CYCLE HELMETS AND CYCLE TRAFFIC SAFETY IN URBAN AND NON-URBAN SPANISH ROADS

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Abstract: *Cycle helmets have been compulsory in Spain on non-urban roads since 2004, whereas they are not compulsory in urban areas. We analyse trends for the number of killed and seriously injured cyclists during the period 1993-2010. Our analysis shows that there are no significant differences in these trends before and after 2004, nor inside and outside urban areas. We also analyse the probabilities of helmeted and non-helmeted cyclist being killed or seriously injured inside and outside urban areas. We find that these probabilities became very similar inside urban areas in recent years, probably as a consequence of the increase in urban cycling that has resulted from the cycling-friendly policies developed in many Spanish cities. We conclude that the improvement in cycling safety introduced by the use of cycle helmets strongly depends on environmental factors: such as urban or non-urban surroundings, cycle friendly infrastructure or simply the number of cyclists commonly found in the roads.*

1.INTRODUCTION

Early analyses of the effect of helmets on the safety of cycle traffic [Dorsch-1987, Thompson-1989] reported a dramatic reduction in head injuries for helmeted cyclists. Following those early analyses, some countries approved regulations requiring cyclists to wear helmets. Thus, in the nineties, Australia, New Zealand, and several Canadian provinces introduced regulations enforcing the use of helmets for all cyclists and, following this wave, other countries introduced regulations enforcing the use of helmets outside urban areas or for children. However, none of the leading nations in cycling mobility, such as The Netherlands, Denmark, or Germany, have introduced such regulations. Instead, most Dutch experts, for instance, have focussed on developing specific infrastructures and campaigns to make cycling safer [Pucher-2008] and have disregarded compulsory helmet regulations because they discourage cycling – which is considered as an inherently healthy activity [de-Hartog-2010]. Moreover some studies, e.g. [Jacobsen-2003], have reported that the safety of cyclists increases with the level of cycling, a concept termed ‘safety in numbers’, and that compulsory helmet laws discourage cycling, e.g. [Robinson-2006], thereby producing a net negative effect on cycle safety. For these reason, the European Cyclists’ Federation (ECF) actively opposes compulsory helmet regulations [Küster-2010], and favours policies that improve safety for cyclists without discouraging cycling or encouraging a false perception of cycling as a risky activity.

Even if it is accepted that the personal safety of cyclists is improved by the use of helmets, it is not apparent that compulsory helmet regulations also improve overall cycling safety. The Netherlands, Denmark, Germany and most countries with high levels of cycling also have the lowest rates of cycling fatalities without any recourse to such regulations [Pucher-2008, ECMT-2004], and there is no clear evidence of improved safety for cycle traffic in countries with compulsory helmet regulations [Robinson-2006, Dennis-2013]. Moreover, in contrast to driving a car or riding a motorbike, massive cycling is a healthy activity that contributes to improving public health [de-

Hartog-2010]. Therefore, the discouraging effect of forcing cyclists to wear helmets may affect the level of cycling and, therefore, have a negative impact on public health that may overcome any positive impact on personal safety for cyclists [Jacobsen-2003, de-Jong-2012]. This effect would be even more negative for modern bike-sharing systems, whose use could be very effectively discouraged by compulsory helmet regulations [Fishman-2012].

In Spain, cycle helmets became mandatory outside urban boundaries in 2004, after a reform of the traffic code that also required the use of reflective clothes at night, as well as other minor measures aimed at self-protection for cyclists against motorised traffic. Sufficient time has passed since the introduction of these measures for a meaningful analysis of their effects on cyclist safety to be made. Moreover, since helmets were not made mandatory in urban zones, the effect of compulsory cycle helmets on non-urban roads can be compared with the evolution of cycling safety inside towns, in order to differentiate for the specific effects (if any) of helmet regulation and other measures aimed at protecting and/or encouraging cycling. The main aim of this report is to present a comparative analysis that adds new evidence to the cycle helmet debate. This analysis becomes even more meaningful after recent announcement (in 2012) by the Spanish interior minister about the possibility of extending regulations on compulsory helmets to include urban areas.

2.METHODOLOGY

Traffic accidents involving cyclists (including the number of helmeted and non-helmeted cyclists inside and outside urban areas) are well documented in Spain. The Spanish national traffic authority (DGT or *Dirección General de Tráfico*) has since 1993 maintained a computerised database that contains information gathered by the traffic police at the scene of every accident nationwide – including information about injuries, damages, type of vehicle, and use of helmet. The database includes all traffic accidents occurring on roads subject to traffic regulation, involving one or more injured people, or material damages of any kind, and with at least one moving vehicle involved [BOE-1993]. It also differentiates between slight and serious injuries, these latter being defined as those resulting in a person being detained in hospital as an in-patient for more than 24 hours. This database is the source of data for our analysis. The most important figures for our analysis, extracted from this database, are listed in the Appendix

In this analysis we first examine the evolution of pre- and post-regulation rates of *killed or seriously injured* (KSI) cyclists inside and outside urban areas. Post-regulation changes in the total number of KSI cyclists are expected if some effectiveness is assumed for compulsory helmet regulations. Moreover, since helmet regulation only applies outside urban boundaries, different post-regulation trends for KSI cyclists inside and outside these boundaries can be expected. Since these changes may also depend on changes in general trends for overall traffic safety (as a consequence, for instance, of other regulations introduced during the same period), the trend for KSI cyclists should be compared with the trends for other road users before reaching any conclusions. Specifically, we will compare the trends for KSI cyclists with KSI car occupants (driver and passengers), which are the main group of traffic victims in Spain. To double check our conclusions, the analysis is also performed for all types of injuries and for head-injuries only.

The above analysis can be confounded by other unknown variables, such as the level of cycling or the actual use of helmets by cyclists. In order to avoid this difficulty, we will directly evaluate the probabilities of helmeted and non-helmeted cyclists being killed or seriously injured. Since helmets are not intended to prevent accidents, but are intended to prevent the worse consequences of an accident, a useful tool for analysing helmet effectiveness is the probability of cyclists involved in an accident being KSI. These probabilities can be computed for helmeted, P(a-h-KSI), and non-helmeted, P(a-nh-KSI), cyclists as:

$$P(a\text{-}h\text{-}KSI) = N(a\text{-}h\text{-}KSI)/N(a\text{-}h) \; ; \quad P(a\text{-}nh\text{-}KSI) = N(a\text{-}nh\text{-}KSI)/N(a\text{-}nh) \tag{1}$$

where N(a-h-KSI) and N(a-nh-KSI) is the total number of helmeted/non-helmeted KSI cyclists; and N(a-h)/N(a-nh) is the total number of helmeted/non-helmeted cyclists involved in an accident. If helmets have some measurable statistical effect, then P(a-h-KSI) and P(a-nh-KSI) should differ for a meaningful number of years and for different scenarios, and the relation

$$P(a\text{-}h\text{-}KSI)/P(a\text{-}nh\text{-}KSI) < 1 \tag{2}$$

can be considered as a good test of usefulness for any proposal for helmet promotion.

It may be argued that this analysis can be confounded by variables acting before the accident, such as a higher probability of non-helmeted cyclists committing an infraction [Farris-1997, Lardelli-Claret-2003], risk compensation by helmeted cyclists [Adams-2001], or a differing behaviour by motorists when encountering helmeted or non-helmeted cyclists [Walker-2007]. However, all these variables are related to the psychological reaction of individuals to helmets, and not to the effect of helmets in themselves, which only appears once an accident has happened. Therefore, we conclude that Eq. (2) is a good test of usefulness for helmets, as well as for any policy of helmet promotion in a given environment, regardless of psychological attitudes that could be eventually modified by such policies. It is worthwhile emphasising that, as previously mentioned, the DGT database includes accidents with victims, as well as accidents with only material damage [BOE-1993]. Thus, cyclists who were involved in an accident and were protected from injury by their helmets also appear in the statistics, and therefore in Eq. (2).

Our study ends with the comparative analysis of the *odds ratios* (OR) and *confidence intervals* (CI) for KSI helmeted and non-helmeted cyclists who were involved an accident. The OR is defined as:

$$OR = [M(a\text{-}h) \cdot N(a\text{-}nh\text{-}KSI)]/[M(a\text{-}nh) \cdot N(a\text{-}h\text{-}KSI)] \tag{3}$$

where N(a-h-KSI)/N(a-nh-KSI) is the number of helmeted/non-helmeted cyclists who were involved in a traffic accident and become KSI as a consequence of such an accident; and M(a-h)/M(a-nh) is the number of helmeted/non-helmeted cyclists who were involved in a traffic accident and were not KSI. That is:

$$M(a\text{-}h) = N(a\text{-}h) - N(a\text{-}h\text{-}KSI) \; ; \qquad M(a\text{-}nh) = N(a\text{-}nh) - N(a\text{-}nh\text{-}KSI) \tag{4}$$

With these definitions, $OR > 1$ implies that Eq. (2) is fulfilled and vice-versa. Therefore, if some protective effect arises from the use of helmets, then $OR>1$, whereas $OR=1$ indicates no effect. This OR is computed separately for urban and non-urban areas, and then compared. Since helmets are intended to protect from head injuries, the analysis will first consider head-injured KSI cyclists (excluding face and neck injuries), which is the most favourable hypothesis for checking any protective effect for helmets. To make our analysis as complete as possible, the ORs were also computed and compared for head-injured KSI cyclists including face and neck injuries, and for KSI cyclists with any kind of injury or injuries.

In practice, the estimation of the aforementioned probabilities and odds ratios has to deal with the presence of the “Unknown” columns in Tables A-1 to A-4. These columns correspond to accidents where the traffic agent did not collect any information regarding the cyclist was or not wearing a helmet. The simplest, and probably the most reasonable hypothesis, is to assume that this event is random. This implies that we can assume that the ensemble of accidents where the agent collected such information (the sum of the “Helmeted” and the “Non-helmeted” columns) is a representative sample of the ensemble of all accidents, and use this sample for the calculations of the probabilities and the odds ratios. In other words, we simply ignore the “Unknown” columns in Tables A-1 to A-4 [Lardelli-Claret-2003]. For instance, in 1993, the probability for helmeted cyclists of being KSI (all kind of injuries) on non-urban roads will be estimated (see Tables A-1 and A-2) as P(a-nh-KSI) ≈ 50/116 = 43%.

Our methodology is simple and robust. The main drawback may come from police records underreporting [James-1991, Derricks-2007]. Since this underreporting is more probable for minor than for serious accidents, the result may be an overestimate of the probabilities (1). However, as far as the presence of cycle helmets is not biasing the behaviour of Spanish policemen, this underreporting will not affect nor the ratio (2) nor the OR (3). Therefore, as a result of possible underreporting of minor accidents, the obtained probabilities (1) must be considered as an upper limit estimate, whereas the comparative magnitudes (2) and (3) are not expected to be affected by underreporting.

3.RESULTS

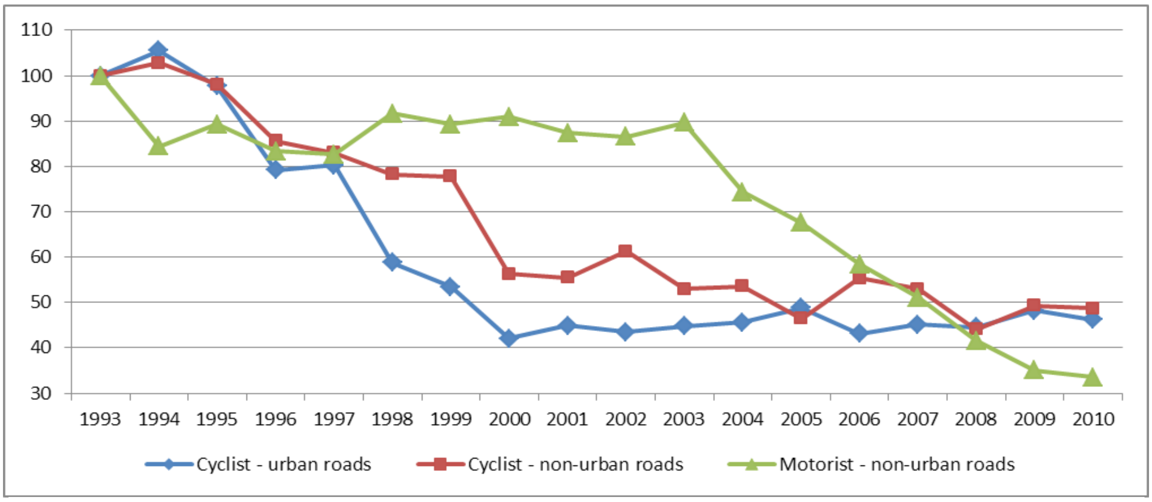

Figure 1: Total numbers of KSI cyclists in urban and non-urban areas, and the total number of KSI car occupants outside urban areas. Absolute units (1993=100).

The data series for the total number of helmeted and non-helmeted cyclists involved in various types of accidents during the period 1993-2010, as taken from the DGT database, are shown in the Appendix. The most salient feature of this data is the very different ratio between minor and severe accidents on urban and non-urban roads, with many fewer severe accidents on urban roads than in non-urban roads. This considerable difference justifies making a separate analysis for both scenarios, as we do in this paper. Another relevant feature is the steady decline in the number of KSI cyclists regardless of the period (before or after 2004) or the location (inside or outside urban areas). This steady decline is also apparent for KSI cyclists with head injuries, regardless of the period and location of the accident. The increase in the rate of helmeted cyclists suffering accidents outside urban areas can be attributed to the effect of the compulsory helmet law. Another salient feature of the data is the rapid growth in the number of minor accidents inside urban areas in recent years – mainly after 2006. This growth can be related to an increase in urban cycling as a consequence of the policies to encourage cycling that have been launched in many Spanish cities. In Seville, for instance, bicycle daily trips have increased ten-fold since 2006 [Marques-2011], with other cities such as Barcelona [Rojas-Rueda-2011], San Sebastián, Valencia, Vitoria, or Zaragoza showing similar results. The relatively small number of non-helmeted KSI cyclists with head injuries inside urban areas in recent years is also remarkable (about 20 per year). This observation is consistent with the‘safety in numbers’hypothesis [Komanoff-2001, Jacobsen-2003], and is relevant in the context of the current debate about government proposals to make helmet use compulsory in urban areas.

Following our methodology, we first analyse the trend for the number of KSI cyclists inside and outside urban areas, and then make a comparison with trends for other groups of road users. For this purpose, we selected car occupants (drivers and passengers) as they are the main group of traffic accident victims in Spain. Figure 1 shows in arbitrary units (1993=100)[1] the number of KSI cyclists inside and outside urban areas, as well as the number of KSI car occupants outside urban areas during the period 1993-2010. Fig. 1 shows that there is no clear change in the trend for KSI cyclists outside urban areas after helmet regulation was introduced in 2004. Moreover, there is little difference between the trends for KSI cyclists inside and outside urban areas after this date. These features are in clear contrast with the trend for KSI car occupants – which shows a sharp change of slope after 2004. This change of slope can be attributed to other measures included in the 2004 reform of the traffic code (the *reglamento general de circulacion*) which included tighter regulations for safety belts, maximum alcohol rates, as well as introducing point penalties for driving licenses. We can conclude that the introduction of compulsory cycle helmet regulation outside urban areas in 2004 has not shown positive effects on the safety of cyclists comparable to the effects shown for other simultaneous reforms intended to improve the safety of car occupants.

Since cycle helmets are intended to prevent head injuries, it is worthwhile analysing the trend in the number of KSI cyclists with head injuries, and then comparing the numbers for non-urban roads (where helmets are compulsory) with urban roads (where helmets are not compulsory). This comparison is shown in Fig. 2, where the trend in the absolute numbers of KSI cyclists with head injuries (excluding face and neck injuries) inside and outside urban areas is shown in arbitrary units (1993=100).[2] The general conclusion arising from an examination of this figure is fully consistent with the conclusions drawn from the analysis of the previous figure. No empirical evidence can be observed of any substantial change in the trend for the number of KSI cyclists with head injuries before and after 2004. Moreover, there are no substantial differences inside and outside urban areas for the whole period 1993-2004.

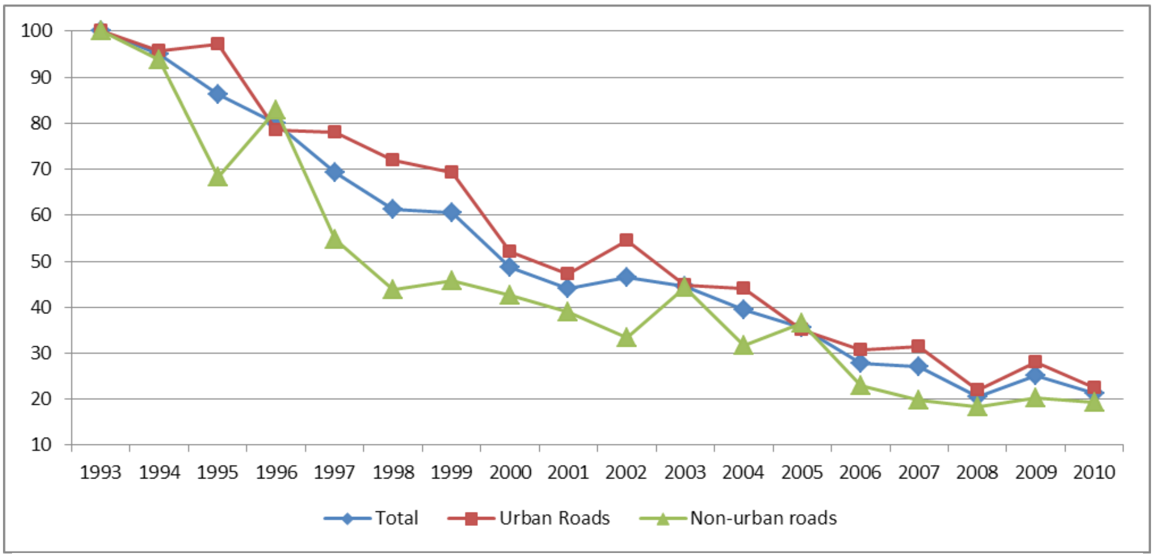

Figure 2: Numbers of KSI cyclists with head injuries (excluding face and neck injuries) on all roads inside and outside urban areas. Arbitrary units (1993=100)

[1] Actual starting numbers in 1993 are: KSI cyclists outside urban areas 631, KSI cyclists inside urban areas 485, KSI car occupants outside urban areas: 3321

[2] Starting numbers in 1993 are: all roads 512, non-urban roads 320, urban roads 192.

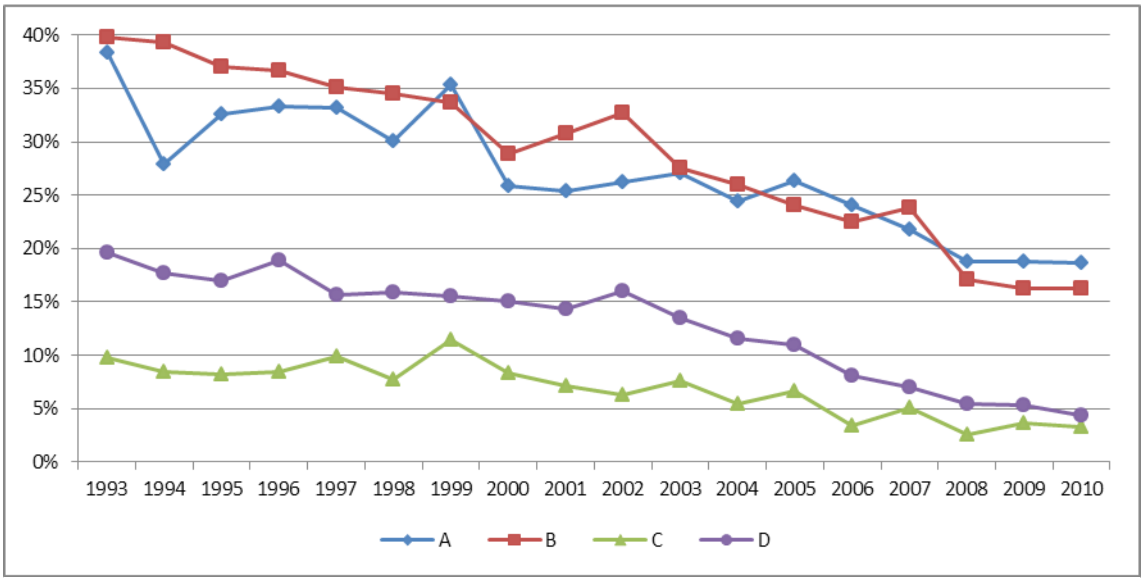

Figure 3: All roads: (A) percentage of helmeted KSI cyclists from among the total number of helmeted cyclists involved in an accident. (B) percentage of non-helmeted KSI cyclists from among the total number of non-helmeted cyclists involved in an accident. (C) percentage of helmeted KSI cyclists with head injuries from among the total number of helmeted cyclists involved in an accident. (D) percentage of non-helmeted KSI cyclists with head injuries from among the total number of helmeted cyclists involved in an accident. Face and neck injuries are not included in the calculations for head injuries.

Let us move now to the determination of probabilities P(a-h-KSI) and P(a-nh-KSI) defined in Eq. (1) of the previous section. Following the hypothesis made in the last paragraph of Section 2, these probabilities will be estimated as the percentage of helmeted / non-helmeted KSI cyclists from among the total number of crashed helmeted / non-helmeted cyclists (Table A-1). The evolution of these percentages is shown in Fig. 3. The figure includes data for KSI cyclists (Table A-2) and KSI cyclists with head injuries, excluding face and neck injuries (Table A-3). The evolution of the percentages is very similar, with a shared downward decline. For all types of KSI cyclists (lines A and B) there is practically no difference between helmeted and non-helmeted cyclists, except for some peaks at the beginning of the series. For head-injured KSI cyclists, however, there is a large difference in the early years in favour of helmeted cyclists, which monotonically declines to negligible values for recent years. As mentioned at the end of the previous Section, underreporting of slight accidents by police records may affect the actual values of the calculated probabilities, which should be better considered as upper limits. However, since this effect will equally affect to helmeted and non-helmeted cyclists, it will very unlikely affect their comparison.

It is worthwhile disaggregating the data shown in Fig. 3 for urban and non-urban roads. The data for non-urban roads is shown in Figure 4; while the data for urban roads is shown in Fig. 5. Fig. 4 shows an almost constant difference in favour of helmeted cyclists, suggesting that P(a-h-KSI)<P(a-nh-KSI) for both categories of all-injury KSI and head-injured KSI cyclists. However, Fig. 5 shows that for urban areas this difference only appears at the beginning of the series, and then monotonically declines to meaningless values in recent years. This behaviour may be related with the efforts recently made in many Spanish cities to encourage safer cycling by opening bike paths and implementing traffic calming – measures that are useful for both helmeted and non-helmeted cyclists. As previously mentioned, these efforts may have contributed to a rapid growth in the number of urban cyclists and helped create safer cycling conditions in accordance with the *safety in numbers* concept [Komanoff-2001, Jacobsen-2003]. These safer cycling conditions may have made injuries for which helmets are useful very unlikely, and therefore made helmets statistically irrelevant for the safety of urban cycling.

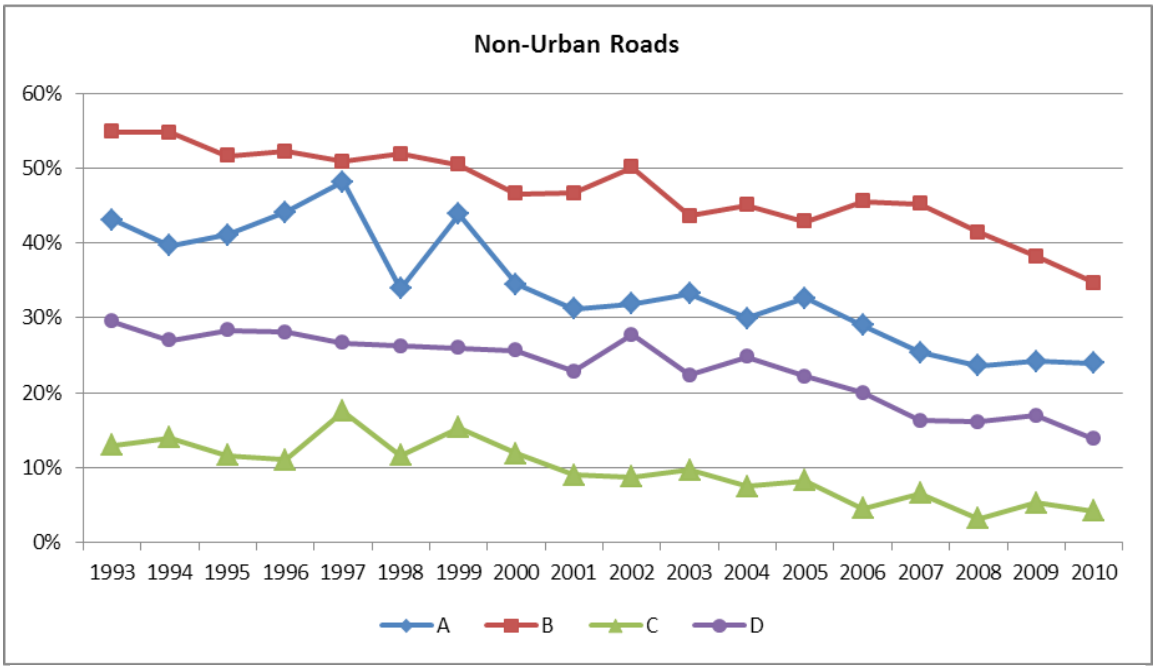

Figure 4: Non-urban roads: (A) percentage of helmeted KSI cyclists from among the total number of helmeted cyclists involved in an accident. (B) percentage of non-helmeted KSI cyclists from among the total number of non-helmeted cyclists involved in an accident. (C) percentage of helmeted KSI cyclists with head injuries from among the total number of helmeted cyclists involved in an accident. (D) percentage of non-helmeted KSI cyclists with head injuries from among the total number of helmeted cyclists involved in an accident. Face and neck injuries are not included in the calculations for head injuries.

The previous analysis suggests that Eq. (2) seems to be fulfilled for non-urban roads (see Fig. 4). Therefore, helmet promotion as well as the present compulsory helmet regulation in non-urban roads will pass the'test of usefulness'of Eq. (2).[3] However, inside urban areas, the probability of suffering any kind of serious accident, including a serious accident to the head, seems to be currently the same for helmeted and non-helmeted cyclists (see Fig. 5) – and therefore there is no justification for promoting helmets or making them compulsory.

To further corroborate the previous results, we have calculated the odds ratio for helmeted and non-helmeted cyclists being head-injured KSI (face and neck injuries excluded) on urban and non-urban roads. This OR is defined by Eq. (3) where N(a-h)/N(a-nh) is the number of helmeted/non-helmeted cyclists who were involved in a traffic accident and became head-injured KSI, and M(a-h)/M(a-nh) is the number of helmeted/non-helmeted cyclists who were involved in a traffic accident and were not head-injured KSI (face and neck injuries excluded). The results are shown in Table I with the 95% confidence interval (95% CI). As is well known, the odds ratio is closely related to probabilities, being OR=1 when probabilities become equal. The results in Table I show that there is no statistical evidence of any protective effect of helmets on urban roads – at least since 2003, where the 95% CI began to span 1.0. Even in previous years, there is little statistical evidence (where the 95% CI also spans 1.0 for 1993 and 1999). However, on non-urban roads, the results in Table I show strong evidence of the protective effect of helmets for the whole period 1993-2010. These results are consistent with the results reported in Figs. 4 and 5, which suggest a measurable protective effect of helmets on inter-urban roads, but a marginal or null effect on urban roads. To have a complete picture of the situation and further confirm our results, we have computed the OR

[3] This last statement, however, neglects other meaningful considerations derived from the discouragement of cycling caused by compulsory helmet regulations and the subsequent negative effects on public health – which may overcome its positive effects on cycle traffic safety [de-Jong-2012].

for head-injured KSI cyclists (face and neck injuries included) in Table II, and for all-injury KSI cyclists in Table III. These results fully confirm our previous analysis, showing poor or null evidence of any protective effect of helmets inside urban areas, and clear evidence of a protective effect on non-urban roads. The results for the OR for all-injury KSI cyclists on non-urban roads only show a moderate protective effect for helmets. This is an expected result, since helmets are designed to only protect from head injuries.

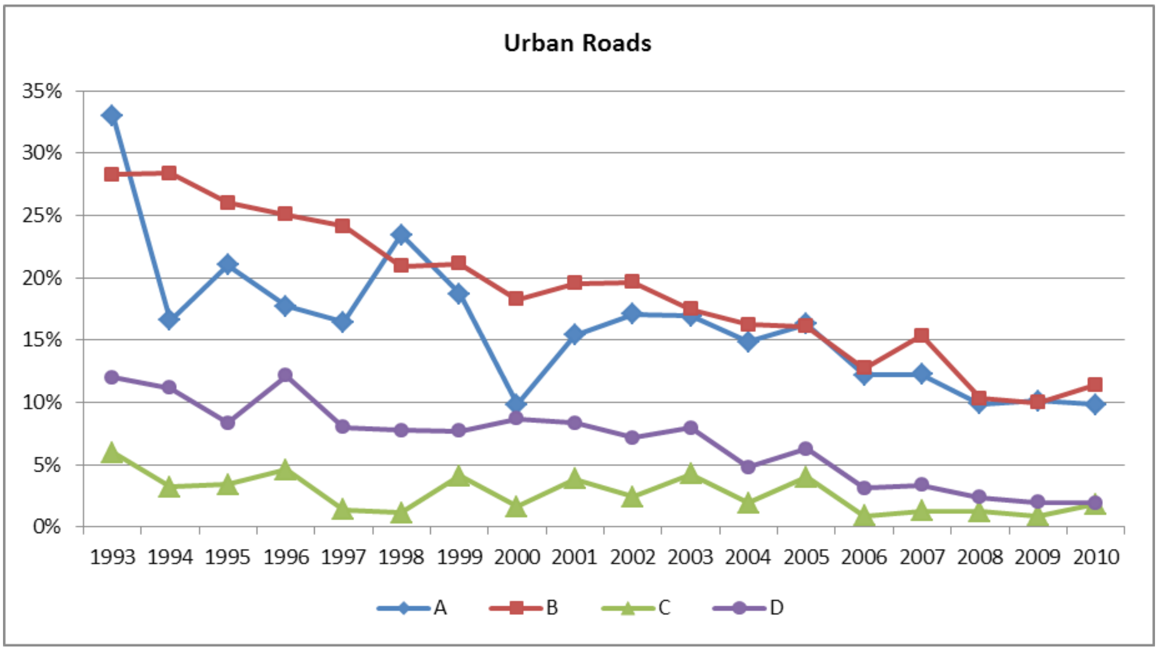

Figure 5: Urban roads: (A) percentage of helmeted KSI cyclists from among the total number of helmeted cyclists involved in an accident. (B) percentage of non-helmeted KSI cyclists from among the total number of non-helmeted cyclists involved in an accident. (C) percentage of helmeted KSI cyclists with head injuries from among the total number of helmeted cyclists involved in an accident. (D) percentage of non-helmeted KSI cyclists with head injuries from among the total number of helmeted cyclists involved in an accident. Face and neck injuries are not included in the calculations for head injuries.

It can be argued that the low number of head-injured KSI cyclists in the last years may affect this conclusion, making it meaningless. In order to have a different view on this subject, we have calculated the cumulative OR and 95% CI for head-injured KSI cyclists (face and neck injuries excluded) in urban Spanish roads in the same period. Results are shown in Table IV, where it can be seen that the CI interval spans unity for the whole period 2008-2010.

Finally, since helmets may also help to prevent slight head injuries, it is interesting to see the effectiveness of helmets for preventing this kind of head injuries. The corresponding OR for cyclists riding his bikes in Spanish urban roads is shown in Table V (the OR is calculated using Table A-5 in the appendix). Now the results show that the there is no statistical evidence of the effectiveness of helmets in the two last analysed years. In this case, the number of crashes helmeted cyclists with head injuries is high enough to make the sample highly representative on each year.

	KSI HEAD					
	NON-URBAN ROADS			URBAN ROADS		
	OR	95% CI		OR	95% CI	
		Upper	Lower		Upper	Lower
1993	2.81	4.92	1.61	2.13	4.95	0.92
1994	2.27	3.55	1.45	3.80	8.72	1.65
1995	3.01	4.58	1.98	2.57	5.95	1.11
1996	3.14	4.80	2.06	2.88	6.01	1.38
1997	1.71	2.47	1.18	6.27	20.02	1.96
1998	2.70	3.99	1.83	7.26	29.89	1.76
1999	1.94	2.75	1.37	1.95	4.33	0.88
2000	2.55	3.77	1.73	5.69	18.31	1.77
2001	2.99	4.65	1.92	2.28	5.08	1.02
2002	4.03	6.17	2.63	3.09	7.87	1.22
2003	2.68	4.14	1.74	1.95	4.15	0.92
2004	4.07	6.18	2.68	2.51	6.45	0.98
2005	3.16	4.85	2.06	1.61	3.14	0.82
2006	5.28	8.52	3.27	3.64	15.44	0.86
2007	2.75	4.22	1.79	2.70	8.95	0.82
2008	5.80	10.16	3.32	1.95	5.67	0.67
2009	3.63	5.66	2.33	2.25	6.58	0.77
2010	3.66	5.96	2.25	1.04	2.32	0.47

Table I: Odds ratios and 95% CI for head-injured KSI cyclists (face and neck injuries excluded) in urban and non-urban roads in Spain. The odds ratio is defined in Eq.(3), and data is taken from Tables A-1 and A-3 in the Appendix

	KSI HEAD+FACE+NECK					
	NON-URBAN ROADS			URBAN ROADS		
	OR	95% CI		OR	95% CI	
		Upper	Lower		Upper	Lower
1993	2.36	3.92	1.42	2.40	5.57	1.04
1994	1.94	2.91	1.29	2.98	5.93	1.49
1995	2.47	3.60	1.69	2.22	4.44	1.11
1996	2.39	3.46	1.65	3.06	6.12	1.53
1997	1.35	1.90	0.96	2.92	6.09	1.40
1998	2.69	3.91	1.85	5.95	19.04	1.86
1999	1.96	2.74	1.40	1.55	3.06	0.78
2000	2.39	3.49	1.64	6.45	20.68	2.01
2001	2.48	3.71	1.66	1.47	2.78	0.77
2002	3.42	5.07	2.30	2.67	5.95	1.20
2003	2.54	3.83	1.68	1.63	3.24	0.82
2004	3.67	5.47	2.47	1.85	3.97	0.86
2005	2.48	3.69	1.67	1.31	2.37	0.73
2006	3.44	5.18	2.28	1.61	4.20	0.62
2007	2.17	3.22	1.47	2.24	6.38	0.78
2008	3.90	6.33	2.41	1.40	3.45	0.57
2009	2.77	4.20	1.83	1.46	3.42	0.62
2010	2.95	4.62	1.88	1.03	2.21	0.48

Table II: Odds ratios and 95% CI for head-injured KSI cyclists (face and neck injuries included) in urban and non-urban roads in Spain. The odds ratio is defined in Eq.(3), and data is taken from Tables A-1 and A-4 in the Appendix

	KSI					
	NON-URBAN ROADS			URBAN ROADS		
	OR	95%CI		OR	95%CI	
		Upper	Lower		Upper	Lower
1993	1.60	2.36	1.09	0.80	1.24	0.52
1994	1.84	2.55	1.33	1.99	2.98	1.33
1995	1.53	2.04	1.15	1.32	1.94	0.90
1996	1.38	1.84	1.04	1.55	2.35	1.03
1997	1.11	1.49	0.83	1.62	2.37	1.10
1998	2.10	2.78	1.59	0.86	1.27	0.59
1999	1.31	1.71	1.00	1.16	1.77	0.77
2000	1.65	2.21	1.24	2.05	3.44	1.22
2001	1.93	2.60	1.43	1.33	2.08	0.85
2002	2.15	2.87	1.61	1.19	1.79	0.79
2003	1.56	2.09	1.16	1.04	1.59	0.68
2004	1.92	2.53	1.45	1.11	1.65	0.75
2005	1.55	2.08	1.15	0.98	1.43	0.68
2006	2.04	2.70	1.55	1.05	1.64	0.67
2007	2.43	3.21	1.84	1.30	2.00	0.85
2008	2.29	3.10	1.68	1.05	1.60	0.69
2009	1.93	2.58	1.45	0.99	1.42	0.68
2010	1.68	2.28	1.25	1.18	1.69	0.83

Table III: Odds ratios and 95% CI for all-injury KSI cyclists (face and neck injuries excluded) in urban and in non-urban roads in Spain. The odds ratio is defined in Eq.(3), and data is taken from Tables A-1 and A-2 in the Appendix.

	KSI cabeza		
	OR	95% CI sup	95% CI inf
1993-2010	3,14330307	3,86980626	2,55319093
1994-2010	3,06379740	3,79909166	2,47081549
1995-2010	2,91452912	3,64333304	2,33151345
1996-2010	2,88703628	3,64022356	2,28968862
1997-2010	2,77827401	3,54891809	2,17497454
1998-2010	2,59405428	3,33504373	2,01769996
1999-2010	2,41459300	3,12055001	1,86834350
2000-2010	2,42019720	3,17380799	1,84552894
2001-2010	2,20201353	2,91381051	1,66409708
2002-2010	2,15670474	2,90888904	1,59902124
2003-2010	2,03732544	2,79562293	1,48471201
2004-2010	1,96686000	2,78952195	1,38681048
2005-2010	1,86608071	2,72041754	1,28004512
2006-2010	1,98441728	3,13889668	1,25455290
2007-2010	1,79118268	2,91587461	1,10029951
2008-2010	1,55845476	2,67370394	0,90839573
2009-2010	1,41338960	2,65534268	0,75232104
2010-2010	1,04038330	2,31683572	0,46718781

Table IV: Cumulative odds ratios and 95% CI for head-injured KSI cyclists (face and neck injuries excluded) in Spanish urban roads. The odds ratio is defined in Eq.(3), and data is taken from Tables A-1 and A-3 in the Appendix

	OR	95% CI sup	95% CI inf
1993	2,144270	3,893484	1,180920
1994	2,338057	3,826635	1,428542
1995	2,256888	3,746287	1,359624
1996	3,012323	5,069577	1,789910
1997	3,176471	5,328168	1,893702
1998	3,478110	6,548492	1,847334
1999	2,604501	4,622077	1,467614
2000	2,987105	5,126986	1,740359
2001	1,692990	2,727483	1,050865
2002	3,504050	6,111751	2,008977
2003	1,758721	2,795241	1,106559
2004	2,567234	4,291742	1,535668
2005	1,881777	2,986632	1,185645
2006	2,404265	4,877724	1,185079
2007	4,143899	10,38365	1,653744
2008	2,787191	5,448616	1,425763
2009	1,549712	2,684347	0,894671
2010	1,538233	2,450087	0,965746

Table IV: Odds ratios and 95% CI for all kind of head-injured cyclists (face and neck injuries excluded) in Spanish urban roads. The odds ratio is defined in Eq.(3), and data is taken from Tables A-1 and A-5 in the Appendix

CONCLUSIONS

Cycle helmets were made compulsory in non-urban Spanish roads in 2004 and remain non-compulsory in urban areas. To illustrate the effects of this regulation we have analysed trends for the total number of cyclists who were killed or suffered serious injuries as a consequence of traffic accidents during the period 1993-2010. The analysis has been developed for all types of killed or seriously injured (KSI) cyclists, and for KSI cyclists with head injuries only. In both cases, we have observed no empirical evidence of a change in these trends as a consequence of this regulation beyond the baseline trend that shows a monotonic decline in the total number of KSI cyclists. Specifically, we observe no meaningful difference in this rate of decline for non-urban roads before and after helmets became compulsory in 2004. This behaviour is in sharp contrast with the behaviour of the total number of KSI car occupants, which shows a clear change of slope in 2004 that can be interpreted as a consequence of the introduction of more restrictive regulations affecting car drivers. Moreover, we have not observed any meaningful difference between the aforementioned decline in rates for cyclists on non-urban roads (where helmets are compulsory) and in urban roads (where helmets are not compulsory) before or after 2004.

We have also analysed the percent of helmeted and non-helmeted cyclists killed or seriously injured (all types of injuries and head injuries only) from among the total number of helmeted and non-helmeted cyclists involved in traffic accidents. This percent can be used as an estimation of the probability of a cyclist involved in an accident being killed or seriously injured. This analysis suggests that on non-urban roads there is a lower probability of being killed or seriously injured for helmeted cyclists than for non-helmeted cyclists. However, inside urban areas, the difference between helmeted and non-helmeted cyclists declines towards meaningless values in recent years, at least since 2003. These results are corroborated by the comparative analyses of the odds ratios for serious head injuries for helmeted and non-helmeted cyclists inside and outside urban areas. We interpret these differing behaviours as a consequence of the efforts made in many Spanish cities to encourage urban cycling. These efforts seem to have substantially increased the number of urban cyclists as well as the safety of cycling for both helmeted and non-helmeted cyclists, thus making the use of helmets statistically irrelevant for cycling safety.

Beyond the specific analysis of helmet effects in Spain, our results show that the effectiveness of helmets for improving cycling safety may vary strongly, even inside a single country, depending on the physical environment (urban or non-urban, for instance) or on the presence of other active policies intended to promote cycling safety (such as the development of cycling infrastructures, or traffic calming). These differences should be taken into account before reaching any conclusion regarding the effectiveness of helmets for improving cyclist safety in a specific scenario. In particular, we feel that our results question the usefulness of helmet promotion in areas where other policies, such as building cycling infrastructure or traffic calming, can provide similar or higher levels of protection without discouraging cycling.

ACKNOWLEDGMENT: This work has been supported by the Universidad de Sevilla, under project *Análisis y prospectiva de la movilidad ciclista en la Universidad de Sevilla y su entorno*. We also acknowledge to the Spanish *Dirección General de Tráfico* for kindly providing the data for this analysis and Mr. John Rawlins for revising the English text.

APPENDIX

		Cyclists involved in a traffic crash							
		Non-Urban Roads				Urban Roads			
	TOTAL	Total	Helmeted	Non-Helmeted	Unknown	Total	Helmeted	Non-Helmeted	Unknown
1993	3045	1191	116	994	81	1854	100	1294	460
1994	3259	1239	179	943	117	2020	187	1315	518
1995	3209	1259	241	931	87	1950	176	1237	537
1996	2860	1094	254	749	91	1766	175	1005	586
1997	2873	1063	245	720	98	1810	219	1024	567
1998	2609	1106	301	706	99	1503	175	904	424
1999	2400	1038	333	620	85	1362	171	833	358
2000	2207	873	336	468	69	1334	183	773	378
2001	2294	875	311	478	66	1419	182	671	522
2002	2364	923	333	519	71	1441	205	683	553
2003	2382	861	310	479	72	1521	189	756	576
2004	2624	922	441	420	61	1702	256	818	628
2005	2482	834	435	329	70	1648	276	783	589
2006	2647	1025	555	356	114	1622	230	841	551
2007	2866	1099	623	345	131	1767	237	866	664
2008	3132	999	593	273	133	2133	324	969	840
2009	3665	1196	714	301	181	2469	445	1052	971
2010	3828	1246	832	260	154	2582	489	993	1089

Table A-1: Total number of helmeted and non-helmeted cyclists involved in a traffic accident inside and outside urban areas.

		Killed +Seriously Injured (KSI)							
		Non-Urban Roads				Urban Roads			
	TOTAL	Total	Helmeted	Non-Helmeted	Unknown	Total	Helmeted	Non-Helmeted	Unknown
1993	1116	631	50	545	36	485	33	366	86
1994	1161	649	71	516	62	512	31	373	108
1995	1093	619	99	481	39	474	37	322	115
1996	924	540	112	391	37	384	31	252	101
1997	913	524	118	366	40	389	36	247	106
1998	779	494	102	366	26	285	41	189	55
1999	750	491	146	313	32	259	32	176	51
2000	559	355	116	218	21	204	18	141	45
2001	568	350	97	223	23	218	28	131	56
2002	598	387	106	260	21	211	35	134	42
2003	551	334	103	209	22	217	32	132	53
2004	559	338	132	189	17	221	38	133	50
2005	530	293	142	141	10	237	45	126	66
2006	558	349	161	162	26	209	28	107	74
2007	553	334	158	156	20	219	29	133	57
2008	494	278	140	113	25	216	32	100	84
2009	545	311	173	115	23	234	45	105	84
2010	531	307	199	90	18	224	48	113	63

Table A-2: Total number of helmeted and non-helmeted KSI cyclists involved in a traffic accident inside and outside urban areas.

Head		Killed +Seriously Injured (KSI)							
		Non-Urban Roads				Urban Roads			
	TOTAL	Total	Helmeted	Non-Helmeted	Unknown	Total	Helmeted	Non-Helmeted	Unknown
1993	512	320	15	293	12	192	6	155	31
1994	486	306	25	254	27	180	6	147	27
1995	442	311	28	264	19	131	6	103	22
1996	410	251	28	210	13	159	8	122	29
1997	355	250	43	192	15	105	3	82	20
1998	314	230	35	185	10	84	2	70	12
1999	310	222	51	161	10	88	7	64	17
2000	249	167	40	120	7	82	3	67	12
2001	226	151	28	109	9	75	7	56	12
2002	238	174	29	144	1	64	5	49	10
2003	228	143	30	107	6	85	8	60	17
2004	202	141	33	104	4	61	5	39	17
2005	182	112	36	73	3	70	11	49	10
2006	142	98	25	71	2	44	2	26	16
2007	139	101	41	56	4	38	3	29	6
2008	105	70	19	44	7	35	4	23	8
2009	129	90	38	51	1	39	4	21	14
2010	109	72	35	36	1	37	9	19	9

Table A-3: Total number of helmeted and non-helmeted KSI cyclists with head injuries[4] involved in a traffic accident inside and outside urban areas.

Head		Killed +Seriously Injured (KSI)							
Face		Non-Urban Roads				Urban Roads			
Neck	TOTAL	Total	Helmeted	Non-Helmeted	Unknown	Total	Helmeted	Non-Helmeted	Unknown
1993	559	347	19	314	14	212	6	172	34
1994	556	343	32	280	31	213	9	172	32
1995	516	348	37	288	23	168	9	132	27
1996	472	287	40	231	16	185	9	143	33
1997	413	279	56	206	17	134	8	102	24
1998	354	253	39	202	12	101	3	85	13
1999	344	244	56	176	12	100	10	73	17
2000	266	175	44	124	7	91	3	75	13
2001	261	172	37	120	10	89	12	63	14
2002	266	190	36	152	2	76	7	59	10
2003	250	157	34	114	9	93	10	63	20
2004	223	151	38	108	5	72	8	46	18
2005	209	126	47	76	3	83	15	55	13
2006	170	118	40	75	3	52	5	29	18
2007	161	119	55	60	4	42	4	32	6
2008	127	84	30	47	7	43	6	25	12
2009	153	105	50	52	3	48	7	24	17
2010	131	88	47	39	2	43	10	21	12

Table A-4: Total number of helmeted and non-helmeted KSI cyclists with head injuries[5] involved in a traffic accident inside and outside urban areas.

4 Excluding neck and face injuries.
5 Including neck and face injuries.

Cabeza	Accidentados								
		Vías Interurbanas				Vías Urbanas			
	TOTAL	Total	Con Casco	Sin Casco	Desconocido	Total	Con Casco	Sin Casco	Desconocido
1993	835	438	23	398	17	397	13	314	70
1994	778	414	36	343	35	364	19	275	70
1995	776	448	37	384	27	328	18	253	57
1996	703	372	49	298	25	331	17	246	68
1997	646	353	53	280	20	293	17	216	60
1998	574	350	53	280	17	224	11	171	42
1999	557	329	76	235	18	228	14	157	57
2000	478	261	63	185	13	217	16	172	29
2001	455	255	42	187	19	200	23	132	43
2002	479	265	47	211	7	214	15	148	51
2003	469	227	48	166	13	242	24	154	64
2004	442	223	60	153	10	219	18	133	68
2005	385	202	63	133	6	183	24	119	40
2006	288	164	44	113	7	124	9	75	40
2007	253	153	63	85	5	100	5	71	24
2008	251	123	47	69	7	128	10	79	39
2009	270	146	60	79	7	124	17	61	46
2010	291	130	64	61	5	161	25	76	60

Table A-5: Total number of helmeted and non-helmeted cyclists with head injuries[6] involved in a traffic accident inside and outside urban areas. Cabeza=Head, Casco = Helmet.

[6] Excluding neck and face injuries, as well as "all body" injuries

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