Høye A. How would increasing seat belt use affect the number of killed or seriously injured light vehicle occupants?

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How would increasing seat belt use affect the number of killed or seriously injured light vehicle occupants?

The expected effects of increasing seat belt use on the number of killed or seriously injured (KSI) light vehicle occupants have been estimated for three scenarios of increased seat belt use in Norway, taking into account current seat belt use, the effects of seat belts and differences in crash risk between belted and unbelted drivers. The effects of seat belts on fatality and injury risk were investigated in a meta-analysis that is based on 24 studies from 2000 or later. The results indicate that seat belts reduce both fatal and non-fatal injuries by 60% among front seat occupants and by 44% among rear seat occupants. Both results are statistically significant. Seat belt use among rear seat occupants was additionally found to about halve fatality risk among belted front seat occupants in a meta-analysis that is based on six studies. Based on an analysis of seat belt wearing rates among crash involved and non-crash involved drivers in Norway it is estimated that unbelted drivers have 8.3 times the fatal crash risk and 5.2 times the serious injury crash risk of belted drivers. The large differences in crash risk are likely to be due to other risk factors that are common among unbelted drivers such as drunk driving and speeding. Without taking into account differences in crash risk between belted and unbelted drivers, the estimated effects of increasing seat belt use are likely to be biased. When differences in crash risk are taken into account, it is estimated that the annual numbers of KSI front seat occupants in light vehicles in Norway could be reduced by 11.3% if all vehicles had seat belt reminders (assumed seat belt wearing rate 98.9%), by 17.5% if all light vehicles had seat belt interlocks (assumed seat belt wearing rate 99.7%) and by 19.9% if all front seat occupants of light vehicles were belted. Currently 96.6% of all (non-crash involved) front seat occupants are belted. The effect on KSI per percentage increase of seat belt use increases with increasing initial levels of seat belt use. Had all rear seat occupants been belted, the number of KSI front seat occupants could additionally be reduced by about 0.6%. The reduction of the number of KSI rear seat occupants would be about the same in terms of numbers of prevented KSI.

1. Introduction

Seat belts have long been known to be one of the most effective vehicle safety measures. All new light vehicles in Europe are equipped with lap and shoulder belts for all seats (except sometimes the center seat) and increasing numbers of new cars are equipped with seat belt reminders. Still, a considerable proportion of all those killed in light vehicles in road traffic crashes did not wear a seat belt. In Norway 96.9% of all front seat occupants in light vehicles were using the seat belt in 2013 according to observations by the NPRA (2014A). Seat belt use among crash involved drivers was 78% in fatal crashes and 85% in crashes with killed or seriously injured (KSI). Seat belt use among drivers who were killed or seriously injured themselves, was still lower, 67% among fatally injured drivers and 76% among killed or seriously injured drivers. Far less is known about seat belt use among rear seat passengers. In the years before 2005 it has been lower than among front seat occupants (85% in the rear seats vs. 92% among drivers). From more recent years information about seat belt use among rear seat occupants is not available.

Two measures that have been found to be effective in increasing seat belt use are seat belt reminders and seat belt ignition interlocks. Seat belt reminders for front seat occupants are standard equipment in practically all new light vehicles sold in Norway, but the proportion of all vehicle kilometers with light vehicles that is driven with seat belt reminders for front seat occupants is still only about 64% (Elvik & Høye, 2015). Rear seat belt reminders were installed in about 73% of all new light vehicles in Norway in 2013. Krafft et al. (2006) estimated that seat belt use on seats with seat belt reminders is 98.9%. Thus, seat belt use would most likely be higher in Norway if all light vehicles had been equipped with seat belt reminders. Seat belt interlocks are currently not available on the market for light vehicles but theoretically possible to install at least in new vehicles. Van Houten et al. (2014) estimated that a seat belt interlock that increases the counterforce of the accelerator pedal at speeds above 20 km/t when the seat belt is not fastened, increases seat belt use to 99.74% (from a baseline of 56.2%). A seat belt interlock that prevented drivers from engaging their transmissions unless the seat belt was fastened, increased seat belt use as well, but only to 96% (from a baseline of 81%). With the latter type of interlock several drivers unfastened their seat belts as soon as the transmission was engaged, thus the counterintuitively smaller effect.

Norwegian road safety policy is based on vision zero according to which no one should be killed or seriously injured in road traffic. Increasing seat belt use is one of the factors that is expected to contribute to a further reduction of the number of killed or seriously injured (KSI). The aim of this study is to estimate the possible reduction of the number of KSI that can be achieved by increasing seat belt use by installing seat belt reminders in all light vehicles, by installing seat belt interlocks in all light vehicles and in the hypothetical case of 100% seat belt use in all light vehicles. The possible reduction of the number of KSI that can be achieved by increasing seat belt use depends on the effects of seat belts on injury severity and the current seat belt use among KSI light vehicle occupants. Additionally, it is assumed that unbelted drivers have higher crash risk than belted drivers and that not taking into account differences in crash risk between belted and unbelted drivers leads to biased estimates of the effects of increasing seat belt use. On this background the study aims to answer the following questions:

What is the effect of seat belt use on the risk of being killed or seriously injured in light vehicles in a crash? In order to answer this question a meta-analysis was conducted of studies that have investigated the effects of seat belt use among occupants of light vehicles on the risk of being killed or seriously injured in a crash. In the meta-analysis it is also investigated

- Whether seat belts are more effective in preventing fatal injuries than in preventing other injuries: Seat belts have in an earlier meta-analysis (Elvik et al., 2009) been found to have greater effects on more serious injuries. A possible explanation is that seat belts aim at preventing some of the most serious types of injuries, such as head and thorax injuries from impacts on the steering wheel or instrument panel, as well as ejection from the vehicle.
- Whether seat belts have different effects at different seating positions: Front seat occupants are more exposed to injuries from contact of the legs or upper body with the instrument panel or the steering wheel. They have about 60% higher risk of being killed or seriously injured than rear seat occupants (Smith & Cummings, 2004). Seat belts may therefore be expected to be more effective among front seat occupants than among rear seat occupants (Elvik et al., 2009).
- Whether methodological characteristics of the studies have affected the results: More severe crashes (in terms of impact speed, vehicle deformation etc.) are likely to involve higher speed and more other risk taking behavior than less serious crashes. Since risk taking behavior has been found to be related to non-use of seat belts, seat belt use is likely to be less common in more serious crashes (Eluru & Bhat, 2007). A lack of control for crash severity is therefore likely to lead to an overestimation of the effectiveness of seat belts. A lack of control for other potential confounding variables such as airbags or drunk driving can also be expected to be related to overestimated seat belt effects.
- Whether effects of seat belts have changed over time: Seat belts may have become more effective over time because of the increased use of pretensioners and load limiters which both were found to reduce injury severity among belted occupants (Bohman et al., 2006; Foret-Bruno et al., 1998; Forman et al., 2008).
- How seat belt use among rear seat occupants affects injury severity among front seat occupants: Unbelted car occupants can, in the same way as unsecured objects in the

vehicle, become projectiles ("back seat bullets", Mayrose et al., 2005) and increase injury risk among other occupants, either by directly increasing the load on the front seat occupant or by moving the front seat closer to the instrument panel (Rudd et al., 2009).

What is the relative risk of being involved in a serious crash for unbelted drivers, compared to belted drivers? Non-use of seat belts has been found to be related to a number of other risk factors such as drunk driving, speeding, night time driving, being a young male driver, previous traffic offences, crashes and criminal offences (Baker et al., 2000; Ball et al., 2005; Eluru & Bhat, 2007; Evans, 1987; Sahai et al., 1998; NPRA, 2014B; Steptoe et al., 2002; UP, 2009). Evans (1987) estimated that injury crash involvement rates of unbelted drivers are on average 53% higher than those of belted drivers. Seat belt use was however far less common in the study by Evans (1987) than it was in Norway in 2013. It is assumed that the difference between unbelted and belted drivers is greater at higher levels of seat belt use.

2. Methods

2.1 Log-odds method of meta-analysis: Effects of seat belt use on fatality risk

Estimated effects of seat belt use on fatality and injury risk from different published studies are summarized using the log-odds method of meta-analysis. Effect estimates are calculated as odds ratios for different groups of light vehicle occupants (drivers, front seat occupants, etc.), different degrees of injury severity and different crash types from published studies. The odds ratios express the odds of a fatality (or injury) in a crash for a belted occupant, against the odds of a fatality (or injury) in a crash for an unbelted occupant. The estimated percentage change of fatality (or injury) risk is equal to the odds ratio minus one, times one hundred. For example an odds ratio of 0.40 corresponds to a percentage change of fatality risk by (0.40 – 1)*100 = -60 %. In order to calculate summary effects, odds ratios are weighted, the statistical weights being a function of the standard error of the odds ratios. The calculation of statistical weights, summary effects and confidence intervals is in detail described elsewhere (Christensen, 2003; Elvik, 2005; Erke, 2009; Høye, 2014; Høye, 2013; Normand, 1999).

Summary effects are calculated with a random effects (RE) model, unless there are too few effect estimates, which allows random variation of the "true" effects of each of the studies around a common average effect (Higgins et al., 2009). In addition to confidence intervals, prediction intervals were calculated for summary effects that are based on three or more effect estimates according to Riley et al. (2011). While confidence intervals indicate the uncertainty of the summary effect, prediction intervals indicate the "extent of variability in treatment effects that would be observed if sampling error were ignored (or the new studies were all infinitely large)" (Langan et al., 2012, p. 516). Heterogeneity is tested with the help of Cochran's Q statistic. Significant heterogeneity indicates that moderator variables are likely to be present (Thompson & Sharp, 1995).

Studies included in the meta-analysis were identified by searching the web (mainly with Google Scholar) and a number of databases such as TRID, sciencedirect and the ISI Web of knowledge. Reference lists of relevant studies have also been checked. Search terms were «seat belt» in combination with either «injury», «fatality» or «crash». Searches were restricted to publications from the year 2000 or later. It is assumed that results from older studies are less applicable to the current vehicle fleet (the cutoff is however arbitrary). In order to be included in meta-analysis, a study had to meet the following criteria: The effect of seat belt use (vs. non-use) in light vehicles on injury or fatality risk is presented or can be calculated (e.g. from regression coefficients), and sufficient information is provided for calculating a confidence interval (such as t-values or standard deviations). Results for lap belts (without shoulder belts) were not included. Results that refer to effects of seat belt laws or wearing rates were not included either. Studies were included independent of the methodology used, except simple comparisons of fatality or injury rates with vs. without seat belts which were excluded. Such studies are bound to overestimate the effects of seat belts. For example de Lapparent et al. (2008) and Meyer & Finney (2005) found fatality reductions among belted drivers of almost 90% with this method. The studies included in meta-analysis have used multivariate methods or compared fatality or injury rates for matched pairs of drivers/passengers (two front seat occupants of the same vehicles or driver-driver pairs in two-car collisions) to control for confounding factors.

Thirty studies were identified that meet these criteria. Twenty-four of these refer to the effects of (own) seat belt use, six studies refer to of the effects of others' seat belt use. Table 1 shows an overview of the studies (in alphabetical order). For each study table 1 shows the years from which crash data are included in the study (vehicle model years would have been preferable but these were for the most part not available), the percentage of belted occupants, whether or not crash severity is controlled for (discussed in more detail in section 3.2), the number of effect estimates that were calculated and included in meta-analysis and the sum of the statistical weights of the effect estimates from each study.

Table 1: Studies of the effects of seat belt use included in meta-analysis.

	Data years	Seat belt use[1]	Contr. for crash severity	N of effect estimates	Sum of stat. weights
Studies of the effects of own seat belt use					
Angel & Hickman, 2009 (USA)	1995-2004	NA	No	3	966
Bedard et al., 2002 (USA)	1975-1998	Low	No	1	141
Braver et al., 2008 (USA)	1998-2005	Medium	Yes	1	92
Crandall et al., 2001 (USA)	1992-1997	Low	Yes	1	235
Cummings et al., 2002 (USA)	1990-2000	Medium	Yes	1	1,110
Cummings et al., 2003 (USA)	1975-1983	Low	Yes	4	4,357
Cummings, 2002 (USA)	1988-2000	Medium	Yes	1	82
Cummins et al., 2011 (USA)	1988-2004	Medium	No	1	672
Dissanayake & Ratanayake, 2007 (USA)	1993-2002	High	Yes	3	19
Donaldson et al., 2006 (USA)	1996-2001	Low	No	1	129
Eluru & Bhat, 2007 (USA)	2003	High	Yes	1	3
Gabauer & Gabler, 2010 (USA)	1997-2007	Medium	Yes	1	2
Jehle et al., 2012 (USA)	2000-2005	Medium	No	1	5,259
Lardelli-Claret et al., 2006 (Spain)	1993-2000	High	Yes	1	26
Martin et al., 2003 (France)	1996-2000	High	Yes	5	1,026
Mayrose & Priya, 2008 (USA)	2000-2003	Low	Yes	1	26
McGwin et al., 2003 (USA)	1995-2000	Medium	Yes	1	206
Meyer & Finney, 2005 (USA)	1997-2002	High	No	2	81
Rivara et al., 2000 (USA)	1993-1996	Medium	Yes	2	31
Sivak et al., 2010 (USA)	1998-2008	NA	No	1	4,295
Smith & Cummings, 2006 (USA)	1990-2001	Medium	No	3	7,924
Toy & Hammitt, 2003 (USA)	1993-1999	High	Yes	2	42
Yannis et al., 2010 (France, Netherlands, Italy, Finland, Sweden, UK, Germany)	2003-2004	NA	No	4	213
Zhu et al., 2007 (USA)	2000-2004	Low	No	2	972
SUM				**42**	**27,866**
Studies of the effects of others seat belt use					
Bose et al, 2013 (USA)	2001-2009	NA	Yes	1	101
Broughton, 2004 (UK)	1984-1988	NA	Yes	2	545
Cummings & Rivara, 2004 (USA)	1988-2000	Low	Yes	2	921
Ichikawa et al., 2002 (Japan)	1995-1999	NA	Yes	4	130
MacLennan et al., 2004 (USA)	1991-2002	NA	Yes	6	1,381
Mayrose et al., 2005 (USA)	1995-2001	NA	Yes	1	292
SUM				**15**	**3,268**

[1]Low: < 50%; Medium: 50-80%; High: > 80%; NA: Not available

2.2 Relative crash risk of belted and unbelted front seat occupants

The relative risk of being involved in a (serious) crash for belted and unbelted drivers can according to Evans (1987) be calculated based on the proportions of all (non-crash involved) drivers and of crash involved drivers who were wearing a seat belt. Formula 1 gives the definition of R, the relative risk of crash involvement for unbelted drivers (the relative risk for unbelted drivers is set equal to one). The terms in the nominator and denominator are calculated with the help of Bayes Theorem (formula 2 and 3). B and $\overline{B}$ denote seat belt wearing and non-wearing, respectively, C and $\overline{C}$ denote crash involvement and non-involvement, respectively.

Formula 1
$$R = \frac{P(C|\overline{B})}{P(C|B)}$$

Formula 2
$$P(C|\overline{B}) = \frac{P(\overline{B}|C) * P(C)}{P(\overline{B}|\overline{C})}$$

Formula 3
$$P(C|B) = \frac{P(B|C) * P(C)}{P(B|\overline{C})}$$

The result of formula 1 is independent of the actual crash risk (P(C)) and information about crash risk is therefore not required. The result is also independent of the effect of seat belt use on injury risk because it is based on crash involvement (not on injury severity).

For front seat passengers crash risk is indirectly related to seat belt use because unbelted front seat passengers are more likely to have an unbelted driver than belted front seat passengers. In Norway, 33% of all unbelted and 96% of all belted front seat passengers who were killed or seriously injured in light vehicles in 2009-2013 had a belted driver. Therefore, relative crash risks were also calculated for unbelted front seat passengers, assuming that 33% of all unbelted front seat passengers (those with a belted driver) have a relative crash risk of one while the remaining front seat passengers have a relative crash risk that is equal to the drivers' crash risk. Information about the proportion of non-crash involved unbelted front seat passengers who have unbelted drivers is not available.

2.3 Estimation of the effects of increased seat belt use on the number of fatalities and KSI among front seat occupants in light vehicles

If crash risk were the same among belted and unbelted drivers one might calculate the effect of increasing seat belt use either based on seat belt use among driver fatalities / seriously injured drivers (formula 4) or among all drivers (formula 5).

Formula 4
$$Rel.N\ of\ K = B(K)_0 + (B(K)_1 - B(K)_0) * Eff. + (1 - B(K)_0)$$

Formula 5
$$Rel.N\ of\ K = \frac{B_1 * Eff. + \bar{B}_1 * RR_{\bar{B}1}}{B_0 * Eff. + \bar{B}_0 * RR_{\bar{B}0}}$$

Rel. N of K is the relative number of killed drivers in the scenario of interest. $B(K)_0$ is seat belt use among killed drivers in the current situation, $B(K)_1$ is seat belt use among killed drivers in the scenario of interest (increased seat belt use) and Eff. is the effect of seat belt use on fatality risk (0.4 if the assumed effect is a reduction by 60%). B_0 and $\overline{B}_0$ are the percentages of belted and unbelted non-crash involved drivers in the current situation, B_1 and $\overline{B}_1$ are the percentages of belted and unbelted non-crash involved drivers in the scenario of interest (increased seat belt use). Effects on numbers of seriously injured and the relative risk among front seat passengers can be calculated accordingly.

When relative crash risk is taken into account, the effect of increasing seat belt use can be calculated as a function of current seat belt use among all drivers (or front seat passengers) as in formula 6.

Formula 6 $$Rel. N\ of\ K = \frac{B_1 * RR_{B1} * Eff. + \bar{B}_1 * RR_{\bar{B}1}}{B_0 * RR_{B0} * Eff. + \bar{B}_0 * RR_{\bar{B}0}}$$

RR_X are the relative fatal (or serious injury) crash risk estimates for of belted and unbelted drivers (or front seat passengers) in the current situation and in the scenario of interest. The relative risk estimates are transformed from those that are estimated as described in the section above, so as to sum up to a relative risk of one for all (belted and unbelted) drivers. The relative risk estimates for unbelted drivers that are estimated as described above are based on a relative risk of one among belted drivers. The relative risk estimates in the scenarios with increased seat belt use were calculated with the help of trend functions that describe the relationships between seat belt use among all drivers and the estimated relative crash risk of unbelted drivers based on data on seat belt use among all and crash involved drivers in Norway in 1998-2013.

3. Results from meta-analysis: Effects of seat belt use on fatality risk

3.1 Exploratory analysis

All available effect estimates that refer to the effect of seat belt use in all crashes are shown in a forest plot in figure 1 in descending order of the effect that was found of seat belt use. The effect estimates range from a reduction of injury risk by 88% to a reduction of fatality risk by 41%. With three exceptions all effect estimates are statistically significant.

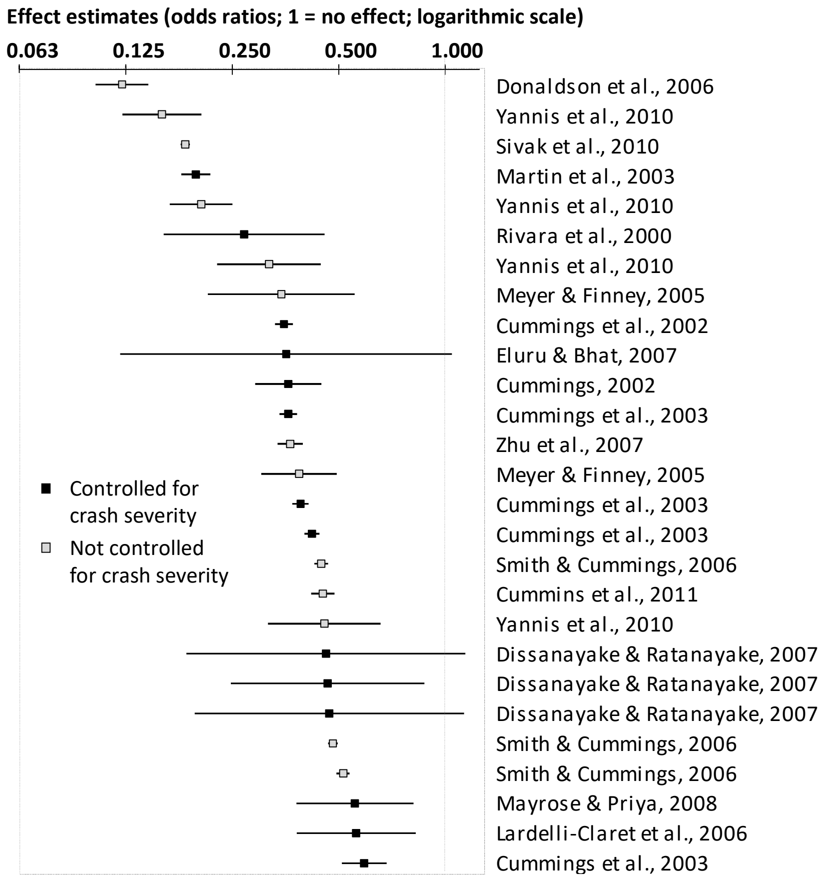

Figure 1: Forest plot of effect estimates referring to the effect of seat belts in all crashes.

The distribution of all available effect estimates that refer to all crashes (regardless of severity) and the corresponding standard deviations is shown in figure 2 in a funnel plot that has been developed according to the guidelines provided by Sterne et al. (2011). The summary effect, based on these effect estimates, is a statistically significant reduction of the number of fatalities / injuries by 65% (95% confidence interval [-71; -59]; 95% prediction interval [-83; -29]).

The distribution in figure 2 is quite broad at the top, which is due to the relatively small confidence intervals of many of the individual effect estimates and the significant heterogeneity in the results. The Cochrans Q-test for heterogeneity (Higgins et al., 2003) is highly significant ($Q = 3119.12$; $df = 26$; $p < .000$). Heterogeneity is taken into account by applying a random effects model of meta-analysis (unless too few effect estimates are available). In order to try to explain heterogeneity, effects of possible moderator variables are investigated in the following by comparing results between several subgroups of results. The distribution of effect estimates is not quite symmetrical and it has therefore been tested whether the results are likely to be affected by publication or outlier bias (section 3.6).

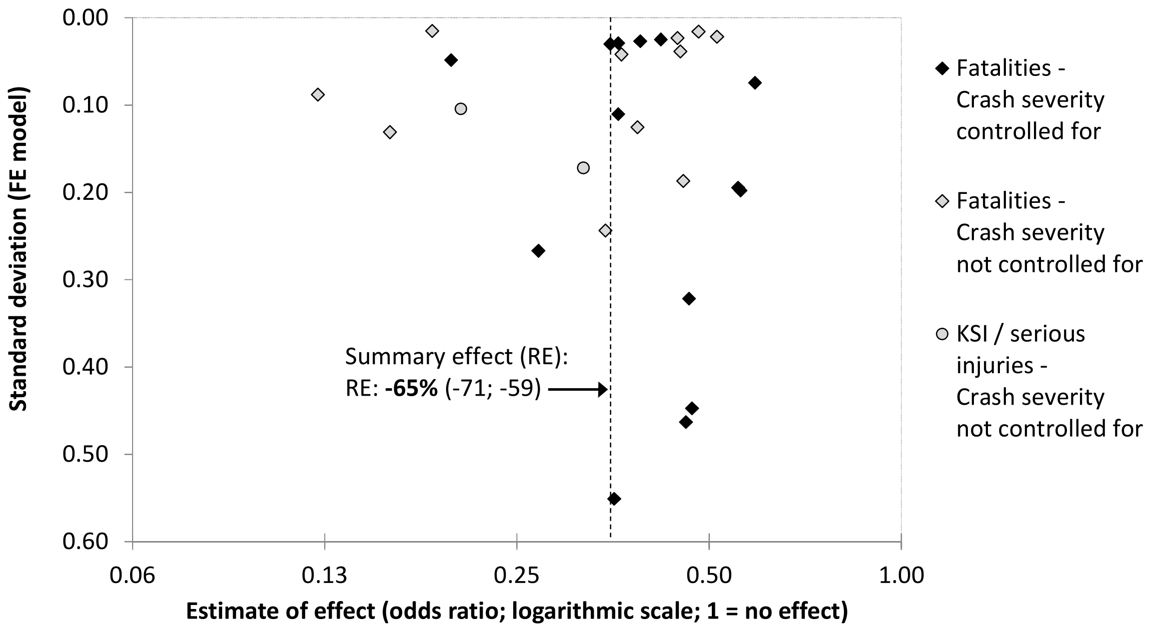

Figure 2: Distribution of the estimates of the effect of own seat belt use on fatality risk and standard deviations, all effect estimates from all studies.

3.2 Control for crash severity and seating position

Two potential moderator variables that can be investigated in meta-analysis are whether or not studies have controlled for crash severity and seating position. Control for crash severity refers to crash characteristics that are not based on injury severity (such as impact speed or vehicle deformation). Results from subgroup analyses for these two variables are shown in table 2. Most results refer to the effects of seat belt use on fatalities among front seat occupants in all types of crashes. Only few results are available for other degrees of severity and several of these refer to specific crash types. Table 2 shows therefore the effects on fatalities in all crashes, and additionally the combined effects on all degrees of injury severity in all crashes for all occupants (the two results that are available for other than fatal injuries in all crashes refer to the effects of seat belts among all vehicle occupants).

Table 2: Results from meta-analysis of the effects of seat belt use on all injuries and on fatalities, tests of heterogeneity, summary effects (percentage differences in fatality/injury risk), confidence intervals, and prediction intervals (RE models unless denoted otherwise).

	Crash severity controlled for				Crash severity not controlled for				All studies			
	df[1]	**Best est.**	**95% CI**	**95% Pred. int.**	**df**[1]	**Best est.**	**95% CI**	**95% Pred. int.**	**df**[1]	**Best est.**	**95% CI**	**95% Pred. int.**
Effects on fatalities in all crashes												
Drivers	3***	**-70**	(-81; -50)	(-95; +105)	0 (FE)	**-82**	(-82; -81)		4***	**-73**	(-82; -60)	(-94; +15)
Front seat passengers	1 (FE)	**-58**	(-60; -56)		0 (FE)	**-55**	(-57; -53)		2	**-57**	(-59; -54)	
Front seat occupants[2]	5***	**-60**	(-66; -53)	(-81; -13)	1 (FE)	**-62**	(-70; -53)		7***	**-60**	(-65; -55)	(-78; -29)
Drivers / front seat occ.[3]	7***	**-65**	(-72; -55)	(-85: -16)	3***	**-68**	(-83; -40)	(-96; +178)	11***	**-66**	(-74; -54)	-85; -23)
Rear seat occupants	1 (FE)	**-44**	(-58; -27)		1***	**-57**	(-69; -39)		3***	**-52**	(-63; -39)	(-83; +34)
All occupants[4]	9***	**-61**	(-69; -52)	(-83; -11)	8***	**-71**	(-80; -56)	(-92; +9)	18***	**-66**	(-73; -57)	(-87; -10)
Effects on all injury severities in all crashes												
All occupants	11***	**-65**	(-73; -56)	(-88; ±0)	8***	**-69**	(-79; -55)	(-90; -8)	20***	**-67**	(-74; -59)	(-87; -15)

[1]Degrees of freedom of the test for heterogeneity; the significance of the test for heterogeneity is indicated as follows: *** if p<.001; ** if p<.01; * if p<.05.

[2]Based only on results that refer to *all* front seat occupants.

[3]Based on results that refer to drivers, results that refer to front seat passengers and results that refer to all front seat occupants (without double counting; if a study has for example reported results for drivers and all front seat occupants, only the latter is used).

[4]Based on results that refer to drivers, front seat passengers, front seat occupants or rear seat occupants (without double counting).

The results in table 2 show that studies without control for crash severity have almost consistently found larger effects than studies that have controlled for crash severity. This is in accordance with the assumption that lack of control for crash severity may lead to an overestimation of the effects of seat belts. Those studies that have controlled for crash severity, have additionally controlled for several other potential confounding factors such as airbags, drunk driving, nighttime crashes, and speed or speed limit, while those studies that have not controlled for crash severity have controlled for none or only few of these factors. Therefore, no other comparisons between studies that have and have not controlled for different factors are shown in table 2.

Since different methods were used for controlling for crash severity, it has been investigated if the results are different between studies that have applied different methods. Most of the studies that have controlled for crash severity have compared injury severity between occupants of the same vehicle, one of which was belted and one of which was unbelted, or they have compared injury severity between drivers of the two vehicles in two-vehicle collisions. Two studies have used multivariate methods (Eluru & Bhat, 2007; Rivara et al., 2000). When these two studies are omitted, none of the results changes by more than 1.2 percentage points. It is therefore concluded that the method that has been used for controlling for crash severity has not affected the results.

The following analyses focus primarily on results from studies that have controlled for crash severity. The results in table 2 indicate that seat belts are more effective for drivers than for front seat passengers and more effective for front seat occupants than for rear seat occupants. The difference between the results for drivers and front seat passengers is statistically significant (studies with control for crash severity: $t = 2.57$; $df = 5$), and the difference between the results for front seat occupants and rear seat occupants is statistically significant as well (studies with control for crash severity: $t = 4.3$; $df = 9$). The difference between the effects among drivers and front seat passengers is investigated further in the sensitivity analysis (section 3.5).

3.3 Injury severity

In order to investigate the effects of seat belts on different degrees of injury severity, table 3 compares the results from studies that have reported effects for other than fatal injuries with corresponding results for fatal injuries (that refer to the same group of occupants and the same type of crashes). Since only few effect estimates are available for other than fatal injuries, results for specific crash types are included in table 3, in addition to results that refer to all crashes. All results that refer to other than fatal injuries are based on only one effect estimate each. Although there are some differences between the results for fatal and other injuries, the estimated effects for other than fatal injuries are not consistently smaller (or greater) than those for fatal injuries. The further analyses are therefore based on the assumption that seat belts are equally effective in preventing (serious) injuries as they are in preventing fatalities.

Table 3: Results from meta-analysis of the effects of seat belt use on other than fatal injuries, tests of heterogeneity, summary effects and confidence intervals (RE models unless denoted otherwise); including corresponding results for fatalities (effects at the same seating positions in the same type of crashes and with the same status of control for crash severity).

	Effect estimates		Corresponding summary effects for fatalities		
	Best est.	**95% CI**	**df[1]**	**Best est.**	**95% CI**
Effects on KSI					
Drivers (two vehicle crashes)	**-63**	(-80; -32)	0 (FE)	**-83**	(-88; -76)
All occupants (all crashes)[3]	**-80**	(-83; -75)	8***	**-71**	(-80; -56)
All front seat occupants (single vehicle crashes)[2]	**-81**	(-96; -6)	0 (FE)	**-80**	(-82; -78)
All occupants (two vehicle crashes)[3]	**-88**	(-89; -86)	1***	**-88**	(-97; -57)
Effects on serious injuries					
All occupants (all crashes)[3]	**-68**	(-77; -56)	8***	**-71**	(-80; -56)
Drivers (two vehicle crashes)[2]	**-74**	(-81; -65)	2**	**-76**	(-83; -67)
Effects on all injuries					
Drivers (two vehicle crashes)[2]	**-83**	(-86; -80)	2**	**-76**	(-83; -67)
All occupants (two vehicle crashes)[3]	**-82**	(-83; -81)	0 (FE)	**-94**	(-96; -91)
Driver/front seat passenger (frontal collisions)[2]	**-53**	(-59; -46)	7***	**-65**	(-72; -55)[4]

[1]Degrees of freedom of the test for heterogeneity; the significance of the test for heterogeneity is indicated as follows: *** if p<.001; ** if p<.01; * if p<.05.
[2]Crash severity controlled for.
[3]Crash severity not controlled for.
[4]Result for fatalities: All instead of frontal crashes.

3.4 Seat belt usage rate

Results from studies with different seat belt usage rates are compared in table 4. Seat belt usage rates are categorized as low (< 50%), medium (50-80%) or high (> 80%). Only studies that have controlled for crash severity, that provide information about seat belt usage rates, and present results that refer to fatalities in all crashes are included. There were only few studies in each of the categories, all results with zero degrees of freedom are based on only one effect estimate. The results do not indicate that seat belts are more (or less) effective when overall seat belt use is low than when it is medium or high. For drivers the results indicate that seat belts are more effective when seat belt use is high than when it is low, but at all other seating positions no or far smaller differences in the other direction were found. Moreover, all results are based on only few effect estimates and the results must therefore be interpreted with some caution.

Table 4: Results from meta-analysis of the effects of seat belt use on all injuries and on fatalities, tests of heterogeneity, summary effects and confidence intervals (RE models unless denoted otherwise).

	Low seat belt use (< 50%)			**Medium seat belt use (50-80%)**			**High seat belt use (> 80%)**		
	df[1]	**Best est.**	**95% CI**	**df[1]**	**Best est.**	**95% CI**	**df[1]**	**Best est.**	**95% CI**
Drivers	0 (FE)	**-64**	(-66; -62)				2	**-80**	(-82; -78)
Front seat passengers	0 (FE)	**-58**	(-60; -56)				0 (FE)	**-54**	(-81; +14)
Front seat occupants[2]	1 (FE)	**-59**	(-61; -57)	2	**-65**	(-67; -63)	0 (FE)	**-53**	(-75; -13)
Rear seat occupants	0 (FE)	**-44**	(-62; -19)				0 (FE)	**-44**	(-62; -17)

[1]Degrees of freedom of the test for heterogeneity; the significance of the test for heterogeneity is indicated as follows: *** if p<.001; ** if p<.01; * if p<.05.; df = 0 indicates that a result is based on only one effect estimate.

[2]Based on results that refer to all front seat occupants.

3.5 *Changes over time*

Based on those studies that are included in meta-analysis it is difficult to assess possible changes of seat belt effectiveness over time. Most studies do not provide information about vehicle model years and crash data are included from only one or very few years in some studies and from up to 11 years in others. In a simplified approach, a correlation coefficient has been calculated between publication year and the estimated seat belt effect among front seat occupants in all crashes. The correlation coefficient is r = -.14 which indicates that seat belt effectiveness has slightly improved over time; the relation is however only weak (R^2 = .02). According to a previous meta-analysis (Elvik et al., 2009) that is based on studies from 1967 to 1996 fatality risk is reduced by 50% among drivers and by 45% among front seat passengers, while injury risk is reduced by 28% among drivers and by 23% among front seat passengers. Both results indicate that seat belt effectiveness may have improved over time.

3.6 *Sensitivity analysis*

Two types of potential bias were investigated in the sensitivity analysis: Publication bias and outlier bias. The distribution of the effect estimates in figure 2 looks asymmetrical. One possible source of asymmetry in funnel plots is publication bias which occurs when non-significant or unexpected results remain unpublished (Sterne et al., 2011). The presence of publication bias has been investigated with the trim-and-fill method that has been developed by Duval & Tweedie (2000). The method is based on a test of the symmetry of the distribution. If the distributions is asymmetric, new effect estimates are generated until the distribution of original and new effect estimates is symmetrical. The results from meta-analysis indicate that control for crash severity and seating position are relevant moderator variables. Trim-and-fill analyses were therefore conducted for each of the summary effects for specific seating positions, with and without control for crash severity. New effect estimates were not generated for any of the summary effects in table 2 that are based on studies with or without control for crash severity. Thus, there is no indication of the presence of publication bias. Each of the trim-and-fill analyses are however based on relatively few effect estimates.

In order to test the presence of outlier bias (Elvik, 2005) in the results that are based on studies with control for crash severity, new summary effects were calculated for each seating position, each with one of the effect estimates omitted. The new summary effects are all, except two, within plus/minus one percentage point of the original summary effects. Those two summary effects that differ are those for driver fatalities and for all occupants when the result from Martin et al. (2003) that refers to driver fatalities is omitted. According to Martin et al. (2003) seat belt use reduces driver fatalities in all crashes by 80% (-82; -78). When this result is omitted, the summary effect for driver fatalities in all crashes diminishes to a reduction by 38% (-75; +52) and the summary effect for all front seat occupants diminishes to a reduction by 60% (-66; -53). The new result for driver fatalities is somewhat illogic. The estimated fatality reduction is smaller than in each of the studies it is based on (-53%, -64%, and -65%) and the corresponding fixed effects result changes far less, from a fatality reduction by 69% (-71; -68) with the result from Martin et al. (2003) to a fatality reduction by 64% (-66; -62) without the result from Martin et al. (2003). These results indicate that the summary effect for driver fatalities may be somewhat overestimated, but most likely not as much as indicated by the new summary effects from the outlier test. The new summary effect for all front seat occupants (based on the results for drivers, front seat passengers and drivers/front seat passengers) is the same as the summary effect that is based on results for drivers and front seat passengers only (see table 2).

3.7 The effect of unbelted rear seat occupants

An overview of the results from six studies that have investigated the effects of non-use of seat belts on other vehicle occupants fatality and injury risk is given in table 5. All studies have controlled for a number of confounding factors, amongst others vehicle and crash characteristics. Most studies have additionally controlled for driver and passenger characteristics such as age and gender. Most results refer to front seat occupants with unbelted vs. belted passengers in one of the rear seats. Although there is significant heterogeneity in the results, the results are consistent in showing that unbelted occupants about double fatality and injury risk among belted occupants, and have more or less no effect on unbelted occupants. There are too few effect estimates for investigating publication bias or other possible biases.

Table 5: Results from meta-analysis of the effects of seat belt non-use among rear seat passengers on fatalities and injuries among front seat passengers, tests of heterogeneity, summary effects (percentage differences) and confidence intervals (RE models unless denoted otherwise).

	df[1]	Best est.	95% CI
Belted occupant fatalities	4***	+119	(+46; +230)
Unbelted occupant fatalities	2 (FE)	+4	(-3; +11)
Belted occupant injuries	2***	+69	(+26; +126)
Unbelted occupant injuries	3*	+5	(-8; +21)

3.8 Conclusions from meta-analysis

Based on the results that are described above, the following analyses are based on the assumption that seat belts reduce the risk of being killed or severely injured by 60% among front seat occupants and by 44% among rear seat occupants. The results from meta-analysis are discussed in more detail below (Summary and discussion).

4. Relative crash risk among belted and unbelted drivers

The relative risk of crash involvement for unbelted drivers has been calculated with the help of Bayes Theorem according to Evans (1987) as described above. Seat belt usage rates in Norway in 2013 were 96.9% among non-crash involved drivers, 78% among drivers involved in fatal crashes and 85% among drivers involved in crashes with KSI (crash involvement rates are based on the crash involvements of all drivers, regardless of whether or not the driver was injured).

According to the formula by Evans (1987) unbelted drivers were 8.3 times as likely of being involved in a fatal crash as belted drivers and 5.2 times as likely of being involved in a serious injury crash in 2013. These relative risk estimates are, as expected, far higher than in the study by Evans (53% higher crash risk among unbelted drivers). However, the estimates are somewhat uncertain because they are highly sensitive for seat belt use among crash involved drivers. Seat belt use among crash involved drivers is more likely to be over- than underestimated (it is often self-reported). If seat belt use among fatal crash involved drivers had been for example 75% instead of 78.6% the estimated relative fatal crash risk of unbelted drivers had been 10.2 instead of 8.3 and if seat belt use among serious injury crash involved drivers had been 80.0% instead of 85.5%, the estimated relative serious injury crash risk of unbelted drivers had been 7.6 instead of 5.2.

5. Effects of increased seat belt use on the number of fatalities and KSI in light vehicles

5.1 Front seat occupants

The estimated effects of increased seat belt use on the numbers of fatalities and serious injuries in the three scenarios of increased seat belt use are shown in table 6. The results under "Different crash risk 1" are based on relative crash risk estimates for unbelted drivers and the effect estimate for seat belt use as described above. The results indicate that the total number of KSI among front seat occupants of light vehicles could be reduced by 11.3% if all light vehicles were equipped with seat belt reminders, by 17.5% if all light vehicles had seat belt interlocks, and by 19.9% if all front seat occupants had been belted. The prediction intervals for these reductions are (-1.7; -22.9), (-2.3; -35.8), and (-2.6; -40.8), respectively. The large size of the prediction intervals is due to the heterogeneity in the results and the fact that the estimated effects of seat belts are based on relatively few studies (see above, section 3.2).

The results under "Different crash risk 2" are based on alternative relative crash risk estimates for unbelted drivers. The alternative estimates are those that one would obtain if seat belt use had been lower among crash involved drivers as described in the previous section. The trend functions for estimating relative crash risk in the scenarios with increased seat belt use were modified accordingly. The results indicate larger effects of increasing seat belt use than those that are based on the original relative risk estimates (-13.5%, -21.3% and -24.5%, respectively).

Under "Same crash risk for all" the effects of increased seat belt use were calculated under the assumption that all drivers have the same crash risk, independent of seat belt use, as described in section 2.3. Two versions of "Same crash risk for all" were calculated, the first is based on seat belt use among KSI drivers in the current situation (formula 4) while the second is based on seat belt use among non-crash involved drivers in the current situation (formula 5). Seat belt usage rates among KSI and non-crash involved drivers in the current situation are not compatible with a seat belt effect of -60% (or any other theoretically possible seat belt effect) and identical crash risk among belted and unbelted drivers. Therefore, one of the two seat belt usage rates (either the one for KSI or the one for non-crash involved drivers) was recalculated in each of the two versions, based on the effect of seat belts and the other seat belt usage rate. Figure 4 shows the estimated relative numbers of KSI front seat occupants (1 in the current situation) in the three scenarios with increased seat belt use, both when taking into account differences in crash risk and in both versions with assumed equal crash risk.

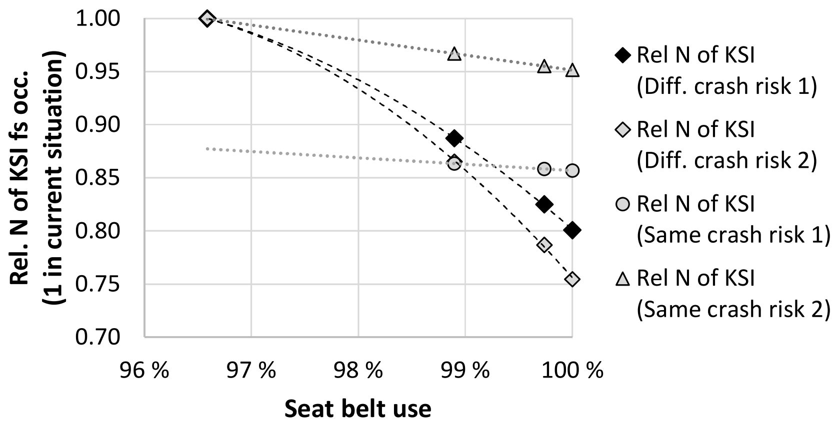

Figure 4: Estimated relative numbers of KSI front seat occupants in three scenarios with increased seat belt use, when taking into account differences in crash risk ("Diff. crash risk 1"), alternative risk difference estimates ("Diff. crash risk 2") and in both versions with equal crash risk ("Same crash risk 1" which is based on seat belt use among KSI and "Same crash risk 2" which is based on seat belt use among non-crash involved).

In the first version of equal crash risk for all drivers (the one that is based on seat belt use among KSI), the estimated reduction of the number of KSI is greater than if one takes into account differences in crash risk in the scenario with seat belt reminders in all light vehicles (-13.7% vs. -11.3%), but smaller in the two scenarios with higher seat belt use (-14.2% vs. -17.5% and -14.3% vs. -19.9%, respectively). The seat belt usage rate among non-crash involved drivers would be far lower than observed by NPRA (2014) which is why the linear trend line does not reach one at a seat belt use of 97.6% (it reaches one at 79.9%).

In the second version of equal crash risk for all drivers (the one that is based on seat belt use among non-crash involved front seat occupants), the estimated reduction of the number of KSI is considerably smaller than if one takes into account differences in crash risk in all three scenarios (between -3.3% and -4.9%). The percentage of seat belt use among killed or seriously injured front seat occupants would be far higher than according to crash statistics which is highly unrealistic because seat belt use in crash statistics is rather over- than underestimated.

These results show that it would be misleading to ignore differences in crash risk between belted and unbelted drivers. The estimated effects of increasing seat belt use would be either over- or underestimated, depending on the assumed increase of seat belt use and on whether the estimates are based on current seat belt use among KSI or non-crash involved drivers.

Moreover, as can be seen in figure 4, when taking into account differences in crash risk between belted and unbelted drivers, the effect of each percentage increase in seat belt use increases at increasing initial levels of seat belt use.

Table 6: Estimated effects of increased seat belt use on the numbers of fatalities and serious injuries in three scenarios for increased seat belt use under different assumptions.

	Different crash risk 1			**Different crash risk 2[a]**			**Same crash risk for all 1[b]**			**Same crash risk for all 2[c]**		
	Drivers	**Front seat pass.**	**Front seat occ.**	**Drivers**	**Front seat pass.**	**Front seat occ.**	**Drivers**	**Front seat pass.**	**Front seat occ.**	**Drivers**	**Front seat pass.**	**Front seat occ.**
Current situation												
Seat belt use (all)	96.8 %	95.8 %		96.8 %	95.8 %	96.8 %	*77.2 %*	*89.3 %*		96.8 %	95.8 %	
Seat belt use (fatalities)	67.1 %	83.3 %		67.1 %	83.3 %	67.1 %	67.1 %	83.3 %		*94.8 %*	*93.1 %*	
Seat belt use (ser. injured)	76.1 %	85.1 %		76.1 %	85.1 %	76.1 %	76.1 %	85.1 %		*94.8 %*	*93.1 %*	
Rel. fat. crash risk (unbelted)	8.3	5.9		10.2	7.2		*1.0*	*1.0*		8.3	5.9	
Rel. SI crash risk (unbelted)	5.2	3.8		7.6	5.4		*1.0*	*1.0*		5.2	3.8	
Scenario 1: Seat belt reminder in all light vehicles (98.8% seat belt use)												
Rel. fat. crash risk (unbelted)	11.1	7.8		15.3	10.6		*1.0*	*1.0*		*1.0*	*1.0*	
Rel. SI crash risk (unbelted)	6.4	4.6		9.1	6.4		*1.0*	*1.0*		*1.0*	*1.0*	
Rel. N of fatalities	0.88	0.83	0.871	0.89	0.82	0.872	0.81	0.91	0.828	0.97	0.96	0.967
Rel. N of serious injuries	0.90	0.86	0.893	0.88	0.83	0.864	0.86	0.92	0.887	0.97	0.96	0.967
Rel. N of KSI	0.90	0.85	**0.887**	0.88	0.82	**0.865**	0.85	0.91	**0.863**	0.97	0.96	**0.967**
Scenario 2: Seat belt interlock in all light vehicles (99.7% seat belt use)												
Rel. fat. crash risk (unbelted)	12.3	8.6		17.35	12.0		*1.0*	*1.0*		*1.0*	*1.0*	
Rel. SI crash risk (unbelted)	7.2	5.1		10.42	7.3		*1.0*	*1.0*		*1.0*	*1.0*	
Rel. N of fatalities	0.79	0.76	0.786	0.77	0.74	0.768	0.80	0.90	0.822	0.96	0.94	0.955
Rel. N of serious injuries	0.84	0.82	0.838	0.80	0.77	0.794	0.86	0.91	0.871	0.96	0.94	0.955
Rel. N of KSI	0.83	0.81	**0.825**	0.79	0.77	**0.787**	0.84	0.91	**0.858**	0.96	0.94	**0.955**
Scenario 3: 100% seat belt use in all light vehicles												
Rel. N of fatalities	0.76	0.74	0.753	0.73	0.71	0.724	0.80	0.90	0.821	0.95	0.94	0.952
Rel. N of serious injuries	0.82	0.80	0.817	0.77	0.75	0.765	0.86	0.91	0.869	0.95	0.94	0.951
Rel. N of KSI	0.80	0.79	**0.801**	0.76	0.74	**0.755**	0.84	0.91	**0.857**	0.95	0.94	**0.951**

[a] Difference in crash risk estimated at lower seat belt wearing rates among crash involved drivers in the current situation.
[b] Seat belt use among non-crash involved front seat occupants calculated based on seat belt use among KSI front seat occupants and seat belt effect.
[c] Seat belt use among KSI front seat occupants calculated based on seat belt use among non-crash involved front seat occupants and seat belt effect.

5.2 Rear seat occupants

Since seat belt use among rear seat occupants is unknown, the potential effect of increasing seat belt use on rear seats could not be calculated. Non-use of seat belts among rear seat occupants was found to about double fatality and injury risk among belted front seat occupants, while no significant effect was found among unbelted front seat occupants. In 2013 in Norway, only 1.7% of all killed or seriously injured belted front seat occupants had an unbelted rear seat passenger (above eight years) in one of the seats behind. If all these rear seat passengers had been belted, the number of killed or seriously injured front seat occupants would be reduced by 0.6% (or 2.7). However, seat belt use is unknown for 37% of all KSI rear seat passengers in 2013. Unless all those rear seat occupants for whom seat belt use is unknown were belted, the number of front seat occupants with an unbelted rear seat passenger behind is underestimated. Among killed or seriously injured rear seat passengers (above eight years), 24% of those with known seat belt use were unbelted. If one assumes that the percentage is the same among all KSI rear seat occupants, that seat belts reduce the risk of being killed or seriously injured by 44%, and that crash risk is the same among belted and unbelted rear seat occupants (which is an unrealistic assumption), then the number of KSI rear seat occupants could have been 10% (or 2.8) lower than it actually was if all rear seat occupants had been belted.

6. Summary and discussion

The present study has investigated the effects of seat belt use on fatality and injury risk among occupants of light vehicles with the help of meta-analysis and estimated the relative crash risk of unbelted drivers. Based on these results the expected impacts of increased seat belt use on the number of KSI light vehicle occupants in Norway in 2013 are estimated. Seat belts were found to reduce fatality and injury risk by about 60% among drivers and front seat passengers and by 44% among rear seat passengers. These estimates are more optimistic than the results from an earlier meta-analysis.

The results are based only on studies that have controlled for crash severity and are therefore not likely to be affected by a bias from lower seat belt use in crashes with higher impact speed. Publication bias or outlier bias are also unlikely to have affected the results as has been shown in a sensitivity analysis, but there is considerable unexplained heterogeneity in the results. Control for other factors than control for crash severity is most likely not responsible for the heterogeneity, but differences between driver populations, vehicle fleets, and other factors that could not be accounted for in meta-analysis may be.

All summary effects are statistically significant and even the upper limits of the confidence intervals are far below zero. The prediction intervals (table 2) are relatively large, the upper limits are for the most part outside the confidence intervals of most of the individual studies. Prediction intervals are according to Riley et al. (2011) most adequate when the studies included in meta-analysis have a low risk of bias and when the number of studies is large. In this case, there are few studies and significant heterogeneity in the results. Both factors are known to contribute to large prediction intervals (Graham & Moran, 2012). Only 12 results were available from studies with control for crash severity that refer to the effect of seat belts on front seat fatalities and all results for specific seating positions are based on still fewer effect estimates. However, even the relatively large prediction intervals do for the most part not include zero and only three of the 27 individual effect estimates (those that refer to the effects of own seat belt use in all crashes) have confidence intervals that include zero. The results that refer to specific seating positions in the front row are very similar between different seating positions (when the result from Martin et al., 2003, is omitted). These findings indicate consistently that that the effect of seat belts on fatalities is both statistically significant and about -60%, although individual studies may find results in the range of about -80% to -10% as indicated by the prediction intervals.

Cummings et al. (2003) have investigated several possible explanations for improved seat belt effectiveness over time (differences in analysis methods, changes of vehicle characteristics or crash characteristics), and concluded that the most likely explanation is that earlier estimates of seat belt effects may be underestimated because of misclassifications of seat belt use, especially prior to 1986. Seat belts in more recent cars models (the study by Cummings et al., 2003, is based on data from 1975 to 1998) may actually have become more effective, e.g. because of increased use of pretensioners and load limiters.

Although it seems reasonable to find improved effects of seat belts over time, there is one factor that may have contributed to an overestimation of the effectiveness of seat belts among front seat occupants. None of the studies included in meta-analysis has controlled for others' seat belt use. Unbelted occupants were found to about double fatality and injury risk among belted occupants and belted occupants are less likely than unbelted occupants to have other unbelted occupants in the car. In Norway 67% of all unbelted KSI front seat passengers had an unbelted driver, vs. 4% of all belted KSI front seat passengers. Similarly, 4.7% of all unbelted

KSI front seat occupants had an unbelted rear seat passenger in one of the seats behind while this is the case for 1.7% of all belted KSI front seat occupants. If the proportion of all belted KSI front seat occupants who had an unbelted driver or rear seat passenger in the car is about equally small in other studies (unbelted rear seat passengers were not found to increase injury risk among unbelted front seat occupants), the impact on the estimated effect of seat belt use among front seat occupants is probably only small.

In contrast to the earlier meta-analysis of seat belt effects (Elvik et al., 2009), no differences were found between different degrees of severity. The results for other than fatal injuries are based on effect estimates from few studies, refer partly only to specific crash types and several of these studies have not controlled for crash severity. However, all available results for non-fatal injuries were compared to results for fatal injuries in the same type of crashes that are based on studies with the same status of control for crash severity. Although none of the results for non-fatal injuries is based on more than one study, there are no specific reasons to assume that the lack of systematic differences between the results for fatal and non-fatal injuries are due to different crash types or methodological aspects of the studies. Thus, the effectiveness of seat belts in preventing non-fatal injuries may actually have improved over time, or earlier effect estimates for non-fatal injuries may have been more underestimated than the effectiveness in preventing fatal injuries.

It was concluded from meta-analysis that seat belts are about equally effective among drivers and front seat passengers. The initial results indicated higher effectiveness among drivers, which was in accordance with the previous meta-analysis by Elvik et al. (2009). However, this result was strongly affected by one study. When this study is omitted, the results became difficult to interpret, and equal effectiveness among drivers and front seat passengers was assumed to be the "best guess".

Unbelted drivers were expected to have higher crash risk than belted drivers. An analysis that is based on the relationship between seat belt use among drivers in general and seat belt use among crash involved drivers indicates that unbelted drivers have about 8.3 times as high fatal crash risk and about 5.2 times as high serious injury crash risk as belted drivers. The large differences in crash risk can be explained by factors such as higher speed, more drunk driving and other risk factors that are more common among unbelted than among belted drivers. The differences in crash risk may even be underestimated because seat belt use among crash involved drivers is often self-reported and may therefore be overestimated.

The reductions of the number of fatalities and serious injuries in Norway that could have been achieved if all light vehicles had been equipped with seat belt reminders or with seat belt interlocks, as well as in a situation with 100% seat belt use among front seat occupants, were estimated based on the effects of seat belt use according to the results from meta-analysis and the estimated relative crash risks of unbelted drivers. The results indicate that the number of all KSI front seat occupants in light vehicles could have been reduced by 11.3 %, 17.5 % and 19.9 % if all light vehicles were equipped with seat belt reminders or seat belt interlocks or if seat belt use were 100 %, respectively. In terms of total number of KSI that could have been avoided this is 47.6 (seat belt reminders), 73.9 (seat belt interlocks) and 84.1 (100% seat belt use). If one assumes that the relative crash risk estimates for unbelted drivers are underestimated, the number of KSI could be reduced even more.

A comparison of the results with and without taking into account differences in crash risk between belted and unbelted drivers shows that not taking into account differences in crash risk most likely leads to an underestimation of the effects of increasing seat belt use, except possibly in the scenario with the smallest increase of seat belt use (seat belt reminders). Without taking into account differences in crash risk the effect of increasing seat belt use is proportional to the increase of seat belt use and thus, the estimated reductions of KSI are only increasing by very small amounts even at high seat belt usage rates. When differences in crash risk are taken into account, the scenario calculations indicate that there is relatively more to gain from increased seat belt use (per percentage increase of seat belt use) at higher initial levels of seat belt use, because the relative crash risk among unbelted drivers increases at increasing levels of seat belt use. A comparable effect could not be observed in the meta-analysis of seat belt effects. Studies in which the initial level of seat belt use was high did not systematically find greater effects of seat belt use. However, these studies have investigated the effects of seat belt use vs. non-use, not potential effects of all drivers using the seat-belt.

Had all light vehicles been equipped with rear seat belt reminders (or interlocks), the reduction of the number of KSI could be still larger. However, in terms of number of prevented KSI the effect would be far smaller than the effects of seat belt reminders or interlocks for front seat occupants. About 2.7 KSI front seat occupants and about 2.8 rear seat occupants could have remained uninjured or sustained less severe injuries if all rear seat occupants had been belted. Both estimates are probably underestimated because seat belt use is unknown for about one third of all crash involved rear seat occupants and it may be overestimated among those where information is available. Additionally, differences in crash risk between belted and unbelted rear seat passengers were not taken into account. However, the expected effect per rear seat passenger who starts using the seat belt would be larger than the expected effect of each front seat occupant who starts using the seat belt because seat belt use among rear seat occupants reduces injury risk among both rear and (belted) front seat occupants.

7. Conclusions

Seat belts were found to reduce both fatal and non-fatal injuries by about 60% among front seat occupants and by 44% among rear seat occupants in a meta-analysis of studies that have controlled for crash severity. The results indicate that the effect of seat belts have improved over time. This is most likely, at least partly, due to methodological aspects of the studies and may additionally be due to actually improved effects of seat belts. While earlier studies indicated that seat belts are more effective among drivers than among front seat passengers, and more effective in preventing fatal than less serious injuries, the current meta-analysis indicates that seat belts are equally effective among all front seat occupants and for injuries of all degrees of severity. Although all results are statistically significant, they are based on relatively few effect estimates (12 for the effects in the front row, two for effects among rear seat occupants) and there is significant unexplained heterogeneity. The results should therefore be interpreted with some caution.

Unbelted drivers were found to have considerably higher risk of serious crashes than belted drivers. These differences in crash risk should be taken into account when estimating potential effects of increased seat belt use. In Norway, the annual numbers of KSI in light vehicles could be considerably smaller if all vehicles were equipped with seat belt reminders or interlocks. If all light vehicles in 2013 had been equipped with seat belt reminders for front seat occupants it is estimated that there could have been 47.6 (or 11.3%) fewer KSI front seat occupants in light vehicles. At higher initial levels of seat belt use, the effects of increasing seat belt use per percentage increase would be still larger.

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