Association of age, sex and seat belt use with the risk of early death in drivers of passenger cars involved in traffic crashes

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Background This study was designed to break down the association of age, sex and seat belt use with risk of death for drivers of automobiles involved in a crash into two theoretical components: intrinsic severity of the crash and occupant resilience.

Methods We studied all 84 338 pairs of drivers and front-seat passengers aged ≥18 years in passenger cars involved in traffic crashes with victims recorded in the Spanish traffic crash registry between 2000 and 2004. Relative risks (RR) for the association of age, male sex and non-seat belt use with risk of death were calculated with Poisson conditional and unconditional multiple regression models.

Results For drivers, the risk of death associated with severity of the crash was slightly higher in men (RR = 1.18), and decreased with age (RR = 0.993 per year). However, resilience-dependent risk of death increased with age (RR = 1.028 per year), and especially among unbelted occupants (RR = 4.02).

Conclusions We conclude that in drivers involved in traffic crashes the association of age, sex and seat belt use with risk of death depends on the component of risk considered: severity of the crash or the occupant’s resilience to energy.

Keywords Accidents, traffic, mortality, methods, risk factor, seat belts, age, sex

Introduction

Many studies have assessed the effect of driver-related factors such as age, sex or the use of protective devices on the risk of death after a traffic crash (i.e. from samples of drivers involved in traffic crashes). From a theoretical viewpoint, the association between one individual-related factor (e.g. age), and the risk of death may operate through two different causal pathways.

− The first (on a temporal scale) is that related to what can be called the ‘intrinsic severity’ of the crash, related in turn to the type of crash and the amount of energy released. For example, we might suspect crashes in which younger drivers are involved to be of higher intrinsic severity than those involving older drivers, because younger drivers tend to drive faster.1−3
− Given a crash of a certain intrinsic severity, the second causal pathway by which an individual factor may influence the risk of death is the ‘resilience’ of the subject to the effect of the released energy. This concept—resilience—is, in fact, a mixture of three successive elements: the proportion of the released energy that is transferred to the individual, the

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injuries this energy causes at the time of the crash, and the prognosis of these injuries. For example, several studies have shown that, for crashes of the same intrinsic severity, older drivers or passengers tend to have a higher risk of death than younger people, probably because older people have both a lower tissular resistance to the effect of the energy and their injuries have a worse prognosis compared with younger people.

As suggested by the previous example, the association of factors such as driver’s age with the risk of death after a crash is likely to differ substantially depending on which of the two causal pathways is taken into account. Nevertheless, few studies have been designed to distinguish between these two types of association. Most available studies do not distinguish between them; therefore, their estimates of association should be considered a mixture of the associations related with each of these two pathways. Other studies considered only one component: e.g. in studies of driver–passenger pairs occupying the same vehicle, the paired design identifies associations between individual-related factors that are related only with resilience.

The aim of our study was to quantify the association of age, sex and seat belt use with the risk of early death in drivers of passenger cars involved in a traffic crash. Our analysis also aimed to disentangle this association into the two theoretical components defined above: the association dependent on severity of the crash, and that dependent on the occupant’s resilience to the energy released.

Methods

The study population consisted of driver–front-seat passenger pairs aged ≥18 years who were occupants of passenger cars involved in traffic crashes with victims in Spain. All crashes occurred between 2000 and 2004 inclusive, and were recorded in the Spanish national traffic authority’s registry of crashes with victims. The characteristics of the registry were described in detail in earlier publications. From the original 119 755 pairs who met the inclusion criteria, we excluded 35 417 driver–passenger pairs for which information was missing for either occupant regarding death within 24 h after the crash (early deaths) (1726 missing pairs), age (15 285), sex (8444) or seat belt use (25 767). A total of 84 338 pairs occupying as many vehicles was included. In addition to the variables noted above, we recorded information on: (i) other driver-related variables (nationality, type of driver—professional or non-professional—years since the driver’s license was obtained, physical disabilities, psychophysical circumstances—DUI, driving under the influence of other drugs, sleepiness, other adverse circumstances—hours driving without a break, administrative infractions; (ii) vehicle-related variables (age of the vehicle, previous defects—none, worn tires, blow-out, others—number of occupants); (iii) crash-related variables: number of injured people, type of crash, number of vehicles involved, speed-related infractions, other driver-related infractions, driver’s maneuver immediately before the crash, other deaths apart from those of the driver and front-seat passenger; and (iv) environmental circumstances (year, month, day of the week, time of day, type of day, zone, type of road, condition of the road surface, visibility, light conditions, weather conditions, other dangerous circumstances, traffic density). The categories of each variable are shown in the Appendix (Supplementary data are available at IJE online).

Analysis

Variable numbers of records were missing values for the following adjustment factors: nationality, type of driver, years since the driver’s license was obtained, physical disabilities, psychophysical circumstances, hours driving without a break, administrative infractions, age of the vehicle, previous defects of the vehicle and speed-related infractions. Complete information for all variables was available for 33 156 drivers. To keep the entire sample in all the models, we first used a multiple imputation process with switching regression (multiple imputation by chained equations), which allowed us to construct 10 files in which missing values for the variables listed above, except nationality, were replaced by their corresponding imputed values. We could not apply this procedure to the variable nationality, with only 265 missing values, because the high number of categories with small counts for this variable produced highly distorted and unreliable imputation models. Therefore each file comprised 84 073 registries. We fitted a model for each file, and coefficients of each model were combined according to the combination rules of Rubin. These operations were done with the Ice and Mim programmes from Stata version 10. We constructed four Poisson multiple regression models in order to estimate relative risks (RRs) and their 95% confidence intervals (CIs) for each age, sex and seat belt use category considered here. We first included age as a categorical variable, using 18-year-old drivers as the reference category. However, because we observed an approximately exponential trend in the RR values for each 1-year increase, we opted to include age as a continuous variable. For the other two variables, we considered female sex and seat belt use as the reference categories.

Model 1

The aim of this model was to assess the overall relationship between drivers’ death and driver-related characteristics, which may be mediated through the two pathways described in the introduction, i.e. severity of the crash and driver’s resilience. In this model, the dependent variable was driver’s death and
independent variables were driver’s age, sex and seat belt use. To adjust for the confounding effect of other well-known risk factors for death, which may also be related with driver characteristics, we also included in the model other driver-, vehicle- and environment-related variables. This model therefore quantified the overall association of driver’s age, sex and seat belt use with the driver’s risk of death after a crash, without distinction regarding the pathway which links them. This was called the ‘joint model’.

Model 2
This model was designed to assess the relationship between passenger’s risk of death and passenger characteristics. The implicit assumption of the model is that, after controlling for confounding, the only pathway that might link passenger’s age, sex and seat belt use with passenger’s risk of death is the passenger’s resilience. Therefore, in this model death of the passenger was the dependent variable and passengers’ age, sex and seat belt use were the independent terms. However, passenger-related characteristics may also be associated with driver’s characteristics, which in turn may be related to the severity of the crash, and through this pathway with the risk of death of any occupant in the vehicle. To exclude this pathway between the passenger’s characteristics and passenger’s risk of death, we also included in the model all driver-, vehicle- and environmental-related characteristics as well as other variables closely related with the severity of the crash: number of victims in the crash, death of the driver, number of other deaths (apart of the driver and the front passenger), speed-related infractions, other driving infractions, driver’s manoeuvre immediately before the crash, number of vehicles involved in the crash and type of crash. We refer to this model as the ‘resilience-model’.

Model 3
This model was designed to estimate the relationship between driver’s characteristics and passenger’s risk of death. In theory, the only pathway that might link these two factors is severity of the crash: if driver’s characteristics are related with crash severity, they may indirectly be related with passenger’s risk of death. Therefore, the dependent variable was death of the passenger and the independent variables were driver’s age, sex and seat belt use. In this model, we also included as independent terms all passenger characteristics, because they may confound the relationship between driver’s characteristics and passenger’s risk of death. Finally, we also included other factors that might confound the relationship between driver’s characteristics and severity of the crash (other driver-, vehicle- and environment-related factors), but we did not include in the model any other direct markers of crash severity. This model is called here the ‘severity-model’.

The three models described above were unconditional Poisson regression models. However, we also designed a conditional Poisson regression model for driver–passenger pairs, in which the dependent variable was death of either of the two occupants, and as independent variables we considered only seating position in the vehicle (driver or front-seat passenger), age, sex and seat belt use. In this analysis, pairs in which no deaths occurred were non-informative for estimating RR. Therefore, the model included only the 4087 driver–passenger pairs in which at least one death occurred. With this paired design, we controlled simultaneously for all factors related with intrinsic severity of the crash, i.e. those related with the characteristics of the vehicle (e.g. its size), the speed at which the crash occurred, or the environmental conditions (time of day or night, road surface conditions, etc.), because exposure to all these variables was the same for both members of each pair. This model was therefore considered the reference for quantifying the association of age, sex and seat belt use with risk of death dependent only on occupant resilience. If this association does not change depending on the position of the occupant (driver or front-seat passenger), the RR estimates obtained with this model should be similar to those obtained with the resilience model. To test whether position in the vehicle modified the association of the other three independent variables with risk of death, we constructed the corresponding interaction terms and tested their statistical significance ($P < 0.05$) with the likelihood ratio test.

All statistical analyses were done with Stata software (v. 8.0).

Results
Table 1 shows the distribution of the 84 338 driver–front-seat passenger pairs according to each of the four main study variables: early death, age, sex and seat belt use. Most drivers were men <35 years of age who had used a seat belt, whereas most passengers were women. Risk of early death was ~3% in drivers and passengers. In both groups the risk was higher in men, in older occupants and particularly in occupants who did not use a seat belt.

Table 2 shows the RR estimates we obtained with each of the four regression models (complete models are shown in the Appendix: Supplementary data are available at IJE online). In the joint model, each 1-year increase in age was associated with a 1.4% increase in risk of early death. However, this increase was considerably greater in the resilience model at 2.8%. In the severity model increasing age yielded an inverse association with death: a 0.7% reduction in risk of early death per 1-year increase in age. With regard to the influence of sex, the joint model and (to a lesser extent) the severity model yielded a slightly higher RR for men than women: 1.34 and 1.18,
Table 1 Distribution of drivers and front-seat passengers of passenger vehicles involved in traffic crashes with victims in Spain from 2000 to 2004, according to age, sex, seat belt use and death

<table>
<thead>
<tr>
<th>Variables</th>
<th>Drivers</th>
<th>Population N (%)a</th>
<th>Deaths N (%)b</th>
<th>Front-seat passengers</th>
<th>Population N (%)a</th>
<th>Deaths N (%)b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>69 829  (82.80)</td>
<td>2252  (3.23)</td>
<td>33 214  (39.38)</td>
<td>1186  (3.57)</td>
<td>14 509  (17.20)</td>
<td>269  (1.85)</td>
</tr>
<tr>
<td>Female</td>
<td>14 509  (17.20)</td>
<td>269  (1.85)</td>
<td>51 124  (60.62)</td>
<td>1246  (2.44)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18–24</td>
<td>19 546  (23.18)</td>
<td>576  (2.95)</td>
<td>23 443  (27.80)</td>
<td>580  (2.47)</td>
<td>24 428  (28.96)</td>
<td>595  (2.44)</td>
</tr>
<tr>
<td>25–34</td>
<td>14 252  (16.90)</td>
<td>353  (2.48)</td>
<td>12 173  (14.43)</td>
<td>304  (2.50)</td>
<td>10 834  (12.85)</td>
<td>335  (3.09)</td>
</tr>
<tr>
<td>35–44</td>
<td>7922  (9.39)</td>
<td>286  (3.61)</td>
<td>8241  (9.77)</td>
<td>275  (3.34)</td>
<td>5614  (6.66)</td>
<td>262  (4.67)</td>
</tr>
<tr>
<td>45–54</td>
<td>5614  (6.66)</td>
<td>262  (4.67)</td>
<td>6172  (7.32)</td>
<td>293  (4.75)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;74</td>
<td>1742  (2.07)</td>
<td>114  (6.54)</td>
<td>2709  (3.21)</td>
<td>189  (6.98)</td>
<td>1763  (2.31)</td>
<td>74 964  (88.89)</td>
</tr>
<tr>
<td>Sebt belt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>76 295  (90.46)</td>
<td>1763  (2.31)</td>
<td>74 964  (88.89)</td>
<td>1672  (2.23)</td>
<td>8043  (9.54)</td>
<td>758  (9.42)</td>
</tr>
<tr>
<td>No</td>
<td>84 338  (100)</td>
<td>2521  (2.99)</td>
<td>84 338  (100)</td>
<td>2432  (2.88)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

aPercentages calculated per column: each value represents the proportion of the total population included in the category.
bPercentages calculated per row: each value represents the number of deaths referred to all subjects included in each category.

Table 2 RRs and 95% CIs to quantify the association of age, male sex and non-seat belt use with risk of death obtained with each of the four regression models (see Methods section and footnotes), in drivers and front-seat passengers of passenger cars involved in traffic crashes with victims in Spain from 2000 to 2004

<table>
<thead>
<tr>
<th>Model</th>
<th>Outcome: death of:</th>
<th>RR refers to:</th>
<th>Variables</th>
<th>Per year increase in age</th>
<th>Male sex</th>
<th>Non-seat belt use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: Joint modela</td>
<td>driver</td>
<td>driver</td>
<td>RR (95% CI)</td>
<td>RR (95% CI)</td>
<td>RR (95% CI)</td>
<td>1.014 (1.010–1.018)</td>
</tr>
<tr>
<td>Model 2: Resilience modelb</td>
<td>passenger</td>
<td>passenger</td>
<td>1.028 (1.025–1.032)</td>
<td>1.04 (0.95–1.14)</td>
<td>4.02 (3.50–4.62)</td>
<td></td>
</tr>
<tr>
<td>Model 3: Severity modelc</td>
<td>passenger</td>
<td>driver</td>
<td>0.993 (0.988–0.997)</td>
<td>1.18 (1.05–1.34)</td>
<td>1.16 (0.99–1.35)</td>
<td></td>
</tr>
<tr>
<td>Model 4: Paired modeld</td>
<td>occupant</td>
<td>occupant</td>
<td>1.029 (1.024–1.034)</td>
<td>0.97 (0.88–1.03)</td>
<td>3.65 (2.97–4.48)</td>
<td></td>
</tr>
</tbody>
</table>

aDependent variable: death of the driver. Independent variables: driver’s age, sex, seat belt use, driver’s country of origin, type of driver, years since the driver’s license was obtained, psychophysical circumstances, physical disabilities, hours driving without a break, administrative infractions, age of the vehicle, previous defects of the vehicle, number of occupants in the vehicle, year, month, day of the week, time of day, type of day, zone, type of road, condition of the road surface, visibility, light conditions, weather conditions, other dangerous circumstances, traffic density.
bDependent variable: death of the passenger. Independent variables: passenger’s age, passenger’s sex, passenger’s seat belt use, driver’s age, sex, seat belt use, driver’s country of origin, type of driver, years since the driver’s license was obtained, psychophysical circumstances, physical disabilities, hours driving without a break, administrative infractions, age of the vehicle, previous defects of the vehicle, number of occupants in the vehicle, year, month, day of the week, time of day, type of day, zone, type of road, condition of the road surface, visibility, light conditions, weather conditions, other dangerous circumstances, traffic density, passenger’s age, passenger’s sex, passenger’s seat belt use.
cDependent variable: death of the passenger. Independent variables: driver’s age, sex, seat belt use, driver’s country of origin, type of driver, years since the driver’s license was obtained, psychophysical circumstances, physical disabilities, hours driving without a break, administrative infractions, age of the vehicle, previous defects of the vehicle, number of occupants in the vehicle, year, month, day of the week, time of day, type of day, zone, type of road, condition of the road surface, visibility, light conditions, weather conditions, other dangerous circumstances, traffic density, passenger’s age, passenger’s sex, passenger’s seat belt use.
dDependent variable: death of the occupant. Independent variables: occupant’s age, sex, seat belt use, position in the vehicle.
Discussion

Our analysis showed that the association of age, sex and seat belt use with the risk of early death after a traffic crash differed depending on which of the two components of risk was considered: the risk dependent on intrinsic severity of the crash decreased as age increased, was lower in women and was slightly higher in drivers who did not wear seat belts. However, the risk dependent on individual resilience clearly increased with age. Furthermore, this risk was especially high among occupants who did not use a seat belt, and was apparently not associated with sex. We should emphasize that our estimates are conditioned by the fact that a traffic crash had actually occurred, so none of our models estimated the risk of being involved in a traffic crash.

Our results are consistent in some ways with earlier studies, most of which found increasing age to be associated with an increased risk of death or of more severe injury. 

Seven, eight, ten, twenty, twenty-seven This association is usually explained as a consequence of lower resilience to released energy, although in the present study we found that this effect was offset in part by the fact that older drivers appeared to be involved in intrinsically less severe crashes. This is in agreement with the reported association between younger age of the driver and a higher frequency of risk behaviours, one to three or a higher risk of being involved in more severe single-vehicle crashes. Twenty-eight With regard to sex, we did not find a higher risk of early death or severe injury in women, in contrast to many earlier publications, four, six, eight, twenty, twenty-five, twenty-seven to thirty. Our finding of a higher overall risk of early death in male drivers—as also reported in other studies, nine, twenty-six, thirty-two—was due to the fact that men were involved in intrinsically more severe crashes. This might reflect the previously reported association between male sex and a more risky driving style, two including driving at higher speeds. One Finally, our results confirm the widely reported protective effect of seat belt use on risk of death, four, six, eight, twenty, twenty-one, twenty-six, thirty-three. As expected, this effect was mainly dependent on increased resilience to the effect of the energy released, but it seems that a small part of the joint association between non-seat belt use and risk of death was explained because non-use was also a marker of more severe crashes.

Aside from the consistency of our results, the validity of our methodology is supported by the finding that, as predicted by our initial hypothesis, the results of our resilience model were similar to those obtained with the paired model, used as the reference to estimate the association between occupant characteristics and the risk of death mediated by resilience. However, this finding does not ensure the validity of our method, which awaits further testing. Another limitation arises from the database that provided the raw data, as discussed elsewhere. Thirteen, fourteen, twenty-seven Some ‘eligible’ crashes were not included, and the accuracy of the information recorded at the scene of the crash may be questionable (e.g. the registry recorded only early deaths, i.e. those occurring within 24 h after the crash). Moreover, there may be some residual confounding because it was not possible to adjust for the effect of other factors not recorded in the registry. For example, the register does not include information about the size or weight of the vehicle, a factor clearly related with mortality and probably also associated with driver- or passenger-related characteristics. Although this lack of information is not relevant in the matched analysis (in which both occupants were paired by vehicle), the RR estimates in the severity model may have been affected by confounding due to this factor. The diverse and complex relationships that may be hypothesized between car type and both driver and passengers characteristics make it difficult to elucidate the magnitude and direction of this source of bias. A similar problem may be related to the absence of adjustment by the presence of an airbag in the vehicle, another factor not recorded in the registry. In this case, bias may lead to underestimation of the protective effect of seat belt use if the presence of an airbag influences the decision of some occupants not to use seat belts. Furthermore, the presence or deployment of an airbag does not seem related with occupant’s age or sex. Finally, we have no information about the quality of medical care the victims received, although we assume that this factor is not a confounder since it is not related with characteristics of the vehicle occupants.

In conclusion, the risk of early death associated with severity of the crash in drivers of passenger cars involved in a traffic crash was slightly higher in men, and decreased as age increased. However, the risk of early death associated with resilience to the energy released by the crash clearly increased with age and among occupants who did not use a seat belt.

Supplementary Data

Supplementary data are available at IJE online.
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Conflict of interest: None declared.

KEY MESSAGES
- The association between a given individual-related factor and the risk of death after a crash may arise through either the intrinsic severity of the crash or the occupant’s resilience to the energy released.
- Few studies have been designed to distinguish between these two types of association.
- We propose a method to disentangle the association between individual-related factors and risk of death after a crash into the two theoretical components defined above.
- In the sample used for our analysis, the association of age, sex and seat belt use with risk of death for drivers involved in traffic crashes depended on the component of risk considered.
- The risk of early death associated with severity of the crash was slightly higher in male and non-belted drivers, and decreased as age increased.
- However, the risk of early death associated with resilience to the energy released clearly increased with age and especially among occupants who did not use a seat belt.

References
Commentary: Causal pathways of relative motor vehicle crash fatality risk are hard to estimate from police records

Paul L Zador

Lardelli-Claret et al. estimated relative driver and front seat (FS) passenger fatality risks as a function of age, sex and belt use (ASB). Four sets of relative fatality risk (RFR) estimates were derived from Poisson regression models based on Spanish traffic crash registry data for the years 2000–04 (N = 84,338 FS occupant pairs). Each of the models related the probability of an FS driver (Model 1), an FS passenger (Models 2 and 3) or an FS occupant (Model 4) fatality to some combination of covariates for occupant, vehicle, crash and environmental factors. The covariates varied by model. Depending on model specification, the RFR estimates of ASB were conceptualized as accounting for the causal RFR effects of these factors through some combination of two ‘causal pathways’ the authors identified as the ‘severity’ or the ‘resilience’ pathway.

Model 1 (‘Joint’) estimated the RFR of drivers due to driver ASB and a mixed group of variables through the severity and resilience pathways.

Model 2 (‘Resilience’) estimated the RFR of passengers due to all variables in Model 1 plus FS passenger ASB through the resilience pathway.

Model 3 (‘Severity’) estimated the RFR of passengers due to all variables in Model 1 plus FS passenger ASB, crash severity and driver history through the resilience pathway.

Model 4 (‘Paired’) estimated the RFR of FS occupants due to FS occupant seating position and FS occupant ASB through the paired pathway.

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