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Crash risk by driver age, gender, and time of day using a new exposure methodology☆,☆☆

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ABSTRACT

Introduction: Concerns have been raised that the nonlinear relation between crashes and travel exposure invalidates the conventional use of crash rates to control for exposure. A new metric of exposure that bears a linear association to crashes was used as basis for calculating unbiased crash risks. This study compared the two methods – conventional crash rates and new adjusted crash risk – for assessing the effect of driver age, gender, and time of day on the risk of crash involvement and crash fatality. *Method:* We used police reports of single-car and multi-car crashes with fatal and nonfatal driver injuries that occurred during 2002–2012 in Great Britain. *Results:* Conventional crash rates were highest in the youngest age group and declined steeply until age 60–69 years. The adjusted crash risk instead peaked at age 21–29 years and reduced gradually with age. The risk of nighttime driving, especially among teenage drivers, was much smaller when based on adjusted crash risks. Finally, the adjusted fatality risk incurred by elderly drivers remained constant across time of day, suggesting that their risk of sustaining a fatal injury due to a crash is more attributable to excess fragility than to crash seriousness. *Conclusions:* Our findings demonstrate a biasing effect of low travel exposure on conventional crash rates. This implies that conventional methods do not yield meaningful comparisons of crash risk between driver groups and driving conditions of varying exposure to risk. The excess crash rates typically associated with teenage and elderly drivers as well as nighttime driving are attributed in part to overestimation of risk at low travel exposure. *Practical Applications:* Greater attention should be directed toward crash involvement among drivers in their 20s and 30s as well as younger drivers. Countermeasures should focus on the role of physical vulnerability in fatality risk of elderly drivers.

1. Introduction

Road traffic collisions are a major global health concern. They account for more than 1.2 million deaths worldwide each year and an even larger number of serious injuries (World Health Organization, 2015). Obtaining a better understanding of the factors that contribute to driver crash risk is critical for the development of effective road safety policies and initiatives.

A wealth of road safety research has assessed driver characteristics, such as age and gender, linked to elevated crash risk. These studies have typically shown that the youngest and oldest drivers have much higher fatal and non-fatal crash risks than drivers in the middle-age ranges (Lam, 2002; Ma & Yan, 2014; McAndrews, Beyer, Guse, & Layde, 2013; Williams, 2003; Williams & Shabanova, 2003; Zhou, Zhao, Pour-Rouholamin, & Tobias, 2015). Several studies have also found differences in fatal and nonfatal crash risks among subgroups of older drivers. For example, there is evidence that drivers aged 70–74 exhibit lower crash risk relative to drivers aged 75–79, with the highest risk seen in drivers aged 80 and older (Cheung & McCartt, 2011; Cicchino, 2015; Cicchino & McCartt, 2014).

Road safety research has also addressed associations between driver gender and elevated crash risk. In general, female drivers are considered safer than male drivers (Åkerstedt & Kecklund, 2001; Kim, Brunner, & Yamashita, 2008; Ma & Yan, 2014; Massie, Green, & Campbell, 1997; Zhou et al., 2015). However, some studies suggest that while women tend to have fewer fatal crashes than men do, their risk of injury crashes may be higher (Massie, Campbell, & Williams, 1995; Santamariña-Rubio, Pérez, Olabarria, & Novoa, 2014).

In addition to crash involvement, driver's age and gender have also been shown to affect the severity of crash outcomes (i.e. the risk of fatal injury given a crash). Male and elderly drivers are more likely to be fatally injured in a crash than female drivers and drivers in the younger age ranges (Huang & Lai, 2011; Kim, Ulfarsson, Kim, & Shankar, 2013; Li, Braver, & Chen, 2003; Valent et al., 2002; Vorko-Jović, Kern, & Biloglav, 2006).

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The risk of crash involvement also appears to vary with environmental factors, such as time of day. Crash risk is higher for nighttime compared with other times of day, with the difference being more pronounced for male drivers and at younger ages (Doherty, Andrey, & MacGregor, 1998; Kim et al., 2013; Li, Baker, Langlois, & Kelen, 1998; Massie et al., 1995). Time of day has also appeared to be associated with crash severity, as drivers are more likely to sustain a fatal injury due to nighttime crashes compared to daytime crashes, particularly among the younger age groups (Huang & Lai, 2011; Valent et al., 2002; Vorko-Jović et al., 2006).

It is well recognized that in order to allow for meaningful comparisons of crash risk among driver groups or driving environments, it is necessary to take into account their differences in intensity of travel exposure (Elander, West, & French, 1993; Wolfe, 1982). If travel exposure is not controlled for, one cannot determine whether a higher number of crashes for a particular group (or environment) is due to a greater tendency for crash involvement or to greater exposure to travel situations that may result in a crash (Chapman, 1973; Muhlrad & Dupont, 2010).

Traditionally, researchers have accounted for differences in exposure by dividing the crash counts of a particular driver group (e.g., age, gender) by either their annual travel (Li et al., 2003; Massie et al., 1995, 1997), their group size in number of licensed drivers (Chen et al., 2010; McAndrews et al., 2013), or a combination of travel and group size (Doherty et al., 1998; Li et al., 1998). However, the use of crash rate to account for differences in driving exposure is appropriate as long as crash counts increase proportionally with increased driving exposure. That is, when the association between crash frequency and driving exposure, known as the 'safety performance function,' is linear (Elander et al., 1993; Qin, Ivan, & Ravishanker, 2004). Crash rate can be defined as the slope of the line from the origins to a particular point on the safety performance function. If the safety performance function is non-linear, then crash rate will vary at different exposure levels. Consequently, crash rates would not allow for meaningful risk comparisons among driver groups or driving conditions with varying levels of exposure (Elander et al., 1993; Janke, 1991; Qin et al., 2004).

Importantly, numerous road safety researchers (Elander et al., 1993; Elvik, 2014; Janke, 1991; Langford, Methorst, & Hakamies-Blomqvist, 2006; Maycock, Lockwood, & Lester, 1991; Qin et al., 2004; see af Wåhlberg, 2009 for review) reported that the relationship between annual crash counts and driving exposure is in fact nonlinear. Specifically, the relationship is often described as following a broadly logarithmic curve, with an initial rapid increase in crash counts at low exposure levels followed by gradually slowing down and finally flattening out at high exposure levels. As a result, as the distance driven increases, the crash rate per distance driven declines. Thus, it is a common finding in the literature that low-mileage drivers have greater crash rate than high-mileage drivers (Alvarez & Fierro, 2008; Antin et al., 2017; Hakamies-Blomqvist, Raitanen, & O'Neill, 2002; Langford et al., 2006).

There are several possible explanations for the nonlinearity of the safety performance function. First, high-mileage drivers clock a greater proportion of their miles on freeways, whereas low-mileage drivers tend to restrict their travel to relatively hazardous urban roads (Hakamies-Blomqvist et al., 2002; Janke, 1991; Keall & Frith, 2004, 2006). Second, high-mileage drivers accumulate greater driving experience than low-mileage drivers and therefore may possess better driving skills (Elander et al., 1993; Elvik, 2014). Finally, older drivers with visual or physical impairments tend to reduce their driving exposure (Alvarez & Fierro, 2008; Stutts, 1998); thus, a low-mileage group might include a larger number of impaired drivers who are more inclined to be involved in crashes (Keall & Frith, 2004; Langford et al., 2006, 2013).

Regardless of the underlying reasons, the exposure–crash relationship is nonlinear, and hence crash rates become smaller with increased driving exposure. Because of this, concerns have been raised in the road safety literature that the use of crash rates may lead to biased risk comparisons when driver groups or driving conditions vary greatly in their travel exposure (Elander et al., 1993; Elvik, 2014; Hauer, 1995; Janke, 1991; Qin et al., 2004). Accordingly, differences in crash rate between groups or driving conditions may reflect variation in exposure rather than variation in crash tendency. Consequently, the rate-based method may lead to overestimation of crash risk for low-exposed drivers, and underestimation for high-exposed drivers (for similar reasoning against the use of rates to control for exposure to risk applied to biological and epidemiological data see Allison, Paultre, Goran, Poehlman, & Heymsfield, 1995; Curran-Everett, 2013; Packard & Boardman, 1999).

A common finding in the literature is that young and elderly drivers have lower driving exposure than other age groups in terms of distance traveled and number of license holders (e.g., Fontaine, 2003; Keall & Frith, 2006; Langford et al., 2006). It follows that in the case of age group comparisons, the use of crash rates may lead to underestimation of crash risk for low-exposed age groups, such as young and elderly drivers, and overestimation of crash risk for high-exposed age groups, such as drivers in the middle-age range. In line with this, the proportion of low-annual travel drivers as a function of age has a U-shaped curve similar to that typically observed for crash rate by age: Elevated values for younger and older drivers relative to the middle-aged drivers (Fontaine, 2003; Janke, 1991; Keall & Frith, 2006). This observation has led to the theoretical notion, referred to as 'low-mileage bias,' whereby the elevated crash risk among elderly drivers might be the result of their low distance traveled (Hakamies-Blomqvist et al., 2002). In accordance with this reasoning, comparing subgroups of drivers of different ages matched for distance driven has led to the oldest drivers being the safest or just as safe as drivers in other age ranges (Alvarez & Fierro, 2008; Fontaine, 2003; Hakamies-Blomqvist et al., 2002; Langford et al., 2006).

Biased estimation of crash rates might also occur for gender comparisons in crash risk. Studies have reported that women of all ages are less likely than men to have a driver's license, and those who do tend to drive lower annual mileage (Fontaine, 2003; Li et al., 1998; Massie et al., 1995; Santamariña-Rubio et al., 2014). It is conceivable then that the rate-based crash risk of female drivers might be underestimated, while their male counterparts might have an overestimated crash risk.

The use of crash rates can be equally regarded as inappropriate for any driving conditions that differ substantially in travel exposure, such as time of day. The proportion of night driving is considerably small across all ages, as most of the driving is done during daytime (Keall & Frith, 2004, 2006; Powell et al., 2007). For example, in one study, researchers found that only 13% of drivers' total driving distance was made at night (Keall & Frith, 2004). The small exposure to risk during nighttime hours may therefore be associated with biased estimates of crash rates, whereby nighttime crash risk is exaggerated relative to other times of day. Moreover, given that age and gender differences in travel exposure vary with time of day (e.g., Keall & Frith, 2004), disaggregating crash risk by time of day would be of relevance for risk comparisons among driver groups.

This paper aims to examine the extent to which the traditional crash rate approach is biased for risk comparisons between age–gender groups and across different times of day. To this end, we compared the results of conventional crash rates to those of adjusted risk estimators computed using a new exposure metric that provides a linear relationship for the safety performance function, as outlined below. We hypothesized that when using conventional crash rate estimators, young and elderly drivers would demonstrate a much higher risk of crash involvement for fatal and nonfatal crashes compared to drivers in the middle-age ranges; in contrast, when using adjusted risk estimators, age differences in crash involvement risk would be substantially reduced. Similarly, we hypothesized that the risk of crash involvement for nighttime driving compared to driving during the day and evening hours would be reduced when using the new adjusted risk estimators compared to the traditional crash rates.

As a further consideration, we also assessed the risk of crash fatality (i.e., driver fatal injury given a crash had occurred) as estimated by the traditional and adjusted methods. Fatality risk was defined as the ratio

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