Risk of motor vehicle accidents related to sleepiness at the wheel: a systematic review and meta-analysis

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ABSTRACT

Study objectives: Sleepiness at the wheel is widely believed to be a cause of motor vehicle accidents. Nevertheless, a systematic review of studies investigating this relationship has not yet been published. The objective of this study was to quantify the relationship between sleepiness at the wheel and motor vehicle accidents.

Methods: A systematic review was performed using Medline, Scopus and ISI Web of Science. The outcome measure of interest was motor vehicle accident defined as involving four or two wheeled vehicles in road traffic, professional and non-professional drivers, with or without objective consequences. The exposure was sleepiness at the wheel defined as self-reported sleepiness at the wheel. Studies were included if they provided adjusted risk estimates of motor vehicles accidents related to sleepiness at the wheel. Risk estimates and 95% confidence intervals (95%CI) were extracted and pooled as odds ratios (OR) using a random-effect model. Heterogeneity was quantified using Q statistics and the I^2 index. The potential causes of heterogeneity were investigated using meta-regressions.

Results: Ten cross-sectional studies (51,520 subjects), six case-control studies (4,904 subjects), and one cohort study (13,674 subjects) were included. Sleepiness at the wheel was associated with an increased risk of motor vehicle accidents (pooled OR 2.51 [95%CI 1.87; 3.39]). A significant heterogeneity was found between the individual risk estimates (Q =93.21; I^2 = 83%).

Conclusions: Sleepiness at the wheel increases the risk of motor vehicle accidents and should be considered when investigating fitness to drive. Further studies are required to explore the nature of this relationship.

KEYWORDS

Sleepiness, sleepiness at the wheel, motor vehicle accidents, systematic review

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STATEMENT OF SIGNIFICANCE

The most frequent causes of sleepiness at the wheel (sleep disorders i.e. sleep apnea, behavioral factors such as sleep deprivation and engagement in shift work) need to be investigated because is a cause of motor vehicle accidents. Indeed, sleepiness at the wheel is associated with an increased risk of motor vehicle accidents (2.56 [95%CI 1.91; 3.43]). Investigation of sleepiness at the wheel should be systematically added to the classical Epworth Sleepiness Scale to efficiently determine fitness to drive and it is important to explain the distinction between these two behaviors to physicians and patients. Because it is a major international public health issue, it is important to continue to develop road safety programs to inform drivers about this risk.

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INTRODUCTION

Behavioral sleepiness can be defined as difficulty in remaining awake even while carrying out activities[1]. Sleepiness at the wheel can be defined as difficulty in remaining awake interfering with driving skills. Motor vehicle accidents are a leading cause of mortality and morbidity worldwide and are expected to be the fourth leading cause of death in 2030[2,3]. In Europe, traffic accidents caused 120,000 deaths and 2.4 million injuries each year[4]. The proportion of traffic accidents attributable to sleepiness varies across countries from 3.9% to 33% in the United States[5], France[6,7] and New Zeeland[8]. In the last fifteen years, several studies suggested that sleepiness at the wheel is an important factor contributing to road traffic accidents[6,7,9-11]. Sleepiness at the wheel is now a major international public health issue as it substantially contributes to the heavy burden of traffic-related morbidity and mortality[8,12]. Ten to thirty percent of fatal accidents have been attributed to sleepiness at the wheel[7,13]. Sleepiness-related motor vehicle accidents have been widely acknowledged as resulting both from falling asleep while driving and from behavior impairment attributable to sleepiness[14]. As shown in previous studies, sleepiness at the wheel is one of the most important sleep-related factors associated with accident risk[6-8, 11]. It can be caused by various sleep disorders (i.e. sleep apnea[15]) but also by behavioral factors such as sleep deprivation[16-18] and engagement in shift work[9, 19]. However, the magnitude of the relationship between sleepiness at the wheel and motor vehicle accidents risk is very different among studies[6, 8, 11, 12, 20].

To our knowledge, a systematic review of studies investigating the relationship between sleepiness at the wheel and motor vehicle accident has not yet been published. The current study was designed to provide evidence by conducting a systematic review of the relevant literature concerning sleepiness at the wheel (as the exposure) and motor vehicle accidents (outcome measure of interest). The literature consists of observational studies in adult drivers providing adjusted risk estimates of motor vehicle accidents related to sleepiness at the wheel with a presence of a comparison group. This review provides valuable input for recommendations about evaluating driving risk in sleepy drivers. Therefore, the primary objective of this study was to study the risk of motor vehicle accidents related to sleepiness at the wheel through a systematic review and a meta-analysis of observational studies. The secondary objective was to study the influence of sleep disorders and behavioral factors on this risk.

Accepted Manuscript

METHODS

This study meets the requirements of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement[21] (Supplement file S8). (*Systematic review registration number: PROSPERO 2015 CRD42015024805).*

Eligibility criteria

Observational studies eligible for this meta-analysis were cohort studies, case-control studies and cross-sectional studies providing adjusted risk estimates of motor vehicle accidents related to sleepiness at the wheel. The outcome measure of interest is motor vehicle accidents defined as involving four- or two-wheeled vehicles in road traffic, professional and non-professional drivers, with or without objective consequences (e.g. police intervention or an economic loss or material or physical damage).The exposure was sleepiness at the wheel defined as self-reported sleepiness at the wheel, which refers to the perception of sleepiness (difficulty in remaining awake) while driving during a specific period. The inclusion criteria were 1) Outcome of interest: motor vehicle accidents 2) Exposure: Sleepiness at the wheel evaluated with a specific question 3) Sleep disorders or sleep hygiene measured through individual declaration or through clinical sleep evaluation 4) Presence of a comparison group. The exclusion criteria were 1) Case reports and case series with no comparison group 2) Experimental studies (real driving, simulator driving) 3) Pedestrian injuries, 4) Bicycle injuries 5) Studies involving children 6) Studies in which the distinction between near-misses accidents and accidents is not clear.

Search strategy

Medline, Scopus and ISI web of knowledge databases were searched using keywords related to *observational studies*, *motor vehicle accidents* and *sleepiness at the wheel*. Three reviewers (JAMF, SB and FS) developed the search strategy; the details of keywords and queries used in the Medline database are reported in the Supplement. No time restriction was applied to the searches. Only studies available in English were considered. The search strategy was developed and performed in July 2015 in each selected database. EndNote X4 (Thomson Reuters) was used to compile the bibliography.

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Study selection

The potentially relevant studies were independently reviewed by two reviewers (JAMF and SB) and first screened by title and abstract. The full text of the articles considered eligible by one of the reviewers was retrieved through the libraries of the University of Bordeaux and the French National Institute of Health and Medical Research (INSERM). Final eligibility was assessed independently. Discrepancies were solved by consensus between the two reviewers if possible. Otherwise a third reviewer (PP) made the final decision.

Evaluation of the quality of studies

The Newcastle-Ottawa Scale was used to assess the quality of the included studies. Each study was scored from zero to nine stars for the selection and the comparability of the groups, and to ascertain either exposure for case-control or outcome of interest for cohort studies[22].

Data extraction

The following data were extracted from each study included using a standardized form: study design (cohort study, case-control study, cross-sectional study) , data collection tool (mail, non-mail (paper questionnaire or telephone call) and face-to-face interview), adjusted risk estimates of motor vehicle accidents related to sleepiness at the wheel, variables used to compute the adjusted risk, number of motor vehicle accidents in the entire group and in the sleepiness at the wheel group, motor vehicle type (car only or mixed motor vehicle type), motor vehicle accident with or without objective consequences and assessment period of accident. The frequency of sleepiness at the wheel was calculated in the studied population. Moreover, the following subjects' characteristics were extracted: gender, age and sleep-related problems such as breathing- and snoring-disordered sleep, sleep deprivation, and engagement in shift work. The definition of sleepiness at the wheel was extracted for each study and sleepiness at the wheel assessment period before the accident (just before the accident, during the year preceding it, or more than a year preceding it) was extracted. Then, data were extracted and recorded in an Excel database and verified for concordance with the full-text articles independently by two reviewers (SB and FS).

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Meta-analysis

The overall risk of motor vehicle accidents related to sleepiness at the wheel was estimated. Adjusted risk estimates were extracted from each selected study and included in a forest plot as odds ratios (OR), which is a good risk measure when the incidence of events is rare and when different study designs are pooled in a single meta-analysis[23]. The pooled OR with 95% confidence interval (CI) for motor vehicle accidents related to sleepiness at the wheel versus other motor vehicle accidents was computed using the inverse variance method and random-effect models[24]. Statistical heterogeneity was evaluated using the Q statistic (with $p<0.10$ considered significant) and the I^2 index[25]. Publication bias was evaluated by visual inspection of funnel plot and the Egger test ($p<0.05$ was considered significant). The meta-analysis was conducted using the "Metafor" package" in the R software (v. 3.0.3)[30]; all p values were two-sided.

Meta-regression

Random-effect meta-regression analyses were performed to explore sources of heterogeneity between the individual estimates of motor vehicle accidents related to sleepiness at the wheel[24,26]. The following potential sources of heterogeneity were studied: i) categorical variables: study design (cohort study, case-control study, cross-sectional study), data collection tool (mail, non-mail (paper questionnaire or telephone call) and face-to-face interview), assessment period of motor vehicle accident, motor vehicle type (car only or mixed motor vehicle type), motor vehicle accident with or without objective consequences and assessment period of accident and sleepiness at the wheel assessment period before the accident (just before the accident, during the year preceding it, or more than a year preceding it), ; ii) continuous variables: rate of women, frequency of participants reporting sleepiness at the wheel, proportion of participants with sleep-disordered breathing and snoring, sleep deprivation and participants in shift work or night work, quality of studies (NOS).

Each potential source of heterogeneity was firstly investigated using univariate meta-regression models. A multivariate meta-regression model was then built using manual backward elimination including only sources associated with $p<0.05$ in the univariate model[27]. The R^2 index was used to quantify the proportion of the variability in the risk of motor vehicle accidents related to sleepiness

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at the wheel associated with each potential source of heterogeneity[28,29]. Meta-regression analyses were performed using R software (v. 3.0.3) via the "Metafor" package[30].

RESULTS

Study selection

The literature search identified 3,758 articles, 826 of which were duplicates and were thus removed. Of the 2,932 remaining articles, 2,697 were found to be irrelevant and were excluded after reviewing the title and abstract. The remaining 233 articles underwent full-text examination (see supplementary information file for selection process details), which generated the final selection of 17 observational studies eligible for the meta-analysis [6-8, 10-12, 16, 20, 31-40](Figure 1).

Characteristics of studies included

Participants

The 17 eligible studies included were published between 1993 and 2014 and comprised a total of 70,098 participants from five continents (Table 1). The sample sizes of the studies varied from 229 to 35,004 participants. Sixteen studies included both sexes, while one from Saudi Arabia (where only men were authorized to drive) was based on males only[32]. Concerning the age of the participants, three studies involved very young people (mainly under 30 years)[8,36, 39], while other studies included older participants. In seven studies participants were aged between 30 and 50 years[10, 11, 16, 31, 32, 34, 35] while the others included drivers aged over 50 years old[6, 7, 12, 33, 37, 38, 40].

Study design and data sources

Of the 17 studies selected, six were case-control studies[8, 10, 11, 16, 34, 37], 10 were cross-sectional studies[6, 7, 31-33, 35, 36, 38-40] and one was a cohort study[12].

Data were collected by face-to-face interview in four studies[8,11,32,37]. Data were collected via electronic mail in three studies[20, 33, 34], in all the other studies by non mail

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(paper questionnaire in six studies[12, 31, 35, 38-40]) and by telephone call in four studies[6, 10, 16, 36].

Concerning quality[22] three case-control studies obtained the highest possible score on the Newcastle-Ottawa Scale (nine stars)[10, 11, 16]. For the cross-sectional studies, this score ranged from five to eight stars, weaknesses concerned the selection of the subjects (representativeness of the sample, sample size and description of non-respondents).

Assessment of sleepiness at the wheel

To assess sleepiness at the wheel, most of the studies used the term of "falling asleep at the wheel". Table 2 shows how sleepiness at the wheel was formulated in studies". The studies by Connor *et al. and* Liu *et al.* [8, 37] used the item in the Stanford Sleepiness Scale "level of alertness immediately before the crash or survey"[37, 41], Hutchens[36] and Stutts[10] used the term of drowsy and Gander the term of dozing[33].

For studies considered sleepiness at the wheel as having the episode "just before" the accident[8, 11,16, 37] while other authors considered sleepiness at the wheel during the previous year[6, 7, 10, 12, 20, 32, 34, 35] or longer[31, 36, 38, 39] before the accident.

In the studies included, frequency of sleepiness at the wheel ranged from 1.1% to 58%; in two studies more than 50% of the participants declared one episode of sleepiness at the wheel[7, 31] in eight studies[6, 10, 16, 32, 36, 38-40] it was comprised between 20% and 50%, while in five studies the frequency of sleepiness at the wheel was lower than 20%[8, 11, 12, 34, 37]. This data was not available for two studies[33, 35].

Assessment of motor vehicle accident

Studies included four- or two-wheeled vehicles, and eleven studies included only cars. Motor vehicle accidents were categorized with or without objective consequences (e.g. police intervention or an economic loss or material or physical damage)(Table 2).

Five studies considered the accident during the year before the data collection[6, 7, 12, 32, 35] while others considered a longer period (varying from three years to lifetime)[31, 33, 36, 38, 39]. This data was not available for one study selected[40] and not attributable in the six case-control studies[8, 10, 11, 16, 34, 37].

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Meta-analysis and meta-regression

Adjusted OR ranged from 0.63 (95%CI 0.22 to 1.82)[37] to 12.90 (95%CI 1.72 to 97.69[31]. Table 3 shown the adjusted factors included for each OR. Experiencing sleepiness at the wheel increased the risk of motor vehicle accidents (pooled OR 2.51 [95%CI 1.87; 3.39]). A significant heterogeneity was found between the individual risk estimates (Q = 93.21; I^2 = 83%, Figure 2). Adjusted OR ranged from 0.63 (95%CI 0.22 to 1.82) in the study of Liu *et al.*[37] to 12.90 (95%CI 1.72 to 97.69[31](Figure 2). Only one study provided a stable OR point estimate[37]. When this study was removed from the analysis, the results were consistent with the principal analysis (OR = 2.66 (1.97, 3.60). Visual inspection of the funnel plot indicate an asymmetry in which larger studies were related to a lower increased risk (Egger test: p<0.01).

Univariate meta-regression analyses found that heterogeneity was not explained by the following variables: study design (p=0.89), data collection tool (p=0.84), assessment period of accident (p=0.84), motor vehicle type (p=0.82), motor vehicle accident with or without objective consequences (p=0.26), sleepiness at the wheel assessment period before the accident (p=0.88), sex (p=0.94), frequency of sleepiness at the wheel (p=0.09), proportion of participants with sleep disorders breathing and snoring (p=0.10), sleep deprivation (p=0.54), shift work/night work (p=0.39) and quality (NOS score) (p=0.53).

DISCUSSION

Despite the wealth of literature on sleep-related accidents, the present systematic review is the first to collect systematically all observational studies investigating the risk of motor vehicle accidents and sleepiness at the wheel. Of the 17 studies included, all except one found that drivers reporting sleepiness at the wheel were at greater risk of motor vehicle accidents compared to other drivers. The pooled risk estimate found a more than two-fold increased risk of motor vehicle accidents due to sleepiness at the wheel. These studies show also a high frequency of reported sleepiness at the wheel in different time frame of evaluation and different populations of drivers. The high frequency of reported sleepiness at the wheel, with a significant odd ratio makes this variable to be considered as an important risk factor for traffic accident. Even if the set of studies selected for our paper looks heterogeneous, the strength of our meta-analysis rely on the fact that we selected only studies

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adjusting the risk of traffic accidents related to sleepiness on other classical accidental factors (age, sex, BMI, sleep disorders...). The present results highlight the importance of evoking sleepiness at the wheel when determining the medical fitness of a patient to drive[20,42]. The positive association between sleepiness at the wheel and motor vehicle accidents found in the present meta-analysis strongly suggests that sleepiness at the wheel should appear in the future version of medical fitness to drive guidelines.

The results of this meta-analysis are in line with the study by Masa reporting that one-half of habitually sleepy drivers reported sleepiness occurring predominantly during driving, for they did not report excessive sleepiness during any other activities[43]. Moreover our results deserve to be compared with the strength of the association between obstructive sleep apnea (OSA) and risk of motor vehicle accidents. Two systematic reviews by Tregear *et al.* (2009) and Ellen *et al.* (2006) showed respectively a pooled OR of 2.43[44] and a median OR of 3.1[15]. Because most of the studies included in our meta-analysis adjusted the computed OR on the proportion nocturnal breathing disorders (Table 3), the pooled OR in our meta-analysis cannot be only attributed to nocturnal breathing disorders. This suggests that it is worth considering both sleepiness at the wheel and OSA as two different factors when evaluating fitness to drive.

The results of our meta-analysis are in line with studies finding a non-significant association between daytime sleepiness as quantified by the Epworth Sleepiness Scale (ESS) and accident risk[8,43,48]. Indeed, evaluation by the ESS and evaluation of sleepiness at the wheel do not concern the same type of sleepiness. The ESS quantifies behavioral sleepiness in relatively passive situations with a low level of alertness ("Sitting and reading or watching TV"), whereas sleepiness at the wheel refers to drivers in a condition requiring a high level of alertness (in a car while driving). Thus, investigation of sleepiness at the wheel should be systematically added to the classical ESS evaluation to efficiently determine fitness to drive in sleepy drivers. The exact formulation of the question about sleepiness at the wheel remains to be determined and there is currently no clear consensus about how to assess it. After reviewing the different ways of evaluating sleepiness at the wheel in our review, we suggest using the following question: "Have you experienced in the previous year at least one episode of severe sleepiness at the wheel that made driving difficult or forced you to stop the car".

Some authors suggest that drivers do not always reliably answer questions evaluating sleepiness at the wheel. Indeed, they may be unaware of such symptoms or deny they have them[45,46]. Concerning the possible unawareness of sleepiness, most experimental studies with driving simulators have found that subjective sleepiness and EEG activity indicative of sleepiness are highly correlated. Thus,

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drivers were aware of their sleepiness at the wheel so questions on it seem to be reliable[47]. Concerning the possible under-reporting of sleepiness at the wheel , there is no evidence of any prevarication bias in any of the epidemiological studies of sleepiness at the wheel , and its high prevalence (above 20% in most of the studies included in the present meta-analysis) does not point to any under-reporting of it by drivers. Moreover, we believe that informing drivers about the risk of sleepiness at the wheel should be mandatory for reinforcing road safety.

Several limitations should be considered. The meta-regression did not find a significant factor to explain the source of heterogeneity between the individual estimates of motor vehicle accidents related to sleepiness at the wheel. A limitation of our study can be that we did not evaluate road categories (freeway, city and open-road) in the meta-regression. Indeed different roads categories could influence the frequency of self-reported sleepiness at the wheel and the inherent accidental risk. Thus road categories could be explaining factors of the heterogeneity.

Several methodological issues should be also considered when interpreting the findings of this meta-analysis. The methods used to recruit participants may have introduced a significant selection bias. Selection criteria and response rates were not commonly reported or were unclear. Moreover, both sleepiness at the wheel and outcome (motor vehicle accident) were self-reported variables, thus raising the possibility of a recall bias. There is no reason to believe that this recall bias would not also concern the reporting of breathing- and snoring-disordered sleep or sleep deprivation.

Potential risk factors for motor vehicle accidents such as age, body mass index, alcohol and drug use, sleep duration, and other medical conditions were not always considered in the adjusted OR in the studies included (see Table 3). The effects of these factors, which all could have a link with both sleepiness at the wheel and accident risk, may therefore have modified some of the estimates of risk due to sleepiness at the wheel. Heterogeneity is also a concern in meta-analyses, yet it may often be high when meta-analyses of observational studies are performed[49]. In the present study we used a random-effects model to reduce its impact in the pooled estimation and used meta-regressions to explore the factors which could explain it. Meta-regressions may also be affected by certain limitations such as aggregation and ecological bias[50].

A publication bias was could also affect the results of the present meta-analysis. Nevertheless, as the funnel plot indicates a lack of large and precise studies with a risk higher than the pooled one, this limitation could results in an underestimation of the risk herein presented.

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Moreover, the large effect size found in this meta-analysis considerably reduces the possibility that new evidence would substantially change the direction of the results.

CONCLUSION

To our knowledge, this is the first review investigating the relationship between sleepiness at the wheel and motor vehicle accidents. The principal finding is that drivers experiencing sleepiness at the wheel are at increased risk for motor vehicle accidents, so further studies are required to explore the nature of this relationship. Moreover, investigation of sleepiness at the wheel should be systematically added to the classical ESS evaluation to efficiently determine fitness to drive in sleepy drivers.

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Practice points

1) Evidence is growing that sleepiness at the wheel is one of the strongest sleep-related factors associated with the risk of motor vehicle accidents.

2) Sleepiness at the wheel is associated with an increased risk of motor vehicle accidents (2.56 [95%CI 1.91; 3.43]).

3) Sleepiness at the wheel should be assessed together with the classical Epworth Sleepiness Scale when determining fitness to drive.

4) “Have you experienced in the previous year at least one episode of severe sleepiness at the wheel that made driving difficult or forced you to stop the car?” seems to be the relevant question to explore sleepiness at the wheel.

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Research agenda

1) The most frequent causes of sleepiness at the wheel (sleep disorders i.e. sleep apnea, behavioral factors such as sleep deprivation and engagement in shift work) need to be investigated.

2) We need to understand better which drivers are vulnerable to sleepiness at the wheel.

3) The difference in terms of accident risk between sleepiness as detected by the Epworth Sleepiness Scale and the question regarding sleepiness at the wheel has to be explained to physicians and patients.

4) Road safety programs should be reinforced to inform drivers about the risk involved in sleepiness at the wheel.

5) Technological and behavioral countermeasures are needed to reduce the risk involved in sleepiness at the wheel.

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Abbreviations list

AHI: Apnea-Hypopnea Index

BMI: Body Mas Index

CI: Confidence Intervals

ESS: Epworth Sleepiness Scale

ISI Web of sciences: Institute for Scientific Information Web of sciences

OSA: Obstructive Sleep Apnea

OR: Odds Ratios

PRISMA: Preferred Reporting Items for Systematic Reviews

SAW: Sleepiness at the wheel

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Accepted Manuscript

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Table 1: Population characteristics of the studies

Study	Nation	Sample size, N (Accidents, n)	Predominant age group	SEX F, %	SAW, N (Accidents, n)	Frequence of SAW, %	Sleep disordered breathing and snoring %	Sleep deprivation as reported in the study,%	OR 95%CI
Abe, 2011 [31]	Japan	2,462 (21)	30-50 yrs	22	1,429 (20)	58	20.5	42.8	12.90 [1.72, 97.69]
Bahammam, 2014 [32]	Saudi Arabia	1,219 (773)	30-50 yrs	0	307 (228)	25.1	1.1	67.3	1.19 [0.85, 1.67]
Connor, 2002 [8]	New zeland	1159(571)	< 30	36.6	71(63)	6.1	1.4	9	8.20 [3.40, 19.70]
Cummings, 2001 [16]	United states	399 (114)	30-50 yrs	31	158 (NR)	39.5	38.8	15	1.60 [1.00, 2.70]
Gander, 2005 [33]	New Zeland	5,368 (644)	30-50 yrs	48	NR	NR	NR	-	1.52 [1.15, 2.02]
Gisllason, 1997	Iceland	1,084 (342)	30-50 yrs	45	12 (5)		9.9	26.7	1.49

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[34]						1.1		[1.01, 2.21]
Gnardellis, 2008 [35]	Greece	1,366 (742)	30-50 yrs	40	NR	NR	NR	1.41 [1.14, 1.76]
Hutchens, 2008 [36]	United states	506 (202)	<30 yrs	46	103 (55)	20.3	NR	36.7	1.79 [1.07, 2.99]
Liu, 2003 [37]	China	844 (406)	> 50 yrs	3.9	19 (8)	2.25	4.9	3.5	0.63 [0.22, 1.82]
Lloberes, 2000 [38]	Spain	229 (60)	> 50 yrs	5	81 (NR)	35.3	82.5	NR	5.05 [2.30, 10.90]
Nabi, 2006 [12]	France	13,674 (260)	> 50 yrs	23	160 (NR)	1.1	NR	NR	2.90 [1.30, 6.320]
Philip, 2014 [11]	France	544 (272)	30-50 yrs	49	20 (17)	3.6	16.2	23.5	9.97 [1.57, 63.50]
Philip, 2010 [20]	France	35,004 (2520)	> 50 yrs	26	20,236 (131)	57.8	5.2	NR	9.48 [4.14, 21.72]
Pizza, 2010 [39]	Italy	339 (80)	<30yrs	42	135 (45)	39.8	5.8	NR	2.06 [1.19, 3.56]
Sagaspe,2010	France	4,774 (278)	> 50 yrs	54	1,411 (138)		2.2	NR	2.03

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[6]						29.5		[1.57, 2.64]
Stutts, 2003 [10]	United states	874 (467)	30-50 yrs	NR	292 (169)	33.4	47.8	18.3	8.25 [4.53, 15.05]
Wu, 1996 [40]	United states	253(66)	> 50 yrs	28	99 (NR)	39.1	83.3	NR	5.72 [2.39, 13.67]

SAW: sleepiness at the wheel; yrs: years; OR: Odds ratio

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Table 2: Methodological characteristics of the studies

Study ***Nation***	**Type studies and Data source**	**How was formulated SAW in the study**	**Definition of motor vehicle accident with (1) or without (0) objective consequences**	**Assessment period of accident**	**Type of Motor Vehicles**	**Quality of studies**	**OR [CI]**
Abe, 2011 [31]	cross sectionnal paper questionnaire	"SAW occasionnaly"	0	Last 5 years	Mixed motor vehicle ***(4 wheeled few 2 wheel)***	5	12.90 [1.72, 97.69]
Bahammam, 2014 [32]	cross sectionnal face to face	"Did you fall asleep at the wheel for an instant at least once during the last 6 months"	1 Material or physical damage	Last 6 months	Mixed motor vehicle *(Excluded truck)*	5	1.19 [0.85, 1.67]
Connor, 2002 [8]	case –control face to face telephon call	"Level of alertness immediately before crash or survey SSS:4-7"	1 Material or physical damage	Case-control	Mixed motor vehicle *Cars, vans and light utility vehicles*	8	8.20 [3.40, 19.70]
Cummings, 2001 [16]	case –control telephon call	"Sensation of falling asleep on trip"	1 Police Intervention	Last 5 years	Mixed motor vehicle *(Excluded 2 wheeled)*	9	1.60 [1.00, 2.70]
Gander, 2005 [33]	cross sectionnal mail sending	"Any chance of dozing while stopped in traffic"	0	Last 3 years	Car only	5	1.52 [1.15, 2.02]

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Gisllason, 1997 [34]	case –control mail sending	"Almost falling asleep whilst driving (1-2/ week, more often)"	1 Material or physical damage	Case-control	Car only	8	1.49 [1.01, 2.21]
Gnardellis, 2008 [35]	cross sectionnal paper questionnaire	"Falling asleep at the wheel"	0	Last 1 year	Car only	6	1.41 [1.14, 1.76]
Hutchens, 2008 [36]	cross sectionnal telephon call	"Drives drowsy alone: almost always/sometimes"	0	Lifetime	Car only	5	1.79 [1.07, 2.99]
Liu, 2003 [37]	case –control face to face	"Level of alertness immediately before crash or survey SSS:4-7"	1 Economic loss	Case-control	Car only	7	0.63 [0.22, 1.82]
Lloberes, 2000 [38]	cross sectionnal paper questionnaire	"Sleepiness while driving"	0	Last 5 years	Car only	5	5.05 [2.30, 10.90]
Nabi, 2006 [12]	Cohort paper questionnaire	"In the 12 past months, have you ever driven while sleepy: once a month or more often"	1 Material or physical damage	Last year/ serious accident	Mixed motor vehicle *(260 accidents:238 car, 3 utility vehicles, 19 2 wheeled)*	5	2.90 [1.30, 6.320]
Philip, 2014 [11]	case –control face to face	"Having a sleep episode just before the accident or interview	1 Material or physical damage	Case-control	Car only	9	9.97 [1.57, 63.48]

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Philip, 2010 [20]	cross sectionnal mail sending	"At least one episode of severe SAW in the previous year"	1 Medical or physical dammage	Last 1 year / Prediction sleepy driving accident	Car only	5	9.48 [4.14, 21.72]
Pizza, 2010 [39]	cross sectionnal paper questionnaire	"Sleepiness while driving"	0	at least one accident/ lifetime	Car only	5	2.06 [1.19, 3.56]
Sagaspe,2010 [6]	cross sectionnal telephon call	"At least one episode of severe SAW in the previous year"	1 Medical or physical dammage	Last 1 year at least one accident	Car only	6	2.03 [1.57, 2.64]
Stutts, 2003 [10]	case –control telephon call	"Time driven drowsy in past year 1-2 times"	1 Economic loss	Case-control	Mixte motor vehicle	9	8.25 [4.53, 15.05]
Wu, 1996 [40]	cross sectionnal paper questionnaire	"Falling asleep at inapropriate times, particularly while driving"	0	NR	Car only	5	5.72 [2.39, 13.67]

SAW: Sleepiness at the wheel; OR : Odds Ratio; CI : Confidence Interval

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Table 3: Matching and/or adjusting variables

Study	Matching and/or adjustement variables	OR [CI]
Abe, 2011(17)	age, driving as profession, shift worker, license acquisition period, annual driving distance	12.90 [1.72, 97.69]
Bahammam, 2014(31)	age,, ESS, sensitivity to caffeine, OSA, experienced at least one near-miss accident caused by sleepiness in the past 6 months, felt very sleepy at least once while driving in the past 6 month	1.19 [0.85, 1.67]
Connor, 2002 (8)	age, sex, educational level, ethnicity, self reported alcohol consumption, time of day	8.20 [3.40, 19.70]
Cummings, 2001(16)	age, trip miles driven by driver, hours since trip started, hours since last trip time of day, day of week, location	1.60 [1.00, 2.70]
Gander, 2005(32)	age, sex, average weekly driving hours, ethnicity, get enough sleep, neck circumference	1.52 [1.15, 2.02]
Gisllason, 1997(33)	age, sex, alcohol consumption, mileage per year, daytime sleepiness, history of snoring	1.49 [1.01, 2.21]
Gnardellis, 2008(34)	age, sex, years of education, possession of driver's license, place of residence, alcohol consumption, lifestyle patterns (amusement, culture, religion, sport work), fatigue while driving, daytime sleepiness, symptoms of sleep disorders	1.41 [1.14, 1.76]
Hutchens, 2008(35)	sex, average hours driven/week, ethnicity, race, length of licensure, household income, region, urban city, sensation seeking, hours slept/night , current smoker, current drinker, current marijuana user	1.79 [1.07, 2.99]
Liu, 2003(36)	age, sex, , alcohol consumption in pre 6h, education level, ethnicity	0.63 [0.22, 1.82]

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Llobere, 2000(37)	age, sex, BMI, alcohol consumption, AHI, self-answered clinical questionnaire	5.05 [2.30, 10.90]
Nabi, 2006(13)	age, sex, marital status, occupational category, driving mileage per year, alcohol consumption, maximum speed greater than +/-10% of legal limits in built-up areas, on rural roads, and on highways, risky use of mobile phone, vehicle categories, traffic ticket fixing, sleep disorder, working overtime, time constraints at work, working night shift, depressive symptoms in 2002, use of drugs in 2001, medical conditions treated in 2001-3	2.90 [1.30, 6.320]
Philip, 2014(11)	age, sex, km driven, per year, years of having a driving license, type of road, medication in the last 24 hours, break during the journey, anxiety, depression, stress, sleeping 6h or fewer in the last three months, quality of sleep in the last three months	9.48 [4.14, 21.72]
Philip, 2010(20)	age, sex, BMI, number of years of license, marital status, professional driver status, socio-professional categories, km driven per year, ESS scores, pathologies , self reported treatment, stimulant effect of caffeine, tea or cola, stimulant effect of napping	9.97 [1.57, 63.50]
Pizza, 2010(38)	sex , bad sleep, smoking	2.06 [1.19, 3.56]
Sagaspe, 2010(6)	age, number of years of license, marital status, professional driver status, ESS scores, pathologies, stimulant effect of caffeine, tea or cola	2.03 [1.57, 2.64]
Stutts, 2003(10)	age, sex	8.25 [4.53, 15.05]
Wu, 1996(39)	age, sex, night work shift, daytime nap, coffee intake, alcoholic beverage intake, SAS, passing destination, concomitant disorders (severe dizziness episode, parkinson, epilepsy, loss of consciousness)	5.72 [2.39, 13.67]

ESS : Epworth Sleepiness Scale; BMI : Body Mass Index; OAS: Obstructive Sleep Apnea; AHI: Apnea hypopnea Index; OR: Odds Ratio; CI: Confidence Interval

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