Bicycle Injuries – the effects on Health-Related Quality of Life and Sickness Absence

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Abstract

Title: Bicycle Injuries – The effects on Health-Related Quality of Life and Sickness Absence
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Language: English with a Swedish summary
Keywords: Bicycle; injuries; crashes; ICF; HRQoL; Sickness Absence; Health; Disabilities; Impairments

From a societal point of view, efforts are made to increase the level of bicycling, due to the positive impacts on health and the environment. However, bicyclists are vulnerable road users at risk of injuries. In Sweden, the number of bicyclists killed per passenger-kilometre has been reported to be five times higher than passenger car occupants. In 2015 bicyclists represented 45% of all hospital reported injuries. In 1997, the Swedish parliament adopted Vision Zero, a road transport safety strategy with the long-term vision of no fatalities or serious injuries in the road transport system. According to Vision Zero, how loss of health is measured should be grounded in basic human values, where fatalities are unacceptable, but injuries of minor importance could be acceptable. Today in Sweden, permanent medical impairment is used to define a serious injury. However, from a holistic perspective on health, individuals' activities and participation in daily life, beside impairments, need to be considered. The International Classification of Functioning, Disability and Health (ICF) framework from the World Health Organization was adopted in this thesis. The overall aim was to investigate different aspects of negative health impacts from road traffic injuries among bicyclists from a biopsychosocial perspective, and not just a biomedical perspective.

This was investigated by two studies. Study I was based on self-reported data from 959 people injured in bicycle and car crashes and investigated health-related quality of life (HRQoL), based on the EQ-5D questionnaire, 1-3 years after injury. Study II was a population-based register study that investigated sickness absence (SA) following a bicycle injury and included all individuals living in Sweden of working ages 16-64 years, who in 2009 to 2011 had in- or specialized outpatient medical care due to a new injury from a bicycle crash (n=22,045).

According to the ICF-framework, both HRQoL and SA together can incorporate all levels of disability. The results showed that different injuries have different impacts on quality of life, for example injuries to the shoulder and upper arm more often lead to negative health impacts compared to injuries to other parts of the arm. It was also shown that HRQoL most often was affected by problems related to pain/discomfort and anxiety/depression. Further, leg injuries were found to most often be associated with reporting problems in HRQoL. Leg injuries were also found to be associated with SA beyond six months. Among these longer spells of SA, the most common injuries were to the lower leg (21%) followed by shoulder and upper arm (17%) and traumatic brain injuries (15%). Spinal injuries showed the highest risk for SA longer than 90 days, followed by traumatic brain injuries and leg injuries. Further, when the distribution of injuries among bicyclists was illustrated, including permanent medical impairment, HRQoL and SA, it was shown that adding

HRQoL and SA changed the scope of which injuries affect health after a bicycle injury.

The findings suggested that a holistic biopsychosocial perspective on health adds new understanding to the negative health impacts of bicycle injuries. Therefore, other aspects of health could be considered as well, and not just medical impairment, in order to prioritize what injuries need to be prevented. This thesis suggested that a few specific injuries among bicyclists need to be further targeted. Firstly, even though a large share of head injuries are concussive injuries that rarely result in SA, the longest durations of SA are related to severe head injuries. Secondly, leg injuries need to be further addressed. Leg injuries are both relatively common and often affects peoples HRQoL in a long-term perspective and also often result in SA, as well as often lead to long-term SA. Third, injuries to shoulder and upper arm have more severe consequences, in terms of HRQoL and SA, compared to injuries to other parts of the arm. Also, this thesis highlighted the need to address spinal injuries among bicyclists as these injuries, although they are rare, often lead to severe consequences when they occur.

Swedish Summary

Utifrån mål om förbättrad hälsa och hållbarhet vill samhället öka andelen resor med cykel. Samtidigt är cyklister en oskyddad trafikantgrupp, vilket gör att man som cyklist är sårbar i en olycka. Givet en olycka så har cyklister, jämfört med bilåkande, 5 till 10 gånger högre risk att dö, och 20 gånger högre risk att skadas. År 2015 utgjorde cyklister 45% av alla sjukhusrapporterade trafikskador. 1997 antog Sveriges riksdag Nollvisionen, en trafiksäkerhetsstrategi med det långsiktiga målet att ingen ska dö eller skadas allvarligt till följd av trafikolyckor. Givet detta mål behöver samhället, för att kunna styra prevention av skador, kunna mäta förlust av hälsa. Som ett första steg för att mäta hälsoförlust antogs i Sverige permanent medicinsk invaliditet som mått för att definiera vad en allvarlig skada är. Medicinsk invaliditet relaterar till nedsättning av den fysiska eller psykiska kroppsfunktionen och bedöms utan hänsyn till yrke och fritidsintressen. Att fokus ligger på kroppsliga funktioner innebär att ett biomedicinskt perspektiv på hälsa är utgångspunkten. Å andra sidan är hälsa ett mer komplext begrepp, där nedsättning av kroppsliga funktioner bara utgör en del, och för att förstå hälsoförlust från skador kan ett mer holistiskt perspektiv på hälsa användas. Syftet med denna avhandling var att undersöka olika aspekter av hälsoförlust bland personer som skadats i en cykelolycka. Utöver det biomedicinska perspektivet antas ett biopsykosocialt perspektiv på hälsa som finns förankrat i Världshälsoorganisationens ”Klassifikation av funktionstillstånd, funktionshinder och hälsa” (ICF).

Två studier genomfördes. Studie I undersökte hälsorelaterad livskvalité 1–3 år efter trafikskada, baserat på ett frågeformulär (EQ-5D) från 959 personer som skadats i cykel- och bilolyckor. Studie II var en populationsbaserad registerstudie och undersökte sjukskrivning bland personer som skadats i en cykelolycka. Inkluderade var personer i åldrarna 16–64 år som under 2009 till 2011 fått specialiserad öppen eller sluten medicinsk vård i samband med cykelolycka (22, 045 personer).

Ramverket ICF visade att hälsorelaterad livskvalité och sjukskrivning tillsammans täcker alla nivåer av funktionsnedsättningar. Resultaten visade att olika skador har olika påverkan på individers livskvalité. Till exempel visades att skador på skuldra och överarm oftare ledde till förlust av hälsa jämfört med skador på andra delar av armen. Resultaten visade också att hälsorelaterad livskvalité oftast påverkades av problem relaterade till smärta samt till ångest och depression. Skador på benet var oftast förknippade med problem i hälsorelaterad livskvalité. Benskador var också relaterade till sjukskrivningar längre än sex månader. Bland dessa längre sjukskrivningar var de vanligaste skadorna på underbenet (21%) följt av skador på skuldra och överarm (17%) samt svårare hjärnskador (15%). Skador på ryggraden visade högst risk för sjukskrivningsfall som varade 90 dagar eller längre, följt av svårare hjärnskador och skador på ben. När fördelningen av skador bland cyklister illustrerades med medicinsk invaliditet, hälsorelaterad livskvalité och sjukskrivning, förändrades bilden av vilka skador som påverkar hälsa.

Resultaten visade att ett biopsykosocialt perspektiv på hälsa bidrar till en vidare förståelse av negativa hälsoeffekter från skador bland cyklister. Därför borde andra aspekter av hälsa inkluderas, och inte endast medicinsk invaliditet, när det kommer till beslut om vilka skador som ska prioriteras med riktade skadepreventionsåtgärder. Från ett biopsykosocialt perspektiv på hälsa kan några specifika skador lyftas fram som viktiga att förhindra. Även

om en stor del av huvudskador är hjärnskakningar som mer sällan leder till sjukskrivning så är de svåra hjärnskadorna vanliga sett till längre sjukskrivningsfall. Vidare så är benskador både relativt vanliga samt att de ofta på lång sikt påverkar människors hälsorelaterade livskvalité. Benskador leder också ofta till sjukskrivning, och är vanliga även bland längre fall av sjukskrivning. Skador på axel och övre delen av armen leder oftare till svårare konsekvenser jämfört med skador på andra delar av armen. Vidare lyfter avhandlingen fram att skador på ryggraden, även om ovanliga, i stor utsträckning leder till svåra konsekvenser när de väl sker.

Preface

This thesis project has been conducted as a collaboration between the Department of Food and Nutrition and Sports Science (IKI) at Gothenburg University and the Department of Applied Mechanics at Chalmers University of Technology. The research was funded by the Swedish Transport Administration.

I would like to thank my supervisors, Professor Anders Lie and Beatrix Algurén, for your support and guidance throughout these two years. I am very grateful for your help, and I look forward to continue working with you. Also, I would like to thank Professor Per Lövsund at Chalmers and Professor Claes Annerstedt at IKI for their support in making this collaboration possible, and for letting me be a part of the 'Chalmers family' as well.

I would like to give a special thanks to my friends Johan Strandroth and Simon Sternlund at the Swedish Transport Administration, and to Claes Tingvall who believed in me and made my research possible. Especially Johan, I would not be writing these words had our paths never crossed. I also want to thank my fellow colleagues at Karolinska Institutet and Folksam for their collaboration, and my fellow PhD students at IKI. I am also grateful to my family and friends for their support, giving me the boost I need to keep on going. Finally, and very close to my heart, Matteo, you and your support mean the world to me.

Content

List of papers

This thesis is based on the following original papers, which will be referred to in the text by their Roman numerals:

I Ohlin M, Berg HY, Lie A, Algurén B. (2017). Long-term problems influencing health-related quality of life after road traffic injury – Differences between bicyclists and car occupants. *Journal of Transport & Health*, 4:180-190. doi:10.1016/j.jth.2016.08.007

II Ohlin M, Kjeldgård L, Elrud R, Friberg E, Stigson H, Alexanderson K. Duration of sickness absence following a bicycle crash, by injury type and injured body region; a population-based study. Manuscript submitted for publication.

Abbreviations

AIS	Abbreviated Injury Scale
EQ-5D	EuroQol five dimensions' questionnaire, standardised instrument for use as a measure of health status
HRQoL	Health Related Quality of Life
ICD-10	International Classification of Diseases and Related Health Problems, Tenth Revision.
ICF	International Classification of Functioning, Disability and Health
MAIS	Maximum Abbreviated Injury Scale
PMI	Permanent Medical Impairment
RPMI	Risk of Permanent Medical Impairment
SA	Sickness Absence
STRADA	Swedish Traffic Accident Data Acquisition System
WHO	World Health Organization

Background

Introduction

In Sweden, the level of physical activity among the population has decreased over the last century, and today only a small percentage of the population acquires minimum levels of physical activity (Schantz, 2015). Worldwide, physical inactivity is recognized as a major public health problem while the positive effects of physical activity on health are well-known (Ainsworth & Macera, 2012). According to a British report by Cavill and Buckland (2012), increased physical activity delivers the greatest health-benefits for those who are physically inactive or sedentary. They found that within this group, a 32% reduction in the risk of premature death could occur if they become moderately active (0.5-1 hour of physical activity per day).

Bicycling has been widely recognized as an important contributor to help increase the level of physical activity (Oja et al., 1998; Sahlqvist et al., 2013) and hence reduce the risk of several diseases related to physical inactivity (Lindström, 2008; Oja et al., 2011) and all-cause mortality (Matthews et al., 2007; Kelly et al., 2014). A Danish study found that among 28 000 people living in Copenhagen, all-cause mortality was 28% lower amongst those who regularly bicycled to work compared to those who commuted by car (Andersen et al., 2000). In the report "Cycling, Health and Safety" the International Transport Forum at the OECD (2013) states that "*…cycling, as a form of moderate exercise, can greatly reduce clinical health risks linked to cardiovascular disease, obesity, Type-2 diabetes, certain forms of cancer, osteoporosis and depression.*". Stigell and Schantz (2015) showed that active commuting behaviors (walking and bicycling to work) overall meet the requirements of daily physical activity levels, but that seasonal effects impacted the level of physical activity among bicyclists, who acquired recommended levels of physical activity only during spring to mid fall.

Several studies have highlighted the positive impacts of increased bicycling regarding both health and environment (Hartog et al., 2011; Rojas-Rueda et al., 2013, Holm et al., 2012; Oja et al., 2011). Summarizing the literature for air pollution, traffic accidents and physical activity, Hartog et al. (2011) found that health benefits associated with bicycling, from a mortality perspective, were larger than the risks of a population shifting their mode of transport from car to bicycle. Other health impact assessment studies for cycling found similar results (Rojas-Rueda et al., 2013; Holm et al., 2012). However, bicyclists now account for a higher proportion of hospital reported crashes and injuries than any other road user category in Sweden (Swedish Transport Administration, 2015), and health impact assessment studies mainly include police reported injuries which do not adequately describe the total number of bicycle injuries (Tingvall et al., 2013; Veisten et al., 2007; Juhra et al., 2012).

There is incontrovertible evidence that regular physical activity contributes to the primary and secondary prevention of several chronic diseases and is associated with a reduced risk of pre-mature death (Warburton et al., 2006). Active transportation, including bicycling, has become a key focus in promotion of physical activity (Bull et al., 2010; Chapman et al., 2014). Today, different stakeholders in society are recognizing increased bicycling as an important contribution to improve health among the population, and as a way to make cities more sustainable by reducing emissions from motorized traffic and as a more energy efficient mode of transport. To promote increased bicycling, aspects of safety becomes relevant to investigate as safety is one important determinant for people choosing to bicycle (Wahlgren & Schantz, 2012; Winters et al., 2013). Safety is related both to the perceived safety, but also to actual (un)safety in regards to crashes and injuries. Therefore, different stakeholders in society are interested in knowledge about how bicycling can become safer, as a way to promote health. Further, by minimizing the negative health impacts from bicycling, the benefits would be even greater. This thesis is written within the subject of sport science, a discipline that studies how sport and physical activity promotes health from a biopsychosocial perspective, and will explore the negative health impacts from bicycling in terms of injuries. The biopsychosocial perspective on health and physical activity is not only important in relation to health-promotion. It is also an important perspective when it comes to understand the impact on health from injuries.

Traffic injuries in a larger context

Traffic injuries are a global safety issue. The World Health Organization (WHO) estimates that 1.2 million people are killed and 50 million are injured annually in road crashes around the world, and millions more suffer injuries with long-term consequences (WHO, 2015). Traffic injuries are the leading cause of death in the age group 15 to 29 years, and are also associated with major costs to society, accounting for 3% of the global Gross Domestic Product (GDP). Current trends also suggest that road traffic injuries will become the seventh leading cause of death by 2030, if proper countermeasures are not implemented (WHO, 2015).

While 90% of road traffic fatalities occur in low-and middle-income countries, these countries only account for 54% of all registered vehicles, meaning that they have a disproportionate number of fatalities in relation to their level of motorization (WHO, 2015). Half of the road traffic deaths worldwide involve vulnerable road users: pedestrians (22%), bicyclists (4%) and Powered Two Wheelers (PTWs) (23%) (WHO, 2015). In the European Union (EU), bicyclists represent 8.1 % of road traffic fatalities, with more than 2100 people killed in bicycle crashes in 2014 (ERSO, 2016).

Sweden, as well as many other countries in Western Europe, has a history of declining numbers of road fatalities since the 1970s (International Traffic Safety Data and Analysis Group [IRTAD], 2012). In Sweden, the number of fatalities per 100 000 inhabitants has declined from 8.7 to 2.7 between 1991 and 2015 (European Commission, 2016), which is among the lowest fatality rates in the world.

However, bicyclists and other vulnerable road users have a higher risk of being injured or fatally injured in a crash compared to car occupants. In Sweden, the number of bicyclists killed per passenger-kilometre has been reported to be five times higher than for passenger car occupants, although motorcyclist have an even higher risk (25-30 times higher compared to car occupants) (Björketun & Nilson, 2006). In a recent study, it was found that the risk of fatal injury was 10 times higher, and the risk of (hospital reported) non-fatal injury was 20 times higher for bicyclists compared to car occupants (Nilsson et al., 2017). In recent years, the number of injured bicyclists has increased, as the number of injured car occupants has decreased (Figure 1), and bicyclists now account for a higher proportion of hospital reported crashes and injuries than any other road user category in Sweden. In 2015, bicyclists represented 45% of all hospital reported injuries but only accounted for around 6% of all road fatalities in Sweden (Swedish Transport Administration, 2015).

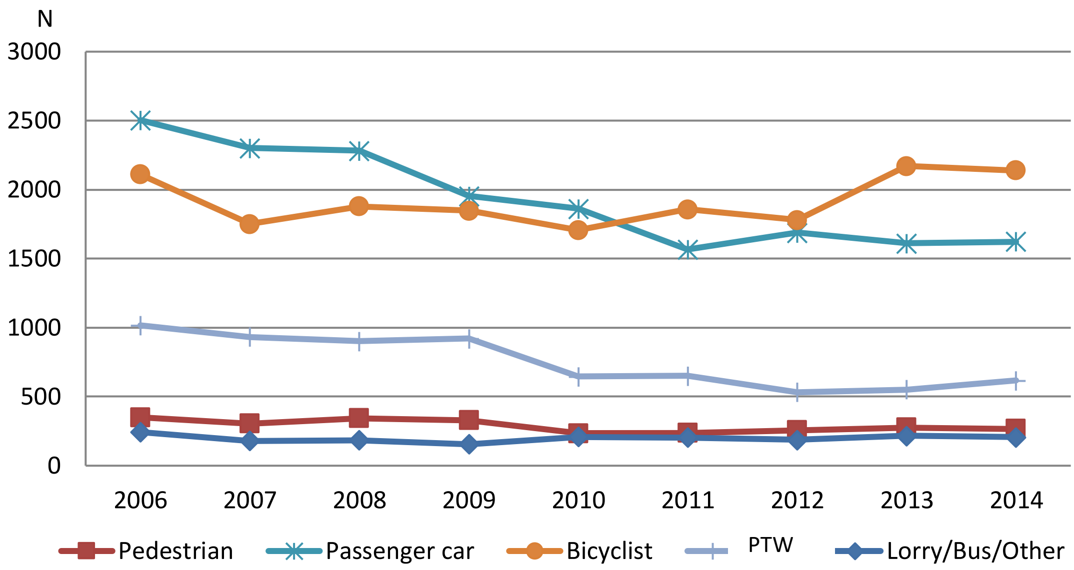

Figure 1. Number of serious injuries in Sweden 2006-2014, displayed by transport mode. Source: STRADA

Traditionally, protection for bicyclists has been addressed by speed management of motor-vehicles, separation of motor vehicles and vulnerable road users, and usage of bicycle helmets.

The correlation between impact speed and fatality risk among pedestrians hit by cars was estimated by Rosén and Sander (2009), who found that the fatality risk at 50 km/h was more than twice as high as the risk at 40 km/h, and more than five times higher than the risk at 30 km/h. In Sweden, lowering of speed limits is most often combined with other traffic-calming countermeasures, such as smaller roundabouts and speed bumps (Swedish Association of Local Authorities and Regions & Swedish Transport Administration, 2013). Separating vulnerable road users from motorized traffic is also a way to make the road environment safer (Pucher at al., 2010). The use of separate bicycling lanes in Sweden is estimated to reduce injuries by 20-30% (Swedish Association of Local Authorities and Regions & Swedish Transport Administration, 2013). Previous studies have shown that crashes involving a motor-vehicle more often result in severe injuries compared to other types of crashes, e.g. non-collision crashes (Cripton et al., 2015). Furthermore, crashes involving motor-vehicles has been reported to account for 64-92% of fatal bicyclist crashes (Bil et al., 2016; Gaudet et al., 2015; Nicaj et al., 2009) Speed management to protect bicyclists only addresses a small share of bicycle crashes, as only 13% of all bicycle crashes involve a motor vehicle, while 77% are single bicycle crashes (Rizzi et al., 2013).

The use of bicycle helmet has been promoted and regulated in some countries. Helmet use in Sweden is estimated to be 37% but with great variations between different regions. In 2005, helmet use amongst children <15 years was legislated and helmet use amongst this group is now around 65% (Swedish Transport Administration, 2015). Wearing a helmet is an effective way to prevent head injuries (Amoros et al., 2012; Attewell et al; 2001). In a recent systematic review including 40 studies, the effectiveness of bicycle helmets was reported to show significant reductions of all head injuries and severe head injuries by 51% and 69%, respectively. Also, facial injuries were found to be reduced by 33% (Olivier & Creighton, 2016). However, other research has shown that, depending on the injury outcome, head and face injuries account for a relatively small proportion of all bicycle trauma, although head injuries account for a large proportion of more severe injuries (Rizzi et al., 2013). An overview of bicyclist injuries is presented in a later section.

Vision Zero

In 1997, Sweden adopted Vision Zero, a road transport safety strategy with the long-term vision of no fatal or serious injuries in the road transport system (Swedish Government, 1997a, 1997b; Swedish Parliament, 1997). Vision Zero takes a holistic approach to road safety, which is based on the idea to design the road transport system around the failing human, and that it is not acceptable that the need for mobility and transportation is associated with a risk of fatality or serious injuries. To design the system around the failing human also means to design a system that, based on the human tolerance for biomechanical forces, does not exceed this tolerance. Vision Zero emphasizes shared responsibility, but that ultimately, the designers of the system are responsible for the level of safety within the transport system (Johansson, 2009).

According to Vision Zero, no one should die or suffer injuries that lead to non-acceptable loss of health in the road transport system (Tingvall, 1997). Elaborating on how loss of health could be defined, Tingvall (1997) states that, "*The first step in the zero vision is therefore to define and quantify a non-acceptable loss of health. It may, for example, be defined and quantified as a degree of medical disability in time after the injury was sustained. A reasonable starting point could be that an injury which has healed after, for example, three weeks, may be defined as an acceptable loss of health - but not death or long- term invalidity.*"

However, when talking about health loss, and further how loss of health or disability can be measured, there is a need to discuss concepts of health and disability.

The concepts of health and disability

There are many different perspectives on the concept of health, e.g. health as an absence of disease, health as a resource, health as a behaviour (lifestyle), health as social relationships, as energy and vitality, as harmony, functioning, or as well-being (Blaxtor, 2001; Hughner & Kleine, 2004; Fagerlind et al., 2010; Seedhouse, 2001). In the western world, the concept of health is mainly illustrated from two perspectives; biomedical or humanistic (Medin and Alexanderson, 2000). From a biomedical perspective, health is the opposite of disease while the humanistic approach views health as a continuum between health and illness or health and illness as different dimensions. Comparing the two approaches, a difference would be that from a biomedical view, a person is either healthy or ill, while in the humanistic approach, a person can be both. The present thesis adopts the humanistic approach. As an example of a biomedical approach to health, Boorse (1977) presented a biostatistical theory on health, where health was defined as "…*normal functioning, where the normality is statistical and the functions biological*".

Yet, even in the 1940´s, it was questioned whether health could simply be defined as the absence of disease (Fraser, 1946). Brüssow (2013) point out the difference between the classical medical definition of health and how the meaning changes if associating it with language, where the focus of health is related to wholeness. Nordenfelt (1995) and his view on health also represents a more holistic and humanistic approach to health. His theory suggests that "*a person´s health is characterized as his ability to achieve his vital goals*". Also, the WHO definition of health focuses on a more holistic approach in that health is defined as "…*a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity*" (WHO, 1948). Today, the concept of health could be said to be moving towards the holistic approach, indicating that health is more than the absence of diseases and not strictly seen as normal functioning (Medin & Alexanderson, 2000).

Alike the different concepts and definitions of health, there are also different approaches as to how disability is conceptualized. There are two main approaches related to understanding disability, and they can be divided into either *biomedical* or *socio-political.*

In the *biomedical* approach, the disability is considered to be caused by pathology, injury or disease, or other deviations from normal functioning (Boorse, 1977). From this perspective, reduced bodily functions is equal to disability, and the disability is seen as a problem related to the individual's impairment. By using this approach, the level of disability can be quantified by comparing it to a normal level of functioning, which does not take into account any social aspects of disability (Smart, 2009; Whalley, 2006). Impairment is within this thesis defined as described in Table 1 as problems in bodily functions and structures such as significant deviation or loss (WHO, 2002).

The *socio-political* approach to assessing disability differs from the aforementioned approach. The former approach considers disability as something related to the individual. In the socio-political approach, disability occurs in the interaction between the individual and the social and physical environment (Hahn, 1985). This means that for an individual with an impairment, disability is a result of restrictions in the physical and/or social environment, e.g. a person who requires a wheel-chair might not have access to certain physical environments because of a lack of sufficient aids (for example an elevator). Hence, the individual is disabled as a function of the environment.

These approaches can also be referred to as two different models, where the biomedical approach refer to disability as something related to the person. This is described by WHO (2002) as the medical model of disability, whereas a socio-political approach is in line with the social model of disability.

Conceptual framework

The International Classification of Functioning, Disability and Health (ICF) conceptual framework is adopted in the present thesis to understand how the aforementioned concepts of health and approaches to study disability relate to each other. The ICF is a systematic framework to describe the full range of human functioning that may be affected by a health condition (WHO, 2001). Within this framework, the term disability is used as an umbrella term that covers impairments, activity limitations and participation restrictions as a result of disturbances in human functioning (WHO, 2002). ICF is an internationally recognized model for health and functioning, and has its foundation in the United Nations (UN) human rights. The ICF is based on a biopsychosocial approach, which incorporates both biological, individual, and social perspectives on health and disability. The ICF enables a holistic view on health, and structures the many factors affecting health in different components, where functioning is the interaction between a health condition, body functions and structures, individuals' activities and participation in their unique life situations and environment (WHO, 2001).

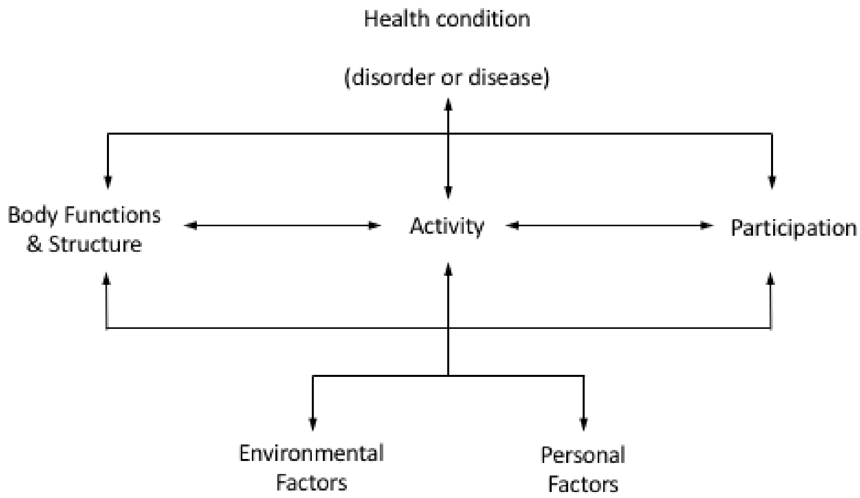

Figure 2. The ICF and the interactions of its components, adapted from WHO (2001).

The model (Figure 2) identifies three levels of human functioning that relate to:

- Body or body part
- The whole person
- The whole person in a social context

Disability is defined by dysfunction in one or more of these levels and are referred to as impairments, activity limitations and participation restrictions (WHO, 2002). This means that both impairments as well as functional and social limitations are seen as different aspects of disability (WHO, 2001). In Table 1, all components included in the framework are specified.

Table 1. Definitions of the ICF components, derived from WHO (2002).

Component	Description
Body Functions	Physiological functions of body systems (including psychological functions)
Body Structures	Anatomical parts of the body such as organs, limbs and their components
Impairments	Problems in body function or structure such as a significant deviation or loss
Activity	Execution of a task or action by an individual
Activity Limitations	Difficulties an individual may have in executing activities
Participation	Involvement in a life situation
Participation Restrictions	Problems an individual may experience in involvement in life situations
Environmental Factors	The physical, social and attitudinal environment in which people live and conduct their lives

Current approaches to assessing road traffic injuries

In Sweden, the terms *severe* injury and *serious* injury are used. A *severe* injury is estimated and reported by the police who are present at the crash scene. These estimations are the basis for national statistics on traffic injuries. The term *serious* injury refers to injuries with risk of long-term medical impairment (Transport Analysis, 2015). In the present thesis, severe injury will be used in relation to police reported injuries as well as to injuries classified by the injury severity assigned by the Abbreviated Injury Scale (AIS) (AAAM, 2005), and serious injury will be used in relation to risk of permanent medical impairment (RPMI) (Malm et al., 2008). In the following sections, these will be further elaborated.

As mainly fatalities and severe injuries are reported by the police, bicyclist injuries are highly underreported in many countries (Rizzi et al., 2013; Tingvall et al., 2013; Veisten et al., 2007; Juhra et al., 2012). For example, Rizzi et al. (2013) found that in Sweden, only 7% of bicycle crashes in hospital records were known by the police. A German study found that 68% of hospital casualties from bicycle crashes lacked a police record (Juhra et al., 2012).

Therefore, in crashes involving vulnerable road users, hospital data are more suitable for describing and analysing injuries among bicyclists (Amoros et al., 2006; Tingvall et al., 2013).

In hospital data, the international classification of diseases and health problems (ICD) is most commonly used to describe injury (and other) diagnoses (WHO, 1993). In road crash-related hospital data injuries are sometimes classified according to the AIS. AIS is a globally used severity scoring system that classifies injuries by body region according to its relative importance on a 1-6 point ordinal scale, where 1=minimum and 6=maximum. This classification system mainly captures the injury severity in terms of risk of fatality. Similar to the ICD, the AIS has a description of each injury, together with the severity score. In order to get an overall injury severity, related to the individual and not each injury, the Maximum Abbreviated Injury Scale (MAIS) is used. The MAIS represents the highest injury severity classification (1-6) given to the individual and hence shows an overall injury severity classification (AAAM, 2005). Both AIS and ICD are mainly intended to describe the nature of injuries, and also (in the case of AIS) grade the severity of the injury based on a threat-to-life approach. But in addition to the description of injuries it is also necessary to describe the (long-term) consequences of injuries.

One way to describe the consequences of injuries is to take into account long-term impairment. The Risk of Permanent Medical Impairment (RPMI) estimates the risk of long-term impairment based on loss of physical and/or mental function. RPMI was developed to estimate the risk for a patient to suffer from a certain level of Permanent Medical Impairment (PMI) based on the diagnosed injury location and the criteria of the Swedish Insurance Companies (Malm et al., 2008; Insurance Sweden, 2004). RPMI is based on approximately 35,000 diagnoses from 20,000 injured car occupants who reported an injury to an insurance company. The injured car occupants were followed for at least 5 years to assess the risk of permanent medical impairment for different body regions and AIS severity levels. The risk is derived from risk matrices based on the location and severity of the injury for 1%+, 5%+ and 10%+ medical impairment. The risk matrices for 1% and 10% level of impairment are shown in Table 2.

Table 2. Risk of Permanent Medical Impairment of at least 1% impairment (left side) and at least 10% impairment (right side). Source: Malm et al. (2008).

RPMI 1+						RPMI 10+					
Body region	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Body region	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Head	8.0%	15%	50%	80%	100%	Head	2,5%	8%	35%	75%	100%
Cervical spine	16.7%	61%	80%	100%	100%	Cervical spine	2,5%	10%	30%	100%	100%
Face	5.8%	28%	80%	80%	n.a.	Face	0,4%	6%	60%	60%	n.a.
Upper extremity	17.4%	35%	85%	100%	n.a.	Upper extremity	0,3%	3%	15%	100%	n.a.
Lower extremity	17.6%	50%	60%	60%	100%	Lower extremity	0,0%	3%	10%	40%	100%
Thorax	2.6%	4.0%	4%	30%	20%	Thorax	0,0%	0%	0%	15%	15%
Thoracic spine	4.9%	45%	90%	100%	100%	Thoracic spine	0,0%	7%	20%	100%	100%
Abdomen	0%	2.4%	10%	20%	20%	Abdomen	0,0%	0%	5%	5%	5%
Lumbar spine	5.7%	55%	70%	100%	100%	Lumbar spine	0,1%	6%	6%	100%	100%
External (skin)	1.7%	20%	50%	50%	100%	External (skin)	0%	0%	50%	50%	100%

For reference, an AIS 2 injury to the lower extremities gives a 50% risk of a 1% or more medical impairment (RPMI 1+) but only a 3% risk of a 10% or more medical impairment (RPMI 10+). Risk of Permanent Medical Impairment of at least 1% (RPMI 1+) is used in Sweden currently as the definition of a serious injury.

RPMI can refer to specific injuries (body regions) but can also be calculated for one individual with several injuries (overall RPMI) according to Equation 1 where *n* is the number of injured body regions and *risk* is the risk for each body region according to the risk matrices in Table 2.

$$RPMI = 1 - (1 - risk_1)\times(1 - risk_2)\times \ldots\times(1 - risk_n) \qquad \text{(Eq. 1)}$$

The predicted number of impaired individuals or impairing injuries is the accumulated risk for all persons or each body region, respectively. Accumulating the risk for each body region makes it possible to analyse the distribution of impairing injuries, as seen in Figure 3 on page 18. This means that such distributions are not based on individuals who are predicted to sustain a certain level of impairment. It is rather the distribution of all impairing injuries, calculated with the accumulated RPMI of all injuries, as described above. When accumulating the risk, the impaired individuals or impairing injuries are referred to as PMI individuals or PMI injuries.

Apart from the description of injuries (ICD, AIS) the link to and the description of the consequences of injuries need to be made in order to understand the impact from injuries. In other words, it is necessary to also describe the functioning and disability related to injuries, which the ICF provides a framework for (WHO, 2001). Medical impairment is one way to describe the consequences of injuries. It is also the current definition of serious injury in Sweden. PMI relates only to the body functions and structures part of the ICF. In addition to this, the present thesis will incorporate two other ways to understand health impacts from road traffic injuries on Health-related quality of life (HRQoL) and Sickness Absence (SA) (these concepts are introduced in detail in later sections). This means that the present thesis will incorporate all levels of disability according to the ICF framework; impairment, activity limitations and participation restrictions.

Health-Related Quality of Life and Sickness Absence

To develop the understanding of consequences of bicycle injuries and go beyond a biomedical perspective toward a biopsychosocial view on health, two other areas are further investigated; HRQoL and SA.

HRQoL

The concept of Quality of Life has been defined by the WHO as "individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the person's physical health, psychological state, level of independence, social relationships and their relationship to salient features of their environment" (The WHOQOL Group, 1995). HRQoL is a subset of QoL that includes health and health-related domains that affects an individual's quality of life. The narrowing of the quality of life concept to HRQoL, including health-related domains, is of interest for those who want to assess the impact from diseases, injuries, and treatments. Even though there is no single agreed upon definition of HRQoL, in general when operationalized it takes into account levels of physical, mental, social, and role functioning (Wood-Dauphinee, 1999). These levels are all associated with the ICF-framework that was previously presented. As implied by the WHO definition of QoL, the individual´s perception is the main focus, which is in line with the shift in health-care from a biomedical to a biopsychosocial view of health, where the patient's view is incorporated (Wood-Dauphinee, 1999). The focus on individual perception emphasizes individual experiences, which makes the concept subjective as this perception will vary from person to person. The assessment of QoL and HRQoL is therefore centred on self-report, where the respondent reports on their experience in relation to specific domains of health (Cieza et al., 2005). There exist a wide variety of scales and instruments to assess HRQoL, both disease specific and generic (general) instruments. To a large extent, generic instruments have been used in studies assessing HRQoL after road traffic injuries (Polinder et al., 2010).

Previous research on HRQoL after road traffic injury

In a study from the United States (US), Alghnam et al. (2014) carried out a longitudinal follow-up study among adult participants (≥18 years, n=62,298) in the Medical Expenditure Panel Survey. The study examined the relationship between traffic-related injuries and HRQoL using the generic health status measure Short Form 12 (SF-12), and found that people who suffered non-fatal motor vehicle injuries (n=993) reported impacts on physical health up to 9 months after injury. Jagnoor et al. (2015) studied HRQoL outcomes among patients with mild to moderate injuries after a motor vehicle crash in Australia (n=364). HRQoL was measured with SF-12 and the EuroQol five dimensions' questionnaire (EQ-5D) (The EuroQol Group, 1990). Results showed that a large proportion of the patients experienced HRQoL problems, although the follow-up was limited to only two months. A Swedish study investigated HRQoL after traffic injury among hospitalized patients and found that among 200 non-fatally injured adults and 30 children, 38% of adults and 13% of children experienced problems in HRQoL one year after injury, and an additional 23% of adults and 10% of children still had problems at 3.7 years after the injury (Maraste et al., 2003).

In a study from the United Kingdom (UK), Mayou and Bryant (2003) investigated the consequences of traffic crashes for different road users (vehicle occupants, motorcyclists, cyclists, and pedestrians) among adults (n=1441) attending an emergency hospital. Outcome measures were all self-reported, including physical health, general health status, post-traumatic stress disorder, mood, and travel anxiety. They found that despite differences between the road user groups in terms of injuries, immediate reactions and treatment, there were few longer-term differences. Compared to other road user groups, bicyclists suffered less severe injuries and their injuries were likely to be head, face, arm and leg injuries. Vehicle occupants reported problems related to pain more frequently than the other groups. In a French study, Nhac-Vu et al. (2014) used a self-report questionnaire on health, social, emotional, and financial status to investigate consequences one year after a road traffic crash. The sample was adults ≥18 years, and 616 out of 886 respondents completed the questionnaire. Results showed that injury type was related to consequences in quality of life at one year after road traffic crash: among groups with poor outcome at one year, more than two thirds had lower limb injuries associated with restricted leisure activity.

No previous studies were found that investigated HRQoL after traffic injury with regards to self-reported problems in HRQoL, taking into account injury severity and injured body region. This is important when considering injury preventive strategies.

Sickness Absence

In Sweden, sickness absence (SA) is common in case of illness or injury (Alexanderson et al., 2004). The purpose of the sickness insurance system is to provide financial security if a person has reduced work capacity caused by disease or injury. Sickness benefit compensates up to 80% of lost income. From a national-economic perspective, sickness absence involves considerable costs for society. In 2014, sickness benefits paid by the Swedish Social Insurance Agency (SIA) summed up to 27.7 billion SEK (Swedish Social Insurance Agency, 2015). The Swedish sickness insurance system covers all people above the age of 16 years, who are living in Sweden and have a minimum annual income from work, those on unemployment benefit, or those on parental leave. The first 2-14 days of sickness absence is compensated by the employer (Swedish Social Insurance Agency, 2015), and from day 15 employees can claim compensated sickness benefits from SIA. Unemployed individuals and individuals on parental leave can be granted sickness benefit from SIA from the second day, and individuals who are self-employed can be granted sickness benefits from SIA depending on their insurance coverage. In all cases of sickness absence, a certificate from a physician is required from day eight. In international research, the terms 'work disability', 'compensated time off work', or 'sick-leave', are all used to describe the same concept, namely being unable to work due to an injury and therefore being eligible for monetary compensation, mainly from social insurance. Therefore, in the following section, all terms related to this same concept will be referred to as SA, even though the social insurance schemes will differ in the way they are designed, for example regarding the amount of payments.

SA is always considered in relation to the individuals work capacity, and it is the functional and activity limitations as a result of the injury or illness, and not the injury or illness itself, that can motivate SA. This means that physicians assessing an individual's work capacity need to be aware of what demands, e.g. physical or cognitive, that the individual's work involve. SA can be granted for part-time or full-time, but the work capacity has to be reduced by at least 25%. For the purpose of assessing work capacity, the ICF-framework can be used. This means that it is not the bodily functions and structures that are assessed, but instead how the individual functions in relation to his or her work activities (i. e activity limitations and participation restrictions according to the ICF-framework). However, it is SIA that decides if an individual can be granted SA, and the physicians provide the basis for the decision (The National Board of Health and Welfare, 2012). SA is considered an active measure, where the individual's capacity is considered, despite limitations. The starting point is always that the individual is actively involved in the rehabilitation process, in order to facilitate a return to work (The National Board of Health and Welfare, 2012).

Apart from high costs for employers, insurers and society, there are studies regarding possible negative consequences for individuals being sickness absent, e.g. regarding physical, mental, and social circumstances (Vingard et al., 2004). Long periods of SA are associated with negative outcomes on one's quality of life, with impacts on leisure activities, sleep, and psychological well-being (Floderus et al., 2005), economic and social conditions (Bryngelson, 2009), as well as both morbidity and mortality (Olsson et al., 2015; Karlsson et al., 2008; Björkenstam et al., 2014).

Previous research on SA related to road traffic crashes

In a previous study among people having a musculoskeletal or orthopedic injury from a road traffic crash, 32% of those injured had a subsequent SA ≥6 months. The study was carried out in Australia among 5970 adults ≥18 years who had compensated time off work as a result of the crash (Berecki-Gisolf et al., 2013). Another study from Sweden investigated SA and disability pension among a smaller sample (n=255) of injured car occupants who visited a hospital after a crash. Results showed that 40% had subsequent SA following the crash, which was mostly related to cervical spine injuries (Bylund & Björnstig, 1998). Based on Swedish hospital admissions in 1970, it was reported that bicyclists, compared to other road users, had the shortest period of SA after a crash, with an average of 29 days (Hansson, 1976). SA as a consequence of non-fatal bicycle crashes among 264 adults in Finland has been studied (Olkkonen et al., 1993). It was found that the mean duration of SA was 82 days among hospitalized patients at two emergency care hospitals. For outpatients, the mean duration of SA was 11 days. They also found that injuries in the upper extremities were most common (33%) and that over half the cases with SA longer than 30 days were due to upper extremity injuries.

No previous nation-wide studies on SA following a bicycle crash in Sweden could be found. Knowledge about injuries, especially about the ones leading to SA of longer durations, is important when considering how to target injury prevention.

Overview of bicyclists' injuries

In a study investigating bicyclist injuries leading to permanent medical impairment in Sweden, it was found that 77% of all bicycle crashes were single bicycle crashes, and that 70% of the injuries leading to medical impairment (PMI 1+) were to the upper (mostly shoulder and wrist) and lower (mostly ankle and knee) extremities. Looking at the more severe level of impairment (PMI 10+), head injuries were most common, accounting for 42% of severe impairing injuries (Rizzi et al., 2013).

In a study from Germany, Juhra et al. (2012) conducted a prospective study on bicycle crashes leading to injuries (of any severity). The study included 1767 people who were treated at a hospital and an additional 484 people who were injured but did not go to a hospital. They found that the injury distribution was 37% upper extremities, 30% lower extremities, 26% head injuries, 7% thorax and abdomen, 5% pelvic, and 5% spinal injuries.

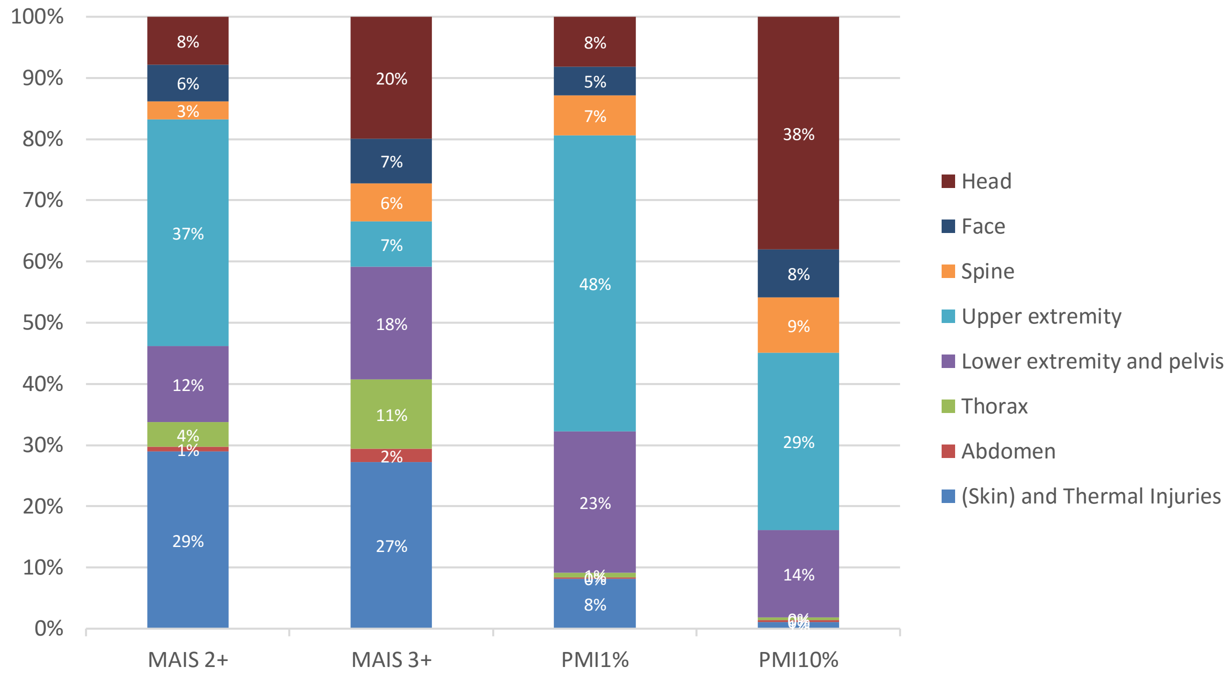

Figure 3. The distribution of bicyclists' hospital reported Maximum Abbreviated Injury Scale (MAIS) 2+ and 3+ and Permanent medical impairment (PMI) 1+ and 10+ injuries between 2007-2014. Source: STRADA.

Figure 3 shows the injury distribution of bicyclists' hospital reported injuries between 2007 and 2014 in Sweden. As it illustrates, the distribution of injuries differs when comparing MAIS (overall injury severity classification, threat to life) and long-term (PMI) consequences, see also previous description on pages 10-12. Depending on what measure is chosen for target measure, this will have implications for what injuries stakeholders in society will prioritize to be prevented. For example, thorax injuries, that account for 11% of all MAIS 3+ injuries (high injury severity), are almost non-existent when considering long-term consequences. Basically, this is a life-threatening injury, but if a patient survives, they are not likely to suffer long-term consequences. In other words, if MAIS 3+ would be considered as target measure thoracic injuries could be targeted for injury prevention, whereas they would not if PMI was considered as target measure. If medical impairment is considered (PMI 1+ and PMI 10+), injuries to the head and upper extremities are most common.

Upper extremity injuries would, on the other hand, not be considered to the same extent with regards to MAIS 3+.

The injury distribution is also affected by crash type, as shown in Table 3. For example, PMI injuries to the head and cervical spine are more common in bicycle crashes involving motor vehicles compared to single bicycle crashes.

Table 3. Distribution of PMI 1+ and PMI 10+ injuries in single bicycle crashes and in bicycle-motor vehicle crashes. Source: STRADA, 2007-2014.

Body region	Single-bicycle crashes		Bicycle-motor vehicle crashes	
	PMI 1+	PMI 10+	PMI 1+	PMI 10+
Head	8%	34%	13%	48%
Cervical Spine	3%	5%	11%	12%
Face	5%	9%	4%	5%
Upper extremity	57%	34%	29%	12%
Lower extremity and pelvis	25%	15%	31%	14%
Thorax	1%	0%	2%	1%
Thoracic Spine	1%	1%	4%	4%
Abdomen	0%	0%	0%	0%
Lumbar Spine	1%	1%	5%	3%
n PMI injuries	12,795	1591	2185	381

Exemplifying the terminology

Due to the many different terms used throughout this thesis, an explanatory text is provided to explain how the terms relate to each-other, and where in time they occur.

A person is injured in a bicycle crash that involves a car. The person is taken to hospital by ambulance. As a car was involved, the police are called, who reports the person as severely injured. At the hospital, the injuries are assigned diagnoses, ICD-10 and AIS. With the AIS, a severity classification of the injuries is also assigned, based on how life-threatening they are. The person has sustained a head injury which is diagnosed as a mild concussion (ICD-10 code S06.0), without loss of consciousness, and is assigned an AIS severity level of 1. Further, a femoral neck fracture (ICD-10 code S72.0) was assigned an AIS severity level of 3. Based on the location and AIS-level of the injuries, the risk of permanent medical impairment of at least 1% will be 63%, and 12% risk of permanent medical impairment of at least 10%. As a consequence of the injury, after the crash the person´s work capacity is reduced, and s/he becomes sickness absent for five months. In terms of disability, the person is limited both in activities and restricted from participating in work or other daily activities. After the initial SA, the person has had to change assignments which means that the work capacity is no longer reduced in relation to the new tasks. Besides work capacity, the person continues to have problems related to the leg injury, affecting mobility, pain sensations and quality of life. After four years, medical impairment is assigned to x% permanent medical impairment due to physical limitations.

Figure 4 illustrates all concepts related to injury outcome included in the thesis in relation to the ICF framework for disability, and also where in time they are evaluated. The mapping of the EQ-5D instrument into ICF categories was derived from Cieza and Stucki (2005).

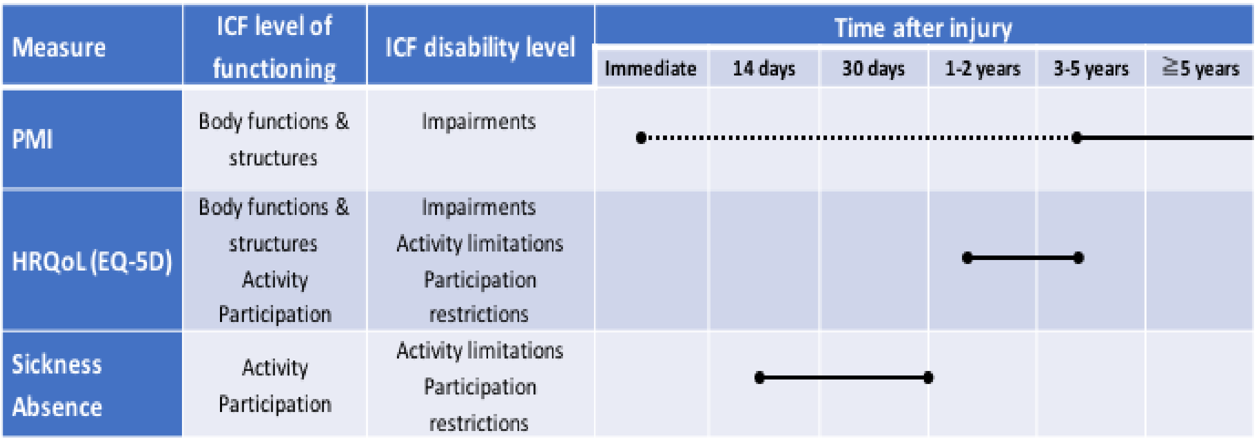

Figure 4. Concepts related to injury outcome and their relation to the ICF level of functioning and disability level, and where in time they are referred to in the thesis.

Summary of introduction

Today, different stakeholders in society are recognizing increased bicycling as an important contribution to improve health among the population, and as a way to make cities more sustainable by reducing emissions from motorized traffic. However, as bicyclists are vulnerable road users, they are at risk of being injured. The societal trends of moving towards more sustainable transportation need to be supported by creating safety for bicyclists in order to minimize the potential negative impacts in terms of severe injuries and fatalities, in line with Vision Zero. In Sweden, the consequences of road traffic injuries are described in terms of Permanent Medical Impairment (PMI). Medical impairment relates to the functional reduction after injury (i. e only body functions and structures), without regard to cause or the injured person's occupation, hobbies or other circumstances (Malm et al., 2008). Hence, it is the functional impairment and not the disability resulting from the impairment that is evaluated (Berg et al., 2016), which, according to the ICF-model is only one aspect of disability. To understand the real impact of an injury on an individual's life, the individual's own preferences and activities in its social and physical context could be considered. This means that the individual's perception of the injury and its impact on their personal life situation, is another way to understand the magnitude of road traffic harms.

With the different approaches to health and assessing disability, one can argue that the measure used in Sweden today (permanent medical impairment), is based on a biomedical view of health, where the disability is seen strictly in relation to the individual's bodily functions. A person who has suffered medical impairment, or sustained an injury with a risk of medical impairment, will, from a biomedical perspective, be 'ill'. By using medical impairment >1%, a very broad spectrum of injuries is classified as serious injuries, based on risk of loss of function. This result in difficulties when assessing what injuries need to be targeted with preventive measures. However, if injury consequences are evaluated from a broader perspective, one might argue that a person is not 'ill' as per the definition just because he or she has suffered injury. This is expressed also by Nagi´s model (1965), where all functional limitations are caused by impairments, but not all impairment leads to functional limitations, which is the case from a medical point of view. In view of this, and in order to understand what injuries are important to prevent, it is necessary to further investigate the consequences of injuries by also taking into account aspects other than medical impairment.

Aim

The overall aim of this thesis is to, in the light of Vision Zero, investigate different aspects of negative health impacts from road traffic injuries among bicyclists from a biopsychosocial and not just a biomedical perspective.

This was investigated by two studies. Study I investigated HRQoL in injured bicyclists and car occupants, and Study II investigated SA following a bicycle injury. Specifically, the aims were to:

a) describe and compare road traffic injuries leading to problems in HRQoL, with regards to road user group, injury severity and injured body region (Study I)

b) investigate durations of SA after a bicycle crash in Sweden, in general and by injury type and injured body region (Study II).

Materials and Methods

In Table 4, Study I and Study II are summarized, and in the following sections further described in more detail.

Table 4. Summary of Study I and Study II

	Study I	**Study II**
Aim	Describe and compare road traffic injuries leading to problems in HRQoL, with regards to road user group, injury severity and injured body region	Investigate durations of SA after a bicycle crash in Sweden, in general and by injury type and injured body region
Design	Cross-sectional survey (EQ-5D), stratified sample + register data	Cross-sectional Population based register study
Data sources	Self-reported + STRADA	National patient registry, Cause of death register, LISA[1], MiDAS[2],
Inclusion criteria	• Bicyclists and car occupants injured in a road traffic crash and visited emergency care hospital. • No previous illness affecting daily life	• Individuals having had in- or specialized outpatient medical care due to a non-fatal injury from a bicycle crash • 16-64 years and living in Sweden the 31st December the year before the crash. • Not on SA or full-time disability pension at the time of crash • Injury diagnosis from ICD-10-SE chapters S00-T89 and Z041
Number of cases	959	22,045
Time period	2007-2009	2009-2011 follow-up to 2013
Injury classification	AIS/MAIS	ICD-10-SE
Outcome measure	Reported problems in HRQoL	Net days of SA
ICF disability level	Impairments, Activity limitations, Participation restrictions	Activity limitations, Participation restrictions
Analytical method	Univariate statistics were used to describe the sample characteristics and prevalence of problems in HQRoL distinguished in injured body region, and injury severity. To investigate differences in subgroups (bicyclists versus car occupants) Fisher's exact test was used.	Univariate statistics were used to describe the sample characteristics and prevalence of SA distinguished in injured body region, and injury types. Logistic regression analysis to assess OR for different durations of SA depending on injured body region and type of injury.

[1]LISA: Longitudinal Integration Database for Health Insurance and Labour Market Studies
[2]MiDAS: Micro Data for Analysis of the Social Insurance

Study I

Medical outcome data regarding injuries were obtained from the data acquisition system Swedish Traffic Accident Data Acquisition (STRADA). HRQoL data was obtained by a self-report survey among individuals injured in road traffic crashes between 1st of January 2007 and 31st of December 2009. A stratified sample based on injured part of the body and its corresponding AIS-value was drawn from STRADA, and a random sample of these people were included in the study. The EQ-5D was used to evaluate HRQoL. The EQ-5D is a commonly used instrument for measuring HRQoL in population health surveys. It is a generic measure of health status, that provides a descriptive profile and a single index value (Rabin & de Charro, 2001). The EQ-5D descriptive system can be used to derive a health state index value. In the descriptive part of the EQ-5D, the respondent reports on his/her health within five different dimensions (mobility, self-care, usual activities, pain/discomfort and anxiety/depression) by grading degree of severity (1=no problems, 2=moderate problems or 3=severe problems). In November 2010, a questionnaire along with a cover letter explaining the purpose of the study was sent out. Two reminders were sent, the first after three weeks and one additional reminder after six weeks. For the purpose of this study, only persons with injuries from a car or a bicycle crash were included (n=3109). Respondents were asked to report previous illness or other long-term health problems affecting their daily lives. From the sample (n=3109), persons having reported previous illness affecting their daily lives were excluded (n=219).

Analysis

Persons were divided into two groups depending on whether they had reported problems in any of the five dimensions in the EQ-5D descriptive system. Two tailed Fisher's exact test was used to compare the injury outcome for bicyclists and car occupants depending on injured body region, and injury severity (MAIS and AIS). Injury outcome was described as % problems reported.

Study II

This was a population-based study, including all individuals who in 2009 to 2011 had in- or specialized outpatient medical care due to a non-fatal injury from a bicycle crash when aged 16-64 years and was living in Sweden on the 31st December the year before the crash (n=26,885). The aim was to investigate durations of SA after a bicycle crash in Sweden, in general and by injury type and injured body region. Several national registers were used to obtain information regarding injury diagnoses, sociodemographic variables, and information on SA for all individuals. Those who already were on SA or full-time disability pension at the time of the crash were excluded from the analyses (n=2,592). Also, persons without injury diagnoses from ICD chapters S00-T89 as well as ICD chapter Z041 were excluded (n=635), leaving 22,045 individuals for analyses. An individual could have more than one visit/hospitalization on the same day. Each visit is coded with a main diagnosis and any contributing secondary diagnoses. Among those with more than one visit/hospitalization and main injury diagnoses, the diagnoses from inpatient care was selected over outpatient care, and any injury diagnoses was selected before other types of diagnoses, in order to only include one main injury.

Analysis

Type of injury and injured body region were set in relation to the individual's SA following the bicycle crash, sociodemographic variables and duration of hospital stay. Descriptive statistics were used to outline study-population characteristics and prevalence of SA. Different durations of SA were categorized in four different groups; "<30 days", "30-89 days", "90-179 days", and "≥180 days". Odds ratios (OR) with 95% confidence interval (CI) for various categories of different durations of SA were calculated by logistic regression analyses using SPSS (Version 23). For the regression analysis, three groups of durations of SA was used; "<30 days", "30-89 days", "≥90 days".

Further analysis of results from Study I and II

In order to combine the results from the two studies, and to compare the results to other measures of injuries, additional injury distributions for MAIS 2+ and 3+, as well as PMI 1+ and PMI 10+ for the years 2007 to 2014 was obtained from STRADA. Body regions were grouped to make the measures comparable, and external (skin) injuries were excluded.

Further, the size of the different populations needed to be considered, and also how the size changes depending on what measure is used. For this purpose, the average number of emergency care visits involving Swedish bicyclists from 2013 to 2014 and corresponding number of different injury severity outcomes (MAIS 2+ and 3+, and PMI 1+ and PMI 10+) was used. The number of MAIS 1, 2, and 3+ from Study I were calculated to match the national levels in STRADA. This was done by calculating and applying the proportion of MAIS 1, 2, and 3+ injuries found in STRADA for the years 2007 to 2014.

In addition, the risk of long-term problems in HRQoL and SA ≥90 days, for different body regions (excluding external injuries) was assessed. For this purpose, ICD-10 diagnoses from the STRADA data in Study I were obtained and grouped in the same manner as in Study II. Risk, in terms of percentage of reported problems in HRQoL (HRQoL <1) as well as percentage of SA beyond ≥90 days was calculated for the different body regions. SA beyond 90 days was chosen due to the limited number of cases. The risk of SA was based on cases that resulted in SA, i.e. only individuals who became sickness absent was included.

Ethical considerations

In all research, there is a need to make ethical considerations in order to protect individuals against various forms of harm (Vetenskapsrådet 2011). Further, if the research involves sensitive information regarding individuals (e. g. health-status, ethnicity, income etc.) the research has to be approved by an ethical committee. Both studies included were approved by the Regional Ethical Review Board in Stockholm, Sweden (Protocol Study I: 2009/5:12, Protocols Study II: 2007/762:31; 2009/23:32; 2011/806:32). In Study I, a survey form was used. Included in the form was a cover letter including information about the study, that participation was voluntary, and that the answers would be treated confidentially. For persons under the age of 16, the form was sent to a parent who needed to provide a written consent for the child to participate in the study. For people aged 16-18, the survey form and an information letter was sent. In addition, the information letter was also sent to the parents. In Study II, data was collected from several registers, and no information was collected from individuals. The people in the different registers were linked by Statistics Sweden (SCB), and hence were anonymous in the dataset and subsequent analysis.

Results

Study I

1178 (38%) out of the 3109 people injured in a bicycle or car crash answered the survey. After excluding people with previous problems in HRQoL, the final sample consisted of 959 respondents, of which 402 were injured in a bicycle crash and 557 in a car crash. Females compared to males reported a higher share of problems, 57% and 48%, respectively. The share of problems reported was lowest among persons aged <10 years (21%), and highest among persons aged ≥80 years (67%). For bicyclists, it was most common to report problems after being struck by a motor vehicle (65%). Overall, 59% of car occupants and 44% of bicyclists reported problems. The most frequently reported problems were pain/discomfort followed by anxiety/depression in the EQ-5D dimension for both bicyclists (37%) and car occupants (51%) (Table 5).

Table 5. Overview of bicyclists´ and car occupants´ self-reported problems in HRQoL for the different EQ-5D dimensions.

EQ-5D dimension	Self-reported problems n (%)		
	Bicyclists	Car occupants	Total
Mobility			
"*I have some problems in walking around*" or "*I am confined to bed*"	44 (11%)	62 (11%)	106 (11%)
Self-care			
"*I have some problems washing or dressing myself*" or "*I am unable to wash or dress myself*"	6 (1%)	17 (3%)	23 (2%)
Usual activities			
"*I have some problems with performing my usual activities*" or "*I am unable to perform my usual activities*"	38 (9%)	103 (18%)	141 (15%)
Pain/discomfort			
"*I have moderate pain or discomfort*" or "*I have extreme pain or discomfort*"	147 (37%)	282 (51%)	429 (45%)
Anxiety/depression			
"*I am moderately anxious or depressed*" or "*I am extremely anxious or depressed*"	78 (19%)	171 (31%)	249 (26%)

The proportion of reported problems increased as overall injury severity increased. When comparing proportion of reported problems with regard to injured body region, car occupants reported significantly more problems. The differences were statistically significant for all body regions apart from the spine and lower extremities and pelvis. The injured body region where both bicyclists and car occupants most often reported problems were lower extremity and pelvis, 78% and 87% respectively. Problems after spinal injuries were also common in both road user groups. For bicyclists, spinal injuries and injuries to lower extremities were to a much higher extent leading to problems in HRQoL compared to other body regions.

When combining injury severity and injured body regions for bicyclists, the share of reported problems increased greatly as injury severity to the lower extremities and pelvis increased. The increase in reported problems was from 38% on AIS 1 level to 86-88% on AIS 2 and AIS 3+. For car occupants' spinal injuries, there was a large increase in reported problems when comparing injury severity AIS 1 with AIS 2 and AIS 3+. The increase in reported problems was from 53% on AIS 1 level to 80 and 85% on AIS 2 and AIS 3+ level.

Study II

In the three years from 2009 to 2011, 22,045 individuals 16 to 64 years of age (excluding persons already on SA or full time disability pension) had in- or specialized outpatient medical care due to a new injury from a bicycle crash. The majority (57%) of the injured were men, but women more often had SA compared to the men; 23% of the women and 18% of the men had an SA spell in connection to the crash. A lower proportion of individuals aged 16 to 24 had a new SA (5%), whereas a new SA spell was most common among individuals aged 55 to 64 years (32%).

In total, 4387 (20%) individuals had a new SA spell in connection to the crash. 61% of those injured receiving inpatient care ≥2 days had a new SA in connection to the crash, compared to 15% of new SA for those with only outpatient care. External (skin) injuries were most common, but the majority (94%) of these did not result in subsequent SA. Fractures were the second most common type of injury, and around 38% of the fractures resulted in subsequent SA.

About 1% (n=235) of the individuals had an SA spell lasting ≥180 days. Among those with a SA spell lasting ≥180 days, the most common injuries were to the lower leg (21%) followed by shoulder and upper arm (17%) and traumatic brain injuries other than concussion (15%). In around 12% of traumatic brain injuries the SA spell lasted ≥180 days. Five percent of the injuries to the spine and neck lead to an SA spell lasting ≥180 days.

The results from the logistic regression analysis is shown in Table 6. Compared to internal injuries, fractures showed higher OR across all durations, with the highest OR for SA 30-89 days (8.09, CI 6.30–10.39). Regarding body region, the OR for SA 15-29 days was highest for upper extremity injuries (3.44, CI 2.95-4.00) in relation to other head, face and neck injuries. Injuries to upper extremities also had the highest OR for SA 30-89 days (9.83, CI 7.55-12.80), followed by spine and back injuries (7.99, CI 5.38-

11.87) and lower extremity injuries (7.51, CI 5.69-9.92). Spinal injuries had the highest OR for SA ≥90 days (11.98, CI 7.38-19.46), followed by traumatic brain injuries other than concussion (6.64, CI 4.01-10.98), and injuries to lower extremities (5.28, CI 3.58-7.78).

Table 6. Adjusted odds ratios and 95% confidence intervals for different durations of SA (no SA reference group) for injury types and body regions.

	15-29 days		30-89 days		≥90 days	
	OR	**(CI)**	**OR**	**(CI)**	**OR**	**(CI)**
Injury type (ref internal)						
Fracture	3.47	2.89-4.18	8.09	6.30-10.39	2.88	2.18-3.79
Dislocation	2.44	1.88-3.16	3.32	2.34-4.72	1.95	1.22-3.12
Sprains and strains	1.11	0.86-1.44	2.12	1.52-2.95	1.26	0.80-1.98
External	0.65	0.53-0.80	0.58	0.42-0.78	0.31	0.20-0.46
Other and unspecified	0.66	0.41-1.07	1.17	0.64-2.15	0.81	0.34-1.91
Body region (ref other head, face, neck)						
Mild Traumatic Brain Injury (concussion)	0.74	0.57-0.97	0.86	0.56-1.32	0.52	0.27-1.00
Traumatic Brain Injury (other than concussion)	2.10	1.44-3.06	2.53	1.51-4.23	6.64	4.01-10.98
Spine and back	1.88	1.31-2.70	7.99	5.38-11.87	11.98	7.38-19.46
Torso	1.76	1.42-2.20	2.82	2.01-3.96	1.34	0.79-2.27
Upper extremities	3.44	2.95-4.00	9.83	7.55-12.80	4.56	3.12-6.65
Lower extremities	1.62	1.34-1.95	7.51	5.69-9.92	5.28	3.58-7.78
Other and unspecified	0.289	0.12-0.71	0.88	0.32-2.47	1.77	0.61-5.18

Combined results - Overview of injuries

With the results from the two studies, the overview of injuries can now be revisited. In the following sections, the results from the two included studies will be presented in relation to previous measures of injury severity and long-term consequences. Firstly by comparing injury distributions and secondly, a more detailed comparison between HRQoL and SA will be presented.

Extended injury distribution

In Figure 5, the distribution of injuries among individuals who report problems in HRQoL after a bicycle crash (Study I) and among individuals who became sickness absent beyond six months after a bicycle crash (Study II), are added to previous measures.

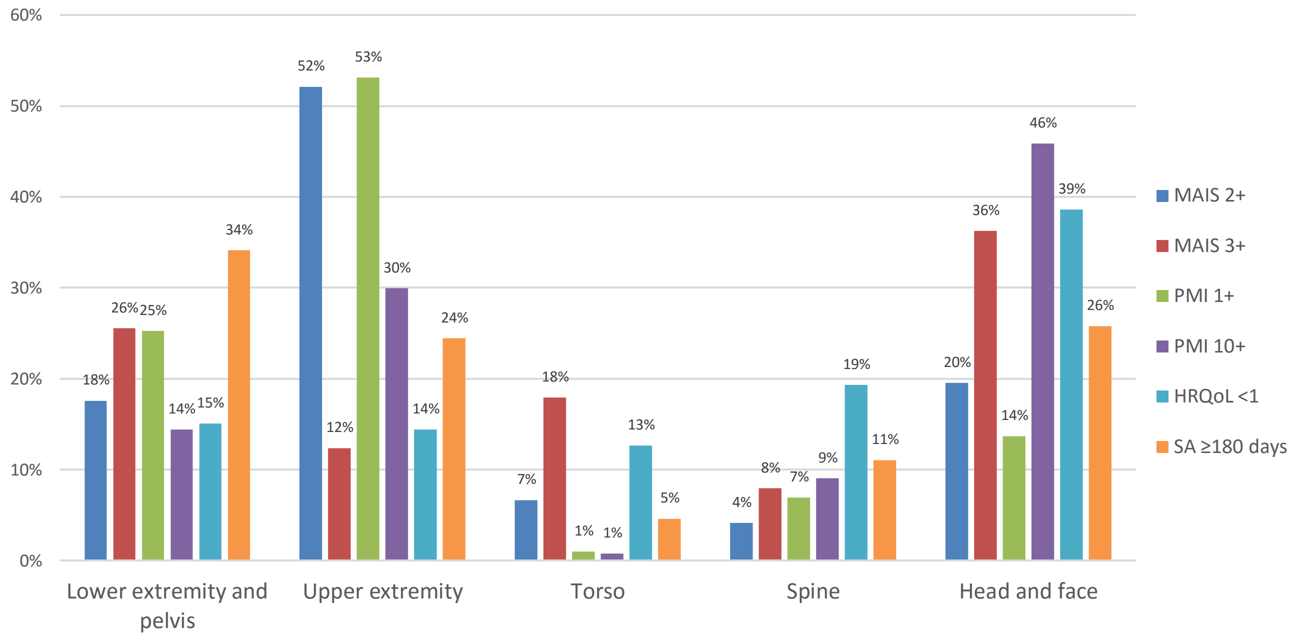

Figure 5. The distribution of injuries by different measures of injury severity (MAIS) and long-term consequences (PMI, HRQoL & SA). Note that the percentages add up to 100% for each measure.

It should be kept in mind that PMI injuries are based on a predictive method rather than the actual outcome. And further that the distributions of PMI injuries are based on the accumulated RPMI for each injury, and not the injury distribution among individuals who are predicted to sustain a certain level of PMI (see also the description in the Introduction). The figure shows that among MAIS 2+ bicyclists, the most common injuries are to the upper extremities, followed by head and face injuries. For MAIS 3+, injuries to the head and face, followed by injuries to lower extremities are the most common. For PMI 1+ injuries, the most common injuries are to the upper extremities, followed by lower extremities. Among PMI 10+ injures, injuries to head and face, followed by injuries to upper extremities are most common. Among people with problems in HRQoL, injuries to the head and face, followed by spinal injuries are the most common. And among those with SA beyond six months, injuries to lower extremities, followed by head and face injuries are the most common.

In conclusion, extending measures of injury severity and long-term consequences by adding HRQoL and SA actually do change the scope of which injuries affect health after a bicycle injury. For example, injuries to lower extremities are far more common among SA cases beyond six months, and spinal injuries become more relevant among those reporting problems in HRQoL. Another difference is that both HRQoL and SA have much smaller proportions of upper extremity injuries compared to PMI 1+.

What also should be considered is that the number of injured individuals or the number of injuries changes depending on what measure is used. Therefore, the magnitude of bicyclist injuries and the injury consequences will differ. To exemplify this, some calculations were made and is presented in Figure 6. On an average year (based on hospital reported bicyclists in STRADA 2013 to 2014), there are approximately 12 500 injured bicyclists reported in emergency care hospitals in Sweden. Of these individuals, around 4800 are MAIS 2+ injured, 440 are MAIS 3+ injured, while 2350 are expected to be PMI 1+, and 280 are expected to be PMI 10+. In Study I, 44% of bicyclists reported problems in HRQoL. Compared to the total distribution in STRADA, MAIS 2+ and MAIS 3+ were overrepresented in the material due to the stratified sampling method. Therefore, for the purpose of comparing the populations, the number of MAIS 1, 2, and 3+ from Study I were calculated to match the national levels in STRADA, resulting in approximately 4700 individuals with problems in HRQoL. Regarding SA, Study II only included individuals aged 16 to 64 years, and covered all in- or specialized outpatient care (not only emergency care hospitals). In total, 20% of the individuals became sickness absent and approximately 1% of the total population of injured bicyclists became sickness absent beyond six months. This 1 % corresponds to approximately 80 individuals in one year. The average number of fatally injured bicyclists can also be added. On average, between 2011 and 2015, 17 bicyclists were fatally injured each year.

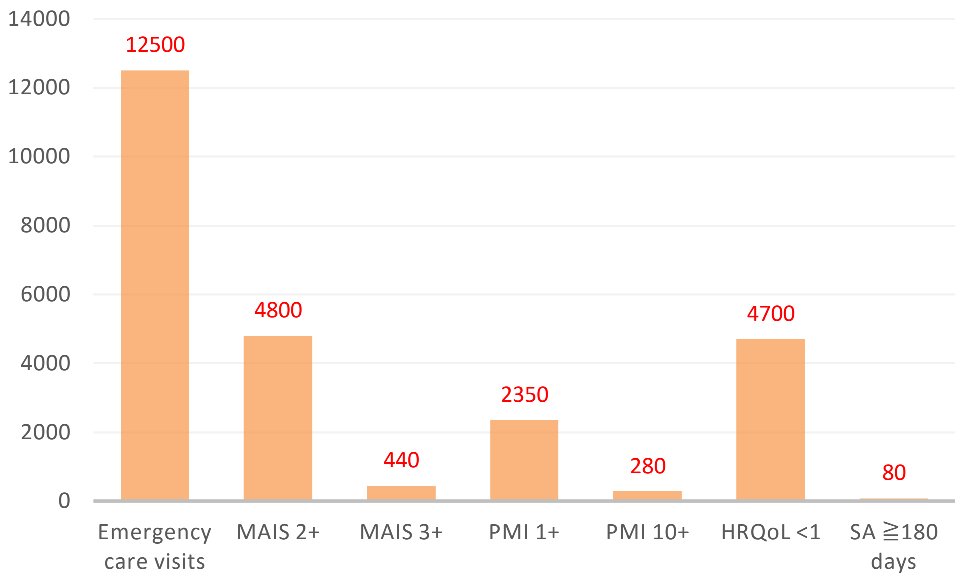

Figure 6. Average number of emergency care visits involving Swedish bicyclists 2013-2014 and corresponding number of different injury severity outcomes and long-term consequences.

It should be kept in mind that the injury distributions among bicyclists vary depending on the crash type (see Table 3 in the Introduction). This of course has implications for injury prevention, even if more detailed data are needed to further discuss preventive measures. This will be further elaborated in the section for future work.

Comparison between HRQoL and SA

In Table 7, a more detailed view of injuries leading to long-term problems in HRQoL and SA beyond 90 days is given. Based on the same material from Study I and Study II, a risk for problems in HRQoL and SA beyond 90 days is presented.

Table 7. Risk of long-term problems in HRQoL and SA ≥90 days, for different body regions.

BODY REGION	STUDY I HRQOL<1	STUDY II SA≥90 DAYS
TRAUMATIC BRAIN INJURY	49%	18%
CONCUSSION	39%	1%
OTHER HEAD, FACE AND NECK	38%	2%
SPINE AND BACK	65%	13%
TORSO	48%	3%
SHOULDER AND UPPER ARM	50%	5%
FOREARM AND ELBOW	40%	3%
WRIST, HAND, OTHER	38%	2%
HIP, UPPER LEG AND THIGH	90%	20%
KNEE	71%	5%
LOWER LEG, ANKLE, FOOT	67%	11%

Overall, the risk for problems in HRQoL is high, but clearly there are differences between different body regions. For example, the risk for injuries to elbow, forearm, wrist, and hand are lower compared to shoulder and upper arm injuries. The highest risk of problems in HRQoL is for injuries to the hip, upper leg, and thigh. This is also the case for SA, where 20 % of those who became sickness absent with injuries to the hip, upper leg, and thigh lead to SA beyond 90 days. The risk for SA is lowest for concussive injuries, but concussive injuries more often are associated with reporting problems in HRQoL. The risk for problems in HRQoL is high for knee injuries, whereas the risk for SA beyond 90 days for knee injuries is lower (5%).

Discussion

Bicycling has been widely recognized as an important contributor to help increase the level of physical activity (Oja et al., 1998; Sahlqvist et al., 2013) and hence reduce the risk of several diseases related to physical inactivity (Lindström, 2008) and all-cause mortality (Matthews et al., 2007). Several studies have highlighted the positive impacts of increased bicycling in regards to both health and environment (Hartog et al., 2011; Rojas-Rueda et al., 2013, Holm et al., 2012; Oja et al., 2011). On the other hand, bicyclists have higher risks of being injured or fatally injured. Although bicyclists only account for around 6% of all road fatalities in Sweden, they account for 45% of all hospital reported crashes and injuries (Swedish Transport Administration, 2015). With Vision Zero, the focus on consequences of injuries moved towards risk of long-term health-loss (Tingvall, 1997). Further, Vision Zero states that the focus should not be to eliminate all crashes that occur, but rather to eliminate injuries that lead to long-term loss of health. The RPMI may be the first step to include long-term consequences of injuries in road safety management. However, describing loss of health simply in terms of impaired bodily functions and structures exclude other important areas related to health. To better target injury prevention to focus on injuries that lead to loss of health, the understanding of negative health impacts from bicyclist injuries need to be further developed, using a holistic approach to define and understand health. The present thesis investigated the outcome in Health-related Quality of Life (Study I) and Sickness Absence (Study II) following a bicycle injury.

Discussion of results from Study I and II

The results from Study I showed that 59% of car occupants and 44% of bicyclists reported problems in HRQoL after a road traffic injury. This result can be compared to Ulvik et al. (2008) who also used the EQ-5D. Among 210 mixed patients in an intensive care unit (where overall injury severity could be assumed to be higher than in the population included in Study I), 80% reported problems. Also in Study I, pain/discomfort followed by anxiety/depression were the dimensions where both injured bicyclists and car occupants experienced the most problems, which is in line with results from Ulvik et al. (2008). Another finding was that car occupants, consistently through all EQ-5D dimensions, reported more problems. This is in line with results from Mayou and Bryant (2003) who showed that vehicle occupants compared to other groups more frequently reported problems with pain/discomfort.

The high proportion of problems related to anxiety/depression and pain/discomfort could indicate that health losses can occur that are not necessarily strictly related to an injury to the body. This is for example shown in Mayou and Bryant (2003) where both anxiety and depression, and travel anxiety phobia were reported after a road traffic crash, and Nhac-Vu et al.

(2014) reported problems regarding psychological health and post-traumatic stress disorder (PTSD).

Injuries to the lower extremities and pelvis had the highest share of problems for both road user groups, a result which is supported in previous research by Nhac-Vu et al. (2014), who found lower limb injuries to be predictive of poorer outcome in quality of life one year after being injured. Among bicyclists having reported problems in HRQoL, only 7-14% of their injuries were to the upper extremities. This finding can be compared to Rizzi et al. (2013) who found that bicyclists' injuries to the upper extremities were the most common PMI 1+ injuries (46%).

In Study I, 42% of the bicyclists reported problems after suffering a head injury, and head injuries accounted for 20% of injuries among the bicyclists having reported any problems in HRQoL. In Rizzi et al. (2013), head injuries accounted for 9% of PMI 1+ injuries, which is lower than in Study I. However, looking at severe PMI 10+, head injuries account for a much higher proportion (Rizzi et al., 2013).

The findings in Study II suggest that SA exceeding two weeks is a rather common outcome after a bicycle crash. For the majority of those with a new SA (47%), the spell had ended within 30 days and for a third (38%) the duration was 30-89 days, and a further 10% became sickness absent for 90-179 days, and 5% were sickness absent for ≥180 days. This elucidates that societal costs related to bicycle crashes are high, which has been shown in previous studies (Aertsens et al., 2010; de Geus et al., 2012; de Geus et al., 2014). The duration of the SA spell was also related to injury type and injured body region. Fractures were common and often lead to subsequent SA. Also, traumatic brain injuries often lead to SA, with 12% of these injuries leading to SA beyond six months.

Among the cases resulting in SA beyond six months, the majority of the injuries were to the lower leg (21%), shoulder and upper arm (17%), or traumatic brain injuries (15%). In one previous study, injuries to these body regions have been shown to be common PMI injuries among injured bicyclists (Rizzi et al., 2013). In total, it was found that injuries to the upper extremities (arm and shoulder) were the most common (46%), followed by leg injuries

(22%) among all impairing injuries. In a Finnish study including 264 adult casualties to emergency hospitals, the mean duration of SA after non-fatal bicycle injury was 82 days among inpatients, and for outpatients the mean duration was 11 days (Olkkonen et al., 1993). In the same study, it was found that injuries to the upper extremities were the most common (33%). Over half the cases with SA longer than 30 days were due to upper extremity injuries. The results from Study II support this finding, and also add that upper extremity injuries most often, with the exception of hand and wrist injuries, account for around 50% of SA >30 days.

In a large study including 55,220 injured bicyclists, Rizzi et al. (2013) found that head injuries were the most common (42%) among PMI 10+ injuries (n=1557). In Study II, traumatic brain injuries were not common, but they most often lead to SA ≥180 days, indicating that traumatic brain injuries can also lead to severe consequences for SA, in line with Larsson et al. (2010). Several other studies have shown that long-term consequences from both mild and severe traumatic brain injuries are common, and impacts both SA (Larsson et al., 2010) and quality of life (Scholten et al., 2015; Dikmen et al., 2003), as well as cognitive, functional and psychosocial impacts (Hellawell et al., 1999; Sinha et al., 2013). Even if the results in Study I suggested that problems in HRQoL after head injury were not very common compared to injuries in other body regions, this should be interpreted as an opportunity to highlight that bicycle-helmets, while important, will not solve all problems related to bicycling. Even if helmet usage rates increase, there will still be a large share of injuries left to address if the ultimate goal is to reduce injuries that have long-term effects on people's health. Therefore, in addition to encouraging helmet usage, other measures will also need to be considered.

Among car occupants in crashes, a large rate of spinal (whiplash) injuries has been found to lead to long-term SA (Berecki-Gisolf et al., 2013; Bylund & Björnstig, 1998). In Study II, spinal injuries were uncommon, accounting for 2% of all injuries. Nevertheless, they accounted for around 10% of the injuries among individuals with SA ≥180 days, and also had the highest OR for SA ≥90 days. It was also found that leg injuries were the most common among cases with SA ≥180 days. This is in line with the results from Study I, which found leg injuries to be common among people reporting long-term problems in HRQoL. This indicates that leg injuries among bicyclists might need additional preventive measures.

Discussion of the combined results

In Figure 6, the distribution of injuries for different measures of injury severity and long-term consequences was shown. As it illustrates, the distribution of injuries changes depending on what measure is used. If injury prevention is to be based on the injury distribution, the more common injuries will be prioritized to be prevented. The distribution of injuries was shown to be different depending on what measure is used as the target measure.

The injury distribution among those with problems in HRQoL (HRQoL <1) is, compared to the other measures, more evenly spread. And considering that the body regions 'head' and 'face' had to be collapsed, the injury distribution would have been even more even if these body regions had been shown separately. As HRQoL, measured with EQ-5D, is a much more generic measure which takes in to account a broader perspective on health compared to the other measures, this is not too surprising.

If looking at injury prevention from the perspective of PMI 1+ injuries, which is the current measure used to define a serious injury, in first hand injuries to the upper extremities, followed by lower extremities and head and face injuries are the three most common to target. Both HRQoL and SA have much smaller shares of upper extremity injuries compared to PMI 1+. The pattern is quite similar for MAIS 2+, which will mainly put focus on the same injuries as PMI 1+. However, from the perspective of long-term SA (≥180 days), lower extremity injuries, not upper extremity injuries, would be the main focus for injury prevention. This is the only one out of the six measures that holds lower extremity injuries as the most common. In a study from the Netherlands, where the health burden from MAIS 2+ injuries, lower leg injuries were found to have large health impacts (Weijermars, 2016). The injury distribution presented in this thesis could not be divided and separate different parts of the leg. However, in Table 7 it was shown that lower extremity injuries that lead to SA and problems in HRQoL mainly referred to the hip, upper leg, and thigh (although the proportion was high even among lower leg injuries).

In Figure 6, the sizes of different injury populations are illustrated. Out of a yearly number of 12 500 emergency care visits, around 4700 people would be expected to report problems in HRQoL 1-3 years after their injury, whereas only 80 people would be expected to be sickness absent beyond six months. Clearly the large size of the HRQoL population showcase the generic aspect of the instrument, and the large population would be difficult to handle when attempting to design preventive measures. Also, the PMI injuries might be difficult to handle from an injury prevention perspective, drawing the line from injury to crash, as the populations related to PMI injured are made up of accumulated RPMI for each individual, which gives a predicted number of PMI individuals. Even if the number of fatally injured were not included in the figure, on average 17 bicyclists are fatally injured each year, and it would be interesting to further investigate whether and how the crashes that result in fatalities differ from other crashes resulting in non-fatal injuries.

Implications for injury prevention

There are different strategies on how to target injury prevention. Either, the focus can be to address the injuries that are most common (depending on outcome measure), irrespective of what risk the injury has for the chosen outcome. Another approach would be to target injuries with high risk for a certain outcome, regardless of how common they are. It could be argued that society would gain most from targeting the injuries that are most common. However, these injuries would also have to involve an outcome that is unacceptable to society.

With the results presented in the present thesis, one can initiate a discussion of what an acceptable or unacceptable health loss can be. When it comes to fatalities, this is not a difficult question to answer, they are unacceptable. But for non-fatal injuries, the answer is neither easy nor clear. Based on the definition of health, and the ICF framework adopted in the present thesis, the consequences of injuries should not only be related to impairments in bodily functions and structures. Also, according to Vision Zero, some injuries can be acceptable to society, if they involve minor consequences. Looking beyond biomedical consequences to biopsychosocial consequences of injuries, the results of this thesis suggests a few specific injuries among bicyclists that might be categorized as unacceptable and thus should be prevented from a Vision Zero perspective. Firstly, even though a large share of head injuries are concussive injuries that rarely result in SA, the longest durations of SA are related to severe head injuries. The severity of these consequences has also been shown in many previous studies (e.g. Scholten et al., 2015; Dikmen et al., 2003; Hellawell et al., 1999; Sinha et al., 2013). Secondly, injuries to the lower extremities (mainly hip, upper leg, and thigh, and also lower leg) need to be addressed. These types of injuries are both relatively common, and often affects peoples' HRQoL and also often leads to SA (both shorter and longer periods). Thirdly, injuries to the shoulder and upper arm have more severe consequences in terms of HRQoL and SA, compared to injuries to other parts of the arm (which is in line with results on medical impairment). By addressing the shoulder and upper arm injuries, a large share of upper extremity injuries could be prevented. Also, compared to previous measures of injury severity, this thesis show a higher share of spinal injuries, indicating a need to address these types of injuries among bicyclists.

One could argue that by using a holistic approach to health, all injuries should be avoided and that the focus should be on crash prevention rather than injury prevention. But in the light of Vision Zero all injuries do not have the same impact on health. Therefore, in the context of this thesis, a holistic approach to health relates to the understanding of health impacts from injuries. This is essential in order for stakeholders in society who need to make decisions on how to allocate resources related to injury prevention. The results presented in this thesis provide new insights into the discussion on what an unacceptable outcome might be. It was shown that different injuries have different impacts on quality of life. Based on the results it could, for example, be argued that an injury to the hand or wrist should be more acceptable than an injury to the shoulder and upper arm. In other words, we will, for example, still accept a crash as long as it does not result in an injury to the shoulder or upper arm. This thesis does not suggest that the focus of injury prevention should not be on serious injuries, but that even among serious injuries specific injuries can be targeted because they have long-term impact on individuals' quality of life.

One can also take the reasoning on acceptable outcome a step further. There is evidence suggesting that PTSD is common after a road traffic injury

(Haagsma et al., 2011; Mayou & Bryant, 2003). In Study I, problems related to anxiety/depression and pain/discomfort were the most common. Also, other studies have reported similar findings. Mayou and Bryant (2003) found that both anxiety and depression, and travel anxiety phobia were reported after a road traffic crash. Also Nhac-Vu et al. (2014) reported problems regarding psychological health and PTSD. The experience of being involved in a traffic crash can in itself negatively impact a person's health. But does this mean that the goal should be to eliminate all types of traffic crashes? According to Vision Zero, crashes that occur are acceptable, as long as they do not result in an unacceptable outcome. If for example PTSD was to be considered an unacceptable outcome, then prevention in relation to road traffic crashes should shift its focus from injury prevention to crash prevention. This means that the lower the threshold for acceptable outcome, the higher the sacrifice in terms of resources and mobility could become. Even if this question of acceptable outcome cannot be solved easily, policymakers should keep discussing these issues, and the results from this thesis add new understanding to this topic. Identifying injuries that are important to prevent is only the first step, and other studies are needed to understand where and how these injuries occur, so that specific preventive strategies can be considered.

Future work

One of the major challenges when it comes to injury prevention is the difficulty in drawing the line between crash/injury to long-term outcome. That is why studies on injury outcome are important, but it is also important to be able to connect the outcome to a crash to understand how such injuries can be prevented. An example is shown below, relating to head and leg injuries, which in this thesis were identified as important prevention areas.

In a previous study by Fredriksson and Rosén (2012), it was found that in crashes where bicyclists had been hit by car fronts, the dominating injured body regions with severe (AIS 3+) injuries among bicyclists were head, leg and chest. Also, previous studies have shown that crashes involving a motor-vehicle more often result in severe injuries and fatalities compared to other types of bicycle crashes, e.g. non-collision crashes (Cripton et al., 2015; Bil, Bilova, Dobias & Andrasik, 2016; Gaudet et al., 2015; Nicaj et al., 2009). Considering injury prevention in relation to this crash-type, a helmet will effectively reduce head injuries (Amoros et al., 2012; Attewell et al; 2001; Olivier & Creighton, 2016), but a helmet will of course not address leg injuries. In addition to using a helmet, other preventive strategies can be incorporated. For example, the design of the car-front can mitigate injuries (Strandroth et al., 2011; 2014). Also, strategies like protective clothing or energy absorbing material in the ground could be considered to protect bicyclists from injuries related to ground impact. Further, previous research has shown that combining different preventive strategies (friendlier car-fronts, speed management, and helmet use) can effectively reduce injuries in bicyclist to motor-vehicle crashes, especially in regards to head and leg injuries (Ohlin et al., 2017). These preventive measures, in combination with Autonomous Emergency Braking (AEB), was estimated to reduce up to 90% of PMI 1+ injuries in this specific scenario. Combining different preventive strategies is in line with the Vision Zero approach, where the road, the vehicle, and the road user, together with a safe speed limit, should interact to create a safe road transport system (Tingvall et al., 2000; Stigson, 2009).

This example shows that it is possible to draw the line from specific injuries, that have been identified as having impact on quality of life, to specific crash scenarios. In other words, with specific injuries, that are identified as important to prevent with regards to long-term health loss as a starting point, researchers can start investigating crash characteristics and assess further preventive measures. Based on the findings from the present thesis, future research should continue to investigate crashes in the same manner as exemplified above. Starting from the injury outcome that identifies injuries important to prevent, relevant crashes should be identified, and injury preventive strategies should be assessed from a Vision Zero approach. A way in which this could be done is to use real life crash data from STRADA hospital and police records, in which the sample would be based on specific diagnoses (e.g. upper leg injuries). It could be possible to identify a limited number of crash-scenarios which could then be analysed to understand what preventive measures could be applied. For the purpose of crash-analysis, the integrated safety chain could be used. The integrated safety chain illustrates the whole chain of events, from normal driving (or in this case bicycling) to the crash, as a process in time in which interventions can be applied at any stage (Tingvall, 2008). The benefit of this approach is that different preventive strategies can be applied and combined. The model has previously been used in a number of studies on crash analysis, e. g. Eugensson et al. (2011), Strandroth (2015) and Rizzi (2016).

However, what should be kept in mind is that this kind of analysis will require detailed data, especially regarding single-bicycle crashes. The literature on single bicycle crashes is limited, and in a study by Schepers (2012) it was concluded that the research on single-bicycle crashes is still in its infancy. The Schepers study investigated the types and characteristics of single bicycle crashes by questionnaires to bicyclists injured and treated at emergency care hospitals, and it is likely that studies on injury prevention for single-bicycle crashes might need to be based on in-depth data, rather than mass data (e.g. STRADA) that most likely will not contain enough detailed data.

An outlook on safety and sustainability

From a societal point of view, the efforts to increase the level of bicycling will be continued, based on the many positive impacts. But from an ethical perspective, it is questionable if this should happen at the cost of increased injuries and deaths related to bicycle crashes. But the two agendas might not necessarily be opposed. Increased safety for bicyclists may also be associated with increased bicycling. This is sometimes referred to as "safety in numbers". Previous research has indicated a potential safety effect just by increasing the number of bicyclists; as the number of bicyclists increase, the number of crashes are reduced (Kröyer, 2015). This effect has also been argued to be a result of a safer environment, and that increased safety leads to larger numbers of bicyclists. Either way, by creating safer and also more attractive environments, health will be increased both in terms of increased physical activity, and also in terms of prevented injuries.

As traffic safety is on the UN's agenda for sustainability (United Nations, 2015) traffic safety becomes a way to create sustainability. The high demand for more sustainable transport modes calls for a need to improve safety for bicyclists, making safety for bicyclists one of the prioritized areas for a sustainable road transport system in the future. In 2015, a target was formulated by the UN regarding good health and well-being, which includes a 50% reduction in the number of deaths and injuries in road crashes by 2020 (UN, 2015). As bicyclists account for the highest share of traffic related injuries in Sweden, increasing the safety for bicyclists should be of high priority.

Methodological considerations

In this section I will mention some limitations related to the concepts of HRQoL and SA in this thesis, as well as some thoughts regarding the EQ-5D instrument and specific limitations related to the analysis in both studies.

If experiencing any problems in HRQoL can be seen as a general view on health, being entitled to SA could be seen as a quite narrow part of health. It can also indicate that you have a job that is dependent on physical aspects, like manual labor and therefore more affected by physical limitations caused by the injury. In that sense, persons with less physical demanding jobs might still be able to work despite their injury. On the other hand, those who are able to work might still be affected in other health-related areas, for example be restricted in participating in sports or other recreational activities. These aspects are not captured when the injury outcome is described in terms of SA. Work is of course in some ways related to the dimensions of health covered in EQ-5D, but experiencing problems in HRQoL does not mean that a person per definition is entitled to SA. However, in line with the ICF framework, both measures capture different aspects related to health, and together they incorporate all levels of disability according to the ICF framework; impairment, activity limitations and participation restrictions. Also, it should again be mentioned that Study I and Study II related to different time-frames. HRQoL was investigated 1 to 3 years after the injury, while the results for SA was limited to a follow-up of beyond 6 months. Even though this could possibly be seen as a limitation, it should be kept in mind that an injury that initially affects a person's capability to work can still be limiting in other ways also after SA has been terminated.

In this thesis, "long-term" has been used in relation to impact from injuries. It is of course a difficult term to use as it can be defined in different ways. Regarding SA there is no agreed upon definition of long-term sickness absence in Sweden. According to Statistics Sweden, it is sometimes referred to as sickness absence longer than 14 days, i.e. sickness benefit is compensated by social insurance and not from the employer

(Statistics Sweden, 2004). In 2003, it was legislated in the annual accounts act that all sickness absence ≥60 days was to be accounted for (Swedish Government, 2002). In this thesis sickness absence beyond 180 days was defined as long-term. In relation to long-term impact from injuries described in Vision Zero, it is suggested that injuries that heal within three weeks can be seen as an acceptable outcome (Tingvall, 1997). In that sense, even if SA beyond 180 days might not be long-term compared to e.g. life-long impairments it could still be considered long-term in relation to SA in general. Also, for example leg fractures the healing time is generally between three to four months, or longer than six months (Massari et al., 2012). Related to HRQoL "long-term impact" has been used in different ways as well, ranging from e.g. two months (Jagnoor et al., 2015), ≥ 1 year (Alghnam et al., 2014), or up to four years (Maraste et al., 2003). Depending on how long-term impact is defined it will affect the design of studies involving health impact from injuries, and further what injuries that will be labelled as "non-acceptable".

Even in the normal population, the average score of the EQ-5D would be below 1 (perfect health). The corresponding mean EQ-5D index value in a general population (n=3069) in Stockholm County was reported to be 0.84 (Burström, Johannesson & Diderichsen, 2001). The results from Study I showed that the prevalence of problems related to anxiety/depression and anxiety/depression was highest. This is also in line with results for the general population (Burström, Johannesson & Diderichsen, 2001). Among the sample in Study I, the mean index value was equivalent to the general population in Stockholm (0.84), and among those injured in a bicycle crash, the average index value was 0.88. In general, the mean index value is lower among older people compared to younger people, and is also affected by socio-economic status and disease. The fact that the mean index value was higher in the study population compared to the general population could raise questions whether the results are reliable. An argument that strengthens the results in this sense could be that persons were asked to answer the survey *in relation to* their traffic injury and how it had affected their daily life. This would be different compared to a study among the general population with regard to their general health. Besides this it could also be suggested that physical activity has been shown to have a positive association with HRQoL (Bize, 2007), and the physical activity gained from bicycling might indicate a higher general health among this group compared to the normal population. This aspect was not investigated in Study I as no data was available on the respondents' bicycling habits.

The EQ-5D is a generic instrument, and could therefore be difficult to use when high sensitivity is needed to discriminate between different injury groups. With a more sensitive instrument (e. g. with more discriminative qualities), it might have been possible to better differentiate between different injuries. It is possible that other results could have been found, if another instrument had been used, for example the SF-36 that covers more health-related dimensions compared to the EQ-5D and has also been used in traffic injury related studies (e.g. Kenardy et al., 2015; Polinder et al., 2010). Although, the EQ-5D is a valid instrument to use in HRQoL-studies, and it has previously been validated for injuries (Öster et al., 2009; Hung et al., 2015) and has also for example been used to evaluate HRQoL after major trauma (Ulvik et al., 2008), polytrauma (Gross et al., 2010), and among general injury patients (Meerding, 2004; Polinder, 2007). There are some studies that have used the EQ-5D to evaluated HRQoL specifically after road traffic injury, for example Jagnoor et al. (2015). But still, the design of the instrument might have impacted the results. For example, one question that relates to mobility is asked in relation to walking, therefore the high share of reported problems related to leg injuries might have been affected by the formulation of this question. The EQ-5D is a simple instrument, and in studies including large populations it might be favourable to use a short instrument that does not require too much effort from the respondent to fill in. Another argument for choosing a generic instrument was that traffic injuries can be located in any body region and hence may have different consequences. Therefore, it is not possible to use a diagnose specific instrument (e.g. it is not possible to use the Quality of Life after Brain Injury instrument for other injuries than brain injuries).

Another limitation, that refers to both studies, is that there was a limited possibility to show causality between the injuries sustained in the crash and the outcome in terms of problems in HRQoL or SA. In other words, it could be argued that the reported HRQoL might not be the result of the injury itself but reflect upon other life-events that happened within this period. In Study I, an attempt to deal with this limitation was made by formulating in the survey that the form was to be considered in relation to the respondent's traffic injury. Further, people who had reported previous illnesses that had affected their daily lives were excluded from the analysis. In Study II people who had been involved in any traffic related crash within three years prior to the "current" crash, or were already on SA or full-time disability pension, were excluded. An important step in Study II was to identify incident cases of SA, i.e that the SA started as a result of the injury. Regarding this, an assumption had to be made that the date of the crash was the same as the date of the specialized in- or out-patient care visit. Incident cases of SA were defined as cases starting +/- 4 days in connection to the date of the specialized in- or out-patient care visit. As only one main injury diagnosis was chosen, the effect of some injuries might have been underestimated as 23% of the study population had more than one main injury diagnosis. Future studies should also consider including secondary diagnoses to better understand the effect of multi-trauma, and also to include the SA diagnoses for comparison to the injury diagnoses to further strengthen the relationship between injury and outcome in SA.

In Study I, only a subset of the EQ-5D was used (i.e. the descriptive system) and the analysis was based on whether people reported *any* problems in HRQoL or not. It could be argued that this was a too simplistic a measure of HRQoL. The limited number of cases did not make it possible to distinguish those who had reported severe problems in HRQoL from those who reported moderate problems. It would have been interesting to investigate whether the results would differ between these groups, making it possible to use a different statistical method, e.g Anova where three or more groups can be analyzed.

On a final remark, besides considering alternative instruments, or SA as outcome measure, different results could have been gained using a qualitative method, i.e. interviews. In depth-interviews or semi-structured interviews could have offered insights into what type of problems people experience. In a survey people have to consider their situation in relation to the questions or statements given to them, rather than providing their own experiences. Future studies could use interviews to better capture peoples' experiences of being injured in a bicycle crash to better understand what problems they face and how their health and life situation has been affected by the injury.

Conclusions

- A holistic biopsychosocial perspective on health adds new understanding to the negative health impacts of bicycle injuries. Therefore, other aspects of health could be considered as well, and not only medical impairment, in order to prioritize which injuries need to be prevented.
- Different injuries have different impacts on quality of life, for example injuries to the shoulder and upper arm more often lead to negative health impacts compared to injuries to other parts of the arm.
- Long-term problems in HRQoL were common among injured bicyclists, and leg injuries most often lead to problems in HRQoL. This body region was also associated with longer durations of SA. Also, spine and back injuries, as well as severe head injuries were also associated with longer durations of SA
- From a biopsychosocial perspective on health impacts, the focus of injury prevention among bicyclists should be on severe head injuries, leg injuries (mainly hip, upper leg, and thigh, and also lower leg), injuries to shoulder and upper arm, and spinal injuries.
- Future studies should focus on analyzing and describing the crashes in which these injuries occur, with the aim to identify relevant preventive strategies that could be effective in mitigating or eliminating these types of injuries.

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