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Injuries among powered two-wheeler users in eight European countries: A descriptive analysis of hospital discharge data

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ABSTRACT

Powered two-wheelers (PTWs – mopeds, motorcycles, and scooters) remain the most dangerous form of travel on today's roads. This study used hospital discharge data from eight European countries to examine the frequencies and patterns of injury among PTW users (age ≥ 14 years), the predicted incidence of the loss of functional ability, and the mechanisms of the head injuries observed (all in light of increased helmet use). Of 977,557 injured patients discharged in 2004, 12,994 were identified as having been injured in PTW collisions. Lower extremity injuries accounted for 26% (25.6–26.7, 95% C.I.) of the total injuries, followed by upper extremity injuries (20.7%: 20.3–21.2), traumatic brain injuries (TBI) (18.5%: 18–19), and thoracic injuries (8.2%: 7.8–8.5). Approximately 80% of the lower extremity injury cases were expected to exhibit some functional disability one year following discharge (predicted Functional Capacity Index, pFCI-AIS98 < 100), compared to 47% of the upper extremity injury cases and 24% of the TBI cases. Although it occurred less frequently, patients that were expected to experience some functional limitation from TBI were predicted to fair worse on average (lose more functional ability) than patients expected to have functional limitations from extremity injuries. Cerebral concussion was the most common head injury observed (occurring in 56% of head injury cases), with most concussion cases (78%) exhibiting no other head injury. Among the AIS3+ head injuries that could be mapped to an injury mechanism, 48% of these were associated with a translational-impact mechanism, and 37% were associated with a rotational mechanism. The observation of high rates of expected long-term disability suggests that future efforts aim to mitigate lower and upper extremity injuries among PTW users. Likewise, the high rates of concussion and head injuries associated with a rotational mechanism provide goals for the next phase of PTW user head protection.

1. Introduction

Despite trends towards increasing helmet use rates, powered two wheelers (PTWs – mopeds, motorcycles) remain the most dangerous form of travel on today's roads. In European Union countries from 2001 to 2002, PTWs resulted in 440 deaths per million passenger-travel hours, compared to 75 for pedestrian travel, 25 each for cars and cycles, and 2 for buses, coaches, and rail (WHO, 2004). There were approximately 7030 PTW deaths in European countries in 2005, accounting for 15% of all road traffic fatalities (SafetyNet, 2009). In a regional Canadian study spanning 1995–2006, Monk et al. (2009) observed that motorcycle users were 3.5 times more likely to be severely injured or killed compared to other motor vehicle users (based on the number of registered vehicles). There were approximately 30,505 motorcycle-related hospital discharges in the United States in 2001, producing estimated hospital charges of over $841 million (Coben et al., 2004). It is possible that the burden of PTW user deaths and injuries will increase in coming years. Recent efforts to promote PTW use (e.g., in response to fuel economy and environmental concerns) have resulted in a substantial increase in PTW sales and users in Europe (e.g., a 172% increase in new PTW registrations

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in Spain between 2004 and 2005; Segui-Gomez and Lopez-Valdes, 2007).

The fatality-reducing benefit of helmets has been demonstrated in the literature (Schuller et al., 1984; Latorre et al., 2002; Liu et al., 2009), and there is little doubt that the greatest reduction of PTW deaths world-wide will result from efforts to increase helmet use. In many developed countries and some developing countries (such as Zambia, Suriname, Solomon Islands, Chile, and Cuba), helmet use is between 90 and 100% (WHO, 2009). As a result, further improvement of PTW safety requires a re-examination of the distribution and determinants of PTW injuries to identify research and intervention priorities (Liu et al., 2009). This is true not just for fatalities, but also for cases resulting in severe injury, hospitalization, and/or long-term functional disability.

The majority of epidemiological studies on PTW injuries in Europe have used either sample-based collision databases (e.g., the Motorcycle Accident In-depth Study, MAIDS; ACEM, 2009) or police report databases. The sample-based collision databases are generally limited to specific geographical regions for data collection, and despite controls and weighting they are not necessarily representative samples of the countries or communities of they seek to represent. In contrast, police databases can be considered a census of collisions occurring within their jurisdiction, but they often lack detailed information on the injuries that occur.

Hospital discharge data have been used before as a source to observe injury patterns and frequencies for specific types of road users (Arregui-Dalmases et al., 2010; Fitzharris et al., 2009; Coben et al., 2004; Latorre et al., 2002). Hospital discharge sources combine a large volume of data with detailed information on injuries and injury severity. Although hospital discharge data is limited in studying fatalities (because it often does not include at-scene deaths), it has proved useful in studying non-fatal injuries by injury severity, injury type, road-user type, and predicted functional outcome. In the current study, we retrieved and consolidated hospital discharge data from eight European countries for the year 2004, creating the second largest gathering of PTW hospital discharge data ever examined. Injury severity, body region, and injury type were described for those discharged patients (age 14 and older) identified as having been injured in PTW collisions. The functional outcomes resulting from those injuries were then predicted, based on the predicted Functional Capacity Index (pFCI-AIS98 – AAAM, 2008; European Center for Injury Prevention, 2007c). Finally, the mechanisms associated with the observed head injuries were examined using injury-code-mapping algorithms previously published (Martin and Eppinger, 2003).

2. Data and methods

A descriptive analysis was performed with hospital discharge data from eight European countries (Bulgaria, Hungary, Netherlands, Norway, Portugal, Slovenia, Spain, and Sweden) for the year 2004. Case information was coded using either the ICD-9-CM (NCHS) or ICD-10 (WHO, 1992) classification systems (depending on the country). Hospital discharge records were included if they had at least one injury code (ICD-9-CM 800.0–995.85 or ICD-10 S00.0-T98.3) in any of the first 3 diagnoses fields. Discharges classified as readmissions were excluded from further analysis. In the discharge data, PTW users were defined as having E-Codes 810–819 or 820–825 but only if the fourth digit was .2 in the ICD-9-CM classification, or V20 to V29 in the ICD-10 classification. The analysis was restricted to subjects 14 years old or older at the time of admission since that is the minimum legal driving age for PTW vehicles in the included countries.

Participating countries submitted their data on age, gender, type of admission, discharge disposition (dead, home, transfer to another hospital), up to 3 diagnoses, the external cause of injury code (E codes in ICD-9-CM or VXYZ codes in ICD-10), and duration of hospital stay. Data on injury diagnoses was further categorized into the Barell Matrix in order to present frequency counts (Barell et al., 2002; European Center for Injury Prevention at Universidad de Navarra, 2007a,b; Fingerhut and Warner, 2006).

These data were augmented with algorithms to derive Abbreviated Injury Severity Score AIS98 (AAAM, 1998), Injury Severity Scores ISS (Baker et al., 1974; Center for Injury Research and Policy of the Johns Hopkins University School of Public Health and Trianalytics, Inc., 1998; European Center for Injury Prevention at Universidad de Navarra, 2007d), as well as the Functional Capacity Index FCI (European Center for Injury Prevention at Universidad de Navarra, 2007c).

The AIS is the most widely used scale in the motor vehicle safety and injury prevention literature to assess severity as defined by a threat to life. The AIS severity score is an ordinal scale ranging from 1 to 6 that uses consensus-derived information on the severity of individual anatomical injuries (six being the highest severity score attainable). Although the score has been revised several times, the 1998 update of the 1990 version was used for this paper (AAAM, 1998). ICD-9-CM codes were mapped to AIS98 using an algorithm developed by the Center for Injury Research and Policy of the Johns Hopkins University School of Public Health and Trianalytics, Inc. (1998). ICD-10 codes were mapped using a complementary algorithm developed by the European Center for Injury Prevention at Universidad de Navarra (2007d). Because ICD-9-CM, ICD-10, and AIS98 differ in the specificity of their injury classifications, certain assumptions and process definitions were required to facilitate the construction of these mapping algorithms. Where such assumptions were required, the mapping algorithms used in this study were based on the processes described in detail by MacKenzie et al. (1986, 1989). The Injury Severity Score (ISS) was then used to integrate the severity of subjects sustaining several injuries. This metric combines the three most severe injuries in three separate body regions to create an ordinal scale ranging from 1 to 75 (Baker et al., 1974).

The Functional Capacity Index (FCI) is a preference-based outcome measure developed for non-fatally injured adult patients that defines health across 10 dimensions (eating, excretory, sexual, ambulatory, hand, bending and lifting, visual, auditory, speech and cognition) and varying levels of functioning within dimension. It was designed to describe reductions in the capacity of an individual to perform "certain tasks considered important for daily living" (MacKenzie et al., 2002). Although the measure can be applied in a variety of formats, one such application involves a consensus-based process of a group of experts who assigned predicted functional limitations to every AIS 1998 code, this is known as the pFCI-AIS98 (AAAM, 2008). The predicted FCI (pFCI) is intended to predict residual functional limitations one year following a particular injury (the terms pFCI and pFCI-AIS98 are used interchangeably here). These predictions can be transformed into a single numeric code ranging from 0 (worst possible state) to 100 (no limitation, perfect health state one year post-discharge). The following simplifying assumptions were made in the development of the pFCI-AIS98: "(1) the afflicted individual survives the injury, (2) the individual is 18–34 years old and has no preinjury morbidities, (3) the acute care and rehabilitation received is appropriate and timely, and (4) the injury described is the only injury sustained by an adult" (MacKenzie et al., 1996). The development of the pFCI is described in detail by MacKenzie et al. (1996). The predictive ability of the pFCI-AIS98 has been investigated by MacKenzie et al. (2002) and Barnes and Morris (2009).

Because of the relevance of traumatic brain injuries in PTW users, AIS diagnoses related to head injury were further classified by injury mechanism according to an algorithm developed by Martin

Table 1
2004 injury-related hospital discharge data by country (N = 88.2 million inhabitants 14 years old or older, 1 January 2005; EuroStat).

	Overall PTW helmet use rate (2007 data; WHO, 2009)	Injury hospitalization counts (all external causes, excluding readmissions)	% Discharges with external cause of injury information	Discharges identified as PTW user	Age-adjusted PTW user hospitalization rates (per 100.000 pop)	PTW users dead during hospitalization
Bulgaria	NR[a]	40,591	14.5	46	NC[b]	1
Hungary	95%	130,417	88.8	1990	23.0	10
Netherlands	92%	119,437	100.0	2279	17.0	28
Norway	100%	103,789	16.8	493	NC	10
Portugal	NR	77,748	99.7	1603	17.82	50
Slovenia	NR	29,587	87.5	662	38.19	2
Spain	98%	310,872	44.8	3403	NC	83
Sweden	95%	164,655	77.7	2518	NC	13

[a] NR: not reported.
[b] NC: not calculated because % of external cause of injury information was available in less than 80% of cases.

and Eppinger (2003; automated algorithm – European Center for Injury Prevention at Universidad de Navarra, 2008). This algorithm classifies head injuries into those related to translational acceleration/impact mechanisms, rotational acceleration mechanisms, or those that can be attributed to either translational or rotational acceleration. This algorithm was based on the work of Gennarelli (1993), who classified brain injuries into two basic categories – diffuse and focal. Focal injuries (such as certain skull fractures, lacerations, and contusions) were observed to be caused by direct, translational impacts to the head. Diffuse brain injuries (such as Diffuse Axonal injury, DAI; some vessel injuries; and some types of hematomas) were observed to occur as a result of inertial loading of the head where there was relative motion of the brain. Some types of diffuse injuries were associated with translational-type acceleration, and others were associated with a rotation of the head. Based on this information, Martin and Eppinger mapped an array of AIS 1998 head injury codes into injuries that were consistent with a translational mechanism (either from direct impact or translational acceleration), a rotational mechanism, or injuries that could be attributable to either mechanism. This algorithm has been used to relate head injuries to assumed mechanisms in previous epidemiological studies (Arbogast et al., 2005; Arregui-Dalmases et al., 2010).

Analyses are individual-based except when specifically presented as injury-based. AIS and pFCI-AIS98 are presented according to the worst such injury sustained by the individual. Country- and age-specific population data (from the end of 2004) were extracted from EuroStat (http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/). Rates per 100,000 population were computed using the direct standardization method. Descriptive analyses with point estimates and 95% Confidence Interval estimates were done using Stata (version 9.0, Stata Corporation, College Station, TX).

3. Results

The eight countries examined represented 103.3 million Europeans at the end of 2004 (1 January, 2005; EuroStat). In the hospital discharge database, 977,557 discharges were identified of injured individuals 14 years old or older (90% of all injury discharges submitted). The proportion of cases identifying the cause of injury (e.g., collision, fall, etc.) varied, ranging from 17% for Norway to 100% for the Netherlands. Injury causation information was available for ≥80% of the cases for the Netherlands, Portugal, Hungary, and Slovenia. In total 12,994 injured individuals were identified as PTW users, and 197 (1.5%) of them died during the hospitalization. Table 1 provides the counts per country, and the age-adjusted PTW hospitalization rates for the four countries with near-complete (≥80%) injury causation coding. The mean age of the hospitalized PTW users was 31.2 (standard deviation = 15.8; quartiles – 25%: 18, 50%: 27, 75%: 40), and 87.7% of the injured individuals were male.

The 12,994 hospitalized PTW user cases contained data on 24,305 injuries, with an average of 1.9 injuries per case (standard deviation = 0.86; quartiles – 25%: 1, 50%: 2, 75%: 3). Ninety-two percent of these injuries could be mapped into the body region and injury type classifications of the Barell matrix (Table 2). Fractures to the lower and upper extremities were the most frequent injuries, accounting for 20.1% (95% confidence interval: 19.5–20.6) and 15.2% (14.7–15.7) of the total number of injuries, respectively. These were followed in frequency by internal traumatic brain injuries (TBI, 13.4%: 12.9–13.8); fractures to the thorax (e.g., rib fractures, 4.0%: 3.7–4.3); and fractures of the head (3.6%: 3.3–3.8). Vertebral fractures occurred in 3.6% (3.3–3.6) of the cases. Ten percent of those (0.36% of the total injuries) occurred in the cervical spine – the remainder (90% of the vertebral fractures) occurred in the thoracic or lumbar spine. Fractures to the pelvis and hip were present in less than 3% of the cases.

It was possible to map approximately 97% of the injuries into AIS98 codes. Most of the hospitalized subjects sustained a maximum AIS score (MAIS) of 2 (57%: 56.4–58.2 C.I.). Twenty-one percent (19.9–21.4) sustained an MAIS of 3; 12% (11.5–12.6) had an MAIS of 1; 3% (2.8–3.4) had an MAIS of 4; 3% (2.5–3.1) had an MAIS of 5; and 0.6% (0.5–0.8) had an MAIS of 6. Sixty-nine percent (67.9–69.5) of hospitalized PTW users had ISS scores in the 1–8 range; 20% (19.5–20.9) had ISS scores ranging from 9 to 15; 4% (3.6–4.3) ranged from 16 to 24; and 3.7% (3.4–4.1) ranged from 25 to 75. Only around 3.0% of the cases had unspecific ISS values.

Of the 12,797 PTW users 14 years old or older who were discharged alive, 7561 had injury codes specific enough to be matched to a predicted Functional Capacity Index, pFCI-AIS98, value. The distributions of injury severity and body region were similar between the cases for which a pFCI value could be determined and those for which a pFCI value could not be determined. The only exception was AIS2 head injuries, which accounted for 1.7% of the cases for which a pFCI could be determined, and 19% of the cases for which a pFCI value could not be determined. Of the individuals for which a pFCI value could be determined, 53.6% (52.5–54.8) were expected to be fully functional and well one year after the injury; the remaining 46.4% were expected to exhibit varying degrees of functional limitations. Of those people that were expected to have some functional limitation after one year, the average pFCI-AIS score was 84 (84.0–84.6), out of a perfect (no limitation) score of 100. The three body region injury classifications with the largest average losses in functional capacity score were spinal cord injuries (average pFCI of cases with limitations: 66.8: 63.9–69.8 C.I.), traumatic brain injury (72.3: 71.1–73.4) and neck injuries (73.0: 70.2–75.7) (Fig. 1). The injury types with the largest predicted losses were crush injuries (66.8: 64.5–69.1), internal injuries (75.6: 74.3–76.9) and amputations (77.7: 75.5–80.0). Fig. 2 presents the percentage of individuals predicted to sustain any limitations (one year post-trauma) by the body region injured and by the type of injury sustained (shown are the worst injuries for each individual). Hip injuries and injuries to

Table 2
Barell matrix for 12.994 hospitalized PTW users (age ≥14 years) in eight European countries in 2004 (BG, HU, NL, NO, PT, SI, ES, SE). Percent distribution and 95% CIs[a] (N = 22,438 injuries).

	Fracture	Dislocation	Internal	Open wound	Amputations	Blood vessels	Contusion/ superficial	Crush	Burns	Others	Unspecified	Total
Traumatic brain injury	3.4 (3.1–3.6)	_[b]	13.4 (12.9–13.8)	0.8 (0.6–0.9)	–	–	–	0.7 (0.6–0.8)	–	0.3 (0.2–0.4)	<0.1	18.5 (18–19)
Other head	3.6 (3.3–3.8)	<0.1	–	1.8 (1.6–1.9)	<0.1	<0.1	0.7 (0.5–0.8)	–	0	<0.1	0.2 (0.1–0.23)	6.2 (5.9–6.5)
Neck	0.1	0	–	0.1	0	–	<0.1	0	0	0.2 (0.1–0.2)	<0.1	0.4 (0.3–0.4)
Neck and head other	–	–	–	–	–	<0.1	0.7 (0.6–0.8)	<0.1	<0.1	<0.1	0.1	0.8 (0.6–0.9)
Spinal cord	0.3 (0.2–0.3)	–	0.4 (0.3–0.5)	–	–	–	–	–	–	–	–	0.7 (0.5–0.8)
Vertebral column	3.6 (3.3–3.8)	0.2 (0.1–0.3)	<0.1	–	–	0	–	–	–	0.6 (0.4–0.7)	–	4.3 (4.1–4.6)
Thorax	4.0 (3.7–4.3)	<0.1	2.9 (2.6–3.1)	<0.1	0	<0.1	0.9 (0.8–1.1)	<0.1	0	0.2 (0.1–0.3)	<0.1	8.2 (7.8–8.5)
Abdomen, pelvis, trunk and lower back	1.9 (1.7–2.1)	0.1	3.2 (3–3.5)	0.3 (0.2–0.4)	0	0.1	1.3 (1.1–1.5)	<0.1	<0.1	<0.1	0.2 (0.1–0.3)	7.2 (6.9–7.6)
Upper Extremity	15.2 (14.7–15.7)	1.9 (1.7–2.1)	–	1.1 (0.9–1.2)	0.1	0.1	1.5 (1.4–1.7)	<0.1	<0.1	0.7 (0.6–0.8)	0.1	20.7 (20.3–21.2)
Lower Extremity	20.1 (19.5–20.6)	0.7 (0.5–0.8)	–	1.6 (1.4–1.7)	0.2 (0.1–0.3)	<0.1	1.6 (1.3–1.7)	0.1	0.1	1.6 (1.4–1.8)	0.2 (0.1–0.3)	26.2 (25.6–26.7)
Hip	1.3 (1.1–1.4)	0.3 (0.2–0.4)	–	<0.1	0	–	0.3 (0.2–0.4)	<0.1	–	0.1	–	2.0 (1.8–2.2)
Multiple body regions, system wide and unspecified	0.6 (0.4–0.6)	0	<0.1	1.5 (1.3–1.6)	0	0.1	1.2 (1.1–1.4)	<0.1	0.1	0.2 (0.1–0.3)	1.1 (0.9–1.3)	4.8 (4.5–5.1)
Total	53.9 (53.2–54.5)	3.2 (2.9–3.4)	19.9 (19.4–20.4)	7.1 (6.7–7.4)	0.3 (0.2–0.4)	0.3 (0.2–0.4)	8.2 (7.8–8.6)	1.0 (0.8–1.1)	0.2 (0.1–0.3)	3.9 (3.6–4.1)	1.9 (1.7–2)	100

[a] Confidence intervals not calculated when $N < 2$.
[b] Cells for which neither ICD-9 nor ICD-10 codes exist.

Table 3
Distribution of head injury types[a], by case, for hospitalized PTW users with head injuries that were discharged alive (N = 3178 subjects 14 years old or older). Eight European countries (BG, HU, NL, NO, PT, SI, ES, SE), 2004.

Cases with cerebral concussion[b]	
Concussion only	44%
+ Other rotational injury	4.7%
+ Translational injury	0.5%
+ Either-type injury	6.6%
Cases without concussion	
Other rotational injury	9.7%
Translational injury	10.7%
Either-type injury	6.2%
Combination	17.6%

[a] Head injury types classified based on the injury code mapping algorithm of Martin and Eppinger (2003).
[b] Note that cerebral concussion is classified by Martin and Eppinger (2003) as a rotational-type head injury. Because of uncertainty of the mechanism of this injury, and the high frequency of this injury in these data, cerebral concussion is presented here separate from other injury-type classifications.

the lower extremity presented the largest percentage of individuals predicted to have some residual disability one year after the crash (almost 80% of the victims). This was followed by injuries to the upper extremity, multiple injuries, injuries to the neck, spinal cord and traumatic brain injury.

Twenty-five percent of the injuries of the admitted PTW users occurred in the head (Table 2). Of these, 3178 individuals sustained at least one injury that could be mapped into the algorithm to determine the head injury mechanism (translational, rotational, either; Martin and Eppinger, 2003). Most of these subjects (44%) exhibited only cerebral concussion, with no other head injuries reported in the top-three ICD codes. Although concussion is classified by Martin and Eppinger (2003) as a rotational head injury, the authors note that this mechanism is less than certain. Because of this uncertainty, and because of the large relative frequency of concussion injury in these data, concussion cases are presented here separate from cases of other rotational-type head injuries (Table 3). Some subjects exhibited concussion plus another rotational head injury (4.7%), concussion plus a translational head injury (0.5%), or concussion plus a head injury categorized as "either" (6.6%). For subjects that did not exhibit concussion, 9.7% (of the 3178 head injury cases) sustained only other types of rotational head injuries; 10.7% sustained only translational head injuries; 6.2% sustained either-type head injuries; and 17.6% sustained multiple head injuries in a combination of categories (not including concussion). Among the head injuries that could be mapped to an injury mechanism, 43% were of AIS severity 3 or greater (cerebral concussions are AIS 2 injuries, and are thus not included in this group). Of these AIS3+ head injuries, 48% were associated with a translational mechanism, 37% were associated with a rotational mechanism, and 15% could be associated with either mechanism.

4. Discussion

4.1. Injury distributions

The general injury distributions observed in this research were consistent with previous large-dataset, hospital discharge studies examining injuries to PTW users. Coben et al. (2004) studied a sample-based hospital discharge database representing approximately 30,505 motorcycle-injury patients in the U.S. in 2001. Coben and colleagues found that the most common principal diagnoses for admitted motorcycle injury patients were fractures of the lower extremity (29.4%) and fractures of the upper limb (13.1%). These findings are consistent with the injury frequency ranking presented in the current study, despite the fact that the Coben

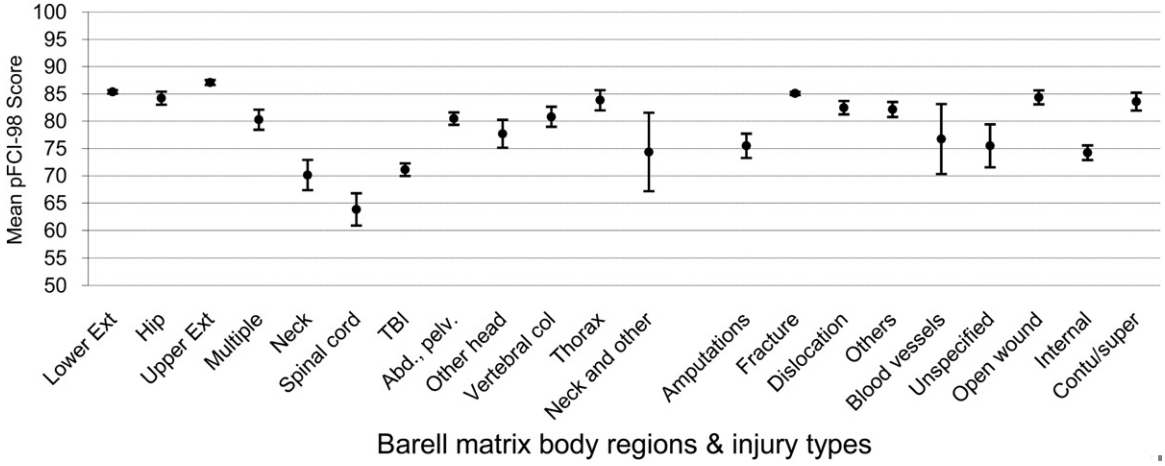

Fig. 1. Mean (and 95% C.I.) Predicted Functional Capacity Index scores (pFCI, based on AIS98) of hospitalized PTW users discharged alive who were expected to have some functional limitation one year post discharge (pFCI-AIS98 < 100), by body region and type of injury. A score of 100 indicates no loss of functional ability; a score of 0 indicates a complete loss of functional ability. Eight European countries (BG, HU, NL, NO, PT, SI, ES, SE), 2004 (N = 4053 subjects 14 years old or older, average pFCI-AIS98 = 84).

study included both on-road and off-road cases. The percentage of intracranial injuries in that study (12.3% of all principal diagnoses) was also consistent with the percentage of internal traumatic brain injuries in the current study (13.4% of all injuries: 12.9–13.8 C.I.), despite a generally lower helmet rate use in the U.S. (58% in 2007; WHO, 2009). Among other factors, this may be attributable to a greater risk of on-scene mortality for non-helmeted riders suffering head injuries in the U.S. data. Massive, unsurvivable, rapidly fatal head injuries are more likely to occur when a rider is not helmeted. Such cases are often not transported to a hospital, and thus do not appear in hospital discharge data. Instead, hospital discharge data tend to describe the distribution of potentiallysurvivable injuries. This is indicated by the low post-admittance mortality rates in the current study (1.5%) and in the study of Coben et al. (2%). Although lesser helmet use may increase the risk of fatal head injury in the population of the Coben et al. study, the distribution of survivable head injuries (compared to other body regions) may be similar to other populations with greater helmet use (such as that studied here).

The injury distributions observed here are also consistent with the smaller European hospital discharge study of Latorre et al. (2002). Hospital data from two large Italian cities (Rome and Naples) were collected during six months in 1999, aiming specifically to analyze the frequency of head injuries. Included in the study were injured PTW users between 14 and 35 years old that had been admitted to the Emergency Department but not necessarily admitted into the hospital afterwards. A total of 736 PTW-injury patients were analyzed. Most of the injuries occurred in the knee or lower leg (27.5%), followed by the head (17.5%), elbow and forearm (8.8%), wrist and hand (8.6%), shoulder and upper arm (8.4%) and ankle and foot (6.9%). Once again, the rate of head injuries in that study was roughly consistent with the overall rate of all head injuries in the current study (24.7%), despite a very low helmet use rate (12%) among the injured in the Italian data. The urban locations of those hospitals, however, may have caused an under-representation of high-speed crashes.

Fitzharris et al. (2009) analyzed hospital records of 378 injured PTW users brought to hospitals in Hyderabad, India. That study included both patients treated at the hospital and fatalities who

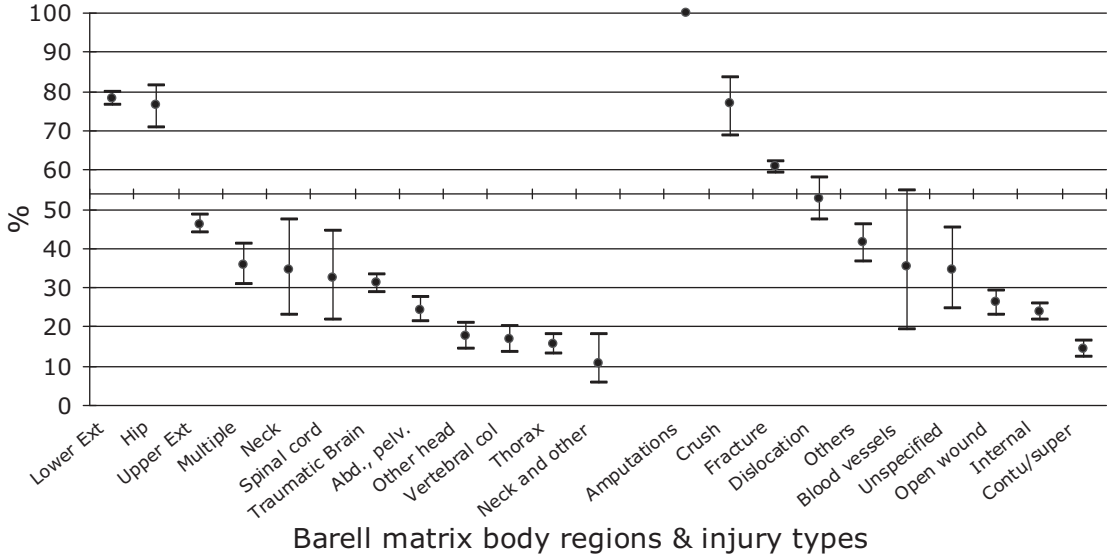

Fig. 2. Percentage (and 95% C.I.) of hospitalized PTW users discharged alive who were expected to have some functional limitation one year post discharge, according to the Predicted Functional Capacity Index based on AIS98 scores by body region and type of injury. Eight European countries (BG, HU, NL, NO, PT, SI, ES, SE), 2004 (N = 12,797 subjects 14 years old or older, average p(pFCI-AIS) < 100 = 46%).

were brought to the hospital post-mortem. In contrast to the current study (and the other hospital studies described above), open wounds and superficial injuries to the head were the most common injury (69.3%), followed by injuries to the upper extremity (27%), and the lower extremity (24%). Only 19.6% of the case subjects had worn their helmet correctly, and failure to wear a helmet was associated with a five times greater risk of intracranial injury (risk ratio 4.99, 95% C.I. 1.23–20.1). Of the 19 pre-hospital deaths, 16 (84%) had not worn a helmet (Fitzharris et al., 2009). Similarly, Zettas et al. (1979) analyzed data from 260 hospital admissions of motorcyclists in the Fresno County, California, over a period of time of 4.5 years – also including roadside deaths and deaths on arrival. Head injury occurred in 31% of those patients and 54% of the patients sustained major long bone fractures.

The current study also observed very few cervical spine injuries, with c-spine fractures representing just 10% of the total vertebral fractures and 0.36% of the total injuries. This is also consistent with previous studies. In a review of the literature, Hinds et al. (2007) observed that most studies reported that damage to the thoracic spine was more common than damage to the cervical spine in motorcyclists. Similarly, in their study of 260 admissions of injured motorcyclists in a region of California, Zettas et al. (1979) found only 1 case exhibiting a cervical spine fracture. In a study of 1121 injured motorcyclists in the UK (1993–2000), Robertson et al. (2002) found cervical spine injury in 1.96% of the cases. It should be noted that the frequency metric used by Robertson et al. (percent of cases with a c-spine injury) is not directly comparable to the frequency metric used in the current study (percent of all injuries that were c-spine injuries). Differences in study selection criteria may also have caused the Robertson study to tend towards more severe cases. The current study included all patients admitted to a hospital (for any length of time), whereas the Robertson study included only patients that were admitted for >72 h, were admitted to a high-dependency unit, or died in the hospital as a result of the trauma.

4.2. Functional disabilities

In this study, 46.4% (45.2–47.5) of the PTW-injury patients were expected to have some functional limitation as a result of their injuries at least one year post-discharge. In discussing the population-level impact of functional disability, it is important to consider not only the magnitude of the individual injuries, but also the relative frequency of the injuries in the population. In this study, spinal cord injuries – when they occurred and when they resulted in some functional limitation – were predicted to result in the largest average loss in function per case compared to other injuries (average pFCI-98 = 66.8: 63.9–69.8). Spinal cord injuries were very rare, however (only 0.7% of the total injuries), and only 30% of the spinal cord injuries that occurred resulted in some functional limitation. In contrast, lower extremity injuries accounted for 26% of the total injuries, and of the lower extremity injury cases 80% were expected to experience some lasting disability. The overall ranking of functional disability frequency in these data (conceptually related to the injury frequency multiplied by the rate of disability per injury case) appears to follow the frequency ranking of the injury distribution. Following lower extremity injury, upper extremity injury accounted for 21% of the total injury count, and 47% of the upper extremity injury cases were expected to exhibit disability one year post-collision. Traumatic brain injury accounted for 19% of the injuries, and 24% of the TBI cases were expected to exhibit disability one year later. Of these three most frequently occurring injuries, traumatic brain injury was predicted to result in the greatest average loss in functional ability (pFCI 72.3: 71.1–73.4) in the cases that were expected to result in some functional disability. The high frequency of expected long-term disabilities from lower and upper extremity injuries suggests that future efforts aim to mitigate lower and upper extremity injuries among PTW users. The high severity and relatively high rate of expected long term disability from traumatic brain injury suggests that efforts to mitigate PTW head injury should be continued, including both surveillance and novel intervention efforts.

4.3. Head injuries and injury mechanisms

Cerebral concussion was the most commonly diagnosed head injury, occurring in 56% of head injury cases. Most of these (44% of head injury cases) exhibited concussion as the only reported head injury (in the top three ICD codes), while combinations of concussion and other head injuries were reported in 11.7% of the head injury cases. While these concussions may be considered a minor injury (AIS 2) relative to other injuries that could occur, they do present a possible area for improvement.

Among the AIS3+ head injuries that could be mapped to an injury mechanism, 48% were associated with a translational-impact mechanism. Because actual helmet use was not recorded in the hospital records, it is unknown whether these injuries resulted from direct impacts of the head with a hard surface, or if they resulted from impacts padded by a helmet. In contrast, 37% of the AIS 3+ head injuries (that could be mapped to a mechanism) were of a type usually associated with a rotational mechanism. Although it is unknown whether or not these subjects were helmeted, it is also unknown the degree to which helmets protect against rotational head injuries. Current European Union helmet performance regulations are based predominantly on the mitigation of translational head acceleration in PTW collisions. Regulation 22 (ECE/ONU, 2002) includes a mandatory head-drop test procedure whereby a helmet fitted on an instrumented headform is dropped onto a rigid anvil (in various orientations). Helmet impact-attenuation performance is assessed based on the linear acceleration measured at the center of gravity of the headform (both in terms of the peak acceleration and the Head Injury Criterion, HIC). Neither this test type nor this assessment measure is designed to assess the risk of rotational traumatic brain injury.

Despite the observed prevalence of concussion, and the high frequency of rotational brain injuries, understanding the exact causes of these injuries may be more difficult than understanding the causes of translational brain and head injury. Conceptually, translational head injuries are caused by a direct, linear impact of the head (either helmeted or not helmeted) against an object. As a result, the design of evaluation tests for translational head injury mitigation is relatively straight forward (e.g., head-form drop tests). The cause of concussion and rotational head injuries may be less obvious – they may occur from a direct impact; a padded impact; a direct eccentric head impact resulting in rapid head rotation; or from inertial mechanisms whereby the head experiences a rapid free rotation secondary to a rapid deceleration of the thorax. These may also occur from tangential forces on the helmet (e.g. from snagging or friction forces) as the helmet moves across a surface (e.g., the road). The current R22 regulation indirectly addresses this final possible mechanism, dictating peak friction and snagging forces that can occur in helmet drag/friction tests. Prior to determining interventions or evaluation tests to mitigate concussion and rotational head injuries, it is necessary to determine the mechanisms that are causing these injuries to occur. This may be best accomplished through in-depth investigations of PTW collisions. Future work should also include determining whether or not the observed higher-severity (AIS3+) translational-impact cases were, in fact, helmeted – and, if so, how we may improve helmets to prevent those injuries from occurring.

4.4. Limitations and future work

The major limitation of the hospital discharge data used in the current study is that it cannot be used to study on-scene fatalities. As a result, these data are of limited use in studying the distribution of injuries resulting in death. This study also did not include the set of patients that were injured, but were not admitted to a hospital. Thus, these data are best suited to the study of the range of injuries that were severe enough to require admittance to a hospital, but were potentially survivable. It is possible, however, that differences in hospital admittance practices may introduce biases in observed injury types and severities across countries. The countries of this study do exhibit different injury-related hospitalization rates (per population; Segui-Gomez et al., 2008). It is currently unknown, however, if this is caused by differing hospital admittance practices, or if this is the result of actual differences in injury incidence. These results may also be affected by differing definitions of various injuries. While some injuries (such as long-bone fractures) are relatively well-defined, injuries that require an assessment based on personal function or subjective observation (for example, cerebral concussion) may vary by locale, by hospital, or by individual physician. Future work should include studying differences in hospital admittance practices and injury definitions across Europe, and how this may affect perceptions of injury prevention priorities.

As with most hospital discharge data, helmet use was not reported on an individual basis in the current study. As a result, it was not possible to determine the rate of helmet use in the population of injured patients studied. It was also not possible to explore the relationship between helmet use and the types of injuries observed. Previous reports have indicated, however, an overall helmet use rate of 92% or greater in at least five of the countries studied (2007 data, Table 1; WHO, 2009). Future work may include comparing these results to regions with lower helmet use rates to study the effects of helmet use on injury patterns, frequencies, and severities.

This study investigated injury patterns among PTW users of age 14 years and older. Injury patterns among younger illegal PTW drivers or patterns may be affected by age, either through differences in collision scenario, collision severity, helmet use, or because of biomechanical factors. Future work could include studying injury patterns among younger PTW users, or as a function of age in general.

The injury data presented here are representative at the population level for the four countries that reported the mechanism of injury (through the E or V codes) for most ($\geq$80%) of their hospital discharge cases (Table 1). There was a lower rate of proper coding in the other countries in this study, and in general in most countries throughout the world. Limited past studies have indicated that such sub-optimal coding may adversely affect the population-representative nature of such data. In a study of ICD-9-CM E codes in hospital discharges in Maryland (time period 1979–1988), Marganitt et al. (1990) found that E code absence was biased by both age and Injury Severity Score (ISS). That study did observe, however, a steady increase in the coding rate throughout the time period studied. It was postulated that E code absences were affected by the available space in record forms, and by changes in hospital reimbursement practices related to ICD-9-CM coded information. Unfortunately, to our knowledge no recent studies have investigated biases in ICD external cause coding in the time period of the current study, or in the European countries investigated here. It is possible that coding bias may exist in the three countries that exhibited relatively low coding rates – but the existence, extent, and nature of any possible bias is currently unknown. If there was bias by ISS (similar to the study of Marganitt et al., 1990), then this may affect counts of multiple-injury cases. If there was bias by injury type or body region, then this may affect our observation of injury distributions and/or predicted functional outcomes. Future work should include investigating the possibility of bias in external-cause information in modern hospital discharge coding (in Europe and elsewhere). Ultimately, this concern may be mitigated through improved coding practices at the hospital level.

Finally, the AIS, ISS, pFCI, and the head injury mechanism classifications are all descriptive measures that were determined from the ICD codes based on translational algorithms. These are all subject to assumptions and case losses inherent to shifting between different coding criteria. For example, the severity coding of certain acute injuries can differ in different versions of the Abbreviated Injury Scale. Thus, care must be taken when comparing these results to other studies to ensure that consistent versions of the AIS code are used. In addition, while the ICD codes could be mapped to the AIS scale for 97% of the injuries, only 60% of the cases contained injury information that could be mapped to pFCI-AIS98 values. This is primarily a function of the compatibility of the injury classification systems (as opposed to being a function of in-specificity in the injury coding). There are also fundamental limitations of using acute injury data to predict functional outcomes. Some injury definitions were intentionally left out of the definition of the pFCI due to uncertainty or variability in their associated long-term outcomes. The pFCI is also intended to predict the functional losses anticipated to occur in otherwise healthy, injured adult patients. In retrospective studies such as this one, however, the study population usually includes patients outside of the specific demographic used in the development of the pFCI (for example, patients with other ages and health statuses). Ideally, such an outcome assessment would be performed in a prospective cohort study following injured patients for a period of time post-discharge. Similarly, the description of the head injury mechanisms is predicated on assumed associations between specific injuries and their causes. Ideally, an investigation of head injury mechanisms would be complemented with a large number of in-depth investigations of PTW collisions.

5. Conclusions

This study examined the second largest collection of hospital discharge data for PTW users ever gathered, and the largest ever gathered for countries in Europe. Based on previous data, at least five of the eight countries studied tended to exhibit very high (>90%) overall helmet use rates (WHO, 2009). Lower extremity injuries were the most common injuries observed, followed by upper extremity injuries and traumatic brain injuries. In addition to being the most common injury, 80% of the lower extremity injury cases were expected to have some functional disability one year post-collision (compared to 47% of upper extremity injury cases and 24% of TBI cases). Although it occurred less frequently, patients that were expected to experience some functional limitation from TBI were predicted to fair worse (lose more functional ability) than patients with functional limitations from upper extremity or lower extremity injuries. Overall, the hospitalized PTW users of this study were predicted to exhibit a disability rate (some functional limitation one year post-trauma) nearly double that previously reported for passenger car occupants hospitalized following collisions.

Cerebral concussion was the most common head injury observed (occurring in 56% of head injury cases), with most concussion cases (78%) exhibiting no other head injury (in the top three ICD codes reported). Among AIS3+ head injuries that could be mapped to an injury mechanism, 48% of these were associated with a translational-impact mechanism, and 37% were associated with a rotational mechanism. This predominance of concussion, and high frequency of rotational head injuries, provides direction for next phase of head protection among PTW users. The exact

mechanism of these concussions remains unknown, however, and neither current helmet performance standards nor current injury criteria are designed to assess the risk of rotational head injuries in collisions. Even with near universal helmet use, these injuries are likely to persist until they are specifically addressed. The development of intervention strategies for concussion and rotational head injuries should begin with in-depth study to determine the exact causes of these injuries (and the situations in which they occur).

Finally, both the high rates of predicted disability from upper and lower extremity injuries suggest a need for a fundamental re-examination of the current and future priorities for reducing the societal burden of PTW user injuries. Lower and upper extremity injuries account for the highest frequency of disability resulting from PTW collisions, despite being traditionally marginalized (in terms of research focus) in favor of more life-threatening injuries. The recent shift towards increasing PTW use has the potential to result in a generation with lasting disabilities, unless specific efforts are made to mitigate upper and lower extremity injuries in PTW collisions.

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