Pedestrian and Cyclist Impact

SOLID MECHANICS AND ITS APPLICATIONS

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Ciaran Simms • Denis Wood

Pedestrian and Cyclist Impact

A Biomechanical Perspective

Springer

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To Lynn

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Foreword

In the world today there are roughly 800 million cars, trucks and buses. There are also perhaps 500 million motorcycles and other motorised two-wheeled vehicles. No one really knows how many bicycles there are but, since 1990 the annual production of bicycles has been around 100 million, so it is likely that there are more bicycles in the world than all other road vehicles put together. Currently of road traffic deaths globally, three quarters of those deaths are to vulnerable road users, mainly pedestrians and cyclists. More important however are the seriously injured survivors. Although data are fragmentary in many parts of the world, for every death there are at least three casualties with serious, disabling injuries; brain or neurological damage or disruption of a major joint in the lower limbs. Financially and socially, the costs of the survivors represent some 80% of the costs of traffic injuries to society.

Hence the importance of this book. Ciaran Simms and Denis Wood have produced a book which is relevant to public health policy makers, transportation planners and particularly vehicle designers and the legislators who influence vehicle exterior design. By giving a biomechanical perspective to the subject of pedestrian and bicyclist impacts, they emphasize the crucial importance of exterior design of all road vehicles. Historically, vehicle crashworthiness has been skewed by activities in the United States where vehicle occupants have been the sole concern because of the highly motorised, car based conditions in North America. Modern car design now provides the occupants with airbags, seat belts and deforming structures which minimise the crash forces by providing large ride-down distances in severe impacts. It seems only right that the much more numerous pedestrians and cyclists in the world should get a few centimetres of useful ride-down distance and the appropriate exterior shape to reduce the severity of the injuries which they receive.

The authors provide an excellent historical perspective of the topic, illustrating its complexity and imperfectly documented epidemiology. They then explain in detail the current tools which are available through experimental testing, improved information on impact injury mechanics, injury criteria and modelling. This leads to the conclusion that although our knowledge is still imperfect what we do know can and should be applied. The benefits of such an approach on a global scale could be enormous.

By bringing together past research and current knowledge the authors have produced an important book which should be in the library of every biomechanical engineer, public health specialist, every car, truck and bus designer and every legislator who is concerned with traffic safety.

Murray Mackay, FREng. Isle of Man, April 2009
President – IRCOBI

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Chapter 1
Introduction

In 2004 the World Health Organisation predicted that road traffic injuries will become the third leading contributor to the global burden of disease by 2020, unless appropriate countermeasures are taken [1]. The proportion of road fatalities who are pedestrians and cyclists varies in different countries, but overall the protection of pedestrians is the most important road traffic safety priority [2]. This is best achieved using a combination of road engineering, vehicle design, legislation/enforcement and accident avoidance technology. The separation of pedestrians and cyclists from fast-moving motorised vehicles is clearly an ideal approach to preventing fatalities, and there are now also pre-crash sensing methods combined with brake-assist technology aimed at preventing the occurrence of pedestrian and cyclist accidents [3, 4]. However, these approaches cannot prevent all accidents, and vehicle/pedestrian and vehicle/cyclist collisions will remain a real and frequent problem in most countries for the foreseeable future.

This book is aimed at understanding the physical processes which occur when pedestrians and cyclists are struck by motorised vehicles. We provide a clear overview of the importance of pedestrian and cyclist impacts and the principal goals are to show how pedestrian and cyclist pre-impact movements and vehicle design influence subsequent injury outcome. This involves recourse to several academic disciplines: epidemiology, mechanics and anatomy/physiology. Therefore, this book presents pedestrian and cyclist impact from a biomechanical perspective.

We have had a basic understanding of the relationship between vehicle design and pedestrian injuries since the 1960s [5], but the safety of pedestrians and cyclists was not a serious consideration in vehicle design until the 1980s. This was encouraged by the popular but mistaken belief that little could be done to protect pedestrians in the event of a vehicle impact [6, 7]. This is best illustrated by a statement in a review paper in the Journal of Accident Analysis and Prevention in 1972 which concluded that "it would appear that pedestrians and vehicles are just not compatible" [6]. This common perception permitted manufacturers to continue to neglect an area of vehicle design not governed by legislation and not considered to provide added value to the vehicle. However, times have changed, and the advent of New Car Assessment

Programs has meant that there is now substantial public appetite in many countries for the regulation of vehicle design for pedestrian safety.

This book provides a comprehensive treatment of the biomechanics of pedestrian and cyclist impacts. It should therefore be of value to new and established researchers alike. We give a detailed treatment of the mechanics of pedestrian impact, as well as a review of the accident databases and the relevant injury criteria used to assess pedestrian and cyclist injuries. A further focus is the effect on injury outcome of the variability of initial position and speed of pedestrians and cyclists relative to the striking vehicle and the influence of vehicle design.

This is the first structured book on the mechanics of pedestrian and cyclist impact presented from a biomechanical perspective. It is intended to become a 'one stop' source for understanding the mechanics of pedestrian and cyclist impacts, and the book features a comprehensive treatment of the impact equations. Therefore, this book will serve as a primer and teaching tool for new researchers but also as a reference text for established researchers. The book highlights important improvements in pedestrian safety in recent decades and provides the necessary theoretical foundations for the reader to fully understand these advances.

This book is principally designed to be read sequentially, with later chapters building on fundamental foundations presented in earlier chapters. However, considerable effort has also been made to bring coherence to individual chapters. The book is structured as follows:

- Chapter 2 summarises pedestrian and cyclist injuries using the available accident databases.
- Chapter 3 provides an analysis of the movements of pedestrian and cyclists when struck by the front of vehicles.
- Chapter 4 presents the relationship between pedestrian projection distance and vehicle impact speed which is used for accident reconstruction and for biomechanics research.
- Chapter 5 is a summary of the injury mechanisms and injury prediction criteria that are used in the assessment of vehicle design.
- Chapter 6 describes the existing standardised tests to assess pedestrian safety in production vehicles.
- Chapter 7 provides mathematical formulations for impact modelling.
- Chapter 8 presents the state-of-the-art of existing simulation tools for modelling pedestrian and cyclist impact.
- Chapter 9 considers the relationship between vehicle related injuries and ground related injuries for pedestrians and cyclists.
- Chapter 10 provides a detailed analysis of the influence of vehicle design on pedestrian and cyclist injuries.
- Chapter 11 presents conclusions and perspectives for future research.

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Chapter 2
Pedestrian and Cyclist Injuries

Introduction

This chapter presents a general epidemiology of pedestrian and cyclist accidents. We begin with an overview of the scale and worldwide variability of both pedestrian and cyclist injuries. However, there is far more information available for pedestrian than for cyclist accidents and it can be difficult to distinguish between them, as they are sometimes jointly categorised in accident databases as Vulnerable Road Users [1]. In other cases, cyclist accidents are excluded from accident databases altogether [2] and even where they are included, underregistration is significant.[1] However, the general pattern of injury severity for pedestrians and cyclists is similar [4] and, due to their higher significance and the increased data available, the focus of this chapter is on pedestrian injuries. Pedestrian accident databases are the principal source of information, but it will be seen that those available mostly contain accidents from a small number of industrialised countries. Therefore, their findings must be interpreted cautiously when assessing pedestrian and cyclist injury levels in less industrialised countries. Nevertheless, the existing accident databases provide the best available overview of pedestrian and cyclist injuries.

Global View of Pedestrian and Cyclist Fatality and Injury Rates

The World Health Organisation has estimated that worldwide 1.2 million people are killed in road traffic crashes and that up to 50 million are injured each year [5]. The proportion of road accident fatalities who are pedestrians and cyclists varies substantially throughout the world, with large divisions evident between low and high income countries, as shown in Table 2.1. For example, in the US, France and Sweden vehicle occupants represent more than 60% of all road fatalities and the proportion of pedestrians and cyclists is 12–13% and 2–9% respectively. However,

[1] For example, only 15% of cycling accidents involving bodily injury are recorded in Belgium [3].

Table 2.1 Proportion of overall road traffic fatalities who are pedestrians and cyclists in different countries, presented in increasing order of pedestrian risk.

Country	Percentage of road accident fatalities who are pedestrians	Percentage of road accident fatalities who are cyclists
The Netherlands	10% [11]	22% [11]
China (Beijing only)	10–15% [12]	ca. 30% [13]
Malaysia	10–15% [12]	NA
Thailand	10–15% [12]	NA
France	12% [14]	3.4% [15]
USA	13% [11]	2% [11]
Germany	13% [14]	NA
Italy	17% [16]	5.3% [15]
Sweden	13% [14, 17]	8.6% [15]
Australia	18% [11]	4% [11]
Ireland	20% [18]	2.5% [18]
UK	21% [19]	4.6% [15]
Portugal	23% [14]	3.8% [15]
Chile	24% [12]	NA
Japan	30% [16]	10% [20]
South Africa	40% [21]	3% [22]
India (Delhi only)	42% [11]	14% [11]
Peru	45% [12]	NA
Ethiopia	51% [12]	NA
Kuwait	55% [6]	NA
Ivory Coast	75% [6]	NA

this relationship is largely inverted in many African, Asian and South American countries. In the Netherlands, pedestrians account for 10% and cyclists for 22% of fatalities. In contrast, pedestrians account for over 50% of road accident fatalities in Kuwait and Ethiopia and 75% in the Ivory Coast [6], and pedal and motorcyclists combined rank first for road accident fatalities in India and Surinam [6]. An explanation of these variations lies in the cultural as well as socio-economic differences between these regions. However, some reports are conflicting as the availability of detailed accident data in lower income countries is generally poor, and the majority of pedestrian fatalities occur in countries which do not routinely collect detailed road accident statistics. Therefore, this information shortfall in countries where it is most needed must be addressed if worldwide pedestrian and cyclist fatalities are to be significantly reduced.

It has been predicted that the number of road accident fatalities will rise to 2 million by 2020, and that 85% of these collisions will occur in low-income countries. Furthermore, these projections indicate that 75% of road accident fatalities will be pedestrians, cyclists and motorcyclists [7].

Apart from regional variations, the urban/rural divide is also important for distinguishing the relative importance of pedestrian fatalities. The majority of pedestrian accidents occur in built-up areas [8], and in London pedestrians account for half of

road fatalities [9]. In Kenya, pedestrians represent 70% of all urban fatalities, but just over 30% of rural traffic fatalities [10].

Main Pedestrian and Cyclist Injury Database Sources

In many countries, the police record basic information following an accident, such as time of day, scene description, vehicle type, presence of tyre/blood/glass traces on the road, etc. Similarly, hospitals usually record the principal injuries. However, detailed accident databases linking police and hospital records and predicting the range of impact speeds and vehicle/pedestrian/cyclist configurations at impact require significant resources. Therefore, pedestrian accident databases are either general and contain a large number of cases, or in-depth and contain a small number of detailed accident reconstructions.

Some highly motorised countries routinely maintain pedestrian accident databases,[2] and these mostly show consistent findings: about 80% of pedestrians were standing up and moving across the road when struck from the side by the fronts of passenger cars [23, 24]. About 60% of pedestrians made no avoidance maneouver such as jumping, accelerating, turning away or stopping [25]. The distribution of impact directions for cyclists is more complex, but lateral impact on the cyclist lower limb by the vehicle front is most common [26], accounting for about 60% of accident configurations [27–30]. A breakdown of the relative importance of the different impact directions for pedestrian accidents in the APROSYS database and for Japanese serious cyclist injuries and fatalities is given in Figures 2.1a&b respectively. While Figure 2.1a shows that 89% of pedestrians are struck on either the left or the right side, Figure 2.1b shows that for cyclists only 66% of fatalities involve side impact, and front/rear impacts are relatively more important for cyclists than for pedestrians.

Older databases such as the US Pedestrian Injury Causation Study (PICS) contain only accidents from the 1970s, and vehicle design and pedestrian injury profiles have changed considerably since then [25]. In recognition of this, the Pedestrian Safety Working Group of the International Harmonised Research Activities (IHRA)[3] body have collated recent pedestrian accidents from Australia, Europe, Japan and the USA to a common format [2], see Table 2.2. The principal IHRA findings are presented here: the dataset consists of 1605 pedestrian accidents which resulted in 9463 injuries, of which 6158 were AIS1[4] injuries and 3305 were AIS2-6 injuries. The IHRA database does not include pedestrian injuries from developing countries or any cyclist accidents, but it is the most comprehensive and up-to-date pedestrian accident database available.

[2] Eg German In Depth Accident Study (GIDAS), US Pedestrian Crash Data Study (PCDS), APROSYS European In Depth Pedestrian Database, Australia Transport Safety Bureau Fatal File.

[3] IHRA are part of the United Nations Economic Commission for Europe (UNECE).

[4] AIS Abbreviated Injury Scale, categorising injuries from minor (AIS1) to unsurvivable (AIS6) [33].

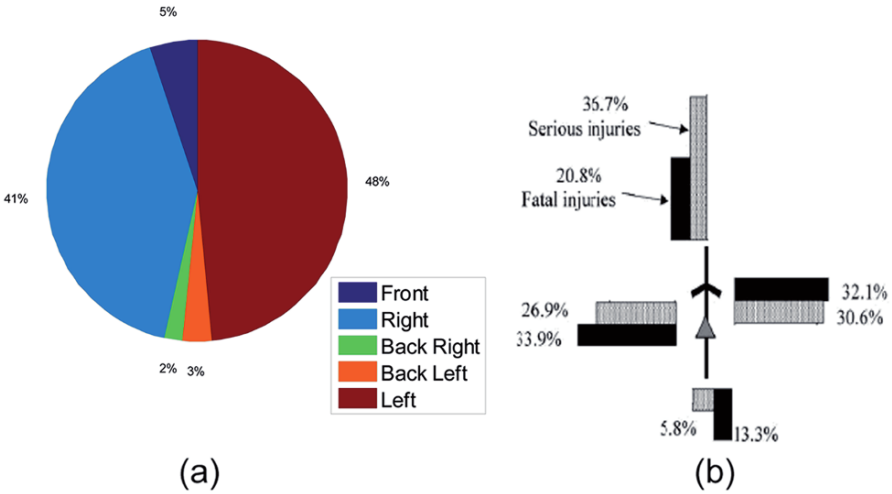

Fig. 2.1 Relative contribution of impact directions for (a) pedestrians in the APROSYS database (impact angles not available) adapted from [31] and (b) Japanese cyclist serious injuries and fatalities, adapted from [32].

Table 2.2 IHRA pedestrian accident data sources [2].

Country	Pedestrian accident database source
Japan	240 urban pedestrian accident cases collected by the Japanese Accident Research Institute (JARI) between 1987 and 1988 and in-depth case study data of pedestrian accidents conducted by the Japanese Institute for Traffic Accident Research and Data Analysis (ITARDA) between 1994 and 1998.
Germany	783 urban and rural cases collected between 1985 and 1998 by the German In-Depth Accident Study (GIDAS). Accidents in which pedestrians were overrun or impact speed could not be established were excluded.
United States	521 urban cases between 1994 and 1999 were collected in the Pedestrian Crash Data Study (PCDS). The first point of contact between the vehicle and the pedestrian had to be forward of the top of the A-pillar.
Australia	80 urban accidents between 1999 and 2000 were collected. These included 64 with passenger cars, SUVs or 1 box type vehicles where the pedestrian was standing, walking or running away. The main point of contact with the pedestrian on the vehicles was forward of the top of the A-pillar.

Distribution of Pedestrian Injuries

The IHRA data shows that a wide variety of pedestrian body regions are injured. However, it is important to distinguish between the severity of different injuries and the frequency with which these occur. In the following presentation of the IHRA data, AIS1 injuries are not included since the large number of these minor injuries considerably skews the dataset. The overall distribution of AIS2-6 pedestrian injur-