patients &gt;18y old admitted to emergency departments</td>
<td>2003</td>
<td>900 drivers after traffic accidents</td>
<td>Detection of drugs in blood samples</td>
</tr>
<tr>
<td>Drummer et al., 2004</td>
<td>Australia</td>
<td>Case-control</td>
<td>Drivers &gt; 20 years old, involved in fatal TAs between 1993-2006</td>
<td>2004</td>
<td>110 drivers selected from moving traffic (stopped for alcohol testing by police)</td>
<td>Positive blood/urine samples</td>
</tr>
<tr>
<td>Movié et al., 2008</td>
<td>The Netherlands</td>
<td>Case-control</td>
<td>Drivers responsible for TA (as indexed by unsafe driving actions)</td>
<td>2008</td>
<td>Drivers not responsible for TA</td>
<td>Blood sample analysis for benzodiazepines, categorised according to half-life</td>
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<tr>
<td>Dubois et al., 2008</td>
<td>Canada</td>
<td>Case-control</td>
<td></td>
<td>2008</td>
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</tbody>
</table>

### Results

**Benzodiazepines:**

- At-fault drivers, vs. drivers not involved in TA
  - At-fault vs. not-at-fault drivers
  - At-fault drivers, vs. drivers not involved in TA
  - At-fault vs. not-at-fault drivers

**Antidepressants:**

- Whether the subjects were on medication during the time accident is not specified.

**Concomitant Drug Exposure:**

- Benzodiazepines: OR=5.2 (0.9-30.0)
- OR=1.0 (0.2-4.6)
- OR=0.8 (0.2-3.0)
- OR=1.3 (0.2-6.7)

**Controls:**

- Only fatal crashes were analysed. Small sample sizes.
- Controls are a group of drivers stopped by police at roadside. This may have introduced a bias towards null if the reason for stopping was suspicious driving behaviour.
- Drivers positive for alcohol studied. Age stratified results: higher risk only 25-55 years.
Table 2: Cohort studies (IRR: Incidence rate ratio, OR: Odds ratio, RR: Relative risk, SIR: Standardised incidence ratio, TA: Traffic accident)

<table>
<thead>
<tr>
<th>Study, Country</th>
<th>Design, period</th>
<th>Study cohort</th>
<th>Ascertainment of exposure</th>
<th>Ascertainment of non-exposure</th>
<th>Outcome measure, and the way of reporting</th>
<th>Adjustment/stratification/controlled variables</th>
<th>Subgroups / different drugs</th>
<th>Results: risk measure (95% CI)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ray et al, 1992 Tennessee, US [31]</td>
<td>Cohort, with a case cross-over component for drivers involved in crashes, 1984-1988</td>
<td>16,262 Tennessee Medicaid enrollees aged 65-84y, holding a driving licence</td>
<td>Receiving prescription for a psychoactive drug. Subgroups: Current use, indeterminate use, past use</td>
<td>No prescriptions for benzodiazepines</td>
<td>Injurious crashes reported to Tennessee Department of Safety, Number of crashes per 1000 person-years</td>
<td>Age, sex, race, county of residence, calendar year. Case-crossover study adjusted for alcohol use &amp; driving frequency</td>
<td>Current use of, Any psychoactive Benzodiazepines</td>
<td>RR = 1.5 (1.2–2.9)</td>
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<tr>
<td>Neutel, 1995 &amp; 1998 Canada [32,37]</td>
<td>Cohort, 1979 - 1986</td>
<td>323,658 individuals &gt; 20y of age included in the Saskatchewan Health Databases</td>
<td>First 2 / 4 weeks following being prescribed a benzodiazepine hypnotic (n=78,070) or an anxiolytic (n=147,726), but not receiving any within 6 months preceding index prescription</td>
<td>Not received a prescription for a benzodiazepine with in 6 months preceding a reference date (n=97,862)</td>
<td>Traffic injury-related hospitalisation following sale of indexed prescription, Number of hospitalisations</td>
<td>Age, Sex</td>
<td>All benzodiazepines Hypnotics (triazolam, flurazepam)</td>
<td>OR=3.1 (1.5–6.2)</td>
<td>Benzodiazepine related odds ratios are similar in young (&lt;60y) and elderly (&gt;60y) drivers. However, young age group is an independent risk factor for traffic accidents.</td>
</tr>
<tr>
<td>Engeland et al., 2007 Norway [30]</td>
<td>Registry-based cohort Apr 2004 – Sept 2005</td>
<td>All Norwegians aged 18 – 69 years (3.1 million)</td>
<td>Drug dispensing information. Exposed periods: First 7 days / 14 days after dispensing or period corresponding to no. of dispensed defined daily doses</td>
<td>Period other than the exposed period for the given drug</td>
<td>TA that resulted in a personal injury, Incidence rate</td>
<td>Stratified for sex and age Adjusted for month of the year</td>
<td>Benzodiazepines: Anxiolytics (oxazepam, lorazepam, diazepam)</td>
<td>SIR = 2.9 (2.5–3.5)</td>
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<td>Opioid analgesics Benzodiazepines + TCA</td>
<td>OR=1.1 (0.5 – 2.4)</td>
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<td></td>
<td>Anxiolytics (flurazepam, oxazepam, midazolam)</td>
<td>OR=3.1 (1.5–6.2)</td>
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<td></td>
<td>Cyclic antidepressants</td>
<td>RR = 2.1 (1.1 - 4.2)</td>
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<td>New users within 4 wks</td>
<td>OR=5.6 (1.7 – 18.4)</td>
<td>Risk reduces with time since prescription.</td>
</tr>
</tbody>
</table>
Bramness et al., 2007
Norway
[19] Registry-based cohort
Apr 2004 – Sept 2005
All Norwegians aged 18 – 69 years (3.1 million)
Drug dispensing information. Exposed periods: First 7 days / 14 days after dispensing or period corresponding to no. of dispensed defined daily doses
Period other than the exposed period for the given drug
TA that resulted in a personal injury. Incidence rate
Stratified according to sex, age
Adjusted for month
Diazepam:
1st 7 days SIR = 1.66 (0.72 – 3.48)
1st 14 days SIR = 1.56 (1.12 – 2.17)
1st 7 days in new users SIR = 1.36 (1.02 – 1.80)

Bramness et al., 2008
Norway
[38] Registry-based cohort
Jan 2004 – Sept 2006
All Norwegians aged 18 – 69 years (3.1 million)
Drug dispensing information. Exposed period: number of days corresponding to no. of dispensed defined daily doses
Period other than the period defined as exposed period
TA that resulted in a personal injury. Incidence rate
Stratified according to sex, age
Adjusted for month
Sedative antidepressants (TCAs, mianserin, mirtazapine)
All users SIR = 1.4 (1.2 – 1.6)
New users SIR = 1.0 (0.7 – 1.4)
Non-sedative antidepressants (SSRIs, MAOIs, SNRIs)
All users SIR = 1.6 (1.5 – 1.7)
New users SIR = 1.6 (1.3 – 1.9)
The degree of the traffic accident (e.g. injurious, non-casualty) not specified. Risk is higher in young drivers and male drivers.

Gustavsen et al., 2008
Norway
[18] Registry-based cohort
Jan 2004 – Sept 2006
All Norwegians aged 18 – 69 years (3.1 million)
Drug dispensing information. Exposed periods: First 7 days / 14 days after dispensing
Period other than the period defined as exposed time
TA entered in Road Accident Registry, incident rate
Month of the year
Other prescribed drugs
Stratified for age and sex
SIR = 2.7 (1.8 – 3.9)
SIR = 2.2 (1.6 – 3.0)

Gibson et al. 2009
UK [28] Cohort (self-controlled case series), 1986 - 2004
Individuals 18 – 74y met with MVA and prescribed with sedative drugs during 1986 – 2004. Non-driving participants excluded.
Drug prescription information. Initial exposure: 1st 4 weeks after prescription, Extended exposure: reminder of the course of treatment
Period beyond the time window that spans 4 weeks prior to 1st prescription to 24 weeks after last prescription.
Motor vehicle crash
Benzodiazepines (all):
- 1st 4 weeks
  - extended use
  - extended use
  - extended use
  - extended use
  - extended use
  - extended use
  - extended use
Opioids (all):
- 1st 4 weeks
  - extended use
  - extended use
IRR (99% CI):
IRR = 1.94 (1.62–2.32)
IRR = 2.38 (2.01–2.81)
IRR = 1.93 (1.54–2.43)
IRR = 2.77 (2.20–3.48)
IRR = 1.56 (1.12–2.17)
IRR = 1.36 (1.02–1.80)
IRR = 1.66 (0.72–3.86)
IRR = 1.55 (0.89–2.70)
IRR = 1.03 (0.68–1.55)
IRR = 1.40 (1.04–1.87)
IRR = 1.04 (0.43–2.48)
IRR = 1.16 (0.60–2.25)
IRR = 1.70 (1.39–2.08)
IRR = 1.29 (1.08–1.54)
<table>
<thead>
<tr>
<th>Study</th>
<th>Registry-based cohort</th>
<th>All Norwegians aged 18 – 69 years (3.1 million)</th>
<th>Drug dispensing information. Exposed period: First 7 days after dispensing codeine or tramadol</th>
<th>Unexposed period: Period not exposed to any CNS impairing drugs</th>
<th>TA that resulted in a personal injury, Incidence rate</th>
<th>Adjusted for month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bachs et al., 2009 Norway [17]</td>
<td>Jan 2004 – Sept 2006</td>
<td>Codeine-1&lt;sup&gt;st&lt;/sup&gt; 4 weeks - extended use</td>
<td>IRR= 1.61 (1.11 - 2.32)</td>
<td>IRR= 1.33 (0.88 - 2.00)</td>
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<td>Morphine- 1&lt;sup&gt;st&lt;/sup&gt; weeks - extended use</td>
<td>IRR= 1.16 (0.39 - 3.45)</td>
<td>IRR= 0.87 (0.43 - 1.75)</td>
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<td>Dihydrocodeine - 1&lt;sup&gt;st&lt;/sup&gt; 4 weeks - extended use</td>
<td>IRR= 1.60 (1.14-2.25)</td>
<td>IRR= 1.05 (0.78-1.42)</td>
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<td>Tramadol – 1&lt;sup&gt;st&lt;/sup&gt; 4 weeks - extended use</td>
<td>IRR = 1.46 (1.02-2.11)</td>
<td>IRR = 1.34 (1.02-1.76)</td>
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<td>SSRIs (all) - 1&lt;sup&gt;st&lt;/sup&gt; 4 weeks</td>
<td>IRR = 0.87 (0.43 - 1.75)</td>
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<td>- extended use</td>
<td>IRR = 1.16 (0.75 - 1.72)</td>
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<td>TCAs (all) - 1&lt;sup&gt;st&lt;/sup&gt; 4 weeks</td>
<td>IRR = 1.05 (0.78-1.42)</td>
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<td></td>
<td>- extended use</td>
<td>IRR = 1.34 (1.02-1.76)</td>
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<tr>
<td></td>
<td></td>
<td>Codeine (all)</td>
<td>IRR = 1.16 (0.75 - 1.72)</td>
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<tr>
<td></td>
<td></td>
<td>Codeine (coprescription of other impairing drugs excluded)</td>
<td>IRR = 1.34 (1.02-1.76)</td>
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<tr>
<td></td>
<td></td>
<td>Tramadol</td>
<td>IRR = 1.34 (1.02-1.76)</td>
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</table>

IRR = 1.9 (1.6 – 2.2)

SIR = 1.3 (1.0 – 1.6)

SIR = 1.5 (0.9 – 2.3)
**Table 3:** Experimental study designs (both benzodiazepines and opioids were tested in one study. Some studies administered both actual and simulated driving tests).

<table>
<thead>
<tr>
<th>Methodological approach</th>
<th>Benzodiazepines (n =48)</th>
<th>Antidepressants (n =20)</th>
<th>Opioids (n = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-blind, placebo-controlled</td>
<td>41</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>Crossover</td>
<td></td>
<td></td>
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<tr>
<td>Intergroup</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Study samples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Healthy volunteers</td>
<td>35</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Patients</td>
<td>13</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Driving test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulator</td>
<td>15</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Actual driving</td>
<td>34</td>
<td>14</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 1: Selection process of studies.

Initially retrieved articles screened for relevance (n = 1271)

Excluded (n = 1160)
- Irrelevant subject area (n=1038)
- Reviews (n=44)
- Letters / editorials (n=17)
- Case studies (n=5)
- Cognitive / psychomotor function tests (n=56)

Original articles relating psychotropic drugs under question either with driving performance or traffic accidents (n = 111)

Traffic accidents (n= 48)
- Excluded (n=33)
  - Descriptive studies (n=30)
  - Duplication of same population (n=3)
- Analytical epidemiological studies (n=15)
  - + Retrieved from reference lists (n=6)
  - Case-control (n=13)

Driving performance (n=63)
- Excluded (n=10)
  - Comparison of patients on drugs with controls (n=5)
  - Duplication of same experimental group (n=5)
- Articles on experimental studies (n=53)
  - + Retrieved from reference lists (n=9)
  - 62 papers (total of 69 experimental studies)

Figure 2

<table>
<thead>
<tr>
<th>Study</th>
<th>Exposed group</th>
<th>Non-exposed group</th>
<th>% Weight</th>
<th>Odds ratio (95% confidence interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skegg et al. 1979</td>
<td>5 / 37</td>
<td>51 / 1440</td>
<td>9.89</td>
<td>4.26 (1.24, 11.63)</td>
</tr>
<tr>
<td>Honkanen et al. 1980</td>
<td>10 / 17</td>
<td>191 / 509</td>
<td>9.89</td>
<td>2.38 (0.60, 7.46)</td>
</tr>
<tr>
<td>Leveille et al. 1994</td>
<td>22 / 62</td>
<td>212 / 619</td>
<td>18.99</td>
<td>1.06 (0.58, 1.87)</td>
</tr>
<tr>
<td>Hemmelgarn et al. 1997</td>
<td>1198 / 12311</td>
<td>3430 / 39030</td>
<td>31.78</td>
<td>1.12 (1.04, 1.20)</td>
</tr>
<tr>
<td>McGwin et al. 2000</td>
<td>7 / 9</td>
<td>440 / 892</td>
<td>4.73</td>
<td>3.60 (0.68, 35.61)</td>
</tr>
<tr>
<td>Mura et al. 2003</td>
<td>85 / 137</td>
<td>815 / 1663</td>
<td>24.74</td>
<td>1.70 (1.17, 2.48)</td>
</tr>
<tr>
<td>Combined [random effects model]</td>
<td></td>
<td></td>
<td></td>
<td>1.59 (1.10, 2.31)</td>
</tr>
</tbody>
</table>

Heterogeneity: Cochran Q = 16.20 (df = 5, p = 0.006), I² (Inconsistency) = 69.1%

Test for overall effect (DerSimonian-Laird): X² = 6.07, p=0.014
<table>
<thead>
<tr>
<th>Study</th>
<th>Accidents / person years</th>
<th>% Weight</th>
<th>Incidence rate ratio (95% confidence interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ray et al. 1992</td>
<td>46 / 2978</td>
<td>31.51</td>
<td>1.31 (0.94, 1.80)</td>
</tr>
<tr>
<td>Neutel et al. 1995</td>
<td>132 / 37633</td>
<td>23.31</td>
<td>2.49 (1.59, 4.06)</td>
</tr>
<tr>
<td>England et al. 2007</td>
<td>265 / 48769</td>
<td>45.18</td>
<td>1.92 (1.69, 2.17)</td>
</tr>
</tbody>
</table>

Combined (random effects model)

Heterogeneity: Cochran Q = 6.65 (df = 2, p = 0.036), I² (Inconsistency) = 70%

Test for overall effect (DerSimonian-Laird): Z = 3.93, p<0.0001
### Table:

<table>
<thead>
<tr>
<th>Study</th>
<th>Exposed Group</th>
<th>Non-exposed Group</th>
<th>% Weight</th>
<th>Odds Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagier et al. 1993</td>
<td>77 / 65</td>
<td>1031 / 841</td>
<td>28.92</td>
<td>0.97 (0.68, 1.38)</td>
</tr>
<tr>
<td>Longo et al. 2000</td>
<td>32 / 14</td>
<td>996 / 891</td>
<td>15.94</td>
<td>2.04 (1.05, 4.17)</td>
</tr>
<tr>
<td>McGwin et al. 2000</td>
<td>4 / 3</td>
<td>245 / 195</td>
<td>4.04</td>
<td>1.06 (0.18, 7.33)</td>
</tr>
<tr>
<td>Drummer et al. 2004</td>
<td>27 / 6</td>
<td>1214 / 376</td>
<td>9.84</td>
<td>1.39 (0.56, 4.16)</td>
</tr>
<tr>
<td>Dubois et al. 2008</td>
<td>1122 / 428</td>
<td>42944 / 26882</td>
<td>41.26</td>
<td>1.64 (1.47, 1.84)</td>
</tr>
</tbody>
</table>

**Combined (random effects model):**

Heterogeneity: Cochran $Q = 9.30$ (df = 4, $p = 0.054$), $I^2$ (Inconsistency) = 57%

Test for overall effect (DerSimonian-Laird): $X^2 = 12.69$, $p=0.034$
<table>
<thead>
<tr>
<th>Study</th>
<th>Accidents / total</th>
<th>% Weight</th>
<th>Combined (random effects model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagier et al. 1992</td>
<td>53 / 59</td>
<td>45.73</td>
<td>7.21 (3.08, 20.60)</td>
</tr>
<tr>
<td>Longo et al. 1995</td>
<td>15 / 16</td>
<td>8.03</td>
<td>13.42 (2.05, 565.52)</td>
</tr>
<tr>
<td>Movig et al. 2007</td>
<td>11 / 23</td>
<td>46.24</td>
<td>7.44 (2.88, 18.91)</td>
</tr>
</tbody>
</table>

Heterogeneity: Cochran Q = 0.33 (df = 2, p = 0.849),
I^2 (Inconsistency) = 0% (95% CI = 0% to 72.9%)

Test for overall effect (DerSimonian-Laird): X^2 = 48.48, p<0.0001
**Supplementary table 1:** Benzodiazepines and driving performance: experimental studies (All treatments are single oral doses unless specified otherwise.
BAC: blood alcohol concentration. RT: Reaction time. BRT: Brake reaction time. DDD: defined daily dose. SDLP: Standard deviation of lateral position. SDS: Standard deviation of speed, b.i.d.: twice a daily, t.i.d.: three times a day)

<table>
<thead>
<tr>
<th>Study [Ref. No.]</th>
<th>a) Experimental design</th>
<th>b) Subjects</th>
<th>c) Treatment conditions: Drug, dose, duration of treatment if &gt;1 dose</th>
<th>d) Timing of test after dosing</th>
<th>e) Task</th>
<th>f) Outcome measures</th>
<th>g) Results</th>
<th>h) Comments/Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linnoila and Hakkinen, 1974</td>
<td>Double-blind, placebo-controlled</td>
<td>70 professional drivers (19-22y) In 7 groups (10 each)</td>
<td>No drug or drink (Zero group) Placebo drug &amp; drink Alcohol 0.5g/kg Diazepam 10mg Diazepam 10mg + alcohol Codeine 30mg Codeine 30mg + alcohol</td>
<td>30 minutes</td>
<td>40-minute drive in a driving simulator</td>
<td>Steering wheel reversals, number of times brakes used, number of times clutch used, number of times turning signal used, Speed, BRT, number of neglected instructions, number of collisions, driving off the road</td>
<td>Diazepam: More neglected instructions and collisions Codeine: Less steering wheel reversals and more collisions Diazepam + alcohol: More steering wheel reversals, neglected instructions and collisions Codeine + alcohol: More collisions (All comparisons with the Zero group)</td>
<td>No comparisons with placebo. Any statistical corrections made for multiple comparisons not mentioned, although several different variables were compared.</td>
</tr>
<tr>
<td>Moore, 1977</td>
<td>Double-blind, placebo-controlled 2-way crossover</td>
<td>14 males with anxiety required hospital admission. (20-40y)</td>
<td>Medazepam 5–30mg/d (mean 16.5mg) Placebo x 3 weeks</td>
<td>At the end of 3 weeks. Time not specified.</td>
<td>30 min drive in a simulator, Actual driving test</td>
<td>Driving Simulator: BRT, speed, forgetting indications, errors in steering and positioning Actual driving: major (dangerous) or minor (technical) driving errors</td>
<td>Increased minor driving errors while on medazepam.</td>
<td></td>
</tr>
<tr>
<td>Hindmarch et al., 1977</td>
<td>Double-blind placebo controlled 2-way crossover</td>
<td>10 volunteers (5 men, 5 women. mean age 27y)</td>
<td>Clobazam 20mg Placebo x 6 nights</td>
<td>morning following 6\textsuperscript{th} dose (day 7)</td>
<td>Multiple car driving manoeuvres</td>
<td>No. of errors and time taken for gap estimation, reverse parking, garage parking, manoeuvring ability</td>
<td>Reverse parking delayed with clobazam. No other changes.</td>
<td>Acute effect not examined. Negative effects on day 7 may be due to absence of drug effect or to tolerance.</td>
</tr>
<tr>
<td>Biehl, 1979</td>
<td>Double-blind placebo-controlled 3-way crossover study</td>
<td>24 male students (18-24y) with high neuroticism score</td>
<td>Clobazam 20mg Placebo morning for 3 days</td>
<td>On day 2, timing not specified</td>
<td>Driving in traffic</td>
<td>29 variables of driving performance: Observer-rated items and objective measurements</td>
<td>Break reaction time delayed with diazepam compared to clobazam. No other differences.</td>
<td>Any statistical corrections made for multiple comparisons not mentioned, although several different variables were compared.</td>
</tr>
<tr>
<td>Hindmarch and Gudgeon, 1980</td>
<td>Double-blind placebo controlled 3-way crossover study</td>
<td>12 female volunteers (26-40y)</td>
<td>Clobazam 10mg Lorazepam 1mg Placebo t.i.d. x 3 days + 1 dose in morning of 4\textsuperscript{th} day</td>
<td>0.5h after last dose</td>
<td>Multiple car driving manoeuvres</td>
<td>Reverse parking, three point turn, slalom about fixed bollards, width estimation, BRT</td>
<td>Poor performance in parking, three-point turn, slalom and braking after lorazepam compared to clobazam and placebo. No difference in any measures between clobazam and placebo.</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Participants</td>
<td>Treatment</td>
<td>Timepoints</td>
<td>Outcome Measures</td>
<td>Findings</td>
<td></td>
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</tr>
<tr>
<td>de Gier et al., 1981</td>
<td>Observer-blinded, two-groups</td>
<td>9 patients with anxiety (45.6 ±9.6y) and 13 controls (40.6 ±8.4y) (all men) treated by same physician</td>
<td>Diazepam 5mg – 20mg/d. Duration of treatment not specified</td>
<td>Varying times</td>
<td>Driving performance measured according to a checklist by a trained observer</td>
<td>Poor performance in patients taking diazepam Temporal relationship between diazepam dosing and testing not specified. Medical conditions of the control group not mentioned.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Betts and Birtle, 1982</td>
<td>Double-blind placebo-controlled 3-way crossover</td>
<td>12 healthy volunteers, all women</td>
<td>Flurazepam 15mg Temazepam 20mg Placebo</td>
<td>12h</td>
<td>Actual driving test maneuvering ability, gap-acceptance</td>
<td>Poor manoeuvring skills with flurazepam. More hits on sides in passable gaps after both drugs. Many drug-unrelated factors may have increased errors: Subjects unfamiliar with vehicle, only 2 minutes of practice. Instructions to drive as fast as possible.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moskowitz and Smiley, 1982</td>
<td>Double-blind placebo-controlled</td>
<td>48 healthy volunteers (24 men, 24 women, 21-40y) in 3 groups (8 men &amp; 8 women each)</td>
<td>Buspirone 20mg Diazepam 15 mg Placebo daily for 9 days.</td>
<td>Before and 1h after day 1, 8 and 9</td>
<td>Driving simulator task (~ 30 min) Numerous measures: Lateral position control Speed control Headway control Target (e.g. road sign) detection Emergency decision-making</td>
<td>Day 1, postdose: Worst overall performance with diazepam and best performance with buspirone. Day 8, predose: No significant difference among groups. Day 8, postdose: Worst performance with diazepam and best performance with buspirone. Diazepam (1.5xDDD) and buspirone (0.67xDDD) doses not comparable. Analyses of extensive number of variables, but no corrections made for multiple comparisons.</td>
<td></td>
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</tr>
<tr>
<td>O'Hanlon et al., 1982</td>
<td>Double-blind placebo-controlled, 5-way crossover</td>
<td>9 healthy male driving instructors (24-34y)</td>
<td>Diazepam 10mg Diazepam 5mg Placebo control Early-morning control</td>
<td>1h</td>
<td>Standardised highway driving test (~100km) SDLP</td>
<td>Increased SDLP after 10mg diazepam than in other conditions.</td>
<td></td>
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<tr>
<td>Hindmarch and Subhan, 1983</td>
<td>Double-blind placebo-controlled, 4-way crossover</td>
<td>7 healthy female volunteers (25-40y)</td>
<td>Placebo Midazolam 15mg Alcohol 0.5g/kg Midazolam 15mg + alcohol</td>
<td>10h (i.e. following morning)</td>
<td>Actual driving test BRT</td>
<td>No impairment with midazolam, alcohol or midazolam alcohol combination.</td>
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</tr>
<tr>
<td>O'Hanlon, 1984</td>
<td>Double-blind placebo-controlled, 4-way crossover</td>
<td>24 former hypnotic drug users, females aged 25-40y</td>
<td>Flurazepam 30mg Flurazepam 15mg Secobarbitone 200mg Placebo 2 nights at 10pm</td>
<td>10-11h &amp; 16-17h after 2nd dose</td>
<td>Standardised highway driving test (~100km) SDLP</td>
<td>Increased SDLP following all active treatment conditions, both in the following morning (10-11h) and afternoon (16-17h)</td>
<td></td>
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</tr>
<tr>
<td>O'Hanlon, 1984</td>
<td>Double-blind placebo-controlled, 4-way crossover</td>
<td>16 former hypnotic drug users, females aged 25-40y</td>
<td>Loprazolam 2mg Loprazolam 1mg Flunitrazepam 2mg Placebo On 2 nights at 10pm</td>
<td>10-11h &amp; 16-17h following 2nd dose</td>
<td>Standardised highway driving test (~100km) SDLP</td>
<td>Increased SDLP following all active treatment conditions, both in the following morning (10-11h) and afternoon (16-17h). Degree of impairment increases with plasma loprazolam concentration</td>
<td></td>
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<tr>
<td>Study</td>
<td>Design</td>
<td>Participants</td>
<td>Interventions</td>
<td>Outcomes</td>
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<tr>
<td>Willumeit et al., 1984a</td>
<td>Double-blind, placebo-controlled, 3-way crossover</td>
<td>12 healthy volunteers (11 men, 1 woman, 21-30y)</td>
<td>Lormetazepam 2mg Flurazepam 30mg Placebo At 10pm daily for 7 days.</td>
<td>Morning after last dose Driving simulator test (30 min) Correct tracking executions with steering Reaction time Flurazepam: less correct tracking executions and prolonged reaction time compared to placebo Lormetazepam: no difference from placebo</td>
<td></td>
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<tr>
<td>Willumeit et al., 1984b</td>
<td>Double-blind, placebo-controlled, 8-way crossover</td>
<td>16 healthy volunteers (10 men, 6 women, 20-33y)</td>
<td>Lormetazepam 2mg Diazepam 10mg Mepindolol 10mg Placebo, with and with alcohol 0.6g/kg.</td>
<td>1h, 3h, 5h Driving simulator test (30 min) Correct tracking executions with steering Reaction time Flurazepam: impaired correct tracking executions and delayed reaction time, both with and without alcohol. Drug effects potentiated by alcohol Diazepam: impaired correct tracking executions only at 1h postdose. Delayed reaction time throughout. No potentiation of alcohol effects</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Laurell and Tornros, 1986</td>
<td>Double-blind, placebo-controlled, 3-way crossover</td>
<td>18 healthy volunteers, 20-34y</td>
<td>Triazolam 0.25mg Nitrazepam 5mg Placebo at 11pm x 3 nights</td>
<td>9h after 1st &amp; 3rd dose Simulated driving (~2.5h) Actual driving test (30 min) Driving simulator; BRT Actual driving: Number of mistakes in an avoidance manoeuvre</td>
<td></td>
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</tr>
<tr>
<td>O'Hanlon and Volkerts, 1986</td>
<td>Double-blind, placebo-controlled 2-way crossover study</td>
<td>11 insomniacs, women, 26-38y</td>
<td>Placebo 2 days &gt; Temazepam 20mg or Nitrizepam 10mg x 8 days &gt; placebo 3 days (dosing at 10pm)</td>
<td>10h &amp; 16h after day 2, 4, 6, 9, 11, 13 dose Standardised highway driving test (~100km)</td>
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</tr>
<tr>
<td>Schmidt et al., 1986</td>
<td>Randomised double-blind</td>
<td>32 (20 men, 12 women) patients with sleep disorders</td>
<td>Two groups (16 each) Flunitrazepam 2mg Temazepam 20mg 7 nights</td>
<td>Baseline, morning (10h) after day 1 &amp; 7 dose Standardised driving test (25km, ~60min) Steering control Better performance with temazepam and worse performance with flunitrazepam on both days.</td>
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</tr>
<tr>
<td>Brookhuis et al., 1990</td>
<td>Double-blind placebo-controlled 3-way crossover</td>
<td>16 patients with insomnia (6 males, 10 females, 26-41y)</td>
<td>Placebo x 2 nights &gt; Lormetazepam 1mg or Lorazepam 2mg or Flurazepam 30mg x 8 nights &gt; Placebo x 3 nights</td>
<td>10h &amp; 16h after 2 placebo doses (baseline), 2, 4 &amp; 7 active drug doses and 1 &amp; 3 resumed placebo doses Standardised highway driving test (72km) SDLP Driving speed Flurazepam: Significant impairment during treatment period. Worse in the morning. Lormetazepam 1mg or 2mg: No impairment during treatment period.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Friedel et al., 1991</td>
<td>Non-blind study</td>
<td>60 university students (male, 22-26y) in 3 groups (20 each)</td>
<td>Diazepam ~7mg Diazepam ~14mg No drug</td>
<td>Not specified Standardised driving tasks in a driving simulator Accuracy of different responses appropriate for each driving scenario No significant effect of diazepam Simulation closer to real-life driving. Wide individual variation may be due to complex tasks and perhaps too short practice sessions.</td>
<td></td>
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</tr>
<tr>
<td>Study</td>
<td>Design Type</td>
<td>Participants</td>
<td>Treatments</td>
<td>Outcome Measures</td>
<td>Results/Findings</td>
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</tr>
<tr>
<td>Laurell and Tornros, 1991</td>
<td>Double-blind placebo controlled 4-way crossover</td>
<td>24 healthy volunteers (20-32y, moderate drinkers)</td>
<td>Fluorazepam 2 mg, Flurazepam 30 mg, Triazolam 0.5 mg Placebo, x 4 nights Drug treatment = Basiprone 5mg t.i.d. x 1wk &gt; 10mg mane, 5mg noon, 5mg nocte x 3wks; or Diazepam 5mg t.i.d. x 4wks</td>
<td>Drive 20 km in the shortest time in a driving simulator</td>
<td>Average speed Number of crashes Following 2h postdose. Increased reaction time after 1.5h. No other significant effects.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van Laar et al., 1992</td>
<td>Placebo-controlled (Drug treatment double-blind, placebo single-blind)</td>
<td>2 groups of 12 outpatients (6 men, 6 women. 18-50y) with generalised anxiety disorder</td>
<td>Placebo x 7 days &gt; Drug treatment x 4 weeks &gt; placebo x 7 days Drug treatment = Basiprone 5mg t.i.d. x 1wk &gt; 10mg mane, 5mg noon, 5mg nocte x 3wks; or Diazepam 5mg t.i.d. x 4wks</td>
<td>Evening of 7 days of each treatment week, 1.5h after last dose of drug or placebo</td>
<td>Standardised highway driving test (~100km) Buspirone: No impairment in SDLP or speed control throughout treatment. Diazepam: Marked increase in SDLP after 1st week, remain significant up to end of 3rd week. Poor speed control after 1 week, normal thereafter.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volkerts et al., 1992</td>
<td>Double-blind placebo controlled 3-way crossover</td>
<td>18 healthy male volunteers, 25-31y</td>
<td>Lorazepam 1mg Oxazepam 50mg Placebo X 2 nights (10pm)</td>
<td>Simulator: 12h (1st dose). On-the-road: 10h (1st dose), 10h &amp; 16h (2nd dose)</td>
<td>Standardised highway driving test (100km) &amp; Model TS2 driving simulator test Both drugs increased SDLP (oxazepam &gt; lorazepam) in the mornings after 1st and 2nd doses. No effects in afternoon following 2nd dose of either drug. Simulated driving: No impairment with any of the drugs. No correlation between performance &amp; plasma drug concentrations.</td>
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<tr>
<td>(Kuitunen, 1994)</td>
<td>Double-blind placebo controlled 6-way crossover</td>
<td>12 healthy volunteers</td>
<td>Diazepam 15 mg Amitriptyline 50mg Mirtazapine 15mg Diazepam + one other drug Placebo</td>
<td>Before, and after 1.5h &amp; 4.5h</td>
<td>Driving simulator test Tracking errors RT Increased tracking errors and prolonged RT at both times with amitriptyline and both drug combinations. Tracking error severity higher with drug combinations. Diazepam prolonged Rt after 1.5h. No other significant effects.</td>
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<tr>
<td>Kuitunen, 1994</td>
<td>Double-blind placebo-controlled 6-way crossover</td>
<td>12 healthy volunteers</td>
<td>Zopiclone 7.5 mg Triazolam 0.25mg Placebo Alcohol 0.8 g/kg Zopiclone / triazolam + alcohol</td>
<td>Before, and after 1.5h &amp; 4.5h</td>
<td>Driving simulator test Tracking errors RT Drugs alone and in combination with alcohol increased RT in both times and tracking errors at 1.5h. Triazolam + alcohol increased tracking errors at 4.5h. NO other significant effects.</td>
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<td>Mattila et al., 1994</td>
<td>Double-blind placebo-controlled 5-way crossover</td>
<td>12 healthy volunteers (6 men, 6 women. 19-32y)</td>
<td>Suriplone 0.4 mg Zopiclone 7.5mg Placebo, alone and together with 50 mg chlorpromazine</td>
<td>Before, and after 1.5h, 3.5h &amp; 6h</td>
<td>Driving simulator test Tracking errors RT Zopiclone increased tracking errors and prolonged reaction time after 1.5h. No significant effect thereafter. Zopiclone chlorpromazine combination prolonged RT even at 6h postdose.</td>
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<tr>
<td>O’Hanlon et al., 1995</td>
<td>Double-blind placebo controlled 4-way crossover</td>
<td>16 healthy volunteers (8 men, 8 women, 25-43y)</td>
<td>Ondansetron 1mg b.i.d. Ondansetron 5mg b.i.d. Diazepam 5mg t.i.d. Placebo 1st evening + 7 days</td>
<td>1h after evening dose on day 1 and day 8</td>
<td>Standardised highway driving test (~100km) SDLP Increased SDLP with diazepam on both days but not with ondansetron</td>
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<td>Study</td>
<td>Designation</td>
<td>Participants</td>
<td>Intervention</td>
<td>Measures</td>
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<td>O’Hanlon et al., 1995</td>
<td>Double-blind placebo controlled 3-way crossover</td>
<td>18 healthy volunteers (9 men, 9 women, 22-34y)</td>
<td>Lorazepam 0.5mg Suriclone 0.2mg Placebo t.i.d. x 9 days starting from midnight day 1</td>
<td>2-3h after afternoon dose of day 2 &amp; day 9</td>
<td>Standardised highway driving test (~100km) SDLP Headway maintenance SDLP: increase with both drugs on both days. Headway maintenance: impairment on both days with lorazepam and day 2 but not day 9 with suriclone</td>
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<td>O’Hanlon et al., 1995</td>
<td>Randomised double-blind placebo controlled</td>
<td>24 men and 36 women with anxiety (24-64y) in 3 groups</td>
<td>Lorazepam 2mg (n=18) Alpidem 5mg (n=19) Placebo (n=19) b.i.d. run-in, treatment and washout periods, 7, 8 &amp; 6 days respectively</td>
<td>Day 1 before run-in, Day 8 &amp; 15, 3-4h after morning dose</td>
<td>Standardised highway driving test (~100km) SDLP Significant increase in SDLP with both drugs on both days 8 and 15. Change is less with alpidem. SDLP of patients were similar to those of healthy volunteers of the previous two studies</td>
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<td>Vermeeren et al., 1995</td>
<td>Double-blind placebo controlled 3-way crossover</td>
<td>17 women (25-51y) with insomnia</td>
<td>Flunitrazepam 2mg Zolpidem 10mg Placebo</td>
<td>10-11h</td>
<td>Standardised highway driving test (~100km) SDLP No significant impairment by any of the drugs</td>
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<tr>
<td>Vermeeren et al., 1998a</td>
<td>Double-blind placebo controlled 4-way crossover</td>
<td>23 healthy women (24-45y)</td>
<td>Chlorpheniramine 8mg / 12mg noce &gt; terfenadine 60 mg mane Flurazepam 30mg night &gt; placebo morning Placebo mighte &amp; morning X 2 cycles</td>
<td>30min after last morning dose (10h after last nightly dose)</td>
<td>Standardised highway driving test (~100km) SDLP SDS RT speed changes of leading car Flurazepam: Significant increase of SDLP and SDS with flurazepam compared to other 3 conditions. Significant delay in RT compared to placebo. Chlorpheniramine / terfenadine combinations: No significant impairment. 2 subjects on flurazepam were too drowsy to complete highway driving test</td>
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<td>Vermeeren et al., 1998a</td>
<td>Double-blind placebo controlled 7-way crossover</td>
<td>28 healthy volunteers (14 men, 14 women, 23-40y)</td>
<td>Zaleplon 10/20mg &gt; placebo Placebo &gt; zaleplon 10/20mg Zopiclone 7.5mg &gt; placebo Placebo &gt; zopiclone 7.5mg Placebo &gt; placebo Bedtime &gt; 5h later</td>
<td>5h after 2nd dose</td>
<td>Standardised highway driving test (~100km) SDLP Zopiclone: Increased after bedtime dosing and after middle of the night dosing. Worse in latter condition. Zaleplon: No significant increase after either bedtime or middle of the night administration of any of the doses,</td>
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<td>(Bocca et al., 1999)</td>
<td>Double-blind, placebo-controlled 3-way crossover</td>
<td>16 healthy volunteers (9 men, 7 women, 20-30y) in 2 groups (9am &amp;11am) of 8.</td>
<td>Zolpidem 10 mg Zopiclone 7.5 mg Flunitrazepam 1 mg Placebo single dose at 11pm</td>
<td>10h (9am group) 12h (11am group)</td>
<td>Driving simulator test (~90 min) Mean variance of lateral position Mean variance of vehicle velocity Mean variance of lateral position: Increased by zopiclone and flunitrazepam at 10h but not by zolpidem. No effect by any drugs after 12h. Mean variance of vehicle velocity: Not affected by any of the drugs. Demand was ‘to drive as quickly as possible’ while maintaining lateral stability. Constant speed was not a direct test demand but was an outcome measure.</td>
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<td>Mercier-Guyon et al., 1999</td>
<td>Randomised double-blind 2-way crossover</td>
<td>16 healthy male volunteers (29-44y)</td>
<td>Lorazepam 0.5mg morning, 0.5mg lunchtime, 1mg bedtime Captodiamine 50mg t.i.d. X 7 days</td>
<td>Before and after 7-day treatment. Time not specified</td>
<td>~15-min drive in 900m circuit with different driving manoeuvres Number of errors due to clumsiness (slalom task), excessive inhibition (braking too early, too conservative gap judging), disinhibition (braking too late, forcing passage when gap is too narrow) Lorazepam cause more errors due to clumsiness and disinhibition compared to captodiamine. No difference in errors due to excessive inhibition The disinhibitory effect of lorazepam is noteworthy.</td>
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<td>Study and Year</td>
<td>Design</td>
<td>Age and Treatment</td>
<td>Outcome Measures</td>
<td>Results</td>
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<td>Vanakoski et al., 2000</td>
<td>Double-blind placebo controlled 3-way crossover</td>
<td>9 young (22-24y) and 9 old (55-77y)</td>
<td>Young: Diazepam 15mg, alcohol 0.8g/kg, placebo Old: Diazepam 10mg, alcohol 0.7g/kg, placebo</td>
<td>1.5h before and 4h after</td>
<td>Driving simulator test</td>
<td>BRT: tracking errors (simple and complex), global driving performance</td>
<td>Impaired reaction time and global driving performance in both young and old groups after diazepam. Increased simple tracking errors in both young and old groups in daylight condition.</td>
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<tr>
<td>Van Laar et al., 2001</td>
<td>Double-blind placebo controlled 3-way crossover</td>
<td>18 healthy male volunteers (25-36y)</td>
<td>Lorazepam 1.5mg, Ritalserine 5mg Placebo</td>
<td>3h after last dose</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP SDS</td>
<td>Significant increase in SDLP with lorazepam. No effect on SDS by any of the drugs. Lack of tolerance to lorazepam after 1 week</td>
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<tr>
<td>Verster et al., 2002a</td>
<td>Double-blind placebo controlled 5-way crossover</td>
<td>30 healthy volunteers (15 men, 15 women), Age (SD): 24.0±2.4y</td>
<td>Zaleplon 10mg or 20mg Zolpidem 10mg or 20mg Placebo</td>
<td>10h</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP SDS</td>
<td>Zolpidem: SDLP and SDS significantly increased with both doses. Significant dose-response relationship. Zaleplon: No significant difference from placebo. 3 subjects on zolpidem made excessive errors in driving and could not complete the test.</td>
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<tr>
<td>Verster et al., 2002b</td>
<td>Randomised double-blind placebo controlled 2-way crossover</td>
<td>12 healthy volunteers (5 men, 7 women, 27-38y)</td>
<td>Lormetazepam 1mg Placebo X 3 nights</td>
<td>Baseline, morning after last dose of each treatment</td>
<td>Simulated drive (~15km) in interacting traffic</td>
<td>Time length of run, number of infractions and speed exceedings, time to collision</td>
<td>No significant differences in any of the measures</td>
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<td>Verster et al., 2002c</td>
<td>Randomised double-blind placebo controlled 2-way crossover</td>
<td>20 healthy volunteers (8 men, 12 women), Age (SD): 25.1±2.9y</td>
<td>Alprazolam 1mg Placebo</td>
<td>1h</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP SDS</td>
<td>6 subjects did not complete driving test after alprazolam. Both outcome measures significantly impaired after alprazolam The SDLP increase equivalent to that caused by alcohol at a blood concentration of 1.5g/l.</td>
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<td>Partinen et al., 2003</td>
<td>Randomised double-blind placebo controlled 3-way crossover</td>
<td>18 insomniaics, women (35-60y)</td>
<td>Temazepam 20mg Zolpidem 10mg Placebo</td>
<td>Baseline and 5.5h after each dose</td>
<td>Driving simulator test (110km)</td>
<td>Lateral position deviation Speed deviation Reaction time Time to collision</td>
<td>Greater lateral position deviation after zolpidem but not after temazepam. No drug effects on other measures.</td>
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<tr>
<td>Staner et al., 2005</td>
<td>Randomised double-blind placebo controlled 4-way crossover</td>
<td>23 patients (9 men and 14 women, 18-65y) with primary insomnia</td>
<td>Zolpidem (10 mg) Zopiclone (7.5 mg) Lormetazepam (1 mg) Placebo x 7 nights at 10:30pm</td>
<td>9-11h (7:30am - 9:30am), on day 2 &amp; day 8</td>
<td>Simulated driving in light traffic (~ 60 min)</td>
<td>Lateral position deviation Speed deviation Number of collisions</td>
<td>Zopiclone increased the number of collisions. Lormetazepam increased the speed deviation. No changes by zolpidem.</td>
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<tr>
<td>Study</td>
<td>Design</td>
<td>Participants</td>
<td>Interventions</td>
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<tr>
<td>Leufkens et al., 2007</td>
<td>Double-blind placebo-controlled 3-way crossover</td>
<td>18 healthy volunteers (9 men, 9 women, 20-45y)</td>
<td>Alprazolam slow release (XR) 1mg, Alprazolam immediate release (IR) 1mg, Placebo</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP, SDS</td>
<td>Increased with both alprazolam preparations. Increase with alprazolam IR is twice the increase caused by alprazolam XR. SDS: No change.</td>
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<td>Boyle et al., 2008</td>
<td>Randomised double-blind placebo-controlled 2-way crossover</td>
<td>32 healthy volunteers (17 men and women, 19–47y)</td>
<td>Eszopiclone 3mg, Placebo</td>
<td>Closed-circuit driving</td>
<td>BRT</td>
<td>No difference in change BRT from baseline either with placebo or eszopiclone</td>
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<tr>
<td>Boyle, et al., 2008</td>
<td>Randomised double-blind placebo-controlled 2-way crossover</td>
<td>23 patients with primary insomnia (22 men, 10 women, 20-55y)</td>
<td>Eszopiclone 3mg, Placebo</td>
<td>Closed-circuit driving</td>
<td>BRT</td>
<td>No difference in change BRT from baseline either with placebo or eszopiclone</td>
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<td>Otmani et al., 2008</td>
<td>Randomised double-blind placebo-controlled 4-way crossover</td>
<td>16 healthy volunteers (12 men and 4 females, 45–55y)</td>
<td>Prolonged-release melatonin 2mg, Zolpidem 10mg, Both drugs, Placebo</td>
<td>Driving simulator test (60min, light traffic)</td>
<td>Number of collisions, standard deviation from the speed limit, standard deviation of absolute speed, standard deviation from ideal route</td>
<td>Number of collisions, standard deviation from speed limit and standard deviation from ideal route increased with zolpidem and zolpidem-melatonin combination at 2h. No significant difference at 13h.</td>
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<tr>
<td>Leufkens et al., 2009</td>
<td>Double-blind placebo-controlled 5-way crossover</td>
<td>25 healthy volunteers (13 men, 12 women, Age (SD): 31.4±7.5y)</td>
<td>Gaboxadol 15mg &gt; placebo, Zopiclone 7.5mg &gt; placebo, Placebo &gt; gaboxadol 15mg, Placebo &gt; zolpidem 10mg, Placebo &gt; placebo 11pm &gt; 4am</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP, SDS</td>
<td>Both SDLP and SDS increased after zopiclone 11pm dose, and zolpidem and gaboxadol 4am doses. Only SDS increased after gaboxadol 11pm dose.</td>
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<td>Leufkens and Vermeeren, 2009</td>
<td>Double-blind placebo-controlled 3-way crossover</td>
<td>18 healthy elderly volunteers (10 women, 8 men, 55-75y)</td>
<td>Temazepam 20mg, Zopiclone 7.5mg, Placebo</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP, SDS</td>
<td>SDLP: Significant increase after zopiclone but not temazepam. SDS: Significantly higher with zopiclone than with temazepam.</td>
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<tr>
<td>Meskali et al., 2009</td>
<td>Double-blind placebo-controlled 3-way crossover</td>
<td>16 healthy elderly volunteers (8 women, 8 men, 55-65y)</td>
<td>Flunitrazepam 1mg, Zolpidem 10mg, Zopiclone 7.5mg, Placebo</td>
<td>Driving simulator test (urban route with accident scenarios)</td>
<td>Number of collisions (of 5 accident scenarios per treatment)</td>
<td>No significant increase with any of the drugs. Total number of collisions among 4 conditions compared with chi-square test.</td>
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</table>
**Supplementary table 2:** Antidepressants and driving performance: experimental studies (All treatments are single oral doses unless specified otherwise.

BAC: blood alcohol concentration. RT: Reaction time. BRT: Brake reaction time. DDD: defined daily dose. SDLP: Standard deviation of lateral position. SDS: Standard deviation of speed, b.i.d.: twice a day, t.i.d.: three times a day)

<table>
<thead>
<tr>
<th>Study</th>
<th>a) Design</th>
<th>b) Subjects</th>
<th>c) Treatment conditions: Drug, dose, duration if &gt;1 dose</th>
<th>d) Timing of test after dosing</th>
<th>e) Task</th>
<th>f) Outcome measures</th>
<th>g) Results</th>
<th>h) Comments</th>
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</thead>
<tbody>
<tr>
<td>Landauer et al., 1969</td>
<td>Randomised double-blind placebo-controlled</td>
<td>21 healthy volunteers in 3 groups (6 men, 1 woman in each group) Mean age(SD): 22.1(1.2)y</td>
<td>Amitriptyline 0.8mg /kg night &amp; morning Amitriptyline morning only Placebo &gt; Alcohol after 1st test</td>
<td>2h after morning dose and 15min after alcohol</td>
<td>Driving simulator test</td>
<td>Steering control (Proportion of steering errors to total correct responses)</td>
<td>Before alcohol: No group differences. After alcohol: no change in double placebo group, but increased in amitriptyline groups. Worst in double amitriptyline group.</td>
<td>Placebo only group did not show any impairment after alcohol despite having a BAC of 0.08% which can impair driving.</td>
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<tr>
<td>Clayton et al., 1977</td>
<td>Randomised double-blind placebo-controlled</td>
<td>40 male volunteers (18-29y) in 4 groups (10 each)</td>
<td>Imipramine 25mg t.i.d. Viloxazine 50mg t.i.d. Placebo t.i.d. x 7 days No drug</td>
<td>Before, 2h after 1st dose, 7 doses (day 3), 21 doses (day 7)</td>
<td>Driving test with a slalom task and a gap estimation task</td>
<td>Number of errors in a weaving task Gap estimation</td>
<td>Weaving task: Imipramine increased the number of errors, when results collapsed across all testing days. No acute effect after a single dose. Gap estimation: No group difference</td>
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<td>Hindmarch et al., 1983</td>
<td>double-blind placebo-controlled 3-way crossover</td>
<td>9 healthy female volunteers (30-45y)</td>
<td>Amitriptyline 50mg Zimeldine 200mg Placebo</td>
<td>Before, 2h &amp; 5h postdose</td>
<td>Brake reaction during actual driving</td>
<td>BRT</td>
<td>Increased SDLP following amitriptyline, doxepin and mianserin. 1/3 of subjects on amitriptyline could not complete the test.</td>
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<tr>
<td>O’Hanlon, 1984</td>
<td>Double-blind, placebo-controlled, 5-way crossover</td>
<td>20 healthy male volunteers (22-32y)</td>
<td>Amitriptyline 25mg Doxepin 25mg Mianserin 10mg Oxpantoline 25mg Placebo t.i.d. x 1 day</td>
<td>1:00h-2:15h after last dose</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP</td>
<td>Increased SDLP following amitriptyline, doxepin and mianserin. 1/3 of subjects on amitriptyline could not complete the test.</td>
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<td>Hindmarch et al., 1988</td>
<td>Double-blind placebo-controlled 5-way crossover</td>
<td>9 healthy female volunteers (28-55y)</td>
<td>Amitriptyline 50mg Lofepramine 70mg Lofepramine 140mg Nomifensine 100mg Single morning doses</td>
<td>Same day, time not specified</td>
<td>Tracking task in a driving simulator</td>
<td>Mean deviation form target</td>
<td>Increased deviation (poor performance) after amitriptyline. No impairment after other drugs.</td>
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<td>Kuitunen, 1994</td>
<td>Double-blind placebo-controlled 6-way crossover</td>
<td>12 healthy volunteers</td>
<td>15 mg of diazepam 50 mg of amitriptyline 15 mg of mirtazapine Diazepam + one other drug Placebo</td>
<td>Before, and after 1.5h &amp; 4.5h</td>
<td>Driving simulator test</td>
<td>Tracking errors RT</td>
<td>Increased tracking errors and prolonged RT at both times with amitriptyline and both drug combinations. Diazepam prolonged RT after 1.5h. No other significant effects.</td>
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<td>Intervention</td>
<td>Outcome Measures</td>
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<td>Ramaekers et al., 1994</td>
<td>Double-blind placebo controlled 3-way crossover</td>
<td>18 healthy volunteers (9 men, 9 women, 26-54y)</td>
<td>Moclobemide 200 mg b.i.d. Mianserin 10 mg t.i.d. Placebo x 8 days</td>
<td>2.5h after 3rd daily dose on day 1 and day 8.</td>
<td>Standardised highway driving test (~100km) SDLP Increased SDLP after mianserin on both days. No change with moclobemide.</td>
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<tr>
<td>Ramaekers et al., 1994</td>
<td>Double-blind placebo controlled 4-way crossover</td>
<td>16 healthy volunteers (8 men, 8 women, 23-40y)</td>
<td>Brofaromine 50mg b.i.d. Brofaromine 75mg b.i.d. Doxepin 25 mg t.i.d. Placebo x 8 days</td>
<td>3h after 3rd daily dose on day 1 and day 8</td>
<td>Standardised highway driving test (~100km) SDLP Increased SDLP after doxepin on day 1 but not on day 8. No change with brofaromine.</td>
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<td>Ramaekers et al., 1995</td>
<td>Double-blind placebo controlled 3-way crossover</td>
<td>18 healthy volunteers (10 men, 8 women, 21-45y)</td>
<td>Dofetilide 75mg night x 8days + 150mg night x 13 days Fluoxetine 20mg at night x 22 days Placebo at night x 22 days</td>
<td>14h after 1st, 8th &amp; 22nd dose</td>
<td>Standardised highway driving test (~100km) SDLP Headway variability No significant effects of either drug on SDLP or headway variability</td>
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<tr>
<td>Robbe and O’Hanlon, 1995</td>
<td>Double-blind placebo controlled 4-way crossover</td>
<td>16 healthy male volunteers (21-28y)</td>
<td>Paroxetine 20mg morning Paroxetine 40mg morning Amitriptyline 50mg &amp; 25mg morning Placebo x 8 days</td>
<td>1.5h &amp; 5h after morning dose on day 1 &amp; 8</td>
<td>Standardised highway driving test (~100km) SDLP Day 1: Impaired with amitriptyline both 1.5h &amp; 5h postdose. No impairment with paroxetine. Day 8: Not impaired by any of the treatments. Effect of TCA imipramine is in contrast to those observed in epidemiological studies.</td>
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<tr>
<td>Van Laar et al., 1995</td>
<td>Double-blind placebo controlled 4-way crossover</td>
<td>12 healthy adults (24-38y) &amp; 12 elderly (60-72y), 6 men, 6 women each.</td>
<td>Nefazodone 100mg Nefazodone 200 mg Imipramine 50 mg Placebo b.i.d. x 7 days</td>
<td>2.25h after morning dose on day 1 &amp; 7</td>
<td>Standardised highway driving test (~100km) SDS Day 1: Imipramine increased SDLP in Adult group but not in Elderly group. No significant effect after nefazodone. Day 7: No significant effect of imipramine on SDS in either group. SDS: No significant effect by drugs.</td>
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<td>Ramaekers et al., 1998</td>
<td>Double-blind placebo controlled 3-way crossover</td>
<td>18 healthy volunteers (9 men, 9 women, 21-35y)</td>
<td>Mirtazapin 15mg x 7days &gt; 30mg x 8days Mianserin 30mg x 8days &gt; 60mg x 8days Placebo x 15days</td>
<td>Morning following the evening dose (15-18h) on day 2, 8, 9, 16</td>
<td>Standardised highway driving test (~100km) SDLP Significant, but minor increase in day 2 &amp;16 with mirtazapine. Marginally increased in day 8 with mianserin.</td>
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<td>O’Hanlon et al., 1998</td>
<td>Randomized, double-blind, placebo-controlled, 4-way crossover</td>
<td>37 healthy volunteers (22-40y) enrolled, 22 completed</td>
<td>Venlafaxine 37.5 mg b.i.d. x 14 days Venlafaxine 37.5 mg b.i.d. x 7 days &gt; 75 mg b.i.d. x 7 days Mianserin 10 mg t.i.d. x 7 days &gt; 20 mg t.i.d. x 7days Placebo t.i.d. x 14 days</td>
<td>2h postdose on day 1, 7, 8 &amp; 15</td>
<td>Standardised highway driving test (~100km) SDLP Increased after mianserin in all 4 test days. No significant effect with venlafaxine. SDS: Increased after mianserin (compared to placebo) on day 1. No other changes. 7 subjects withdrew due to adverse effects of venlafaxine or mianserin. Results may underestimate the actual effect.</td>
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<td>Ridout and Hindmarch, 2001</td>
<td>Double-blind placebo controlled 4-way crossover</td>
<td>16 healthy volunteers (10 men, 6 women, 21-44y)</td>
<td>Tianeptine 12.5 mg Tianeptine 37.5 mg, Mianserin 30 mg Placebo</td>
<td>1.5h, 3h, 4.5h &amp; 6h</td>
<td>Drive on a closed circuit at 30 miles/h BRT Mianserin delayed BRT significantly longer than other three conditions. Tianeptine 37.5mg causes a marginal delay. No effect by tianeptine 12.5mg.</td>
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<td>Authors, Year</td>
<td>Study Design</td>
<td>Participants</td>
<td>Intervention</td>
<td>Time Points</td>
<td>Outcome Measures</td>
<td>Results</td>
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<td>Richet et al., 2004</td>
<td>Double-blind placebo-controlled 4-way crossover</td>
<td>12 healthy male volunteers (18-30y)</td>
<td>Milnacipran 50mg + alcohol, Placebo + alcohol (b.i.d. x 1 day)</td>
<td>2h</td>
<td>Driving test with reactions to visual and auditory stimuli</td>
<td>BRT: Driving performance evaluated by instructors</td>
<td>Impaired with alcohol. Milnacipran has no effect compared to placebo and does not modify the effect of alcohol.</td>
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<td>Wingen et al., 2005</td>
<td>Randomised double-blind placebo-controlled 3-way crossover</td>
<td>18 healthy volunteers (9 men, 9 women, 21-40y)</td>
<td>Escitalopram 10mg x 7 days &gt; 20mg x 8 days, Mirtazapine 30mg x 7 days &gt; 45mg x 8 days, Placebo x 15 days</td>
<td>10:30am (following the evening dose) on day 2, 9, 16</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP: Increased SDLP day 2. No effect on day 9 or 16. No effect on SDS. Escitalopram: No effect on either SDLP or SDS.</td>
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<td>Veldhuijzen et al., 2006</td>
<td>Randomised double-blind placebo-controlled 2-way crossover</td>
<td>7 chronic neuropathic pain patients (4 men, 3 women, 42-58y)</td>
<td>Amitriptyline 25mg Placebo at night x 15 days</td>
<td>13h, on day 2 and day 16</td>
<td>Standardised highway driving test (~100km)</td>
<td>SDLP: Subjective self-assessment of driving quality. Amitriptyline increases SDLP on day 2 but no significant effect on day 16. No difference in subjective assessment of driving quality.</td>
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<td>Brunnauer et al., 2008</td>
<td>Randomised comparative clinical study</td>
<td>40 depressed patients (18 women, 22 men, 25-57y) + 10 matched healthy controls</td>
<td>Long-term treatment with, Reboxetine (for 20 patients) Mirtazapine (for 20 patients)</td>
<td>Before, 7 &amp; 14 days after initiation of treatment</td>
<td>Driving simulator test</td>
<td>Number of collisions: Before treatment: More collisions in patient groups. Day 14: Significant decline in collisions compared to baseline, with both drugs. Number of collisions similar in patients and healthy controls in day 14. Timing of dosing before testing is not specified.</td>
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<td>Iwamoto et al., 2008a, Iwamoto et al., 2008b</td>
<td>Double-blind placebo-controlled 3-way crossover</td>
<td>17 healthy male volunteers (30-42y)</td>
<td>Paroxetine 10mg Amitriptyline 25mg Placebo</td>
<td>Pre-treatment and 1h &amp; 4h postdose</td>
<td>Simulated driving with road tracking, car following and braking</td>
<td>SDLP: Variability of headway BRT: 1h: No differences between conditions. 4h: Amitriptyline increased SDLP and variability of headway. Paroxetine no effect. No differences in BRT. Moderate positive correlation between SDLP and plasma amitriptyline concentration.</td>
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<td>Shen et al., 2009</td>
<td>Randomised controlled trial</td>
<td>28 patients with major depressive disorder: 14 treated (12 women, 2 men. 29-67y), 14 no treatment (10 women, 4 men. 26-62y)</td>
<td>Mirtazapine 30mg night x 30 days</td>
<td>Morning and afternoon: baseline, day 2, 9, 16 and 30 (untreated group tested baseline, day 2 &amp; 9)</td>
<td>Computerised driving simulator test</td>
<td>Number of crashes, deviation of lateral position</td>
<td>Mirtazapine group: Improvement in road positioning in day 2, 9, 16, 30 compared to baseline. Significant reduction of crashes on day 30 compared to baseline. Untreated: No improvement of driving performance on day 2 or 9. Not tested beyond 9 days. Significant group difference on day 9. Incomplete follow up of the untreated group.</td>
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Supplementary table 3: Opioids and driving performance: experimental studies (All treatments are single oral doses unless specified otherwise. SDLP: Standard deviation of lateral position. SDS: Standard deviation of speed)

| Study                          | a) Design                      | b) Subjects                                    | c) Treatment conditions: Drug, dose, duration if >1 dose | d) Timing of test after dosing | e) Task                                   | f) Outcome measures                                      | g) Results                                                                                       | h) Comments                                                                                     |
|-------------------------------|-------------------------------|-----------------------------------------------|-------------------------------------------------------|-------------------------------|------------------------------------------|-----------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Linnoila and Hakkinen, 1974   | Double-blind, placebo-controlled | 70 professional drivers (19-22y) In 7 groups (10 each) | No drug or drink (Zero group)                        | 30 minutes                    | 40-minute drive in a driving simulator  | Steering wheel reversals, number of times brakes used, number of times clutch used, number of times turning signal used, Speed, brake reaction times, number of neglected instructions, number of collisions, driving off the road | Diazepam: More neglected instructions and collisions Codeine: Less steering wheel reversals and more collisions Diazepam + alcohol: More steering wheel reversals, neglected instructions and collisions Codeine + alcohol: More collisions (All comparisons with the Zero group) | No comparisons with placebo. Any statistical corrections made for multiple comparisons not mentioned, although several different variables were compared. |
| Menefee et al., 2004          | Prospective one group pre-test, post-test design | 23 patients (17 men, 6 women. 18-67y) on <15mg equivalent of oxycodone | Transdermal fentanyl 1month titration period and 1 month stabilization period (median 50micrograms/h) period | Not applicable                  | Driving simulator task                     | Reaction time and errors in braking, steering, speed and signalling | No differences in outcome measures before and during treatment. | |
| Verster et al., 2006          | Randomised double-blind placebo-controlled 5-way crossover | 18 healthy volunteers (6 men, 12 women). Mean (SD) age: 24.0 (1.6)y | Oxycodone / Paracetamol 5/325mg, 10/650mg Bromofenac 25mg, 50mg Placebo | 1h                            | Standardised highway driving test (~100km) | SDLP SDS                                   | No difference between active drugs and placebo conditions in any of the measures. Significant dose-response relationship for oxycodone / paracetamol | 
References:


Vermeeren A, O'Hanlon JF, Declerck AC, Kho L. Acute effects of zolpidem and flunitrazepam on sleep, memory and driving performance, compared to those of partial sleep deprivation and placebo. Acta Ther 1995;21(1):47-64.

Vermeeren A, Ramaekers JG, Leeuwen CJV, Hanlon JFO. Residual effects on actual car driving of evening dosing of chlorpheniramine 8 and 12 mg when used with terfenadine 60 mg in the morning. Hum Psychopharmacol 1998b;13(S2):S79-S86.


