Title:

Modeling offenses among motorcyclists involved in crashes in Spain.

Authors' names and affiliations:

Patricia Perez-Fuster[a,*], Maria F. Rodrigo[a,b], Maria Luisa Ballestar[a,c], Jaime Sanmartin[a,b]

[a]Institut Universitari d'Investigacio en Transit i Seguretat Viaria (INTRAS). Serpis 29, 46022. Universitat de Valencia, Spain.
[b]Departament de Metodologia de les Ciencies del Comportament. Blasco Ibañez 21, 46010. Universitat de Valencia, Spain.
[c]Departament d'Infermeria. Jaume Roig, 46010. Universitat de Valencia, Spain.

* Corresponding author: Tel.: +34609977821; Fax: +34963393881.
Postal Address: INTRAS. Serpis 29, 46022. Valencia, Spain.
E-mail addresses: Patricia.Perez-Fuster@uv.es (P. Perez-Fuster), Maria.F.Rodrigo@uv.es (M.F. Rodrigo), M.Luisa.Ballestar@uv.es (M.L. Ballestar), Jaime.Sanmartin@uv.es (J. Sanmartin).

ABSTRACT

In relative terms, Spanish motorcyclists are more likely to be involved in crashes than other drivers and this tendency is constantly increasing. The objective of this study is to identify the factors that are related to being an offender in motorcycle accidents. A binary logit model is used to differentiate between offender and non-offender motorcyclists. A motorcyclist was considered to be offender when s/he had committed at least one traffic offense at the moment previous to the crash. The analysis is based on the official accident database of the Spanish General Directorate of Traffic (DGT) for the 2003-2008 time period. A number of explanatory variables including motorcyclist characteristics and environmental factors have been evaluated. The results suggest that inexperienced, older females, not using helmets, absent-minded and non-fatigued riders are more likely to be offenders. Moreover, riding during the night, on weekends, for leisure purposes and along roads in perfect condition, mainly on curves, predict offenses among motorcyclists. The findings of this study are expected to be useful in developing traffic policy decisions in order to improve motorcyclist safety.

Keywords: Motorcycle, rider offender, crash, binary logit model

1. Introduction

The high accident rate of two-wheeled vehicles has been the main issue in several European studies. In 2009, this group of road users represented 16% of the total number of fatalities in road accidents in the EU-24 countries (Yannis, 2011). Motorcycle drivers specifically do have a greater risk of being victims (fatalities or injuries) in a traffic accident compared with any other vehicle user (Elliott et al., 2007; Keall and Newstead, 2012). The risk of having an accident to which they are exposed is several times higher than the other drivers' (Horswill and Helman, 2003) and, compared with passenger car drivers, the risk of fatality is seven times higher for motorcyclists (ONISR, 2007).

If we consider the evolution of the fleet of motor vehicles in Spain, the motorcycle has been the kind of vehicle that has increased in number the most in recent years, representing 6% of the total of the vehicle fleet in 2003 to approximately 8,1% in 2008 (DGT, 2009). This rise has been favored by the legislative changes that occurred during that period of time. From 2004 (Ministerio de la Presidencia, 2004) the holders of a valid class B driving license with more than 3 years' experience are allowed to drive motorcycles of up to 125 cc. This regulation has fostered the use of these vehicles, especially in cities, to lighten traffic flow. Taking into account the number of registered vehicles during the 2003-2008 period in Spain, the general number of accidents tended to decrease while motorcycle accidents showed a trend of constant growth (Fig. 1). Thus, the DGT recorded an increase of 35% of fatal motorcycle accidents in 2008 compared to 2003, representing in the latter year 19% of the total of traffic accidents with victims in Spain.

(Insert here Fig. 1)

Prior research on motorcycle accident rate has mainly been focused on these two aims: crash risk, understood as the probability of suffering an accident, and crash severity, understood as the level of injury to the motorcyclist in the event of accident (Branas and Knudson, 2001; Evans and Frick, 1986; Gabella et al., 1995; Mcknight and Mcknight, 1995; Quddus et al., 2002; Savolainen and Mannering, 2007). Some of the variables that explain crash risk and crash severity are linked with motorcyclist characteristics and environmental factors (Branas and Knudson, 2001; Gabella et al., 1995; Gkritza, 2009; Lardelli-Claret et al., 2005; Morris, 2006). In the following sections, it is shown how these variables have an influence on crash severity and crash risk.

1.1. Motorcyclist characteristics

Age and gender. Several authors have studied the effect of these variables on motorcycle crash severity and crash risk (Mannering and Grodsky, 1995; Rutter and Quine, 1996). Savolainen and Mannering (2007) found that increased motorcyclist age is associated with more severe injuries. However, the official accident statistics (DGT, 2009), as well as the results obtained from different research (Braddock et al., 1992; Keall and Newstead, 2012; Lardelli-Claret et al., 2005; Lin et al., 2003; Shankar et al., 1992), show that young people are more prone to be involved in an accident and to be seriously injured or even die than older drivers. As far as gender is concerned, a recent study developed in Spain indicated that males have a higher risk of death in motorcycle accidents than females (Donate-Lopez et al., 2010).

Purpose of the journey. It has been found that most motorcycle accidents occur while travelling for leisure purposes, but that crash severity is higher for work trips (De Lapparent, 2006; Moskal et al., 2012; Oluwadiya et al., 2009).

Safety equipment use. Not wearing a helmet is a common risky practise that accounts for most of the motorcycle crashes resulting in injuries (Donate-Lopez et al., 2010; Lin and Kraus, 2009; Oluwadiya et al., 2009; Savolainen and Mannering, 2007). More specifically, the effectiveness of the helmet in the prevention of head injuries has been widely reported (Deutermann, 2004; Iowa Comprehensive Highway Safety Plan, 2006; Lawrence et al., 2002; Majdzadeh et al., 2008; Peden et al., 2004).

Riding experience. Experience in driving seems to be more important for two-wheeled motor vehicle users than for car drivers, possibly because driving a motorcycle requires special control and balance skills (Chang and Yeh, 2007). Traditionally, the effect of this factor has been found controversial. On the one hand, less driving experience has been associated with a higher crash risk and crash severity (Lin et al., 2003; Lin and Kraus, 2009; Liu et al., 2009; Machin and Sankey, 2008; Wong et al., 1990). On the other hand, Savolainen and Mannering (2007) indicate that experienced motorcyclists are more likely to be involved in severe-injury crashes. This could be explained by the fact that experienced motorcyclists have greater self-confidence and a lower risk perception (Liu et al., 2009; Wilde, 1998).

Other additional motorcyclist characteristics that have been found in the literature to predict a larger number of motorcycle crashes and higher crash severity are *alcohol consumption* (e.g. Lin and Kraus, 2009; Moskal et al., 2012; NHTSA, 2007; Savolainen and Mannering, 2007; Shankar, 2003; Shankar and Mannering, 1996), *distraction* (Ballestar et al., 2007; Cheng and Ng, 2010; Elliott et al., 2007; RANDOM, 2005) and *fatigue* (Peden et al., 2004; Philip et al., 2003; Sanchez, 2001).

1.2. Environmental factors

Time and weekday. The *time* and the *weekday* have been identified as the factors that have the greatest influence on fatal road accidents (Massie et al., 1995; Hijar et al., 2000). Although most motorcycle accidents happen during the day, motorcycling during the night or at weekends significantly increases the probabilities of a severe or a fatal crash (Yau, 2004). In Spain, there is a significant increase of the driving risk at dawn (Donate-Lopez et al., 2007). The day of the week has also been studied to predict fatalities among riders in Spain, but significant effects were not found (Donate-Lopez et al., 2010). It is not possible to know if the effect of alcohol intake is confused with the *time* and *weekday* effects, since this variable was not considered in the previous motorcycle studies.

Road condition and road layout. Opposite results have been found for *road condition*. Adverse conditions, such as rain or wet surface, have been found to raise the probability of crash severity and crash risk (Caliendo et al., 2007; Majdzadeh et al., 2008; Yau, 2004). However, other studies have found that adverse conditions have a preventive effect on the incidence of injury (Zhang et al., 2000), and good road conditions could increase the probability of a fatal crash (De Lapparent, 2006; Quddus et al., 2002). These studies did not take into account the level of risk exposure (accidents per kilometer). Only Caliendo et al (2007) included in their study, focused on accidents on freeways, the traffic flow (average daily traffic, ADT). Unfortunately, as these authors point out, it is difficult to obtain this information and there is little research to consider. Regarding the *road layout*, Oluwadiya et al (2009) found that most motorcyclists crash more on straights or on bends than on intersections. However, the probability that an accident is severe or fatal when it happens at intersections is higher than at non-intersections (Clabaux et al., 2012; De Lapparent, 2006).

Apart from crash severity and crash risk, another response variable used in general road safety studies is the committing or not of offenses which could trigger a crash. For example, the binary variable *offender* versus *non-offender* has been used to describe differences among drivers (Lev et al., 2008). Another study on general road safety has evaluated the closely related term *at-fault crashes* and *not-at-fault crashes*, by considering if an offense was involved in the crash (Elliot et al., 2000). Particularly, in motorcycle research, the term *at-fault cases* has been used against *not-at-fault cases* (Haque et al., 2009) and the term *at-fault accident risk* against *not-at-fault accident risk* (Yannis et al., 2005). Since there is evidence that likelihood of fatality is 126% higher when the motorcyclist is at-fault (Savolainen and Mannering, 2007), and committing an offense could be understood as a possible precedent of at-fault crashes

(Elliot et al., 2000), the relevance of being motorcyclist offender or non-offender is clear.

In Spain, similar studies have been developed, but considering all types of vehicles. Ayuso et al (2010) applied the multinomial logistic regression model to find the probability that an accident with victims is slight, serious or fatal, given the presence/absence of thirty different types of traffic offenses (related to speed limitations, administrative infringements or faults concerning the driver). Data was obtained from the official database of the DGT on accidents with victims that occurred from 2003 to 2005. They found evidence that some traffic offenses are associated with a higher probability of serious or fatal accidents. Crash severity increases when the number of traffic offenses increases from one to five. The percentage of slight accidents diminishes with respect to the percentage of serious or fatal accidents as the number of traffic offenses increases.

Another similar approach developed in France (Moskal et al., 2012) considers, instead of the traffic offense, accident responsibility for each rider as the dependent variable determined by using the method developed by Robertson and Drummer (1994). This analysis is also based on the exploitation of national data from police reports from 1996 to 2005. They conclude that the factors with the strongest association with accident responsibility were alcohol consumption, followed by being novice PTW riders, older riders and going on a leisure trip.

The objective of this paper is to perform an exploratory analysis oriented to identify the factors, considering the main effects and interactions, that predict the likelihood of being *offender* relative to *non-offender* specifically in motorcycle accidents in Spain. This is carried out by formulating a logit model based on the binary response variable motorcyclist *offender* versus motorcyclist *non-offender*.

It seems that without the consideration of whether the motorcyclist is offender or not, the true interpretation of the factors influencing crash risk and crash severity may not be suitable. Hence it may be difficult to design corrective measures to improve motorcycle safety and any program to modify motorcyclist behavior may not be productive. For example, tickets are an effective means for reducing accidents and injuries, while the effect of ticket issuance on fatalities is less conclusive (Makowsky and Stratmann, 2011). Furthermore, Kim et al (2011) found that drivers in the group whose license had been suspended (for a short period) committed traffic offenses and caused traffic crashes less often for all time periods than those whose license had been revoked (typically 12 months and the need to pass a test). Thus, a comprehensive understanding of the committing of offenses before the crash may be helpful to better understand motorcycle accidents as well as to recommend the best corrective programs to the authorities (Moskal, et al., 2012).

2. Methodology

2.1. Data

The data source for the analysis is the accident database of the DGT (for more information about the quality of this database, see Chisvert et al., 2007), which covers police-reported accidents with at least one person injured. Therefore, the general criterion for including an accident in the database is that it involves victims. Crashes are registered by means of the DGT's statistical questionnaire of road accidents with victims (Ministerio de Relaciones con las Cortes y de la Secretaría del Gobierno, 1993). This registry contains the information for each collision collected by the police at the scene of the accident, i.e. the type of crash, the vehicle(s) and person(s) involved and the environmental conditions (Lardelli et al., 2003; Rueda-Domingo at al., 2004). The final dataset has been obtained from a selection of cases according to three criteria: time period, vehicle type and vehicle position. The selected time period is 2003-2008: 2003 coincides with the worsening of the motorcycle accident problem in Spain and the latest consolidated data correspond to 2008. Moreover, the accidents that have been selected are those in which at least one motorcycle is involved and only these drivers have been selected. The final database contains a total of 74968 motorcyclists involved in a traffic accident with victims between 2003 and 2008, which 68% are *offenders* and 32% are *non-offenders*. A motorcyclist was considered to be *offender* when he had committed at the moment previous to the crash at least one of the offenses listed in the DGT's statistical questionnaire of road accidents with victims. This includes *alleged rider offenses* and *alleged speeding offenses* that triggered the accident. It should be stressed here that offenses related to alcohol or drug abuse or not using safety equipment were not considered because the information about some of these faults is not available when the accident occurs (Ayuso et al., 2010). All the others were considered *non-offenders.*

2.2. Analysis

Attending to the binary response variable, a multivariable logistic regression model is a suitable technique to use (Agresti, 2002). The binomial logistic regression analysis has been used in previous road safety research where the response variable is dichotomous (Haque et al., 2009; Koppel et al., 2008; Shibata and Fukuda, 1994; Strahan et al., 2008; Tay et al., 2008). In this model, the logit is the natural logarithm of the odds of being in category 1 (*offender*) as opposed to being in category 0 (*non-offender*). Being π the probability of motorcyclist offender, we have the linear model:

$$Logit = \ln\left(\frac{\pi}{1-\pi}\right) = \beta X$$

where β is a vector of parameters to be estimated and X is a vector of explanatory variables. When an explanatory variable X_i increases by one unit, while all other factors remain constant, the odds of the response variable increase by a factor $\exp_{(\beta)}$ which is called the odds ratio (OR) and ranges from 0 to positive infinity. This indicates the relative amount by which the odds of the outcome, *offender* compared with *non-offender*, increase (OR>1) or decrease (OR<1) when the value of the explanatory variable increases by one unit.

In order to develop the model, 12 categorical variables were selected from the database to be included in the analysis: *gender*, *age*, *purpose of the journey, safety equipment use*, *experience, alcohol consumption, distraction*, *fatigue*, *time*, *weekday*, *road condition* and *road layout*. *Distraction* and *fatigue* are collected in the DGT's statistical questionnaire of road accidents with victims as possible concomitant factors of the crash. This means that the data of both variables is based on the professional criteria of the specialized agent in charge of collecting the accident information. Dummy coding was generated to include all these variables in the model (see reference categories in Table 1).

A guided backward procedure of comparisons of hierarchical models was carried out in order to select the best-fitted model (Kleinbaum et al., 1988). The initial model consisted of introducing the main effects of the 12 variables as well as all the possible first order interactions between them. The process was based on dropping in a sequential way (one each time) those variables and interactions whose effects had higher and non-significant *p*-values in the Wald test. The final model included all the statistically significant effects ($p \leq 0.05$). Data analysis was performed using SPSS (PASW Statistics 17).

3. Results and discussion

Descriptive information about the explanatory variables is shown in Table 1. The final logistic model obtained from the backward selection fits significantly better than the model with only the intercept (Chi-squared=3520.367; degrees of freedom=19; $p<0.001$). The summary of the estimated parameters for the main and interaction effects in this model is shown in Table 2 and discussed in the following sections.

(Insert here Table 1)

3.1. Main effects

In terms of *purpose of the journey*, it has been found that those motorcyclists who mainly ride for leisure purposes are more likely to commit an offense than those who ride for working purposes (OR=1.272; 95%CI=1.204-1.344). Bearing in mind the results obtained for this variable in crash severity research, this finding is not in concordance with the results obtained by Oluwadiya et al (2009) and De Lapparent (2006), who found that working purposes, compared with leisure purposes, were more related to crash severity. If the most severe accidents occur for working purpose trips, it could be expected that motorcyclists that commit offenses prior to the accident also drive for working purposes. However, the leisure trips are the ones that predict offenses among motorcyclists. A possible explanation for this can be found in the characteristics of both pieces of research. On the one hand, the Oluwadiya et al (2009) research was carried out with data from Nigeria, where most people use motorcycles for working purposes. And on the other hand, De Lapparent (2006) based the analysis on crashes occurring in urban zones, where the volume of motorcyclists with working purposes is expected to be much higher than on highways. Therefore, the use that is given to motorcycles in each country, and the selected location to be analyzed must be considered to interpret properly the effect of this variable. On the other hand, taking into account the results obtained for this variable in crash risk research, these findings are in concordance with Moskal et al (2012), since they found an association between crash risk and leisure purposes.

Safety equipment use is found to be significant in predicting crashed *offenders* (OR=2.389; 95%CI=2.018-2.828). This variable is by itself an offense, since not wearing a helmet is an action penalized by Spanish law (Ministerio de la Presidencia, 2003). However, the crash data report considers this offense separately from the rest, since safety equipment use is considered to be passive safety because it involves road user protection from injuries. Thus, the result entails that the rider who does not take care of his own safety is expected not to take care of the safety of the rest of road users, committing, therefore, any of the collected offenses.

Regarding riding *experience*, low experience multiplies the odds of being an offender by about 43% (OR=1.432; 95%CI=1.234-1.660). This result coincides with that obtained by Haque et al (2009), who state that inexperienced riders overestimate their riding skills and underestimate risks approaching hazards with inappropriate actions. Likewise, the results obtained in the current study and in Haque et al (2009) are in line with those obtained by Lin et al (2003), Lin and Kraus (2009), Liu et al (2009), Machin and Sankey (2008) and Wong et al (1990) in their studies on crash risk and crash severity. So, motorcyclists with low experience have previously been found to be a factor that increases crash risk, crash severity, at-fault crashes and, from this study, can also be considered to be a factor that increases the probability of committing offenses prior to the traffic accident.

Distraction while riding has been found to be significant in predicting offenses (OR=1.369; 95%CI=1.296-1.446). Committing offenses when a motorcyclist is absent-minded could be expected, since the rider should stay alert while driving. Paying attention and obeying traffic laws are motorcyclist-related obligations and, according to the obtained results, the non-fulfillment of the first predicts the non-fulfillment of the second. These results are in line with those obtained in previous research as far as the relationship between distraction and accident rate is concerned (RANDOM, 2005; Cheng and Ng, 2010; Elliott et al., 2007), given that distraction increases the offending behavior of the motorcyclist involved in an accident.

It has been found that the odds of motorcyclist *offender* are 2.620 higher (95%CI=2.146-3.199) when there is an absence of *fatigue* in the crash. *Fatigue* is considered to be a feeling of tiredness and reduced alertness that is associated with drowsiness, which impairs both capability and willingness to perform a task (Craig et al., 2006; Lal and Craig, 2001). From this, motorcyclists who are not fatigued have, in principle, no problem staying alert while riding. Instead, they are more likely to be offenders than fatigued motorcyclists. This finding is not in line with the results obtained in road safety research (Peden et al., 2004; Philip et al., 2003; Sanchez, 2001), where the presence of fatigue is considered to be a factor that has an influence on crash risk and crash severity by increasing them. Further research is needed to investigate this discrepancy, to find the reasons for which fatigue is a risk factor that has an influence increasing crash risk and crash severity but not motorcyclists committing offenses.

With regard to the *time* variable, the odds of being *offender* increase by about 13% at night compared to during the day (OR=1.126; 95%CI=1.061-1.195). This result matches up with the data obtained by Haque et al (2009) which showed that nighttime significantly affects the fault of motorcyclists in crashes and that obtained by Yau (2004), who indicates that driving at night is a risk factor that increases crash severity. To this, our study adds that driving at night also increases the likelihood of being motorcyclist offender.

In relation with the *weekday*, motorcyclists who ride on the weekend are more likely to commit offenses than those who ride during the week (OR=1.216; 95%CI=1.148-1.289). Consequently, Saturdays and Sundays are the days which, on the whole, better predict the offenses of motorcyclists involved in an accident. The general statistics of accidents in Spain (DGT, 2009) point out that, on Saturdays and Sundays, motorcycle trips that end in an accident are mainly for leisure purposes and especially in good weather, when the road surface is in perfect condition. Weekday, purpose of the journey and road condition have all been included in the model since univariate significant effects between them have not been found and, what has been obtained in the analysis shows that the probabilities of being an offender is in line with the accident rate studies, it being more probable that the motorcyclist who rides during the weekend, for leisure purposes and along roads in perfect condition will commit an offense.

(Insert here Table 2)

3.2. Interaction effects

Two first order interaction effects are statistically significant (see Table 2): *gender* x *age* (Wald test=12.941; *p*-value=0.005), and *road condition* x *road layout* (Wald test=89.443; *p*-value<0.001). To clarify the interpretation of these interactions, Table 3 first shows the simple effects of *gender* in each *age* category and second, the simple effects of *road condition* in each *road layout* category.

(Insert here Table 3)

The first interaction, which is illustrated in Fig. 2, shows that rider *gender* difference is mainly present in younger and older groups. While males remain more likely to be *offender* than women in the two first groups, this tendency disappears in the 33-40 age group, where males and females have no different probabilities, and it is inverted in the >40 group, where females have higher probability of being *offenders* than males. However, the difference between males and females is only significant for the oldest group, where females are more likely to commit offenses than males (OR=0.715; 95%CI=0.564-0.907). Thus, according to the data, older female is a potential risk group to be considered. In previous research, the effects of *age* and *gender* on crash severity and crash risk have been considered separately (Braddock et al., 1992; Lardelli-Claret et al., 2005; Savolainen and Mannering, 2007; Shankar et al., 1992; Wong et al., 2010; Donate-Lopez et al., 2010) but, according to our results, the effects of both variables, at least on being offender, must be considered not separately but simultaneously.

The second interaction, which is illustrated in Fig. 3, confirms that motorcyclists who ride along roads in perfect condition have more probability of being *offender* than those who ride in adverse conditions regardless of *road layout*, but this effect is higher for curves than for straights or intersections (OR=3.398; 95%CI=2.928-3.942). The result shows that motorcyclists ride in a more cautious manner in adverse situations, which is in concordance with Savolainen and Mannering (2007). However, these findings are not in concordance with Haque et al (2009), who found that the motorcyclist who rides on a wet road surface is more likely to be at-fault in the crash in the case of non-intersection. For the sake of discrepancy, it must be considered that our study includes not only wet road surface conditions but also other adverse conditions, such as oil or gravel. Moreover, the inclusion of an interaction term in the statistical model between *road condition* and *road layout* provides a higher statistical power than to perform several regression models for each level of *road layout*, as done by Haque et al (2009). This difference in the statistical analysis could explain that we found more statistically significant effects. A higher probability of being offender while riding on curves could be explained by the fact that many multi-vehicle accidents are not caused because the rider violates the right of way. The other vehicle could have crossed the path of the motorcycle when turning in an intersection or overtaking in a straight without having perceived it ("looked-but-failed-to-see". See Clabaux et al., 2012; Shahar et al., 2012), therefore the driver of the other vehicle would be the offender. This is more likely to happen at an intersection or on a straight than on a curved road section where there is no reason for the vehicle's paths to cross.

(Insert here Fig. 2)
(Insert here Fig. 3)

4. Conclusions and suggestions

In this research, a logit regression model is applied to Spanish motorcycle accidents collected by traffic police for the time period 2003-2008, in order to identify the factors that might affect the probability of being *offender* relative to *non-offender* in motorcycle accidents.

Some factors that are significantly related to motorcyclist offenses included riders' characteristics as well as environmental factors. Motorcyclists who do not have much experience, who ride not wearing a helmet, with distraction and absence of fatigue, are more likely to be *offenders*. Also, riding during nighttime, on the weekend and for leisure purposes increases the odds of being a motorcyclist *offender*. Moreover, we have found two significant interaction effects: *gender* x *age* and *road condition* x *road layout*. Firstly, the effect of gender on being offender or not is only significant for age > 40, females being more likely to be offender. Secondly, riding along roads in perfect condition raises the probability of being offender and this effect is higher for curves than for straights or intersections.

Some of these findings, such as not wearing a helmet, riding with distraction or being *offender* in perfect road conditions, show the tendency of motorcyclists towards risk-taking behaviors. Previous research suggests that motorcycle accidents in which the motorcyclist is at fault are, for the most part, not the result of misjudgments but the result of reckless riding (Mannering and Grodsky, 1995). Our results are in concordance with these findings since a motorcyclist predisposition towards non-safety riding is observed. For example, it can be expected that the rider will commit an offense in adverse conditions given that the situation may lead him to perform improper maneuvers, but the results show that he commits an offense mostly when conditions are excellent. Consequently, we may think that when driving in good conditions, the rider feels safety and control and this leads him to perform riskier maneuvers. This is one of the reasons why the study of *offenses* as a response variable is important, given that it enables a better understanding of motorcyclist risk behavior. Moreover, the data shows that the effect of the explanatory variables considered in the literature is not always the same but varies in intensity and direction according to the response variable (crash risk, crash severity, at-fault crashes, offender).

One strength of this work is to have included the first order interaction effects between all the explanatory variables in the regression model, given that the most common practise in previous research is to obtain the effect of these variables separately. According to our results, the effect of *gender* and *age* on the one hand, and *road condition* and *road layout* on the other, should be jointly studied by including their interaction in statistical models. These interaction effects are implicative to develop programs to reduce the committing of offenses and, in accordance with these results, programs should be addressed equally to male and female drivers, and mainly to older women, and special attention should be paid in raising safety behavior while driving on curves on roads in perfect condition.

The information obtained in this study allows us to know a little more about the problem of offenses committed by motorcyclists involved in an accident and could contribute, all in all, to the reduction of the motorcycle accident rate in Europe, this being a priority goal of the European Road Safety Program (2011-2020). In Spain, the DGT, in its 2010-2020 Road Safety Strategy, includes the same objective as the European Program: to reduce motorcycle accidents. In order to reach this objective, the DGT carries out advertising campaigns that give information about the risks of motorcyclists, offers training through *safe driving courses for motorcyclists*, and implements police actions through stationary and mobile methods of enforcement. Although the effects of these actions on accident rate reduction are generally unknown (Elvik et al., 2009), these may make the reduction of offenses easier. These information and prevention programs could be optimized considering the results obtained in this study by focusing on those drivers and driving situations where the likelihood of being motorcyclist offender is higher.

A limitation of this study is that *fatigue* and *distraction* are variables that are measured through the perception of the police officer who collects the data when the accident happens, and the reliability of those measures should be studied through an inter-rater agreement study.

A possible extension of this paper could be the inclusion of other explanatory variables related to motorcyclist safety, such as motorcycle engine capacity (Harrison and Christie, 2005; Yannis et al., 2005) or road speed limit (Haque et al., 2009). Psychological factors related to risk behavior (Chen, 2009; Lev et al., 2008; Machin and Sankey, 2008; Ulleberg and Rundmo, 2003) have not been included in this study and should be considered in future research. Another possible extension could be the application of a mediational model (Mackinnon, 2008) where motorcyclist *offender* is the intermediate variable between a number of explanatory variables and the criterion variables crash risk or crash severity.

Acknowledgements

This research was supported by Grant PSI2010-16270 (to the second author) from the Spanish Ministry of Science and Innovation, and 0100DGT16663 project from the Spanish General Directorate of Traffic (DGT). We thank the DGT for providing the data. We also thank Carlos Martinez, J. Gabriel Molina and Josep Maria Losilla, for their helpful comments on previous drafts of this work, and the two anonymous reviewers for their suggestions and constructive comments on an earlier version of this paper. We wish to thank Barbara Szulc for improving the use of English in the manuscript.

References

Agresti, A., 2002. Categorical Data Analysis. 2nd edition. Wiley, New York.

Ayuso, M., Guillem, M., Alcañiz, M., 2010. The impact of traffic violations on the estimated cost of traffic accidents with victims. Accid. Anal. Prev. 42 (2), 709-717.

Ballestar, M.L., Lopez-de-Cozar, E., Tormo, M.T., Martinez, C., Chisvert, M., 2007. EMOVE: Estudio estadistico de los accidentes de motocicleta y las colisiones con turismo y otros vehiculos. Informe tecnico (No. EMOVE/0707F). Valencia: INTRAS-Universidad de Valencia/Linea Directa Aseguradora S.A.

Braddock, M., Schwartz, R., Lapidus, G., Banco, L., Jacobs, L., 1992. A population-based study of motorcycle injury and costs. Ann. Emerg. Med. 21, 273-278.

Branas, C.C., Knudson, M.M., 2001. Helmet laws and motorcycle rider death rates. Accid. Anal. Prev. 33(5), 641-648.

Caliendo, C., Guida, M., Parisi, A., 2007. A crash-prediction model for multilane roads. Accid. Anal. Prev. 39(4), 657-670.

Chang, H., Yeh, T., 2007. Motorcyclist accident involvement by age, gender, and risky behaviors in Taipei, Taiwan, Transp. Res. Part F: Traffic Psychol. and Behav. 10(2), 109-122.

Chen, C., 2009. Personality, safety attitudes and risky driving behaviors - Evidence from young Taiwanese motorcyclists. Accid. Anal. Prev. 41 (5), 963-968.

Cheng, A.S., Ng, T.C., 2010. Development of a chinese motorcycle rider driving violation questionnaire. Accid. Anal. Prev. 42, 1250-1256.

Chisvert, M., Lopez-de-Cozar, E., Ballestar, M.L., 2007. Quality and representativity of the traffic accident data in urban areas: state of the Art. Valencia, Spain, INTRAS linea editorial. (SAU project report). Available at: http://www.uv.es/sau/Docs/SAU_Deliverable_I_State_of_Art_final.pdf. Accessed December 2011.

Clabaux, N., Brenac, T., Perrin, C., Magnin, J., Canu, B., Van Elslande, 2012. Motorcyclists’ speed and “looked-but-failed-to-see” accidents. Accid. Anal. Prev. 49, 73-77.

Craig, A., Tran, Y., Wijesuriya, N., Boord, P., 2006. A controlled investigation into the psychological determinants of fatigue. Biol. Psychol. 72, 78-87.

De Lapparent, M., 2006. Empirical Bayesian analysis of accident severity for motorcyclists in large French urban areas. Accid. Anal. Prev. 38 (2), 260-268.

Deutermann, W., 2004. Motorcycle helmet effectiveness revisited. Report DOT HS 809 715, National Highway Traffic Safety Administration, US Department of Transportation, Washington, DC. Available at: http://www-nrd.nhtsa.dot.gov/Pubs/809715.PDF. Accessed December 2011.

DGT [Direccion General de Trafico], 2009. Anuario Estadistico de Accidentes. Ministerio del Interior, España.

Donate-Lopez, C., Espigares-Rodriguez, E., Jimenez-Moleon, J.J., Luna-del-Castillo, J.d.D., Bueno-Cavanillas, A., Lardelli-Claret, P., 2007. Effect of environmental factors on the risk of death for drivers of two-wheeled motorized vehicles involved in road crashes. Gac. Sanit. 21 (3), 197-203.

Donate-Lopez, C., Espigares-Rodriguez, E., Jimenez-Moleon, J.J., Luna-del-Castillo, J.d.D., Bueno-Cavanillas, A., Lardelli-Claret, P., 2010. The association of age, sex and helmet use with the risk of death for occupants of two-wheeled motor vehicles involved in traffic crashes in Spain. Accid. Anal. Prev. 42 (1), 297-306.

Elliott, M.A., Baughan, C.J., Sexton, B.F., 2007. Errors and violations in relation to motorcyclists' crash risk. Accid. Anal. Prev. 39 (3), 491-499.

Elliot, M.R., Waller, P.F., Raghunathan, T.E., Shope, J.T., Little, R.J.A., 2000. Persistence of violation and crash behavior over time. J. Safety Res. 31(4), 229-242.

Elvik, R., Hoye, A., Vaa, T., Sorensen, M., 2009. The Handbook of Road Safety Measures. 2nd edition. Emerald Group Publishing Limited, Bingley: UK.

Evans, L., Frick, M.C., 1986. Safety belt effectiveness in preventing driver fatalities versus a number of vehicular, accident, roadway, and environmental factors. J. Safety Res. 17, 143-154.

Gabella, B., Reiner, K.L., Hoffman, R.E., Cook, M., Stallones, L., 1995. Relationship of helmet use and head injuries among motorcycle crash victims in El Paso County, Colorado, 1989–1990. Accid. Anal. Prev. 27, 363–369.

Gkritza, K., 2009. Modeling motorcycle helmet use in Iowa: Evidence from six roadside observational surveys. Accid. Anal. Prev. 41(3), 479-484.

Haque, M.M., Chin, H.C., Huang, H., 2009. Modeling fault among motorcyclists involved in crashes. Accid. Anal. Prev. 41 (2), 327-335.

Harrison, W.A., Christie, R., 2005. Exposure survey of motorcyclists in New South Wales. Accid. Anal. Prev. 37 (3), 441-451.

Hijar, M., Carrillo, C., Flores, M., Anaya, R., Lopez, V., 2000. Risk factors in highway traffic accidents: a case control study. Accid. Anal. Prev. 32, 703–709.

Horswill, M.S., Helman, S., 2003. A behavioral comparison between motorcyclists and a matched group of non-motorcycling car drivers: factors influencing accident risk. Accid. Anal. Prev. 35 (4), 589–597.

Iowa Comprehensive Highway Safety Plan, 2006. Available at: http://www.iowadot.org/traffic/chsp/. Accessed December 2011.

Keall, M. D., Newstead, S., 2012. Analysis of factors that increase motorcycle rider risk compared to car driver risk. Accid. Anal. Prev. 49, 23-29.

Kim, K. S., Myeong, M. H., Kweon, Y. J., 2011. Differences in traffic violations and at-fault crashes between license suspension and revocation. Accident Analysis & Prevention 43 (3), 755-761.

Kleinbaum, D.G., Kupper, L.L., Muller, K.E., 1988. Applied Regression Analysis and Other Multivariable Methods. 2nd edition. Duxbury Press, Belmont, CA.

Koppel, S., Charlton, J.L., Fitzharris, M., Congiu, M., Fildes, B., 2008. Factors associated with the premature graduation of children into seatbelts. Accid. Anal. Prev. 40 (2), 657-666.

Lal, S., Craig, A., 2001. A critical review of the psychological determinants of driver fatigue. Biol. Psychol. 55, 173-194.

Lardelli, P. Luna del Castillo,J. Jiménez Moleón, J.J., Bueno Cavanillas, A., García Martín, M., Gálvez Vargas, R., 2003. Age and sex differences in the risk of causing vehicle collisions in Spain, 1990 to 1999, Accid. Anal. Prev, 35(2), 261-272.

Lardelli-Claret, P., Jimenez-Monleon, J.J., de Dios Luna-del Castillo, J., et al., 2005. Driver dependent factors and the risk of causing a collision for two wheeled motor vehicles. Inj. Prev. 11, 225-231.

Lawrence, B.A., Max, W., Miller, T.R., 2002. Costs of injuries resulting from motorcycle crashes: a literature review. Report DOT HS 809 242, US Department of Transportation, Washington, DC.

Lev, D., Hershkovitz, E., Yechiam, E., 2008. Decision making and personality in traffic offenders: A study of Israeli drivers. Accid. Anal. Prev. 40 (1), 223-230.

Lin, M., Chang, S., Pai, L., Keyl, P.M., 2003. A longitudinal study of risk factors for motorcycle crashes among junior college students in Taiwan. Accid. Anal. Prev. 35 (2), 243-252.

Lin, M., Kraus, J.F., 2009. A review of risk factors and patterns of motorcycle injuries. Accid. Anal. Prev. 41 (4), 710-722.

Liu, C.C., Hosking, S.G., Lenné, M.G., 2009. Hazard perception abilities of experienced and novice motorcyclists: An interactive simulator experiment. Transp. Res. Part F: Traffic Psychol. and Behav. 12 (4), 325-334.

Machin, M.A., Sankey, K.S., 2008. Relationships between young drivers' personality characteristics, risk perceptions, and driving behaviour. Accid. Anal. Prev. 40 (2), 541-547.

Mackinnon, D.P., 2008. Introduction to statistical mediation analysis. Lawrence Erlbaum Associates, New York.

Majdzadeh, R., Khalagi, K., Naraghi, K., Motevalian, A., Eshraghian, M.R., 2008. Determinants of traffic injuries in drivers and motorcyclists involved in an accident. Accid. Anal. Prev. 40 (1), 17-23.

Makowsky, M.D. , Stratmann, T., 2011. More tickets, fewer accidents: How cash-strapped towns make for safer roads. Journal of Law and Economics, 54 (4), 863-888.

Mannering, F.L., Grodsky, L.L., 1995. Statistical analysis of motorcyclists' perceived accident risk. Accid. Anal. Prev. 27 (1), 21-31.

Massie, D.L., Campbell, K.L., Williams, A.F., 1995. Traffic accident involvement rates by driver age and gender. Accid. Anal. Prev. 27, 73–87.

McKnight, A.J., McKnight, A.C., 1995. The effect of motorcycle helmets upon seeing and hearing. Accid. Anal. Prev. 27, 493–501.

Ministerio de la Presidencia, 2003. Real Decreto 1428/2003, de 21 de noviembre, por el que se aprueba el Reglamento General de Circulacion, para la aplicacion y desarrollo del texto articulado de la Ley sobre Trafico, Circulacion de Vehiculos a Motor y Seguridad Vial, aprobado por Real Decreto Legislativo 339/1990, de 2 de marzo, que contiene el texto consolidado, B.O.E. 306 (23 DE DICIEMBRE). Available at: http://www.boe.es/boe/dias/2003/12/23/pdfs/A45684-45772.pdf. Accessed December 2011.

Ministerio de la Presidencia, 2004. Real Decreto 1598/2004, de 2 de julio, por el que se modifica el Reglamento General de Conductores, aprobado por el Real Decreto 772/1997, de 30 de mayo, que contiene el texto consolidado, B.O.E. 173 (19 DE JULIO). Available at:

http://www.boe.es/boe/dias/2004/07/19/pdfs/A26183-26205.pdf. Accessed December 2011.

Ministerio de Relaciones con las Cortes y de la Secretaría del Gobierno, 1993. Orden de 18 de febrero por la que se modifica la estadística de accidentes de circulación, B.O.E. 47 (24 DE FEBRERO). http://www.boe.es/boe/dias/1993/02/24/pdfs/A06016-06020.pdf. Accessed December 2011.

Morris, C., 2006. Generalized linear regression analysis of association of universal helmet laws with motorcyclist fatality rates. Accid. Anal. Prev. 38, 142–147.

Moskal, A., Martin, J.L., Laumon, B., 2012. Risk factors for injury accidents among moped and motorcycle riders. Accid. Anal. Prev., 49, 5–11.

NHTSA [National Highway Traffic Safety Administration]. Dept. of Transportation (US), 2007. Traffic safety facts 2005: alcohol. NHTSA, Washington, DC.

Oluwadiya, K.S., Kolawole, I.K., Adegbehingbe, O.O., Olasinde, A.A., Agodirin, O., Uwaezuoke, S.C., 2009. Motorcycle crash characteristics in Nigeria: Implication for control. Accid. Anal. Prev. 41 (2), 294-298.

ONISR [Observatoire National Interministeriel de la Securite Routiere], 2007. Deux-roues motorises – Grands themes de la securite routiere en France, Février 2007.

Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A., Jarawan, E., Mathers, C., (2004) World report on road traffic injury prevention. Available at: http://whqlibdoc.who.int/publications/2004/9241562609.pdf. Accessed December 2011.

Philip, P., Taillard, J., Klein, E., Sagaspe, P., Charles, A., Davies, W., et al., 2003. Effect of fatigue on performance measured by a driving simulator in automobile drivers. J. Psychosom. Res. 55, 197-200.

Quddus, M. A., Noland, R. B., Chin, C. H., 2002. An analysis of motorcycle injury and vehicle damage severity using ordered probit models. J. Safety Res. 33, 445-462.

RANDOM, 2005. Perfil de los motoristas. Informe de resultados (Report Nº. R-30814YQ01). Available at: http://www.dgt.es/was6/portal/contenidos/documentos/seguridad_vial/estudios_informes/est_info_segVial031.pdf. Accessed December 2011.

Robertson, M.D., Drummer, O.H., 1994. Responsibility analysis: a methodology to study the effects of drugs in driving. Accid. Anal. Prev. 26 (2), 243–247.

Rueda-Domingo, T., Lardelli-Claret, P., Luna-del-Castillo, J., Jiménez-Moleón, J.J, García-Martín,M., Bueno-Cavanillas, A., 2004. The influence of passengers on the risk of the driver causing a car collision in Spain: Analysis of collisions from 1990 to 1999, Accid. Anal. Prev, 36(3), 481-489.

Rutter, D.R., Quine, L., 1996. Age and experience in motorcycling safety. Accid. Anal. Prev. 28, 15–21.

Sanchez, J., 2001. Campaña contra las distracciones. Trafico 149, 24-25. Available at: http://www.dgt.es/revista/archivo/pdf/num149-2001P.24-25.pdf. Accessed December 2011.

Savolainen, P., Mannering, F., 2007. Probabilistic models of motorcyclists' injury severities in single- and multi-vehicle crashes. Accid. Anal. Prev. 39 (5), 955-963.

Shahar, A., van Loon, E., Clarke, D., Crundall, D., 2012. Attending overtaking cars and motorcycles through the mirrors before changing lanes. Accid. Anal. Prev. 44 (1), 104-110.

Shankar, B.S., Ramzy, A.L., Soderstrom, C.A., et al., 1992. Helmet use, patterns of injury, medical outcome, and costs among motorcycle drivers in Maryland. Accid. Anal. Prev. 24, 385-396.

Shankar, U.G., 2003. Alcohol involvement in fatal motorcycle crashes. National Highway Traffic Safety Administration, Washington, DC.

Shankar, V., Mannering, F., 1996. An explanatory multinomial logit analysis of single-vehicle motorcycle. Accident severity. J. Safety Res. 27, 183-194.

Shibata, A., Fukuda, K., 1994. Risk factors of fatality in motor vehicle traffic accidents. Accid. Anal. Prev. 26 (3), 391-397.

Strahan, C., Watson, B., Lennonb, A., 2008. Can organisational safety climate and occupational stress predict work-related driver fatigue? Transp. Res. Part F: Traffic Psychol. and Behav. 11 (6), 418-426.

Tay, R., Rifaat, S.M., Chin, H.C., 2008. A logistic model of the effects of roadway, environmental, vehicle, crash and driver characteristics on hit-and-run crashes. Accid. Anal. Prev. 40 (4), 1330-1336.

Ulleberg, P., Rundmo, T., 2003. Personality, attitudes and risk perception as predictors of risky driving behaviour among young drivers. Saf. Sci. 41 (5), 427-443.

Wilde, G.J.S., 1998. Risk homeostasis theory: an overview. Inj. Prev. 4, 89-91.

Wong, J., Chung, Y., Huang, S., 2010. Determinants behind young motorcyclists' risky riding behavior. Accid. Anal. Prev. 42 (1), 275-281.

Wong, T., Lee, J., Phoon, W., Yiu, P., 1990. Driving experience and the risk of traffic accident among motorcyclists. Soc. Sci. Med. 30 (5), 639-640.

Yannis, G., Evgenikos, P., Papantoniou, P., Broughton, J., Knowles, J., Brandstatter, C., Candappa, N., Christoph, M., van Duijvenvoorde, K., Vis, M., Pace, J. F., Martínez-Pérez, C., Sanmartín, J., Haddak, M., Bouaoun, L., Amoron, E., Kirk, A., 2011. Traffic Safety Basic Facts 2011. Motorcycles & Mopeds. European Road Safety Observatory. Available at: http://ec.europa.eu/transport/road_safety/pdf/statistics/dacota/bfs2011-dacota-ntua-motomoped.pdf. Accessed January 2013.

Yannis, G., Golias, J., Papadimitriou, E., 2005. Driver age and vehicle engine size effects on fault and severity in young motorcyclists accidents. Accid. Anal. Prev. 37 (2), 327-333.

Yau, K.K.W., 2004. Risk factors affecting the severity of single vehicle traffic accidents in Hong Kong. Accid. Anal. Prev. 36 (3), 333-340.

Zhang, J., Lindsay, J., Clarke, K., Robbins, G., Mao, Y., 2000. Factors affecting the severity of motor vehicle traffic crashes involving elderly drivers in Ontario. Accid. Anal. Prev. 32 (1), 117-125.

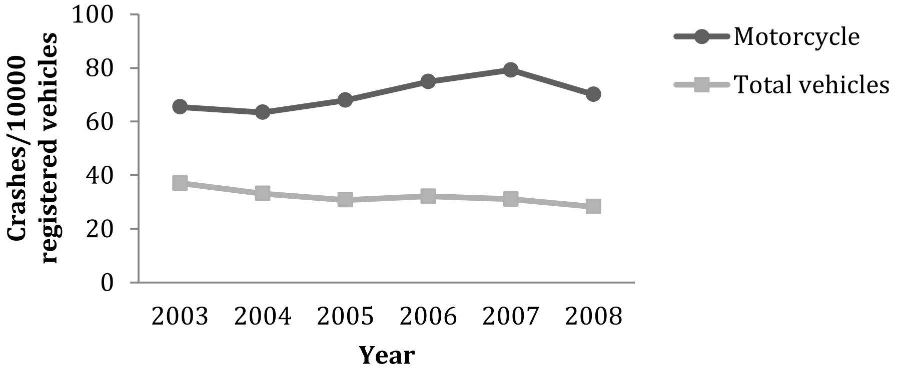

Fig. 1. Year trend of crashes per 10000 registered vehicles.

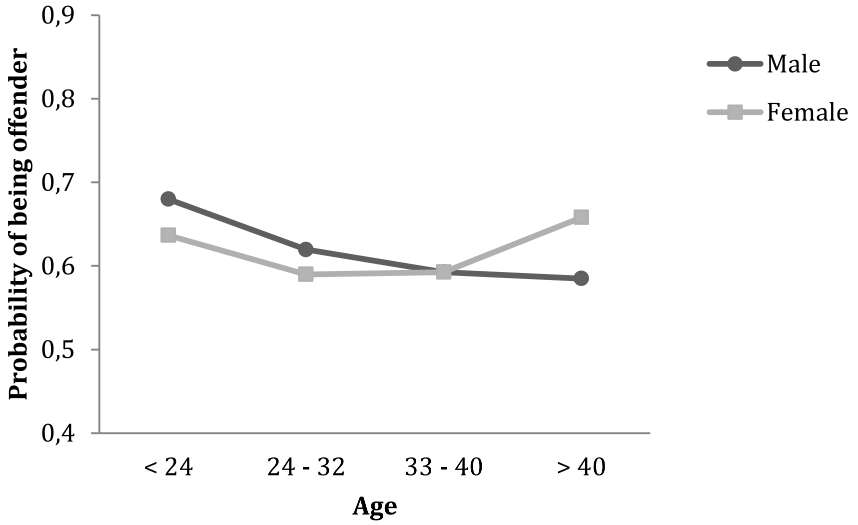

Fig. 2. Interaction effects of *gender* x *age*.

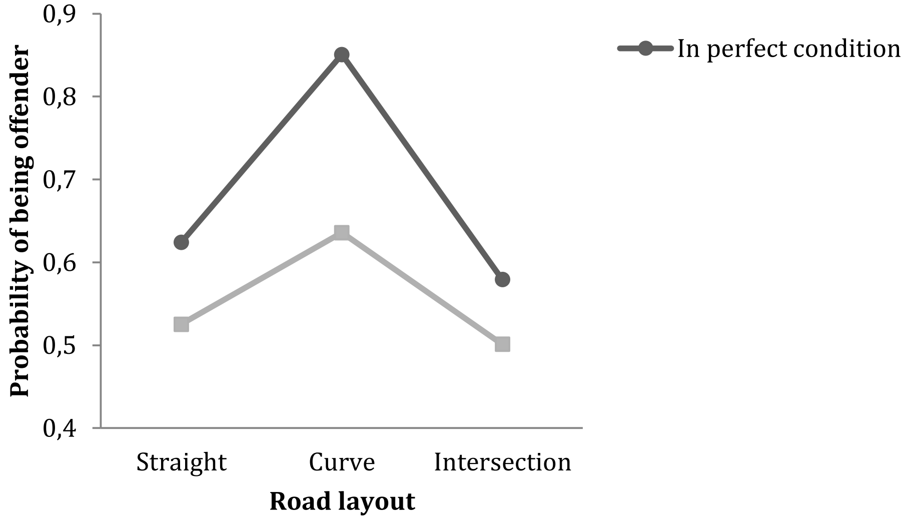

Fig. 3. Interaction effects of *road condition* x *road layout*.

Table 1

Descriptive statistics of the explanatory variables.

Explanatory variables	*P*i
Gender	
Male	91.50%
Female (*Ref.)	8.50%
Age	
< 25	12.90%
25-32	33.70%
33-40	26.70%
> 40 (*Ref.)	26.70%
Purpose of the journey	
Work (*Ref.)	41.20%
Leisure	58.80%
Safety equipment use	
Yes (*Ref.)	93.10%
No	6.90%
Experience	
High (*Ref.)	97.40%
Low	2.60%
Alcohol consumption	
Yes	2.20%
No (*Ref.)	97.80%
Distraction	
Yes	29.10%
No (*Ref.)	70.90%
Fatigue	
Yes (*Ref.)	1.00%
No	99.00%
Time	
Daytime (*Ref.)	75.50%
Nighttime	24.50%
Weekday	
During the week (*Ref.)	73.40%
Weekend	26.60%
Road condition	
In perfect condition	90.60%
In adverse condition (*Ref.)	9.40%
Road layout	
Straight	40.80%
Curve	16.80%
Intersection (*Ref.)	42.40%

(*Ref.)= Reference category in the regression analysis.

Table 2

Summary of the estimated parameters for the final model.

	β	exp(β)	95%CI exp(β)	Wald χ²	*p*-value
Intercept	-1.079	0.340		41.537	0.000
Gender					
Male	-0.336	0.715	[0.564 – 0.907]	7.661	0.006
Age				5.913	0.116
< 25	-0.105	0.900	[0.629 – 1.290]	0.327	0.567
25-32	-0.305	0.737	[0.558 – 0.974]	4.606	0.032
33-40	-0.289	0.749	[0.561 – 1.000]	3.833	0.050
Purpose of the journey					
Leisure	0.241	1.272	[1.204 - 1.344]	74.180	0.000
Safety equipment use					
No	0.871	2.389	[2.018 - 2.828]	102.162	0.000
Experience					
Low	0.359	1.432	[1.234 - 1.660]	22.511	0.000
Distraction					
Yes	0.314	1.369	[1.296 - 1.446]	126.647	0.000
Fatigue					
No	0.963	2.620	[2.146 - 3.199]	89.423	0.000
Time					
Nighttime	0.119	1.126	[1.061 -1.195]	15.363	0.000
Weekday					
Weekend	0.196	1.216	[1.148 - 1.289]	44.020	0.000
Road condition					
In perfect condition	0.318	1.374	[1.189 – 1.588]	18.556	0.000
Road layout				35.881	0.000
Straight	0.457	1.579	[1.309 – 1.905]	22.829	0.000
Curve	-0.092	0.912	[0.754 – 1.103]	0.906	0.341
Gender*Age				12.941	0.005
Male by < 25	0.575	1.778	[1.228 - 2.573]	9.305	0.002
Male by 25-32	0.467	1.595	[1.198 - 2.122]	10.246	0.001
Male by 33-40	0.322	1.379	[1.025 - 1.856]	4.505	0.034
Road condition*Road layout				89.443	0.000
In perfect condition by Straight	0.091	1.095	[0.898 - 1.335]	0.811	0.368
In perfect condition by Curve	0.905	2.473	[2.010 – 3.042]	73.384	0.000

Table 3

Simple effects analysis for interactions.

	β	exp(β)	95%CI exp(β)	Wald χ^2	*p*-value
Gender*Age					
Male vs. Female|< 25	0.240	1.271	[0.957 - 1.688]	2.743	0.098
Male vs. Female|25-32	0.131	1.140	[0.972 - 1.337]	2.588	0.108
Male vs. Female|33-40	-0,014	0.986	[0.825 - 1.179]	0.024	0.877
Male vs. Female|> 40	-0,336	0.715	[0.564 - 0.907]	7.661	0.006
Road condition*Road layout					
In perfect condition vs. adverse condition |Straight	0.409	1.505	[1.314 - 1.724]	34.784	0.000
In perfect condition vs. adverse condition |Curve	1.223	3.398	[2.928 - 3.942]	260.007	0.000
In perfect condition vs. adverse condition |Intersection	0.318	1.374	[1.189 - 1.588]	18.556	0.000