Factors associated with injury severity in bicycle-related traffic accidents

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Summary

Background

Cycling is a common activity involving an increasing number of individuals all over the world. It is not only an environmentally friendly means of transportation, but also an excellent way of increasing physical-activity levels. Despite its benefits cyclists are at an increased risk of injuries as they are exposed to a whole array of hazards, especially when commuting with minimal or no protection. Cycling is embedded in the Dutch culture, characterized by some of the most avid bicycle users in the world. Consequently, bicycle-related traffic accidents have a great socioeconomic impact in the Dutch society. Therefore, the determination of factors that predict injury severity in bicycle-related traffic accidents is of primary importance to better organize prevention strategies. Because cycling accidents are multifactorial in its nature, one must encompass a wide range of variables when studying such a complex topic. Although previous literature has established potential influential factors, such as age, gender and bicycle type, culture and surrounding environment must be also taken into account. To our knowledge no study has yet assessed which factors are associated to injury severity of bicycle accident-related injuries specific to the Netherlands.

Methods

A cohort study was conducted, including patients above 18 years of age, seeking medical attention at the trauma center of the University Medical Center Groningen (UMCG) between July 2014 and December 2016. Data was collected through means of electronic patients files, the “Landelijke traumaregistratie” (LTR) and questionnaires. Considering the multifactorial nature of this study a multivariable logistic regression analysis was conducted, where Injury Severity Score (ISS) was the dependent variable. Primary outcome was potential effect predictors of multi-trauma (ISS>15) in bicycle-related traffic accidents.

Results

During the research period 1010 patients were admitted to the trauma center, UMCG. From these patients 539 (53,4%) were male and 471 (46,6 %) were female. Patients presented with a broad spectrum of injuries. The most frequent injured body regions were the upper body (39.2%) and the head (31.2%). Effect predictors of multi-trauma due to a bicycle-related traffic accident were: age above 60 years old (OR=4.14), male gender (OR= 2.84), two-sided collision type of accident (OR=3.48), “other collision type” (OR=4.02) and collision type with an object had (OR=3.45).

Conclusion

We have identified potential variables associated with ISS>15 in bicycle traffic-related accidents specific to the Netherlands. Further data collection with the advised improvements is recommended as to provide means for a more accurate data analysis. Prevention strategies can then be established with the goal of maximizing benefits for the population

Samenvatting

Achtergrond

Fietsen is een alledaagse activiteit, die door steeds meer mensen over de hele wereld wordt uitgevoerd. Het is niet alleen milieuvriendelijke manier van reizen, maar ook een uitstekende manier om meer te bewegen. Ondanks de voordelen lopen fietsers meer risico op letsel omdat ze te maken hebben met veel verschillende gevaren, vooral wanneer ze weinig of geen bescherming dragen. Fietsen is onderdeel van de Nederlandse cultuur, die gekenmerkt wordt door de meest fanatieke fietsers ter wereld. Als gevolg hiervan hebben ongevallen waarbij fietsers betrokken zijn een grote sociaaleconomische impact op de Nederlandse samenleving. Om ongevallen waarbij fietsers betrokken zijn beter te kunnen voorkomen, is het daarom van groot belang de factoren te bepalen die de ernst van het letsel voorspellen. Omdat fietsongevallen van nature multifactorieel zijn, moet men veel verschillende variabelen meenemen in het onderzoeken van zo'n complex onderwerp. Hoewel bestaande literatuur potentiele factoren die van invloed kunnen zijn heeft opgesteld, zoals leeftijd, geslacht en type fiets, moet er ook rekening worden gehouden met cultuur en de omgeving. Voor zover bij ons bekend, is er tot op heden geen onderzoek gedaan naar factoren die gerelateerd zijn aan de ernst van het letsel van ongevallen waarbij fietsers betrokken zijn, specifiek in Nederland.

Methode

Er is een cohortstudie uitgevoerd onder patiënten ouder dan 18 jaar, die medische hulp zochten bij het traumacentrum van het Universitair Medisch Centrum Groningen (UMCG,) tussen juli 2014 en december 2016. Er is data verzameld door middel van elektronische patiëntendossiers, de Landelijke Traumaregistratie (LTR) en vragenlijsten. Vanwege het multifactoriële karakter van het onderzoek is een multivariabele logistische regressieanalyse uitgevoerd, waarbij "Injury Severity Score" (ISS) de afhankelijke variabele was. De voornaamste uitkomst werd gevormd door potentiële voorspellers van multi-trauma (ISS>15) in ongevallen waarbij fietsers betrokken waren.

Resultaten

Tijdens de onderzoeksperiode werden 1010 patiënten toegelaten tot het traumacentrum van het UMCG. Van deze patiënten waren 539 (53.4%) van het mannelijk geslacht en 471 (46,6%) van het vrouwelijke geslacht. De patiënten hadden veel verschillende soorten letsel. De meest voorkomende letselgebieden waren het bovenlichaam (39.2%) en het hoofd (31.2%). Voorspellers van multi-trauma door een ongeval waarbij fietsers betrokken waren, waren: leeftijd boven de 60 jaar (OR=4.14), mannelijk geslacht (OR=2.84), tweezijdige botsing (OR=3.48), "ander botsing type" (OR=4.02) en botsing met een object (OR=3.45).

Conclusie

We hebben potentiële variabelen geïdentificeerd die worden geassocieerd met ISS>15 bij ongevallen waarbij fietsers betrokken zijn in Nederland. Verdere dataverzameling met de geadviseerde verbeteringen wordt aangeraden ten behoeve van meer accurate data-analyse. Daardoor kunnen er preventiestrategieën worden opgesteld met als doel het maximaliseren van de voordelen voor de populatie.

Abbreviations

ISS	Injury severity score
QOL	Quality of Life
WHO	World Health Organization
SWOV	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid
BAC	Blood alcohol concentration
LTR	Landelijke traumaregistratie
AIS	Abbreviated injury scale

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1 – Introduction

In the Netherlands the use of cycling as a common way of commuting is well established in its culture. With its flat terrain and excellent infrastructures, the Netherlands provides their population with the ideal conditions for the use of bicycles as means of transportation transportation. It is estimated that on a daily basis 31% of the Dutch population uses a bicycle as the main way of transportation; this is highest percentage in the European Union.[1] A Dutch resident makes on average 300 bicycle trips for a total of 878 kilometres per year.[2] Daily bicycling has many advantages to its user, such as increasing fitness levels and reducing obesity. In addition, it is non-polluting and does not contribute to the increase in greenhouse gas levels often associated to travelling. On the other hand, while bicycles do not offer any physical protection in an event of a crash, cyclists often must share the motorway with other motorized vehicles and are consequently more exposed to road hazards. Bicycle users are therefore more vulnerable to traffic-related injuries than other motor vehicle users.

Concurrent with studies from China and the United States, in the Netherlands the number of bicycle users as well as the number of injured cyclists have increased.[34] In the Netherlands cyclists make up around 25% of the traffic deaths and around 50% of all traffic accident related injuries. Even though in the last decade the number of deaths among cyclists due to traffic accidents has actually decreased, on average 180 cyclists still as a result of traffic related accidents per year.[5] In 2012, 75,000 treatments in the emergency department and 15.000 hospital admissions were due to bicycle-related accidents.[6]

Despite its major negative impact on health-related quality of life, traffic bicycle accidents also represent an economic burden for its countries' economies through work absence and medical costs.[7] Notwithstanding the great social and economic impact, little is known about causation of traffic bicycle accidents and extent of its injuries. Although most of the injuries from cycling accidents are considered not severe, 72% of patients still suffered from pain and other physical symptoms more than 6 months after the accident, with effect on activities of daily living. Patients also reported a negative outlook/emotions after the accident.[8]

Cyclists are vulnerable to motorized traffic and other external conditions, as a bicycle does not offer any protection against collision. To better understand the epidemiology of traffic-related accidents many associated factors need to be analyzed. Because these factors are not independent but rather influence each other, their analysis can be quite challenging. Factors that have previously been shown to be related to the severity of bicycle-related traffic accidents injuries are nature of the crash, such as collision with a motor vehicle and use of e-bikes.[9,10] Other implicated factors include: demographic factors (with emphasis on age) and individual factors, such as helmet and alcohol use.[11,12] Some studies have already examined factors associated with injury severity in bicycle traffic accidents, however their results may not replicate the ones potentially from the Netherlands. Each country has its very particular culture, demographics and infrastructures, which will not only influence cycling habits but also the extent and pattern of injury.[13]

With the rise in bicycle-related traffic accidents, disability and economic burden are expected to increase. In order to develop prevention strategies that will apply to a particular country one must look at the factors influencing injury severity specifically to that country. To our knowledge no study has yet accessed which factors are associated to injury severity specific to the Netherlands. This master thesis will attempt to determine which factors are associated with injury severity in bicycle traffic-related accidents in the Netherlands. Due to the exploratory nature of this research it is not possible to formulate a hypothesis.

2 - Background

Road safety for bicycle users is a topic that has not received the same attention as for other means of transportation. However, with the increase in the number of cyclists all over the world and an aging population, it is expected that the burden of disease as well as the economic burden due to bicycle-related traffic accidents will rise. Due to the multifactorial nature of this topic, one needs to look into a multitude of variables in order to establish which factors may influence injury severity.

In addition to its multifactorial nature, bicycle-related traffic accidents may cause a wide range of injuries. Although bicycle crashes' mortality is often related to head injuries, upper and lower body fractures and abdominal injuries are also quite prevalent.[11,14] Soft tissue damage such as abrasions, lacerations and contusions occur in the great majority of the cases. However, when isolated, soft tissue injuries seldom pose a threat to the patients' lives and as a result primary care at the emergency department is sufficient. The body regions most commonly affected are the extremities. According to present literature, injury of body extremities is reported in 48%-73% of the cases and fractures in 18%-31%.[14,39] Notwithstanding traumatic brain injury is the leading cause of hospital admission, being associated with high mortality. Traumatic brain injuries occur in between 5%-10% of the cases and are implicated in 70% of fatal accidents. [9,15]

Consequently, when analyzing bicycle-related injuries due to traffic accidents, one cannot focus solely on isolated injures, as multiple injuries may account for 40%-65% of the patients admitted to the emergency department.[1617] It is fundamental to realize that as multiple injuries occur the risk of mortality and morbidity also increases. In the study of *Rivara et al.* regarding bicycle-related traffic accidents, while approximately one half (52%) of subjects sustained two or fewer injuries, 37% had three to five injuries, and 11% had more than five.[11] A multiple injury pattern as a result of bicycle accidents is also confirmed by *Geus et al.* where about 68% of the study population suffered more than one injury.[16]

In order to quantify these injuries, the injury severity score (ISS) is a measure of trauma for single or multiple trauma and is considered the "golden standard" in trauma severity grading.[18,19] It serves as a standardized anatomy platform to assess the extent of traumatic injuries. It ranges from 1 to 75 and an ISS>15 is frequently used as benchmark as to when the extent of the injury is considered multi-trauma and predictive of 10% mortality.

2.1 - Factors Implicated in Injury Severity

Not much is known as to what extent different factors associated to bicycle-related traffic injuries might influence injury severity. Despite being a common occurrence all over the world, injuries arising from bicycle-related traffic accidents have not yet been thoroughly studied. Despite its intricacy due to its multifactorial nature, some trends have recently emerged from the available scientific literature.

2.1.1 – Nature of the crash

Crash with a motor vehicle

Many factors have been implicated as potential causes for bicycle-related traffic accidents. The factor that may be more closely related to injury severity is collision with a motor vehicle. From those hospitalized, 20% are involved in a collision with another vehicle [9]. Most severe injuries seem to result from a collision with motor vehicles, where traumatic brain injuries are implicated in 29% of the cases. [10,16] Taking into consideration the high morbidity and mortality of traumatic brain injuries, it is not surprising that motor vehicle involvement increases the risk of hospital admission by 4 fold and patients are 14.1 times more likely to die as a result of the injuries sustained from the accident. Furthermore, in vehicles traveling at speeds higher than 50km/h the probability of a cyclist suffering a fatal injury doubles and increases 16-fold in vehicles traveling at 80 km/h.[20]

Bicycle type

The nature of cycling has been changing in recent years. An increasing number of cyclists have adopted the e-bike, especially among the elderly. With increase speed capacity a cyclist may ride on average up to 3.6km/h faster on an e-bike than on a conventional bike in normal traffic conditions.[21] With the introduction of e-bikes and increase cycling speeds, bicycle user may be exposed to collision forces that until now had rarely occurred. Because e-bikes are also heavier, they may pose a threat when the cyclist falls. In addition, some research suggests that head and neck injuries are more prominent in e-bike traffic accidents.[22] When taking all these factors into consideration, one may speculate that the use of e-bikes will have an impact on injury severity.

Although the great majority of cycling injuries results from day to day cycling, recreational bicycle use such as mountain biking or road race cycling are also very popular cycling activities which should not be disregarded. With regards to road race cycling, participants can reach speeds of 50km/h with minimum protective gear. This combination of factors, together with diverse weather and road conditions, makes road race cyclists prone to traumatic injuries.[23] In the study of *Decock et al.*, 16% of road race cyclists suffered at least one injury during the time frame of one year and severe injuries were seen in 29.5% of the incidents.[23] Mountain biking has a very specific set of conditions in which it is practiced. The terrain is usually irregular, unpaved with constant changes in inclination. Depending on the terrain there may be hidden rocks, tree branches and other dangerous hazards which increase the risk and severity of injuries. Its participants also frequently attempt various jumps in addition to a variety of tricks. According to *Roberts et al.* there is a difference is the mechanism of injury between mountain bikers and street cyclist.[24] Major injuries (ISS>12) in street cyclists are in the majority of cases due to collision with a motor vehicle, while mountain bikers are more commonly severely injured due to faulty jump attempts or tricks. Although the median ISS was the same for both groups, the injury pattern differed with spinal injuries being more prevalent in the mountain bike group.[24]

2.1.2 – Demographic factors

Demographic distribution seems to affect the extent of injuries among cyclists as well as injury pattern and mechanism of accident.[9-25,26] The relationship between bicycle traffic accidents and injury severity has not yet been empirically established. Patterns among each age group, interaction with other road users or health conditions may influence injury prevalence severity.[27]

Age

Consistent with other reports, age seems to a play a fundamental role in injury severity. Although younger cyclists are more frequent bike users, mortality is more often associated with older age.[9,17,28] Regarding injury severity, children under 12 years of age and adults over 40 have on average more severe injuries.[11] Head trauma and fractures of the upper extremities were more often observed in individuals aged 20 to 29 years and over 70 years. Chest trauma seems more frequent among older patients than younger patients. It also seemed that collision with a motor vehicle was more common in adults aged 20-29, while injury as a result from a fall without external causes was more common among the population above 60 years and below 9 years of age.[9]

Gender

In the population between 30-39 years, males were more susceptible to bicycle traffic accidents in comparison to females. On the other hand, above 70 years of age, females were more frequently injured. Overall, males were 2.4 times more likely to die as a result of a bicycle traffic accident related injury than females.[9-11]

Comorbidity

There seems to be a relation between injury severity and medical history of disease. *Hitosugi et al.* found that patients who were victims of a disease-related death after a bicycle traffic accident had a significantly higher prevalence of diabetes mellitus, hypertension, hyperlipidemia, heart disease and cerebrovascular diseases.[29] These conditions are associated with an aging population and can play a role in the post-injury outcome. In addition to the burden of various comorbidities on injury severity itself, the use of certain drugs may also influence the outcome of a bicycle traffic accident. For instance, the use of anticoagulants may have a negative effect on injury severity, especially with regards to head injuries. Anticoagulants are associated with increase bleeding and thus worsen the outcome.[30]

2.1.3 – Individual factors

Next to particular demographic factors there are individual behaviors which influence the outcome of a bicycle traffic accident. Almost half of the bicycle accidents can be traced back to the cyclist behavior.[16,31] Helmet use and alcohol consumption are prominent factors shown to influence injury severity in bicycle traffic accidents.[9,25,32]

Helmet use

Various studies have looked at the efficacy of helmet use in the prevention of head injuries.[12,33] As a whole the use of helmet decreased the risk of head injury, brain and severe brain injury between 63% and 88%. Its use seems to be equally efficient among all age groups and associated with protection from crashes against motor vehicles and other miscellaneous causes.[34] In accidents involving a motor vehicle, *Maimaris et al*. demonstrated that 18% of those not wearing a helmet suffered head injuries in comparison to 7% of those wearing one. With regards to Quality of Life (QOL), reported post-concussion symptoms are less prominent and less severe in those wearing helmets.[33] In some studies, helmet use does not seem to significantly decrease the occurrence of head injuries but rather its severity. Nevertheless, considering the increase risk of mortality and morbidity of head injuries it is comprehensible that helmet use is still advised by most studies.[3,12,33] Concurrent with these findings, the World Health Organization (WHO) has recommended countries the implementation of legislation making the use of helmets compulsory.[35]

Alcohol use

The Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (Foundation for Road Safety Research, SWOV) has identified that bicycle accidents frequently result from the behavior of the cyclist self. Among these factors the effects of alcohol use is emphasized.[1] Cycling requires a high level of psychomotor abilities that have been shown to decline progressively as blood alcohol concentrations (BAC) increase. As result, increase in BAC is associated with increase injury severity. From those attending the emergency department as a result of a bicycle-related traffic accident, elevated alcohol blood level is found in up to 8% of the cases and 32% from those who have died as a result of their injuries.[32] Of the cyclists that were seriously injured after a bicycle traffic accident not involving a motor vehicle, 5% of those could be traced back to the use of alcohol prior to the crash.[1,31]

2.1.4 – Interaction between variables

When riding a bicycle, the cyclist is dependent on a multitude of variables which not only act independently but also influence each other when determining the occurrence and injury severity in bicycle-related traffic accidents. One may speculate that older cyclists are more inclined to using e-bikes because of the presence of various comorbidities. The higher speeds of an e-bike and various co-morbidities may subsequently influence injury severity. In fact, international research suggests that e-bike users are predominantly male and the great majority above 40 years old.[22,36] In addition mental workload while riding an e-bike is higher in older cyclists when compared to other age groups. This implies not being able to process the complicated traffic situations and leaving them more susceptible to injuries due to collision with other traffic participants.[21] In its turn, younger individuals are more inclined to use bicycles for other purposes (i.e. race cycling and mountain biking) which entails its own risks.[24]

The risk of injury due to bicycle-related traffic accidents varies throughout life, depending on gender. This phenomenon has been associated with risky behavior. From various studies males seem more often injured as a result of bicycle-related traffic accidents, either in day-to-day or recreational cycling.[14,23,24] This pattern is even more marked during teenage years, where hormonal changes and inability to cope with stressful situations leads to increased risky behavior.[5] Moreover, males are also more likely to participate in road race cycling and mountain biking, where stunts and high speeds may play a role in injury severity.

In the age group between 18-59 years, alcohol use remains relatively high particularly on weekends at night.[14] Due to their behavior and not age per se these cyclists are at an increase risk of injury. In addition, due to its time frame at which alcohol is usually consumed, bicycle-related traffic accidents occurring at night are dependent on different traffic conditions, lighting and behaviors.

2.2 - International differences

It is essential to realize that each country has its own cycling culture, urban form, infrastructure and demographics. Behavior factors, as well as external factors such as climate, average road vehicle size and condition/existence of cycling lanes may vary immensely from one population to the other. Each of these factors plays a role in the multifactorial nature of bicycle-related traffic accidents and can impact injury severity.[20]

While in the Netherlands on average 31% of the population uses cycling as a main means of transportation, only 1% of daily trips are made by cycling in North America. When compared to Dutch cyclists, North Americans have a higher rate of cycling-associated injury, with a two-to-three fold higher risk of death and an eight to 30-fold higher risk of injury per kilometer.[13] While demographic differences may be subtle, especially among studies carried out in Europe, the differences can be significant if the study would be carried out in countries with different cultural costumes. As an example, a study realized in Iran by *Vahdati et al.* only included men in the study population.[25] Appropriate infrastructure, provided with street lighting and in good conditions for cycling (i.e. cycle tracks at roundabouts, bike routes, cycling lanes and bike paths) seems to be associated with lower risk of injury among cyclists. More importantly the existence of cycling lanes may reduce risk of injury or crash rates by half among cyclist, when compared to cycling on normal motorways.[37,38] Another important infrastructural difference is the existence of roundabouts. Although very common in the Netherlands and to some extent throughout Europe, roundabouts are quite rare in the USA. Looking at the infrastructure construct in the USA interceptions are much more common, yet this may increase the risk of a bicycle-related traffic accident by 30-50%.[28] *Davidson et al.* carried out a study in the United Kingdom (UK). In their study, men cycling on isolated roads without bicycle paths during light hours were more likely to sustain injuries. It was consequently advised that the UK should follow the example of countries like the Netherlands and Denmark in order to prevent bicycle related injuries by creating proper infrastructure and raising awareness about bicycle traffic accidents among the community.[17]

The Netherlands, with its personal cycling culture and good infrastructure presents very different cycling conditions from those found in China, USA, UK or Australia. Accounting for the multitude of factors associated with traffic accident bicycle injuries and the great variations of these factors between countries, it is expect that the trauma profile would also differ. A direct comparison of the patient profile between Australia and the Netherlands revealed that the patients presenting to the trauma center in the Netherlands were on average older and that there was a greater proportion of females.[26] Most injuries in the Netherlands occurred in patients above 60 years old, while the age group between 40 and 59 years of age was the most affected in Australia. In addition, Australian males in the younger age group suffered more often injuries. Both countries reported collisions with motor vehicles as the main mechanism of injury. Additionally, more patients were admitted to the trauma center in Australia due to falls. Helmet use was also more common in Australia. The patients at trauma center in the Netherlands also had more serious injuries in the head and neck region, while the Australian group had more serious injuries in all of the other body regions. Explanations for such differences laid on cycling culture differences and infrastructure. It was argued that cycling is the Netherlands is encouraged from a young age, with motor vehicle drivers being aware of the vulnerability of cyclists. In Australia, cyclists start at an older age and for the larger part have never been exposed to cycling in traffic. The type of cycling is also different, as Australians tend to do more recreational cycling with appropriate gear and longer distances (road racing and mountain biking), while the Dutch wear casual wear and tend to cycle shorter distances. Finally, in Australian cyclists often have to share the main road with motorized vehicles going at 80-100km/h. In the Netherlands the infrastructure is suitable for cycling with separate bicycle lanes.

3 – Materials & Methods

3.1 – Design

A cohort study was conducted, including any adult individual who had been involved in a bicycle traffic accident, seeking medical treatment at the trauma center of the University Medical Center Groningen (UMCG), The Netherlands, from July 1st 2014 to December 15th 2016. The UMCG trauma center is a level 1 trauma center and the largest in the Netherlands. Data up to June 2015 had already been collected from a previous study. The UMCG serves a region containing around 1/5 of the Dutch population and 200-250 multi-trauma patients are admitted per year. The study received approval from the Medical Ethics Committee of the University Medical Center Groningen.

3.2- Participants

The study population included any patient above 18 years of age, seeking medical attention at the UMCG due to a bicycle accident related injury. A bicycle injury is defined as an injury resulting from a bicycle in motion with any physical damage notwithstanding cause. In case of multiple attendances to the emergency department due to the same injury, only the first attendance will was counted. Patients already deceased on arrival were also not included in the study.

3.3 – Procedure

Data was collected from the trauma department at the UMCG and complementary data from the Landelijke traumaregistratie (National Trauma Register, LTR). The database includes demographic data, medical relevant information, type of bicycle, environmental factors, mechanism of trauma and details of injuries (including abbreviated injury scale (AIS) as well as ISS). More specifically: season, type of bicycle (e-bike, normal, race-bike, mountain bike, other), helmet usage, collision type (one-sided – fall without external causes, two sided – collision with another road user, collision with stationary object, other), crash with a car, number of surgical treatments, submission to- and length of stay in the intensive care unit, length of hospital stay, survival rate, number of comorbidities (cardiac, hypertension, pulmonary, kidney failure, diabetes mellitus, neurologic, endocrine, musculoskeletal", psychiatric), polypharmacy (>5 medications) and use of anticoagulants. Data concerning bicycle-related car accident only began to be collected from June 2015. LTR records between 2014 and 2015 were included in this study. The LTR database includes: cause of accident, nature of the injury, ambulance time, clinical data (surgical interventions, admission dates), demographic data (gender, age) and the AIS and ISS.

The AIS is a consensus derived anatomically-based system to classify injuries by body region. It is based on an ordinal scale with 6 being the highest severity (untreatable) and 1 the lowest severity.[39] The AIS however does not assess the combined effects of multiple body region injuries. The ISS is consequently much better suited as a grading system for accessing injury severity and mortality in patients with multi-trauma. The ISS is calculated based on the sum of the squares of the highest AIS in three body regions. With regards to this study patients with two or more injuries on different body regions were defined as poly-trauma and patients with an ISS > 15 were defined as multi-trauma patients. For further instructions on how to calculate and use the AIS and ISS please refer to "The Abbreviated Injury Scale – 1990 Revision, Update 98".[39]

The trauma department carried out the initial triage and consultation. Electronic patient files were then accessible for extraction of relevant data. Additional information regarding the type of bicycle, helmet use, collision type, cause of the accident, location of the accident and lane type where the accident occurred was obtained through questionnaires (**Appendix 1**). Participants were given the opportunity to indicate the option "other" for type of bike, collision type, cause of the accident and lane type next to the standardized choices, as well as a written explanation for their answers. The questionnaire was constructed specifically for this study. Each study participant received a paper version of the questionnaire by mail. In addition the questionnaire was also made available online. The online questionnaire was identical to the paper version in its totality. Data from the paper questionnaire was directly included in the database. The data from the online version was first processed in an Excel file for Windows and then added to the database. After two weeks non-responders received a reminder by mail. By persisting non-response, patients were approached by phone and the questionnaire was carried out verbally. Participants who could not be reached by post, or phone were assessed as non-responders. The privacy and confidentiality of any medical data of the research subjects was protected by de-identifying patients.

3.4 – Statistical analysis

Descriptive statistics were carried out to summarize the profile of the study population using mean, standard deviation and percentages. For not normally distributed data the median and the interquartile range (IQR) were used.

Due to the right skewed nature without the possibility of normalization, ISS was dichotomized. For this study we used a common benchmark for multi-trauma where ISS>15. Hence the independent variable was dichotomized into ISS≤15 and ISS>15. For preliminary selection, each independent variable was examined through a univariable logistic regression model. Any variables with less than 50 individuals were not included in the model. Based on the scientific literature, the independent variables initially chosen to carry out the univariable logistic regression model were: age (categorized into 18-39, 40-59, ≥60 years old), gender (female/male), comorbidity (yes/no), bicycle-related car accident (yes/no), alcohol use (yes/no), bicycle type (road bicycle, e-bike, speed bike, race bike, mountain bike, other), collision type (one-sided, object, two-sided, other), helmet use (yes/no) and lane type (cycling lane, crossing without traffic, traffic lane without bicycle lane, other). Variables with a p-value <0.20 (p) in the overall test variable were further analyzed.

Variables with possible associations were checked for effect modification and the occurrence of proxy variables. Effect modification between variables was analyzed by including an interaction term in the multivariable model and looking if p-value <0.05. If p-value of the interaction terms was <0.05, it was said to exist effect modification.[40] Proxy variables and variables with effect modification were removed from the study based on their Wald score. The variable with the lowest Wald score on the univariable logistic regression model was removed from the study.

The remaining variables were computed in multivariable logistic regression model according to their Wald value where the variable with the highest Wald value would be inserted first in the model. A p-value ≤0.05 in was considered statistically significant. The confidence interval (CI) was set to 95%. The regression coefficient (B) was used to calculate the odds ratio (OR) in which OR >1 indicates a higher chance of multi-trauma. Chi-square test was used for additional analysis.

All analyses were performed using the Statistical Package for the Social Sciences (SPSS) for Windows (version 23.0).

4 – Results

4.1 – Study population characteristics

4.1.1 – Demographics

Altogether 1010 patients were admitted to the trauma center, UMCG between July 2014 and December 2016 **(Table 1)**. From these patients, 539 (53%) were male and 471 (47%) were female, with ages ranging from 18 to 93 years old. Median age was 47 years (IQR, Q1=25 and Q3=62).

Among the study population 439 (43%) participants were diagnosed with one or more comorbidities prior to the accident. Comorbidity was proportionately higher in older participants, where 77% of cyclists aged 60 years and older had one or more comorbidities. In this group, cardiac disease and hypertension were the most common conditions.

Around 20% of the total study population was under the influence of alcohol at the time of the bicycle-related traffic accident. Alcohol intoxication was more frequent in the younger age groups, between 18 and 39 years of age. Overall, males were comparatively more often intoxicated than females.

Finally the questionnaire's response rate was of 58%.

Table 1 – Demographic distinction of the study population (n=1010)

	N (%)
Age	
18-39	441 (43.7%)
40-59	259 (25.6%)
≥60	310 (30.7%)
Gender	
Male	539 (53.4%)
Female	471 (46.6%)
Comorbidity	
Yes	439 (43.5%)
No	571 (56.5%)
Alcohol	
Yes	205 (20.3%)
No	805 (79.7%)

4.1.2 – Crash characteristics

The bicycle type most often used at the occurrence of a bicycle-related traffic accident was the common road bicycle in 675 (67%) of the cases **(Table 2)**. E-bike users were the second most occurring group with 187 (19%) of the cases. Seventy-four percent of all e-bikes were used by individuals above 60 years, of which half were cycling normal road bikes and half e-bikes at the time of the accident.

Helmet use at the time of a bicycle-related traffic accident was registered in only 8% of the cases. Additionally, 69% of helmet use occurred in individuals riding a race bike. Only 3 participants wore a helmet when riding a normal road bicycle or an e-bike.

The majority of accidents were one sided (54%). Two sided accidents were also quite prevalent, occurring in 339 (34%) of the cases. In total 77 (14%) patients had suffered a bicycle-related car accident.

Unlike other variables, lane type was exclusively dependent on questionnaire response. Thirty-nine percent of those accidents occurred on a traffic lane without traffic light. Cycling lane and "other" (e.g. bridge, parking lot) had similar occurrence rates with 24% and 21% respectively.

Table 2 – Crash characteristics of the study population

	N (%)
Bicycle Type (n=1010)	
Road bike	675 (66.8%)
E-bike	187 (18.5%)
Speed bike	8 (0.8%)
Race bike	79 (7.8%)
Mountain bike	39 (3.9%)
Other	22 (2.2%)
Helmet (n=1010)	
Yes	77 (7.6%)
No	933 (92.4%)
Collision type (n=1001)	
One-sided	545 (54.4%)
Two-sided	339 (33.9%)
Object	66 (6.6%)
Other	51 (5.1%)
Car accident (n=572)	
Yes	77 (13.6%)
No	495 (86.4%)
Lane Type (n=584)	
Cycling lane	141 (24.1%)
Crossing with traffic light	15 (2.6%)
Crossing w/out traffic light	63 (10.8%)
Roundabout	9 (1.5%)
Crosswalk	10 (1.7%)
Traffic lane with cycling lane	40 (6.8%)
Traffic lane w/out cycling lane	185 (31.7%)
Other	120 (20.5%)

4.1.3 – Injury description

Patients presented with a broad spectrum of injuries **(Fig. 1)**. The most frequent injured body region was to the upper body in 397 (39%) of the cases. In this body region, the most common injury was a clavicle fracture (5%), followed by a closed radius fracture (4.7%). Injuries to the head were also quite prominent (31%), where short loss of consciousness without any other physiological brain changes was the most common cause of injury (n=63). Injuries to the lower body occurred in 286 (29%) cyclists. About a quarter of the cyclists (n=260) reported injures in the face region. Other body regions had a considerably lower incidence. The neck region was affected in 16 cases (1.6%), the thorax in 79 cases (7.8%) and the abdomen and spine accounted for 26 (2.6%) and 52 (5.1%) of the cases respectively.

External injuries, including abrasions, contusions and lacerations from any body region were registered about in about half of the cyclists.

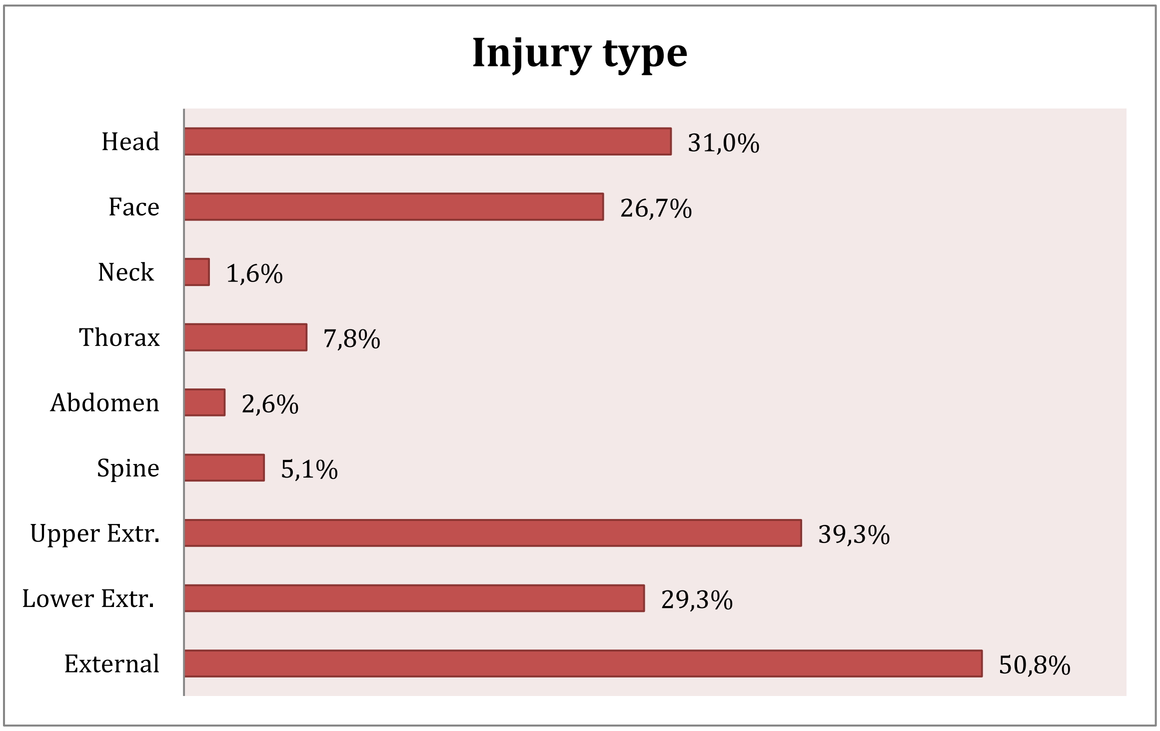

Fig. 1 – Injury description per body region of the study population

4.1.4 – Injury severity

The median ISS was 4 (IQR: Q1=1 and Q3=9). The most common ISS was 1, reported in 276 cases. Highest recorded ISS was 41. Ninety patients had an ISS >15. During the conduction of the study, 22 deaths (2.2%) were recorded, from which 13 had an ISS above 15.

4.2 - Univariable analysis

From **Table 3**, the potential predictive variables ($p<0.20$) were: age, gender, comorbidity, bicycle-related car accident, bicycle type, collision type and lane type. Alcohol use and helmet use were not predictors of a multi-trauma injury resulting from a bicycle-related accident. Helmet use seemed to decrease the risk of multi-trauma (OR=0.85), however this result is not statistically significant. Based on Wald-value the variables which demonstrated the strongest association with multi-trauma were, age (Wald= 45.82) followed by collision type (Wald= 35.12)

Table 3 – Univariable Logistic Regression Analysis on Multi-trauma

	B	SE	Wald	P	OR	CI 95%	
Age			**45.82**	**<0.001**			
18-39				Indicator			
40-59	0.43	0.36	1.38	0.24	1.53	0.75	3.16
≥60	1.75	0.29	37.07	<0.001	5.74	3.27	10.08
Gender	0.61	0.23	**6.86**	**<0.001**	1.84	1.17	2.91
Comorbidity	0.89	0.23	**15.14**	**<0.001**	2.43	1.55	3.81
Car accident	1.29	0.34	**13.76**	**<0.001**	3.56	1.82	6.95
Alcohol	-0.26	0.29	0.8	0.37	0.77	0.43	1.37
Bicycle Type			**15.86**	**<0.001**			
Road bike				Indicator			
E-bike	0.92	0.25	13.92	<0.001	2.5	1.55	4.05
Race bike	0.67	0.53	0.58	0.45	0.67	0.23	1.9
Collision type			**35.12**	**<0.001**			
One-sided				Indicator			
Two-sided	1.55	0.26	34.87	<0.01	4.7	2.81	7.87
Object	0.87	0.48	3.25	0.07	2.38	0.93	6.09
Other	0.95	0.52	3.35	0.07	2.58	0.94	7.14
Helmet	-0.16	0.44	0.13	0.72	0.85	0.36	2.02
Lane Type			**4.93**	**0.18**			
Cycling lane				Indicator			
Crossing w/out traffic light	-0.71	0.66	1.16	0.28	0.49	0.14	1.79
Traffic lane w/out cycling lane	-0.58	0.44	1.74	0.19	0.56	0.24	1.32
Other	0.26	0.41	0.42	0.52	1.3	0.57	2.89

4.3 – Effect modification and proxy variables

Analysis for effect modification and proxy variables was carried on variables where p<0.20 in the univariable logistic regression model **(Table 3**).

There was a strong indication for an association between age and comorbidity. From the individuals above 60 years of age, 77% had one or more comorbidities, while this percentage was 19% in the group between 18-39 years. In addition a chi-square test between age and comorbidity had a p-value <0.001. Due to the strong relation between comorbidity and age and the higher Wald-value of age, we have proceeded to eliminate comorbidity from our multivariable logistic regression model.

The two-sided collision type and bicycle-related car accident were considered to be proxy variables. An association between these variables was already expected as all bicycle-related car accidents are per definition two-sided. From the 77 individuals who had a bicycle-related car accident, 100% were “two-sided”. Car accident (Wald=13.76) had a lower Wald-value than two-sided collision type (Wald=34.87). It was therefore decided to remove the variable “car accident” from the model.

No effect modification was observed between variables.

4.4 – Multivariable analysis

From **Table 4**, the significant predictive variables of multi-trauma injury (ISS>15) are: age, gender and collision type. The risk of multi-trauma seemed to increase with age. Although the risk increased consistently with increasing age group category (40-59 OR=0.8 and ≥60 OR=4.14) that risk was only statistically significant in the group above 60 (p=0.01). Gender is a strong predictor for multi-trauma, where males had and increased risk of multi-trauma (OR=2.84, p=0.01) than females. Type of bicycle does not appear to be a predictor. Neither e-bike (p=0.62) nor race bike (p=0.54) showed a statistically significant difference with regards to multi-trauma occurrence as compared to a normal road bicycle. This is in contrast with the univariable logistic regression analysis (**Table 3**) that showed a statistically significant higher incidence of multi-trauma in individuals riding e-bikes compared to those riding normal road bikes (OR=2.5, p<0.001). Collision type was a statically significant predictor for multi-trauma. When compared to a one-sided bicycle-related traffic accident, a two-sided bicycle-related traffic accident increases the risk of multi-trauma by 3.48-fold (p=0.01). An accident against an object had 3.45-fold (p=0.04) increase, while the "other" collision type a 4.02-fold (p=0.02) increase in the risk of multi-trauma. From the categories selected for the variable lane type, none were statistically significant. Crossing without traffic light had an OR=0.38 (p=0.17), traffic lane without cycling lane an OR=0.69 (p=0.45) and "other" an OR=1.34 (p=0.54). Together with age above 60 years (OR=4.14), a collision type "other" had the second highest predictive odds ratio (OR=4.02), followed by a two-sided bicycle-related traffic accident (OR=3.48).

Table 4 – Multivariable Logistic Regression Analysis on Multi-trauma

	B	SE	Wald	P	OR	CI 95%	
Age							
18-39	Indicator						
40-59	-0.22	0.71	0.1	0.75	0.8	0.2	3.22
≥60	1.42	0.56	6.37	**0.01**	**4.14**	1.37	12.49
Gender	1.04	0.39	7.1	**0.01**	**2.84**	1.32	6.13
Bicycle Type							
Road bike	Indicator						
E-bike	0.21	0.42	0.25	0.62	1.23	0.54	2.8
Race bike	-0.43	0.71	0.37	0.54	0.65	0.16	2.60
Collision type							
One-sided	Indicator						
Two-sided	1.25	0.45	7.63	**0.01**	**3.48**	1.47	8.43
Object	1.24	0.61	4.16	**0.04**	**3.45**	1.05	11.35
Other	1.39	0.61	5.16	**0.02**	**4.02**	1.21	13.35
Lane type							
Cycling lane	Indicator						
Crossing w/out traffic light	-0.96	0.7	1.92	0.17	0.38	0.1	1.49
Traffic lane w/out cycling lane	-0.37	0.49	0.58	0.45	0.69	0.27	1.79
Other	0.29	0.48	0.37	0.54	1.34	0.53	3.41

5 – Discussion

This master thesis intended to determine which factors are associated with injury severity in bicycle-related traffic accidents in the Netherlands. More specifically, it attempted to draw a conclusion as to what factors are effect predictors of multi-trauma (ISS>15). Due to the lack of scientific literature and international differences concerning cycling culture, urban form, infrastructure and demographics, a preliminary study was necessary to determine which factors are associated with injury severity in bicycle-related traffic accidents in the Netherlands. With regards to this study, the variables associated with multi-trauma were age, gender and collision type. Individuals above 60 years of age and individuals involved in two-sided accidents seem to have the highest risk of multi-trauma as a result of a bicycle-related traffic accident.

Cycling is an essential component of the Dutch culture and the Netherlands has been considered a pioneer in the use of bicycles as a means of transportation.[13,38] There is however a great social and economic impact due to bicycle related traffic accidents, comprising 10% of the of patients admitted to the hospital after an accident in 2015 and costing annually around 3.5 billion euros on health care and productivity.[7,41]

This study included a total of 1010 participants with a questionnaire response rate of 58%. Our data included information from electronic patient files and a questionnaire sent to each participant. Potentially variables associated with multi-trauma in bicycle-related traffic accidents were extrapolated from other international research. [3,9-17,20-37]. The variables selected for this study were: age, gender, comorbidity, bicycle-related car accident, alcohol use, bicycle type, collision type, helmet use and lane type. The effect of these variables on multi-trauma (ISS>15) was then analyzed. Because cycling is a multifactorial activity, it was essential to take into consideration how variables would influence each other. To achieve this we carried out an initial pre-selection of variables and proceeded to compute the chosen variables in a multivariable regression model.

5.1 – Factor implicated in injury severity

Age

Predominantly injury severity in bicycle-related traffic accidents is increased in individuals above 60 years of age. We have found a statistically significant increase in the age group above 60 years old (OR= 4.14; p=0.01). This finding is consistent with current scientific literature.[9,14,26,28] A common trend observed in the studies analyzed was that although younger cyclists were more often involved in bicycle-related traffic accidents, the elderly had higher injury severity score. Furthermore, in a previous report published by the SWOV in the Netherlands, individuals above 65 years old had higher mortality rates than younger individuals.[6]

The cycling behavior as well as cycling abilities changes throughout the lifetime of an individual. The vulnerability index (measured by the number of deaths divided by the number of severely injures) increases dramatically in cyclists over the age of 65. In addition, older individuals are also more prone to traumatic brain injuries than younger cyclists.[5,42] It is not surprising that increasing age was closely associated with increased comorbidity. In its turn, both were significant variables in the univariable logistic regression model. The effect of comorbidity on multi-trauma should be objectively evaluated in further studies by correcting the model for age. With declining auditive, muscular and sensory functions as well as the increased burden of comorbidities, the elderly may not possess the necessary conditions to cycle safely. The 4.14-fold increase in the risk of multi-trauma in the age category above 60 years, may suggest that individuals in this age category are cycling even though they are not optimally physically fit to do so. Unlike driving a motorized vehicle, cycling does not require a license and the individual is not required to undergo a mandatory medical check-up. In a country like the Netherlands, which heavily relies on cycling as a means of transportation, a mandatory medical check-up is not feasible. Rather, older individual must be made aware of their limitations and the risks associated with cycling. This practice has already been implemented on an individual basis by some hospitals in the Netherlands. However the results of this study suggest the need for a broader awareness campaign.

Gender

Across all age groups males had a higher percentage of multi-trauma compared to females. These findings are consistent with those from previous scientific literature where males were found to have a 2.84-fold increase in the risk of multi-trauma compared to females.[9,11] Complex interactions may explain this phenomenon, potentially due to risk-taking behaviors in younger groups and lack of awareness in one's capabilities in the older age groups.[31] Furthermore, behavior is a potential cofounder, as cyclists under the same situations might choose different course of actions depending on their values, beliefs and personal traits. Risk or non-risk behavior is solely dependent on the individual's actions. Differences in risk-taking behavior have been found across cultures, social economic status, gender and age.[16,43,44] Unfortunately, behavioral observations lay outside of the spectrum of this research. Knowledge of the cyclists' values and perceptions of risk are consequently vital in designing future studies.

Collision type

Two-sided bicycle-related traffic accident increased the risk of multi-trauma by 3.48-fold. Considering that the great majority of motorized crashes would fall into two-sided, the increase in risk may be explained by the greater impact forces to which cyclists are exposed when colliding with a motorized vehicle. Due to a generalized cycling culture, a Dutch vehicle driver is more aware of the cyclist's vulnerability. From the data obtained, 7.6% of the accidents were due to a collision with a motorized vehicle. This percentage is much smaller than the 20% presented by *Juhra et al.* on bicycle-related traffic accidents in Germany.[9] Although cultural awareness may have an effect on incidence of the accidents against motorized vehicles, it will not affect injury severity.

The largest effect when analyzing injury severity due to a crash with a motorized vehicle is speed prior to impact.[20] There is a 93% increase in the probability of fatal injury when a prior vehicle speed is 32–48 km/h and up to a 504% increase in crashes with vehicles over 80.5 km/h. The type of vehicle is also a potential link between injury severity with heavier motorized vehicles, as these may increase the probabilities of fatal injury and incapacitating injury.[20] The speed and type of vehicle were however not noted in our study. Understanding the importance of speed and type of vehicle as predictors of injury severity, it is strongly advisable for further studies to take these into consideration as well. Moreover, necessary improvement is a clear definition and sub categorization of "two-sided collision type". Crashes with a motorized vehicle only represented 39% of the total "two-sided" crashes and we did not have any additional information as to further differentiate what was meant by "two-sided". It is assumed that a great majority would be crashes against other bicycles, but we cannot confirm this hypothesis. A reviewed "collision type" variable should include: collision with motorized vehicle, collision with other bicyclist, fall without external force and collision with fixed object.

Although the categories "object" and "other" only constituted 6.5% and 5% of the study population respectively, they were predictors of injury severity. We can infer that the increase in the probably of injury severity with an object results from the counter-force that the object will transfer to the cyclist. With regards to “other” we do not possess any additional information as to what might be the reason for the probability increase in multi-trauma. No correlation could be established between “other” collision type and other variables. Such situation further calls for the revision of the variable configuration.

Bicycle type

Type of bike was not a statistically significant predictor of multi-trauma. Because the introduction of the e-bikes to the market is a relatively new phenomenon, no studies have yet investigated e-bike role in injury severity to a control group. In the study from *Papoutsi et al.,* e-bike related traffic accidents had an mean ISS of 8.48.[22] In comparison to our study, which included a whole array of bicycle types, the ISS' value obtained by *Papoutsi et al.* was two times higher than our median. An increase in ISS is consistent with our univariable model in which e-bike related traffic accident increases the risk of multi-trauma by 2.5-fold. One must realize that a cycling accident at 30km/h is equivalent to a fall from a height of 3.6m.[9] Considering that e-bikes have an increased speed capacity as compared to normal road bikes, the increase in the risk of multi-trauma is comprehensible. On the other hand in the multivariable model the OR is merely 1.23 and not statically significant. The extent to which e-bike may influence injury severity in bicycle-related accidents is therefore unclear. The complicated interactions between variables during cycling hinder an objective interpretation of the data. E-bike use is commonly associated with increasing age and this may act as a proxy variable for age.[22,35]. E-bike use among 60-year-old individuals accounts for 74% of the total. Furthermore the distribution of normal road bike and e-bike use among this group is evenly divided. The possible association between these two variables was however not taken into consideration in our study. Long-term studies need to be carried out comparing e-bike related traffic accidents injury severity to a control group. Ideally this would be carried out in a multivariable model.

Lane type

Cycling infrastructure, in particularly lane type, does not seem to influence chance of multi-trauma in a bicycle-related traffic accident. Nonetheless the impact of infrastructure on injury incidence as well as injury severity has been documented in previous studies.[37,38] Cycling lanes have been associated with 50% reduction in injury risk and crash rates among cyclists, when compared to cycling on normal motorways. Unlike Australia and the USA, the Netherlands has a vast cycling infrastructure network, in which separate cycling lanes are a common occurrence. Owing to these ideal conditions, Dutch cyclists are theoretically less vulnerable to the motorized traffic stream and greater injury severity. The impact of the Dutch infrastructure on injury severity due to bicycle-related traffic accidents must be further investigated and compared to international data.

Helmet use

From the available scientific literature, helmet use has been virtually always recommended as a means to reduce injury, especially due to traumatic brain injury.[3,12,33] The WHO goes farther as advising compulsory helmet use laws.[35] In our study we could not confirm this hypothesis with respect to prevention of multi-trauma. Although this study showed that helmet use seemed to be associated with a 15% reduction in multi-trauma, this was not statistically significant. Helmet legislation is scarce in the Netherlands and helmet use is only required during competitive cycling.[45] From January 2017, helmet legislation will also be in place for speed bikes.[46] Nevertheless helmet wearing in the Netherlands is mostly left at the discretion of the individual. According to our study, helmet use was almost exclusively limited to recreational activities, such as race cycling of mountain biking. These two biking activities are carried out in a very specific set of conditions and as result any benefits of wearing a helmet on multi-trauma may not translate into other bicycle types. Unlike the Netherlands, compulsory helmet laws are in place in Australia. There, studies have found up to 39% reduction in the risk of head injuries.[12,33,47] In a post ten-year evaluation after the implementation of helmet wearing laws, the risk of sustaining a head injury as a result of a bicycle-related traffic accident decreased after the implementation of the law.[48] Although helmet use rates are higher in Australia, this must be also interpreted in a cultural context. Bicycle use is different in Australia; where cyclists tend to use bicycles for recreation in contrast to the daily commute activities seen in the Dutch population. Considering that the factors associated with each type of cycling as well as the cyclist behavior will differ, any direct comparisons of the effects of helmet use must be first controlled for type of bicycle. Unfortunately we do not possess sufficient data at the time to carry out this analysis. Future collaborations with international centers, especially in countries where helmet requirement laws are in place can be established to further analyze the impact of helmet use on injury severity resulting from bicycle-related traffic accidents.

Alcohol use

Although alcohol use seems to be associated with the frequency of bicycle-related traffic injuries, it does not seem to influence injury severity. In our study 20% of the population was under the influence of alcohol at the time of the accident. This percentage is higher than the 8% indicated in the report from the Rijkswaterstaat Dienst Verkeer en Scheepvaart (Department of Transport and Navigation).[31] Our higher percentage of cyclists under influence of alcohol may be explained by the fact that Groningen is a young student town. As cycling under the influence mainly occurs in younger groups this may have affected our results. The percentage of cycling while under the influence of alcohol can go up to 60% between the age groups of 18-24 during weekends at night.[1] Increasing age was found to significantly influence the incidence of multi-trauma in bicycle-related traffic accidents. Because alcohol intoxication was proportionately higher in younger individuals at the time of the accident, age may explain the 23% decrease in the chance of multi-trauma while cycling under the influence of alcohol. This is not necessary due to the influence of alcohol itself but due to the correlation of cycling under the influence and younger age. Alcohol use should be adjusted for age in further studies. Another possible inclusion in further research is the actual BAC measurements and not the sole reliance on patients' report. Higher BAC has been associated with increased risk of fatal or serious injury difference levels of intoxication may have different effects on injury severity.[32]

The increase in incidence of bicycle-related traffic accidents while driving under the influence of alcohol may not translate into increase injury severity. Falls without external cause have been linked to alcohol use, especially in younger age categories.[9] Therefore, although an increase in the incidence of bicycle-related accident exists, it may not translate directly into injury severity. While there is a growing awareness of effects of alcohol and drugs while driving motorized vehicles, the same level of awareness does not seem to be present when it comes to cycling. As a result, awareness of the risk posed by cycling under influence may be delayed. Awareness campaigns targeting the younger age groups are thus recommended.

5.2 – Limitations

As aforementioned, some revisions are necessary with regards to the format of our independent variables. The most concrete example is "other collision type" which was a significant predictor of multi-trauma, however we cannot provide any further explanation of what may cause this. The category "other" was an option in other variables from the questionnaire including: type of bike, collision type, cause of the accident and lane type. Such a category may only cause confusion to the participant and does not provide any additional information. The “other” category should be removed and the participants instructed to leave the question blank if none of the options fit their situation. Furthermore the use of questionnaire implies that the research is dependent on the interpretation and memory of the participant. The response rate also varied considerably by age group, with a 66% response rate among the participants above 60 years old but only 34% in participants between 18-39 years of age. It is important to realize that the lack of precise information on behavioral differences, physical capacities and cognitive abilities between age groups, as well as the lack of data among the younger age group prevent us from having a clear picture of the whole population. In instances where the data is 100% dependent on questionnaires as it is the case of the variable “lane type”, it may have affected the validity of our conclusion.

It is essential to continue with data collection for this topic in an efficient and systematic manner. The data extracted from patient files should become standardized. In order to avoid missing data, the anamnesis of every patient visiting the emergency department due to a bicycle-related traffic accident should be available through a standard form. Medical personnel may also be trained on potential factors associated with injury severity to better conduct anamnesis. More patients should be continuously added to the database. Although 1010 patients were included in the study some categories had to be discarded since they included less than 50 individuals. With special attention to the variable “lane type” it included eight categories, four of which had to removed. A recommend new format for “lane-type” question would include: separate bicycle lane, motorway with bicycle lane, motorway without bicycle lane and crossing.

Data collection was carried out at the UMCG in Groningen. Groningen is a known student-city in the Netherlands with a great percentage of young individuals. It has in total 26,000 students, with 10% of students coming from abroad. Groningen is also bicycle-oriented city with 145km of separate bicycle lanes.[49] The demographic composition and infrastructure characteristics of Groningen do not represent the whole of Netherlands. Notwithstanding, efforts have already been made to extent this study internationally in order to create a more realistic picture of the demographic composition of bicycle users. It is also advised setting-up local research partnerships with general practitioners (GPs) as minor injuries in the Netherlands are usually treated at GPs and may be underrepresented by an trauma 1 centers such as the UMCG.

5.3 – Conclusion

The factors associated with multi-trauma in bicycle traffic accidents are age, gender and collision type. Individuals above 60 years of age had the highest risk of multi-trauma (OR=4.14), followed by “other” collision type of accident (OR=4.02) and two-sided bicycle-related traffic accident (OR=3.48). It is strongly advised to continue this line of research in the future, as prevention focused on target variables will increase its efficiency.

6 - References

1. SWOV. *SWOV-Factsheet*. Leidschendam; 2013.
2. Weijermars W, Veilig D. *Tien Jaar Duurzaam Veilig*. Vol 100. Leidschendam; 2007.
3. Hu F, Lv D, Zhu J, Fang J. Related Risk Factors for Injury Severity of E-bike and Bicycle Crashes in Hefei. *Traffic Inj Prev*. 2014;15(3):319-323. doi:10.1080/15389588.2013.817669.
4. R.J. Davidse, K. van Duijvenvoorde, M.J.A. Doumen, M.J. Boele, C.W.A.E. Duivenvoorden WJRL. *2013 ICSC Davidse - Causes of Cyclists Crashes above 50 Years*. Den Haag; 2013.
5. Reurings MCB, Vlakveld WP, Twisk DAM, et al. Van fietsongeval naar maatregelen: kennis en hiaten. 2012:203.
6. SWOV. *SWOV-Kwetsbare Verkeersdeelnemers*. Leidschendam; 2012.
7. Polinder S, Haagsma J, Panneman M, Scholten A, Brugmans M, Van Beeck E. The economic burden of injury: Health care and productivity costs of injuries in the Netherlands. *Accid Anal Prev*. 2016;93:92-100. doi:10.1016/j.aap.2016.04.003.
8. Zibung E, Riddez L, Nordenvall C. Impaired quality of life after bicycle trauma. *Injury*. 2015;47(5):1078-1082. doi:10.1016/j.injury.2015.11.015.
9. Juhra C, Wieskötter B, Chu K, et al. Bicycle accidents - Do we only see the tip of the iceberg?: A prospective multi-centre study in a large German city combining medical and police data. *Injury*. 2012;43(12):2026-2034. doi:10.1016/j.injury.2011.10.016.
10. Tin Tin S, Woodward A, Ameratunga S. Injuries to pedal cyclists on New Zealand roads, 1988-2007. *BMC Public Health*. 2010;10(1):655. doi:10.1186/1471-2458-10-655.
11. Rivara FP, Thompson DC, Thompson RS. Epidemiology of bicycle injuries and risk factors for serious injury. *Inj Prev*. 1997;3(2):110-114. doi:10.1136/ip.3.2.110.
12. Kett P, Rivara F, Gomez A, Kirk AP, Yantsides C. The Effect of an All-Ages Bicycle Helmet Law on Bicycle-Related Trauma. *J Community Health*. 2016. doi:10.1007/s10900-016-0197-3.
13. Pucher J, Dijkstra L. Promoting Safe Walking and Cycling to Improve Public Health Walking and Cycling : the MOST sustainable transport modes. *Am J Public Health*. 2003;93(9):1509-1516. doi:10.1016/j.ypmed.2009.07.028.
14. Sikic M, Mikocka-Walus AA, Gabbe BJ, McDermott FT, Cameron PA. Bicycling injuries and mortality in Victoria, 2001-2006. *Med J Aust*. 2009;190(7):353-356. doi:sik11001_fm [pii].
15. Scholten AC, Polinder S, Panneman MJM, Van Beeck EF, Haagsma JA. Incidence and costs of bicycle-related traumatic brain injuries in the Netherlands. *Accid Anal Prev*. 2015;81:51-60. doi:10.1016/j.aap.2015.04.022.
16. De Geus B, Vandenbulcke G, Int Panis L, et al. A prospective cohort study on minor accidents involving commuter cyclists in Belgium. *Accid Anal Prev*. 2012;45:683-693. doi:10.1016/j.aap.2011.09.045.
17. Davidson JA. Epidemiology and outcome of bicycle injuries presenting to an emergency department in the United Kingdom. *Eur J Emerg Med*. 2005;12(1):24-29. doi:10.1097/00063110-200502000-00007.
18. Copes WS, Champion HR, Sacco WJ, Lawnick MM, Keast SL, Bain LW. The Injury Severity Score Revisited. *J Trauma Inj Infect Crit Care*. 1988;28(1):69-77. doi:10.1097/00005373-197403000-00001.
19. Lavoie A, Moore L, LeSage N, Liberman M, Sampalis JS. The Injury Severity Score or the New Injury Severity Score for predicting intensive care unit admission and hospital length of stay? *Injury*. 2005;36(4):477-483. doi:10.1016/j.injury.2004.09.039.
20. Kim JK, Kim S, Ulfarsson GF, Porrello LA. Bicyclist injury severities in bicycle-motor

vehicle accidents. *Accid Anal Prev*. 2007;39(2):238-251. doi:10.1016/j.aap.2006.07.002.
21. Vlakveld WP, Twisk D, Christoph M, et al. Speed choice and mental workload of elderly cyclists on e-bikes in simple and complex traffic situations: A field experiment. *Accid Anal Prev*. 2015;74:97-106. doi:10.1016/j.aap.2014.10.018.
22. Papoutsi S, Martinolli L, Braun CT, Exadaktylos AK. E-Bike Injuries : Experience from an Urban Emergency Department — A Retrospective Study from Switzerland. *Emerg Med Int*. 2014;2014(Table 1):1-5. doi:10.1155/2014/850236.
23. Decock M, De Wilde L, Vanden Bossche L, Steyaert A, Van Tongel A. Incidence and aetiology of acute injuries during competitive road cycling. *Br J Sports Med*. 2016:bjsports-2015-095612. doi:10.1136/bjsports-2015-095612.
24. Roberts DJ, Ouellet JF, Sutherland FR, Kirkpatrick AW, Lall RN, Ball CG. Severe street and mountain bicycling injuries in adults: A comparison of the incidence, risk factors and injury patterns over 14 years. *Can J Surg*. 2013;56(3):32-38. doi:10.1503/cjs.027411.
25. Vahdati SS, Ghafouri RR, Razavi S, Mazouchian H. Bicycle-Related Injuries Presenting to Tabriz Imam Reza Hospital , Iran. 2016;21(2):4-7. doi:10.5812/traumamon.20856.Research.
26. Yilmaz P, Gabbe BJ, McDermott FT, et al. Comparison of the serious injury pattern of adult bicyclists, between South-West Netherlands and the State of Victoria, Australia 2001-2009. *Injury*. 2013;44(6):848-854. doi:10.1016/j.injury.2013.03.007.
27. Yeung JHH, Leung CSM, Poon WS, Cheung NK, Graham CA, Rainer TH. Bicycle related injuries presenting to a trauma centre in Hong Kong. *Injury*. 2009;40(5):555-559. doi:10.1016/j.injury.2008.08.015.
28. Chen WS, Dunn RY, Chen AJ, Linakis JG. Epidemiology of Nonfatal Bicycle Injuries Presenting to United States Emergency Departments, 2001-2008. *Acad Emerg Med*. 2013;20(6):570-575. doi:10.1111/acem.12146.
29. Hitosugi M, Koseki T, Miyama G, Furukawa S, Morita S. Comparison of the injury severity and medical history of disease-related versus trauma-related bicyclist fatalities. *Leg Med*. 2016;18:58-61. doi:10.1016/j.legalmed.2015.12.001.
30. Foks KA, Volovici V, Kwee LE, Haitsma IK. Ernstige late intracraniële afwijkingen na licht schedel- hersenletsel bij oraal anticoagulantiagebruik. 2016:1-4.
31. Ormel W, Klein Wolt K, den Hertog P. Enkelvoudige fietsongevallen. *Rijkswaterstaat D Verkeer en Scheepv*. 2009;(november):90.
32. Li G, Baker SP, Smialek JE, Soderstrom CA. Use of Alcohol as a Risk Factor. 2013;285(7):893-896.
33. Maimaris C, Summers CL, Browning C, Palmer CR. Injury patterns in cyclists attending an accident and emergency department: a comparison of helmet wearers and non-wearers. *BMJ*. 1994;308(6943):1537-1540. doi:10.1136/bmj.308.6943.1537.
34. Thompson DC, Rivara FP, Thompson R. Helmets for preventing head and facial injuries in bicyclists. *Cochrane Database Syst Rev*. 2000;(2):CD001855. doi:10.1002/14651858.CD001855.
35. World Health Organization. *Helmets: A Road Safety Manual for Decision-Makers and Practicioners*.; 2006. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Helmets+A+road+safety+manual+for+decision-makers+and+practitioners#0.
36. Du W, Yang J, Powis B, et al. Understanding on-road practices of electric bike riders: An observational study in a developed city of China. *Accid Anal Prev*. 2013;59:319-326. doi:10.1016/j.aap.2013.06.011.
37. Boufous S, De Rome L, Senserrick T, Ivers R. Risk factors for severe injury in cyclists

involved in traffic crashes in Victoria, Australia. *Accid Anal Prev*. 2012;49:404-409. doi:10.1016/j.aap.2012.03.011.
38. Reynolds CCO, Harris MA, Teschke K, Cripton PA, Winters M. The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. *Environ Health Perspect*. 2009;8(1):47. doi:10.1186/1476-069X-8-47.
39. Association for the Advancement of Automotive Medicine. *Abbreviated Injury Scale - 1990 Revision*.; 1998.
40. Eckel S. *Lecture 15 : Effect Modification , and Confounding in Logistic Regression Today ' S Logistic Regression Topics Including Categorical Predictor*.; 2008.
41. Berden HJJ, Leenen LPH. Landelijke Traumaregistratie. 2015.
42. SWOV. *SWOV Fact Sheet Senior Cyclists*. Vol 2010.; 2013.
43. Kipping RR, Smith M, Heron J, Hickman M, Campbell R. Multiple risk behaviour in adolescence and socio-economic status: Findings from a UK birth cohort. *Eur J Public Health*. 2015;25(1):44-49. doi:10.1093/eurpub/cku078.
44. Osberg JS, Stiles SC, Asare OK. Bicycle safety behavior in Paris and Boston. *Accid Anal Prev*. 1998;30(5):679-687. doi:10.1016/S0001-4575(97)00097-3.
45. Krag T. Helmet laws in progress. 2005.
46. De Rijksoverheid. Welke regels gelden voor speed-pedelecs en wat verandert er per 1 januari 2017? https://www.rijksoverheid.nl/onderwerpen/bijzondere-voertuigen/vraag-en-antwoord/welke-regels-gelden-voor-speed-pedelec. Accessed January 1, 2017.
47. Vulcan P, Lane J. Bicycle helmets reduce head injuries and should be worn by all. *Inj Prev*. 1996;2(4):251-252. doi:10.1136/ip.2.4.251.
48. Cameron MH, Vulcan AP, Finch CF, Newstead S V. Mandatory bicycle helmet use following a decade of helmet promotion in Victoria, Australia-An evaluation. *Accid Anal Prev*. 1994;26(3):325-337. doi:10.1016/0001-4575(94)90006-X.
49. Marketing Groningen. Facts & Figures Groningen. 2017. https://toerisme.groningen.nl/over-groningen/stad-groningen/facts-figures-groningen. Accessed February 14, 2017.

7 – Appendix

Appendix 1

U kunt de vragenlijst ook online invullen op www.fiets.umcg.nl. **Uw deelnemernummer is: 797**

Wilt u het meest passende antwoord aankruisen en, indien gevraagd, toelichting geven op uw antwoord?

2737. Op wat voor soort fiets reed u?

- ☐ Gewone fiets
- ☐ Elektrische fiets (E-bike/Pedelec, trapondersteuning tot 25 km/h)
- ☐ Elektrische fiets (Speed-bike, trapondersteuning tot 45 km/h)
- ☐ Race fiets
- ☐ Mountainbike
- ☐ Anders, namelijk ....

2738. Droeg u een helm?

- ☐ Nee
- ☐ Ja

2739. Soort ongeval

- ☐ Botsing met andere weggebruiker, namelijk ....
- ☐ Botsing met 'object' (bv een paal), namelijk..
- ☐ Eenzijdig, zelf gevallen door ....
- ☐ Anders, namelijk ....

2740. Oorzaak van het ongeval

- ☐ Eigen toedoen, namelijk ....
- ☐ Toedoen andere weggebruiker, namelijk ....
- ☐ Weersomstandigheden, namelijk ....
- ☐ Verkeerssituatie omstandigheden, namelijk ....
- ☐ Anders, namelijk ....

2741. Locatie van het ongeval

- ☐ Binnen bebouwde kom
- ☐ Buiten bebouwde kom

2742. Soort weg waar het ongeval plaatsvond

- ☐ Kruising met verkeerslichten
- ☐ Kruising zonder verkeerslichten
- ☐ Rotonde
- ☐ Oversteek provinciale weg
- ☐ Apart fietspad
- ☐ Fietsstrook op straat (met strepen/kleur afgegrensd)
- ☐ Straat, zonder fietsstrook
- ☐ Anders, namelijk ....

Hartelijk dank voor uw medewerking. Aanvullende opmerkingen kunt u op de achterkant van dit formulier noteren.