Road traffic mortality in the Slovak Republic in 1996–2014

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\section*{ABSTRACT}

\textbf{Objective}: Road traffic mortality takes an enormous toll in every society. Transport safety interventions play a crucial role in improving the situation. In the period 1996–2014 several road safety measures, including a complex new road traffic law in 2009, were implemented in the Slovak Republic, introducing stricter conditions for road users. The aim of this study is to describe and analyze the trends in road user mortality in the Slovak Republic in individual age groups by sex during the study period 1996–2014.

\textbf{Methods}: Data on overall mortality in the Slovak Republic for the period 1996–2014 were obtained from the Statistical Office of the Slovak Republic. Mortality rates were age-adjusted to the European standard population. Joinpoint regression was used to assess the statistical significance of change in time trends of calculated standardized mortality rates.

\textbf{Results}: Mortality rates of all types of road users as well as all age groups and both sexes in the Slovak Republic in the period 1996–2014 are decreasing. The male : female ratio decreased from 4:1 in 1996 to 2:1 in 2014. Motor vehicle users (other than motorcyclists) and pedestrians have the highest mortality rates among road user groups. Both of these groups show a significant decline in mortality rates over the study period. Within the age groups, people age 65 years and over have the highest mortality rates, followed by the age groups 25–64 and 15–24 years old. Joinpoint regression confirmed a steady, significant decline in all mortality rates over the study period. A statistically significant decrease in mortality rates in the last years of the study period was observed in the age group 25–64 and in male motorcycle users. Assessing the impact of the 2009 road traffic law, a drop was observed in the average standardized mortality rate of all road traffic users from 14.56 per 100,000 person years in the period 1996–2008 to 7.69 per 100,000 person years in the period 2009–2014. A similar drop in the average standardized mortality rate was observed in all individual road user groups.

\textbf{Conclusions}: The implementation of the new traffic regulations may have contributed significantly to the observed decrease in mortality rates of road users in the Slovak Republic. A significant decrease in mortality was observed in all population groups and in all groups of road users. The introduction of a new comprehensive road traffic law may have expedited the decrease of road fatalities, especially in the age group 25–64 years old. This type of evidence-based epidemiology data can be used for improved targeting of future public health measures for road traffic injury prevention.

\section*{Introduction}

Road traffic injuries (RTIs) and related fatalities impose a great burden on societies worldwide due to disability and death of large numbers of people, particularly among the most productive population groups. Road traffic injuries are among the top 10 leading cause of death and cause of years of life lost globally and the number one cause for people aged 15–29 (Lozano et al. 2012). Many efforts were introduced to reduce road traffic injuries in the second half of the 20th century. Road safety and RTI incidence is influenced by such factors as individual risk behaviors, vehicle safety, roadway infrastructure, and trauma care. Changes in the demographic and socioeconomic composition of the world’s population influence the incidence of road traffic injuries as well (Park et al. 2010).

High-income countries succeeded in reducing the transportation injury rates in the last decades. In the 1990s, both the United Kingdom and the United States managed to reduce road deaths from 1990 to 1999 by 34 and 6%, respectively (Richter et al. 2005). Several European countries showed a decline in road fatalities since the mid-20th century; the steepest decline was observed in Spain (Lassarre 2001). The European Union as a whole reduced road fatalities by 43% between 2001 and 2010 (Shen et al. 2013). Eastern European countries have higher rates of road accidents and related mortality than Western European countries (Hyder and Aggarwal 2009). Worldwide, the highest burden is carried by middle-income countries that are rapidly motorizing and increasing traffic density, without having appropriate infrastructure to prevent and treat RTIs (GBD 2015;
The key risk factors for road traffic injuries have been identified as traffic speed, drink driving, improperly or unused motorcycle and bicycle helmets, and improper or nonuse of seat belts and child restraints (WHO 2011). Evidence from many countries shows that concerted efforts at the national level result in dramatic successes in preventing road traffic injuries (WHO 2013).

The Slovak Republic, a central European postcommunist country, belongs to the group of high-income countries that have been successful in reducing road fatalities during the last 2 decades (BESIP 2014; European Commission 2015; Lassarre 2001; Shen et al. 2013). The temporal trends of road user mortality (as the traditional main indicator of road safety) in the Slovak Republic have not been studied yet. Apart from the description of the situation in formal reports developed and issued by the Ministry of Transportation of the Slovak Republic and its subordinate organizations, there are no analyses of the road traffic injury incidence and mortality in the country (BESIP 2014). It is crucial to study such long-term trends in order to be able to identify the effect of the adopted safety measures on the individual population groups.

The aim of this study is to present and describe the trends of road user mortality in the Slovak Republic in the overall period 1996–2014 and to investigate the impact of the adopted road safety measures on males and females, individual age groups, and individual road traffic user groups. Our hypothesis was that the changes in fatal accident trends were due to developments in traffic safety. We used joinpoint regression to assess road traffic fatality trends in the Slovak Republic by all ages and stratified by age, sex, and road user groups between 1996 and 2014.

Country characteristics and the list of road safety measures adopted in the Slovak Republic during the period 1993–2014 are included in the online supplement. Later in the article we present the methodology of the study; the results presenting time trends of road traffic–related mortality for total population and males and females separately according to age groups and types of road users; a discussion comparing our results to findings from other countries; an elaboration of possible factors influencing the presented fatality trends and the limitations of the study; and conclusions summarizing our findings and presenting possible public health implications.

**Methods**

**Data**

Data for this study were provided by the Statistical Office of the Slovak Republic. The mortality database for the whole country for the period 1996–2014 was obtained, which contains information on date of death, sex, age, cause of death, and external cause of death. The mortality data were obtained from death certificates completed by examining physicians and provided to the National Vital Statistics System of the Statistical Office of the Slovak Republic. Information on road traffic–related fatalities was extracted according to the International Classification of Diseases, 10th edition, codes of external causes of death: codes V01–V89 for all road traffic accidents, broken down as follows: V00–09 pedestrians, V10–19 bicyclists, V20–29 motorcyclists, V30–89 motor vehicle users (other than motorcycles).

Using the road traffic–related data, crude mortality rates were calculated for total population, females and males separately, all road user groups (4 groups were considered: other than motorcycle–motor vehicle users, motorcyclists, bicyclists, and individual age groups (4 age groups were created: <15, 15–24, 25–64, ≥65). For calculations, the aggregated numbers of death by age, sex, year of death, and mechanism of injury were used as numerators and mid-year population count (total and/or broken down to males and females and/or to age groups) as denominators. The latter was obtained from the website of the Statistical Office of the Slovak Republic (SOSR 2015; MetaInfo Explorer). The same source was used for the collection of data on the number of registered motor vehicles and length of highways and local roads (SOSR 2015). Mortality rates were standardized by the method of direct standardization to a European standard population (Waterhouse et al. 1976).

Policy documents on road safety and traffic related issues—both Slovak and international—adopted in the study period were reviewed.

**Statistical analysis**

A joinpoint regression model was used to assess the statistical significance of change in time trends of standardized mortality rates. This analysis involves fitting a series of joined straight lines to the age-adjusted rates and choosing the best-fitting point or points, where the rate of increase or decrease changes significantly. The number and location of these changes in trends (known as change-points or joinpoints) is unknown before the analysis and the main goal is to assess their existence and determine their location (in our case this is a certain time point; i.e., year). Number of joinpoints is decided by the model and therefore varies for individual variables. The resulting line segment between joinpoints can be described by an annual percent change (APC) that is based on the slope of the line segment. The number is given as a percentage. A negative APC describes a decreasing trend, and a positive APC describes an increasing trend. A significant change in a trend is defined as the slope of the curve being statistically significant (P < 0.05). For the analysis, the Joinpoint Regression Program, Version 4.2.0, was used, which was developed by the Statistical Methodology and Applications Branch, Surveillance Research Program, National Cancer Institute (Kim et al. 2000).

**Results**

During the study period 1996–2014, 434,552 road traffic users died in the Slovak Republic. Table 1 presents a list of parameters used for the descriptive analysis of trends of road traffic mortality in the study. In Table A1 (see online supplement), age-standardized mortality rates for all road users and for the 4 road user groups (other than motorcycle–motor vehicle users, pedestrians, bicyclists, and motorcyclists) by sex in the Slovak Republic from 1996 to 2014 are presented. An increase in mortality rates is observed for the period 1996–1998. There is a steady decline from 1998 to 2008, after which a drop in mortality rates for all road user groups is observed. We also present the average
Table 1. List of variables used for description of road traffic mortality in the Slovak Republic in 1996–2014.

| Variable/Description | Unit |
|----------------------|------|
| Road traffic mortality, total population | Rate per 100,000 person years |
| Road traffic mortality, males | Rate per 100,000 person years |
| Road traffic mortality, females | Rate per 100,000 person years |
| Road traffic mortality, total population—age groups: <15, 15–24, 25–64, 65+ | Rate per 100,000 person years |
| Road traffic mortality, males—age groups: <15, 15–24, 25–64, 65+ | Rate per 100,000 person years |
| Road traffic mortality, females—age groups: <15, 15–24, 25–64, 65+ | Rate per 100,000 person years |
| Mortality, total population—Road traffic user groups: motor vehicle, pedestrian, bicyclist, motorcyclist | Rate per 100,000 person years |
| Mortality, males—Road traffic user groups: motor vehicle, pedestrian, bicyclist, motorcyclist | Rate per 100,000 person years |
| Mortality, females—Road traffic user groups: motor vehicle, pedestrian, bicyclist, motorcyclist | Rate per 100,000 person years |
| Number of motor vehicles registered in the country | Millions in given year |
| Highway length in the country | Kilometers in given year |
| Local road length in the country | Kilometers in given year |

Table 2. Number of registered motor vehicles, kilometers of highways, kilometers of local roads, Slovak Republic.

| Year | Number of MV (million) | Highways (km) | Local roads (1,000 km) |
|------|------------------------|---------------|-----------------------|
| 1996 | 1.53                   | 215           |                       |
| 1997 | 1.62                   | 219           | 24.98                 |
| 1998 | 1.72                   | 288           |                       |
| 1999 | 1.71                   | 295           |                       |
| 2000 | 1.75                   | 296           | 25.22                 |
| 2001 | 1.78                   | 296           |                       |
| 2002 | 1.83                   | 302           |                       |
| 2003 | 1.88                   | 313           |                       |
| 2004 | 1.65                   | 316           |                       |
| 2005 | 1.80                   | 328           | 25.94                 |
| 2006 | 1.84                   | 328           |                       |
| 2007 | 1.99                   | 365           |                       |
| 2008 | 2.16                   | 384           |                       |
| 2009 | 2.24                   | 391           |                       |
| 2010 | 2.34                   | 416           |                       |
| 2011 | 2.44                   | 419           |                       |
| 2012 | 2.54                   | 419           | 36.85                 |
| 2013 | 2.62                   | 420           |                       |

Source: SOSR (2015).

For all age groups declined after 1998. The oldest age group, for those 65 years old and older, has the highest mortality in traffic-related injuries, followed by the age groups 25–64 and 15–24. In Figure 3, the results of joinpoint analysis are presented; that is, the modeled trends of age-standardized mortality rates of 4 types of road users (MV, pedestrians, bicyclists, motorcycle users) in the Slovak Republic in 1996–2014 for all road users and separately for males and females.
The joinpoints (years at which trends change significantly) and APCs are presented in Table 3. Both MV and pedestrians showed a significant decline for the whole period: the MV mortality rate declined significantly by 5.4% per year, and the pedestrian mortality rate declined significantly by 5.3% per year. The bicycle users’ mortality rate increased in 1996–2000 and showed a significant decline in 2000–2014, when it declined by 10.6% per year (this is the largest average annual decline in all observed groups). Motorcycle users’ mortality had a joinpoint in 2007, when after the 1996–2007 incline it declined significantly by 10.4% per year (this is the second largest observed average annual decline). For females, MV, bicyclists', as well as pedestrian mortality showed a significant decline in the whole period 1996–2014. The MV mortality rate declined significantly...
by 4.2%, pedestrian mortality rate by 4.5%, and bicyclists’ mortality rate by 8.4% per year. The number of female motorcycle users who died in the study period was too small for analysis. The mortality of male MV and pedestrians declined significantly during the whole period 1996–2014. The male MV mortality rate declined significantly by 5.5%, and the pedestrian mortality rate declined by 5.7% per year. Bicycle users’ mortality increased in 1996–1998 and after the joinpoint in 1998, it declined significantly by 9.4% per year. Motorcycle users’ mortality increased in 1996–2007 and then declined significantly in 2007–2014 by 10.2% per year.

In Figure 4 and Table 4 we present joinpoints and APCs of long-term trends of age-standardized mortality rates in individual age groups of road users in the Slovak Republic in 1996–2014. For all road users, mortality rates of all age groups showed a significant decline in the study period. The age groups <15, 15–24, and 65+ declined significantly over the whole period 1996–2014: the mortality rates of the group <15 declined significantly by 8.5%, the age group 15–24 by 4.6%, and the age group 65+ by 5.8% per year. In the 25–64 years old age group, the joinpoint was observed in 2007, when after the significant decline of 2.9% per year for 1996–2007, the APC began to be steeper, more significant decline of 9.4% per year. Female mortality rates for the age groups <15 and 15–24 declined significantly in the whole period 1996–2014 (the age group <15 declined significantly by 7.9% per year and the age group 15–24 by 4.5% per year). In the age group 25–64 years old, a nonsignificant decline of 0.5% per year in the period 1996–2007 changed to a nonsignificant decline of 16.9% per year in the period 2007–2010. The rates increased nonsignificantly by 2.4% per year in 2010–2014. The model detected 3 joinpoints for the age group of females 65+: the significant decline by 7.2% per year in 1996–2004 changed to a nonsignificant decline of 7.5% per year in 2004–2007. For the period 2007–2012 the mortality rates declined significantly by 15.1% per year and in 2012–2014 increased nonsignificantly by 7.2% per year. Mortality rates of males declined significantly in the age group <15 in 1996–2014 by 8.7%, in the age group 15–24 by 4.7% per year, and in the age group 65+ by 5.8% for the whole period. In the age group 25–64 the decline was significant by 3.2% per year in 1996–2007 and changed to an even steeper significant decline of 10% per year in 2007–2014.

### Discussion

This study is the first comprehensive analysis of time trends of road user mortality in the Slovak Republic since it became an independent state in 1993. During this period, various measures have been adopted to improve road safety. The implemented measures have proven effective. In 2014, the Slovak Republic received the 2014 Road Safety Performance Index award from the European Transport Safety Council for achieving “very substantial progress in improving its road safety, with a 64% reduction in road deaths since 2001, and a particularly steep reduction since 2009” (European Transport Safety Council 2014: p. 23).

The Slovak Republic has been a member of the European Union since 2004. In the area of road safety, European Union legislation had to be transposed into the Slovak legal system in many areas. The system of control of technical status and emission control of a vehicle was changed. This is regulated by Directive No. 96/1996 of the European Community that was adopted in the Slovak Republic in 2005. The road infrastructure has developed over the study period. The length of highways almost doubled from 215 km in 1996 to 420 km in 2013, and the length of local roads also increased (Table 2; SOSR 2015). In 2009 the Slovak government subsidized the purchase of new cars in order to promote the phasing out of old, technically outdated models; 44,200 cars of an average age of 21 years were eliminated through this measure (Association of Automotive Industry of the Slovak Republic 2009). This led to an increase in the quality of motor vehicles on the roads; for example, more were equipped with safety systems such as anti-lock braking system and electronic stability control. The need for further promotion of passive safety devices and monitoring of safe behavior led the Slovak government and the Slovak Parliament to develop and adopt a new comprehensive traffic law in 2008 (effective as
of February 1, 2009). This act decreases speed limits, requires mandatory headlights on motor vehicles to be used all year round and all day long, requires winter tires in certain climate conditions and/or from November 15 to March 31, requires the use of reflective markings by pedestrians and bicyclists, requires mandatory helmet use for motorcyclists and bicyclists (children everywhere, adults outside of town), bans cell phone use while driving, and increases fines for violation of these regulations.

During the period 1996–2014 in the Slovak Republic, we see an increase in mortality rates of all types of road users in the period 1996–1998. After 1998, they decline continuously with few exceptions (Tables A1 and A2 and Figures 1 and 2). Despite the decline, within the European Union, the Slovak Republic is still above the European Union average in fatality rate for road accidents and is the country with the highest road fatality rate among high-income European Union countries and has a larger share of bicyclist road deaths than the European Union average (European Commission 2015). The rise in 1996–1998 (confirmed by joinpoint regression model for bicyclists and motorcyclists; Table 3) can be attributed to the increasing number of motor vehicles and corresponding increase in traffic (Table 2) as well as inadequate road safety measures in place at that time. The continuous decline in road traffic mortality rates in both men and women and in all age groups and in all 4 road user groups after 1998 is in line with findings of other international studies, describing a steady decline of road traffic incidence and mortality in high-income countries in the last decades (Majdan et al. 2015; Shen et al. 2013). Low- and middle-income countries still have a continuous increase due to rapid motorization and inadequate infrastructure and/or inadequate enforcement of driver training and behavior (Hyder and Peden 2003; Perel et al. 2007; Sethi et al. 2006; WHO 2013). As research into implementation of road safety measures shows, a reduction in road traffic injuries appears to be achieved most effectively by adopting and enforcing legislation and policies relating to the important risk factors such as driving while intoxicated, traffic speed limits, mandatory safety belts, child safety seats, helmets for 2-wheeled vehicle riders, etc. (Chekijian et al. 2014; WHO 2013).

This all took place in the Slovak Republic after 1993 through the adoption and enforcement of already described legislation and policies. The most comprehensive law was adopted in 2009 and its effect is visible in the reduction of the average mortality rate by one half for all road user groups when comparing the study periods before its adoption and after (Table A1). Though the declining trend was already in place, the adoption and enforcement of this law appears to have expedited the decrease of road traffic fatalities. As noted by both national and international road safety reports, there was a great road traffic mortality rate drop between 2008 and 2009 (BESIP 2014; European Transport Safety Council 2014). The lowering of speed limits in towns is one of the main features of the law and most probably played a role because the speed of a motor vehicle is an important factor in measuring the severity of crash injuries; that is, the lower the speed, the less severe the injury (Richter et al. 2006; Wilson et al. 2006, 2010). In contract, an increase in speed limits increases the number of road deaths, as has been confirmed by studies in the United States and Israel (Richter et al. 2004, 2005). A systematic review of studies from high-income countries also confirmed that reduced traffic speeds have a decreasing effect on road user deaths (Bunn et al. 2003). Another measure reinforced by the law is mandatory helmet use, which is believed to lessen head injuries and their consequences, among both motorcycle (Liu et al. 2008) and bicycle users (Debinski et al. 2014; Macpherson and Spinks 2007). Additionally, mandatory seat belt use on all seats and the use of child restraints are other requirements of the law that, when enforced, have yielded strong evidence of significant reductions (33–55%) in risk of motor vehicle occupant injury (Turner et al. 2005).

The joinpoint regression model has confirmed the declining trend of mortality rates of road users in the Slovak Republic in 1996–2014. The already statistically significant decline was even more pronounced after 2007 for motorcyclists (Table 3) and for all road users in the age group 25–64 (Table 4). These may be the road user groups that have been most affected by the stricter road traffic regulations. Even though the joinpoint regression did not prove a direct statistically significant effect of the 2009 Road Traffic Act, both the time trends as well as the analysis confirm the decline in road traffic mortality in the country for the majority of the study period. This is most probably the outcome of the long-term dedication of the Slovak authorities to improving road safety.

Joinpoint regression as well mortality rates trend analysis indicate an issue that deserves attention; that is, mortality rates of motor vehicle users as well as pedestrians started rising after 2012 in the Slovak Republic. The European Commission's (2015) report on road safety addresses this matter, as well as the fact that the Slovak Republic is not the only country with such a trend. The European Community has issued a policy orientation document on road safety for the years 2011–2020, aimed at reducing further the number of road user casualties (European Commission 2010). The document encourages the European Union member states to adopt strategies addressing all aspects of road safety. In addition to legislation and law enforcement measures, it includes campaigns through education and training that reduce the numbers of road accidents (Phillips et al. 2011). In general, road safety initiatives can assume either a population or high-risk individual approach (Nakahara et al. 2011). In the long run, it is the combination of both that results in road safety improvement. Despite all of the measures that have been implemented, there is still a strong need to address road traffic injuries as a public health priority (Ameratunga et al. 2006).

A major limitation of the study is the accuracy of the data from the death certificates. There is a possibility of misclassification of deaths from accidents, which leads to underestimation of deaths due to RTIs, as proven by the ANAMORT project (Belanger and Ung 2008). At the same time, there is a chance for overestimation of deaths by transport accident in the case of unidentified suicide by car crash. The reliability of the data is to some extent questionable due to a limited data quality control mechanism (Messite and Stellman 1996; Selinger et al. 2007). However, the national statistics on mortality that are the official source of data on causes of death worldwide use standardized data collection methodology and thus the data are internationally comparable.

Our findings suggest that the continuous introduction and updates of road traffic laws and regulations in the Slovak Republic during the period under study (1996–2014) may have significantly contributed to the observed declines in road fatalities. The
period of increased road safety activity after 1998 corresponded to a greater decline in mortality among males than females, especially in those age 25 years and older. The patterns presented in this study could be used to evaluate the effectiveness of legislative measures in prevention of road traffic fatalities and in planning further interventions and programs targeting the groups affected by the adopted measures to a lesser extent; that is, young adults and women.

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