Journal of Safety Research 87 (2023) 54–63

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Increased bicycle helmet use in the absence of mandatory bicycle helmet legislation: Prevalence and trends from longitudinal observational studies on the use of bicycle helmets among cyclists in Denmark 2004–2022

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ARTICLE INFO

Article history:
Received 30 January 2023
Received in revised form 23 April 2023
Accepted 5 September 2023
Available online 12 September 2023

Keywords:
Road safety
Protective equipment
Behavior change
Cyclist behavior
Road safety campaigns
Education
Consensus
Stakeholders
Road safety-oriented behaviors
Self-reinforcing processes
Legislation

ABSTRACT

Introduction: Using a bicycle helmet reduces the risk of serious head injuries among cyclists substantially. This makes it highly relevant to increase the use of helmets and to measure the prevalence of bicycle helmet use over time and across different groups. *Method:* Since 2004, the use of bicycle helmets in Denmark has been measured observationally in two nationwide time series: one among cyclists in city traffic across all age groups, and one among cycling school children (aged 6–16) around schools. The observations have been conducted on a regular basis in different parts of the country following the same methodology over the years. *Results:* Bicycle helmet use among cyclists in city traffic in Denmark has increased from 6% in 2004 to 50% in 2022. Among cycling school children, helmet use has increased from 33% in 2004 to 79% in 2022. Throughout the years, helmet wearing rates have been highest among young children and lowest among young adults. Since 2015, female cyclists in city traffic have had a slightly higher helmet use than male cyclists. *Discussion*: Several factors might have affected bicycle helmet use in Denmark. One possible factor is a nationwide focus on traffic safety education and behavior change campaigns to encourage helmet wearing. Furthermore, among stakeholders on cycling safety there has been consensus on recommending bicycle helmet use and supporting the promotion of helmets while not recommending or promoting helmet legislation. Finally, more safety-oriented behavior in road traffic in general, and self-reinforcing effects of increased helmet use have plausibly been important factors. *Practical Applications*: Increasing bicycle helmet use in a country where cycling is popular is possible in the absence of mandatory bicycle helmet legislation. Persistent behavior change campaigning and education, stakeholder consensus, higher levels of road safety-oriented behaviors, and self-reinforcing processes could potentially be important factors.

1. Introduction

Using a bicycle helmet markedly reduces the risk of head injuries among cyclists. The most recent systematic review and meta-analysis has documented that the use of bicycle helmet reduces the risk of serious head injuries by 60%, 95% CI [54, 65] and fatal head injuries by 71%, 95% CI [44, 85] (Høye, 2018a). These risk reductions make it highly relevant to increase the use of bicycle helmets and measure the prevalence of helmet use over time across different groups of cyclists. The importance of increasing helmet wearing rates is also highlighted by the fact that helmet use among cyclists is a key performance indicator (KPI) in the European Road Safety Policy Framework 2021–2030 (European Commission, 2020).

One approach to increase helmet use is through legislation that makes it mandatory for cyclists to wear a helmet. Legislation and proposals of legislation on helmet use for cyclists have sparked considerable debate among policymakers and experts (Bachynski & Bateman-House, 2020), and several studies have evaluated the effects of introducing helmet laws. Systematic reviews on the impacts of helmet legislation show that introducing such laws in general bring about significant increases in helmet use (Karkhaneh et al., 2006) and significant reductions in head injuries (Du et al., 2020; Høye, 2018b). Regarding the hypothesis that helmet laws could deter some people from cycling, which has been one of the major concerns around introducing helmet laws, the evidence is mixed (Høye, 2018b).

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https://doi.org/10.1016/j.jsr.2023.09.003
0022-4375/

Another strategy to increase helmet wearing rates among cyclists is to promote the voluntary use of helmets through means such as traffic safety education at schools, behavior change campaigns, and interventions that inform of the importance of bicycle helmets and make helmets more attractive to wear and increase their availability. Research has documented that bicycle helmet campaigns can increase helmet use among children (Boele-Vos et al., 2020; Owen et al., 2011). Such non-legislative means of increasing bicycle helmet use is particularly relevant for countries or jurisdictions that lack public support to introduce bicycle helmet legislation and/or that prefer to increase helmet use through voluntary means.

In this regard, Denmark as a country is an interesting case. Denmark does not have legislation requiring cyclists to wear a helmet.[1] Consequently, it is not mandatory to wear a helmet and there is no penalty for not wearing one. Although it has occasionally been debated, there has not been any public or substantial considerations of introducing a universal law to require all cyclists to wear a helmet. Instead, helmet use has been encouraged through behavior change campaigns and traffic safety education in primary and secondary schools. Denmark is also an interesting case on cyclist behavior, as it is one of the countries in Europe where people cycle the most as measured per capita (Schepers et al., 2021).[2] At the same time, there are few scientific studies assessing the long-term prevalence and trends in bicycle helmet use across different groups in settings where helmet legislation has not been introduced and where cycling is popular. The paper aims to fill this gap in the literature by using Denmark as a case.

More specifically, the main objective of the present study is to evaluate the prevalence and trends in bicycle helmet use among cyclists in Denmark through two observational time series. Secondarily, the paper seeks to discuss the broader potential factors that could have affected the upward trajectory in bicycle helmet use in Denmark. The case study might serve as inspiration as to how helmet use among cyclists can be increased through non-legislative means in other countries and jurisdictions.

2. Methods

2.1. Data sources

Since 2004, the Danish Road Safety Council has systematically carried out nationwide bicycle helmet observational studies among cyclists in cities in Denmark to evaluate the prevalence and trends of bicycle helmet use. Most observations are carried out by employees from the municipalities and local observers who receive remunerations for their work. Registrations have been carried out biannually from 2004 to 2010 and annually since 2010. The observations are conducted at the same time of year (middle of August to beginning of September).

The method of observation and observational protocol has been largely unchanged since the first study in 2004. The only significant change in the method of observation is that airbag helmets started being counted as a helmet from 2018, as this new bicycle helmet type began appearing in road traffic. However, only a very small minority of cyclists (less than 0.4%) used this type of bicycle helmet in 2018. The addition of airbag helmets to the time series in 2018 thus arguably does not constitute a substantial time series break.

The nationwide registrations consist of two separate time series: "city traffic" and "school traffic." The first time series ("city traffic") consists of observations of cyclists across all age groups in cities. In this time series, cyclists are observed on cycling lanes and roads on weekdays during the morning (7:30 am to 9 am), midday (11 am to 1 pm), and afternoon (3 pm to 5 pm). Observations are not carried out on evenings, nights, or during the weekend.

In the second time series ("school traffic"), only cycling school children (aged 6–16) are observed. These observations take place around primary and lower secondary schools in the morning on weekdays as school children arrive to school. Since 2004, between 7,001 and 11,731 cyclists in city traffic and 6,173 to 8,332 cycling children in school traffic have been observed in each of the study-years where the bicycle helmet observations have been conducted.

In both time series, the observers register helmet use, gender, and age groups. Cyclists on regular bicycles as well as cyclists on e-bikes (25 km/h) and speed pedelecs (45 km/h) are registered. Children transported in child bike seats or passengers in cargo bikes are not registered. More details on the methodology can be found in the technical reports documenting the bicycle helmet observational study (Kany & Olsson, 2023; Olsson, 2021).

The observations are conducted in different regions of the country in small, medium-sized, and large cities. The registrations have been conducted at roughly the same geographical locations over the years. The only substantial adjustment regarding the geographical locations in the time-series is that additional geographical locations were introduced from 2019 onwards.[3] Robustness tests have documented that the additions to the time series in 2019 did not have any substantial effect on the overall estimates on bicycle helmet use and thus arguably did not constitute a time series break. See the technical report on the bicycle helmet observational study for more information (Olsson, 2021).

2.2. Data analysis methods

Data were analyzed using R-4.2.2. and Microsoft Excel. Confidence intervals for proportions of cyclists wearing a helmet were calculated using confidence levels of 0.95. The confidence intervals were calculated using the estimated standard errors of the proportion assuming a normal distribution (Agresti & Finlay 2009). When comparing two proportions, Pearson's Chi-squared tests with Yates's continuity correction were used (Field et al., 2012).

The analytical approach does not involve more complex statistical time-series modelling. There are two reasons for the methodological choice of not using time-series modelling. First, the primary purpose of the study is to evaluate the prevalence and trends in bicycle helmet use. Second, while the paper includes a discussion of the many broader factors that could potentially have affected the upward trajectory in bicycle helmet use in Denmark (e.g. behavior change campaigns and education, stakeholder consensus, more safety-orientated behavior in general, and self-reinforcing processes), there are no existing data over time for these broader factors (except for specific national behavior change

[1] In Denmark, it is mandatory to wear a helmet on speed pedelecs (fast e-bikes with motor assistance up to 45 km/h) (Retsinformation, 2018), but for cyclists on bicycles without motors or cyclists on e-bikes with motor assistance up to 25 km/h, there is no legislation. For e-scooter riders, it has been mandatory to wear a helmet since January 1st 2022 (Retsinformation, 2021).

[2] During 2014–2017, the average person in Denmark cycled 616 km each year (Schepers et al., 2021). Especially in the larger cities, cycling is very common, and cycling is prevalent among adults as well as children (Danish Centre for Cycling Knowledge, 2022).

[3] From 2004 to 2018, there were 28 geographical locations in "city traffic", increasing to 34 locations in 2019 onwards. In school traffic, there were 57 geographical locations from 2004 to 2018, a number that rose to 68 from 2019 onwards. Furthermore from 2019 onwards, at some locations with many cyclists, observers were asked to register male cyclists and female cyclists on separate days in order to be able to register all the passing cyclists. The primary purpose of the additions from 2019 onwards was to increase the number of observations and thus statistical power. Secondarily, the additions also specifically increased the number of geographical locations within the Greater Copenhagen area to reflect the fact that cycling over the years had increased in this particular region (Olsson, 2021).

campaigns) that could be used as predictors in statistical time-series modeling.

3. Results

3.1. Bicycle helmet use among cyclists in Denmark from 2004 to 2022: Overall prevalence and trends

In the "city traffic" time series where cyclists across all age groups are registered, helmet use has increased from 6.3%, 95% CI [5.8, 6.9] in 2004 to 49.8% [48.8, 50.8] in 2022. In the "school traffic" time series where only cycling school children (aged 6–16) are registered, helmet use has increased from 33.4% [32.2, 34.6] in 2004 to 78.5% [77.6, 79.4] in 2022. Fig. 1 shows the prevalence over time for each time series with 95% confidence interval bands. The number of observations and the helmet wearing rate for each year can be found in Appendix 1.

Apart from illustrating a general continuous trend of increasing bicycle helmet use, Fig. 1 also highlights how bicycle helmet use in Denmark especially increased in two waves. The first wave took place from 2004 to 2010. During this period, helmet use rose from 33.4% [32.2, 34.6] to 55.9% [54.6, 57.1] among cycling school children, equivalent to an average annual rise in helmet use of 3.8 percentage points. In city traffic, across all age groups, helmet use increased from 6.3% [5.8, 6.9] in 2004 to 24.6 [23.6, 25.5] in 2010, corresponding to an average annual increase of 3.1 percentage points.

In the years from 2010 to 2014, helmet use increased at a slower pace from 55.9% [54.7, 57.1] to 59.5% [58.4, 60.7] in school traffic and from 24.6 [23.6, 25.5] to 27.6% [26.6, 28.6] in city traffic, equivalent to average annual increases below 1 percentage points.

In 2014, the increase in the use of bicycle helmets started accelerating again. In school traffic, helmet use among school children rose from 59.5% [58.4, 60.7] in 2014 to 81.6% [80.8, 82.4] in 2020, equivalent to an average annual rise in helmet use of 3.7 percentage points, before dropping to 78.5% [77.6, 79.4] in 2022. In city traffic, helmet use increased from 27.6% [26.6, 28.6] in 2014 to 46.6% [45.7, 47.5] in 2020, corresponding to an average annual increase of 3.2 percentage points. Contrary to the time series in school traffic, helmet use continued its upward trajectory in city traffic from 2020 to 2022 where helmet use was at 49.8% [48.8, 50.8].

3.2. Bicycle helmet use among cycling school children: Age groups and gender

In the time series in school traffic, cycling children have been registered according to three age groups: 6- to 9-years-old, 10- to 12-years-old, and 13- to 16-years-old. It should be noted that the age of the cyclists is assessed by the local observers. While there is likely to be some random error in the categorization of the cyclists, these random errors are likely to be consistent over the years. Fig. 2 shows the prevalence of helmet use according to these age groups over time, including 95% confidence interval bands.

In line with Fig. 1, the data on age groups in school traffic illustrate the two waves of increased bicycle helmet use from 2004 to 2010 and from 2014 to 2020. The data also show that the youngest children aged 6 to 9 years have had the highest helmet use rate throughout the years and that the oldest children have had the lowest use of helmet.

As illustrated by Fig. 2, the difference in helmet wearing rates between those aged 6 to 9 years and those aged 10 to 12 years have narrowed, as the latter age group has almost caught up with the youngest school children in recent years. In each of the study-years from 2004 to 2014, the differences in the helmet wearing rates between the 6- to 9-year-old and 10- to 12-year-old were between 22.6 and 29.9 percentage points. Although the difference in the helmet wearing rate between these age groups was still statistically significant in the most recent data from 2022 ($p < 0.001$, $X^2 = 87.3$), the gap had closed to 7.7 percentage points. This indicates that the preteen cyclists (10- to 12-year-olds) to a higher degree than before do not stop using a bicycle helmet.

As to the oldest cycling school children aged 13 to 16 years, the age group has had the lowest helmet wearing rate throughout the school traffic time series. Still, the age group has seen a substantial increase in helmet use from 12.6% [11.1, 14.1] in 2004 to 57.1% [55.3, 58.9] in 2022. This also indicates that over time, fewer of the 13- to 16-year olds stopped using a bicycle helmet. From 2020 to 2022, however, helmet use decreased substantially from 62.8% [61.0, 64.6] to 57.1% [55.3, 58.9], a difference that was statistically significant ($p < 0.001$, $X^2 = 19.3$).

Concerning the use of bicycle helmets among boys and girls in school traffic, there has not been any substantial systematic differences in helmet use throughout the study-years (see Appendix 1).

3.3. Bicycle helmet use in city traffic: Age groups and gender

In the city traffic time series, the age groups are much wider than in the school traffic time series. In city traffic, cyclists are registered as being younger than 11 years old, 11- to 15-year-olds, 16- to 25-year-olds, 26- to 60-year-olds, and those older than 60. The rationale behind having wide age groups in city traffic is to make the observational procedure simple and reduce errors, while also making it possible to count all or almost all passing cyclists. The results on helmet use among the age groups in the city traffic time series are shown in Fig. 3. Some caveat is required when evaluating the differences among the age groups and across time in city traffic, as some of the age groups encompass relatively few observations, especially in the age groups of those younger than 11 years old and the 11- to 15-year-olds.

Fig. 3 illustrates how helmet use has increased among all age groups in city traffic, and that it was only among children younger than 11 years old, where using a helmet was common in 2004. The figure also highlights how young people aged 16 to 25 years have had the lowest helmet wearing rate during almost the full length of the time series. In 2022 those aged 16 to 25 had a helmet wearing rate at 36.5% [34.4, 38.6], which is much lower than the helmet wearing rate at 50.6% [49.3, 51.8] of the group of cyclists aged 26 to 60 years ($p < 0.001$, $X^2 = 121.3$).

When it comes to helmet use in city traffic across gender, there are some substantial differences not found among cycling children in the school traffic time series. Fig. 4 shows the prevalence of helmet use among girls/women and boys/men across time in city traffic.

While helmet use did not systematically differ between girls/women and boys/men from 2004 to 2014, helmet use has been significantly higher among female cyclists than among male cyclists since 2015 ($p < 0.01$, $X^2 > 6.9$). Furthermore, the difference increased from 4.5 percentage points in 2015 to 8.5 percentage points in 2020, before decreasing to 6.8 percentage points in 2022.

3.4. Bicycle helmet use across other parameters

Apart from age groups and gender, bicycle helmet use has also been registered across other parameters. One interesting parameter is time of day. In the school traffic time series, all observations have been conducted in the morning, but for the city traffic time series, registrations have been carried out during the morning (7:30 am to 9 am), midday (11 am to 1 pm), and afternoon

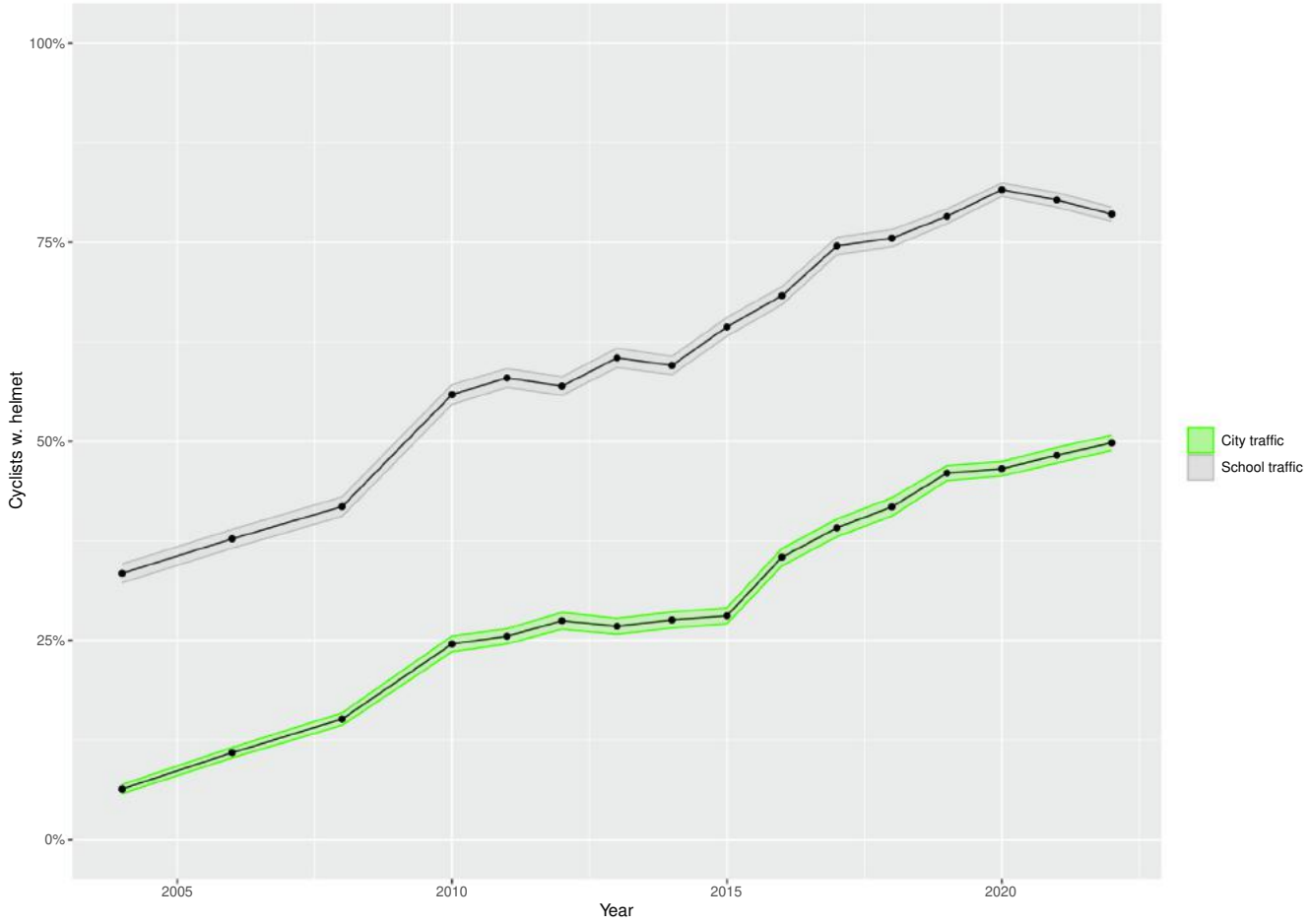

Fig. 1. Bicycle helmet use in city traffic (across all age groups) and school traffic (school children).

(3 pm to 5 pm). Fig. 5 illustrates the prevalence of bicycle helmet use among cyclists in city traffic across time of day.

Fig. 5 shows how helmet use has increased gradually in the registrations taking place in the morning, midday, as well as afternoon. The trend lines also illustrate that in almost all the study-years, helmet use has been significantly higher during the morning than the other studied times of day and that helmet use has consistently been lowest during midday. In 2022, 55.0% [53.5, 56.5] of observed cyclists in city traffic in the morning used a helmet, which is a substantially and significantly higher prevalence than the helmet use of 47.3% [45.7, 48.8] during the afternoon ($p < 0.001$, $X^2 = 50.0$). Helmet use during the afternoon in 2022 was also significantly higher than the prevalence of 44.2% [42.1, 46.3] during midday in 2022 ($p = 0.02$, $X^2 = 5.1$).

As noted in the methods section, helmet registrations in the city traffic and school traffic time series have taken place in both small cities (population < 20,000), medium-sized cities (population of 20,000 – 100,000), and large cities (population > 100,000). Throughout the study-years, there have not been any consistent systematic trends or patterns according to city size (see Appendix 1). However, the estimates for different city sizes should also be taken with caveat, given that each category of city size is represented by relatively few geographical locations on which registrations take place.[4]

[4] In 2022, each category of city size was represented by between 6 and 16 geographical locations in the city traffic time series. For the school traffic time series, there was roughly twice as many geographical locations.

4. Discussion

What are the likely factors behind the uptake of bicycle helmet use in the case of Denmark? How did bicycle helmets go from being rarely used in city traffic to something that approximately half of all cyclists in city traffic and 8 out of 10 cycling school children use? There are several potential factors, ranging from national behavior change campaigns and traffic safety education in schools to stakeholder agreement, self-reinforcing processes, and secular trends of increased general levels of safety behaviors in general.

4.1. National behavior change campaigns and education in primary and lower secondary schools

In Denmark, bicycle helmets have been promoted nationwide, primarily through traffic safety education in primary and lower secondary schools, interventions, and behavior change campaigns. The strategy of promoting bicycle helmets has focused on increasing *awareness* about how bicycle helmets reduce the risk of serious head injuries, on making bicycle helmets *attractive* to wear, and on increasing the *availability* of helmets.

The two waves of increased bicycle helmet use from 2004 to 2010 and from 2014 to 2020 (cf. Fig. 1) coincided with nationwide behavior change campaigns that promoted bicycle helmets. In contrast, the period from 2010 to 2014 where bicycle helmet use increased at a substantially lower pace, was marked by an absence of nationwide bicycle helmet campaigns, though traffic education in schools still focused on bicycle helmets. The second wave of

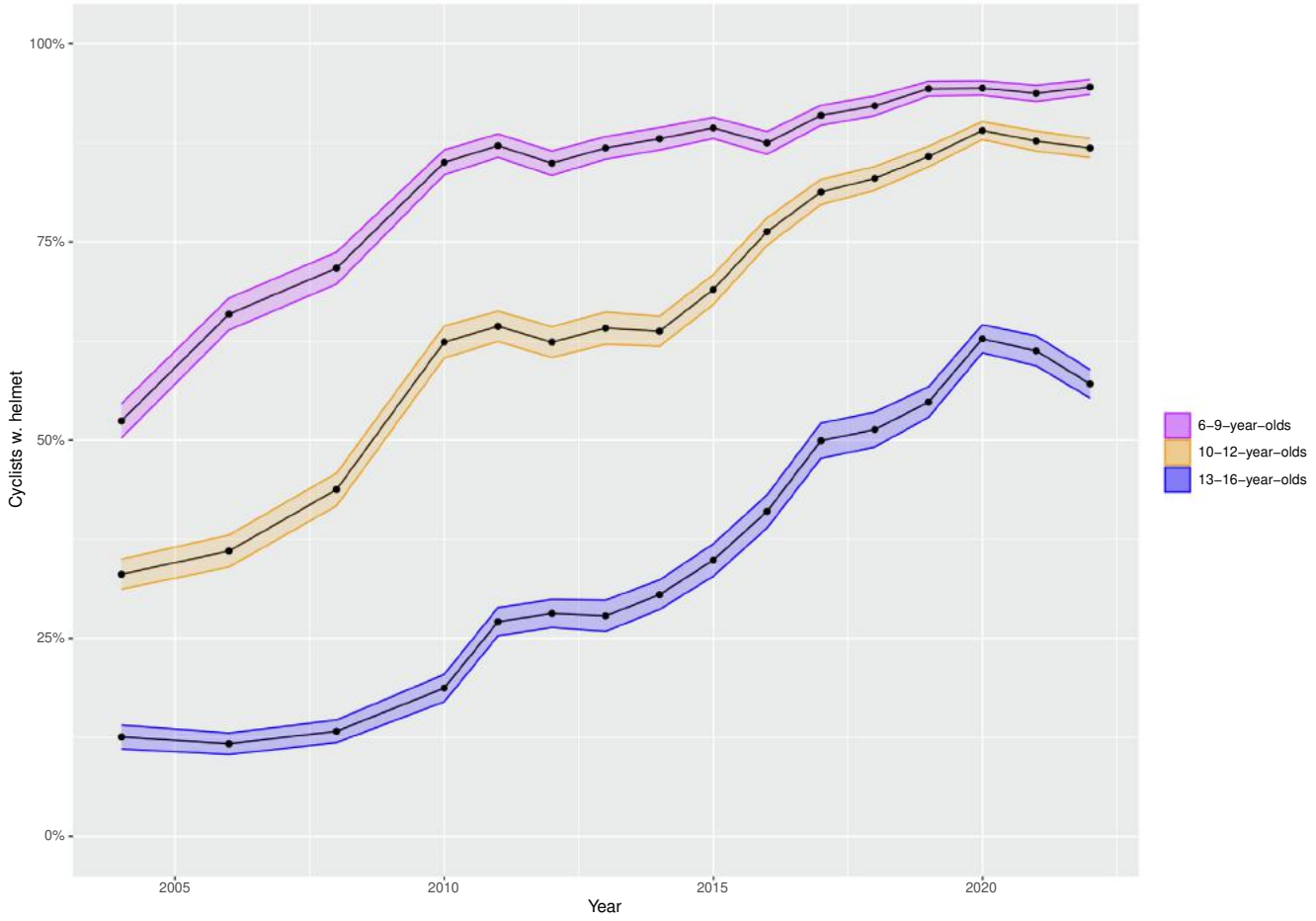

Fig. 2. Bicycle helmet use among cycling school children in school traffic.

increasing bicycle helmet use started with the launch of a new nationwide behavior change campaign in 2014 called "Annoying Parents" (in Danish: "Nederen Foraeldre") that lasted until 2020. The campaign targeted parents of preteen school children and praised parents for insisting that their children use bicycle helmets. The campaign primarily consisted of several humorous music videos that went viral on Youtube.[5] An evaluation of the first campaign video in 2014 showed that 65% of parents with children aged 8 to 12 years old could remember having been exposed to the campaign - and of those, 25% had been speaking with their children about their use of bicycle helmet (Advice, 2014). In evaluations of the subsequent music videos the following years, 59% (in 2016) and 61% (in 2017) of parents with children aged 6 to 16 years could remember having been exposed to the new campaign videos, and 29% (in 2016) and 21% (in 2017) of those parents had been speaking with their children about their use of bicycle helmets (Epinion, 2016; Epinion, 2017a). These evaluation results in combination with the increased helmet use from 2014 onwards indicate that the campaign could have played a role in increasing helmet use after the 4-year period from 2010 to 2014 where helmet use had only slowly increased. Given the many potential confounders, however, one should be cautious in estimating the exact effect of the campaign. Still, the plausible positive results of the national campaign would be in line with studies from other countries documenting that bicycle helmet campaigns as part of non-legislative policies can increase helmet use among children (Boele-Vos et al., 2020; Owen et al., 2011).

Apart from the large national campaigns in recent years - including a new bicycle helmet campaign targeting adults that was launched in 2021 ("A helmet has always been a good idea") - there has also been a persistent focus throughout the years on bicycle helmets in traffic safety education in primary and lower secondary schools. Especially in the so-called "cyclist test" where school children are taught about the traffic rules for cyclists using both theory and practice.

Finally, there have been various small-scale interventions and campaigns over the years - also long before 2004 where the time series on bicycle helmet use started. Examples include local interventions in which cyclists can buy helmets at a low price at pop-up shops at university campuses, free handouts of bicycle helmets in schools, as well as various local media campaigns over the years.

4.2. Stakeholder consensus

Multiple governmental and non-governmental stakeholders work together on improving road safety, and thus also cycling safety in Denmark. Some of these stakeholders include (but are not limited to) the Ministry of Transport, the Danish Road Directorate, the Danish Road Traffic Authority, the Danish Cyclists' Federation, the Danish Road Safety Council, The Federation of Danish Motorists, regions, municipalities, schools, insurance companies, and philanthropic foundations. Among these key stakeholders

[5] As of 2022, the first campaign video from 2014 had more than 6 million views, and the third campaign video from 2017 had more than 12 million views. In comparison, the population of Denmark is 5.8 million. Some of the music videos can be accessed here: https://sikkertrafik.dk/til-toppen/kampagner/tidligere-kampagner/nederen-foraeldre-2014–2020/.

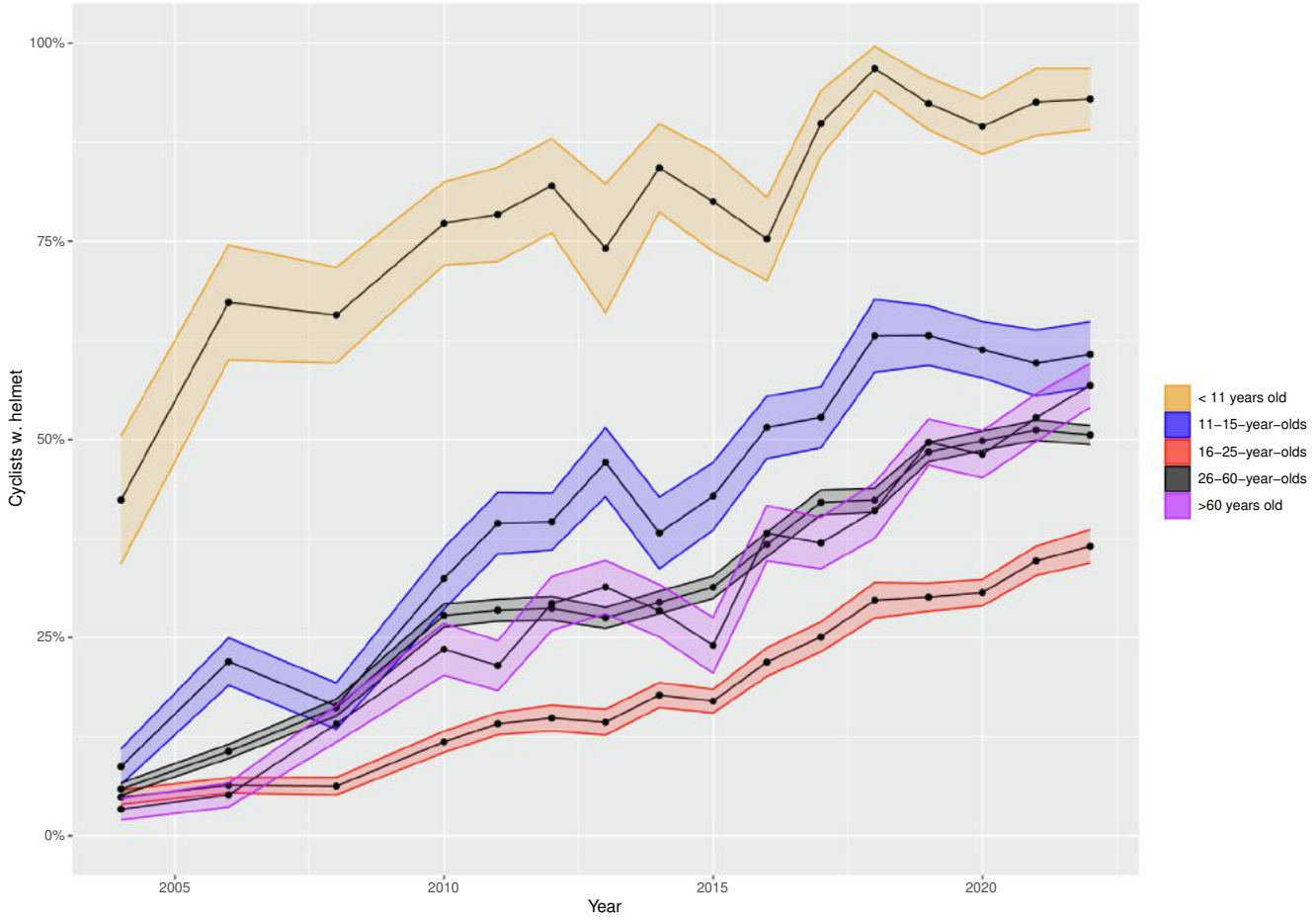

Fig. 3. Bicycle helmet use in city traffic across age groups.

there has been a long-held consensus regarding bicycle helmets: Legislating on making bicycle helmets mandatory for cyclists has been ruled out as an option, while there has been widespread support for promoting bicycle helmet use through behavior change campaigns, education, and other non-legislative means. The consensus among stakeholders most likely arose from the fact that relatively few used a bicycle helmet in the 1990 s and early 2000 s and that legislation was therefore considered to be unacceptable among cyclists and would thus have a neglectable effect (Faerdselssikkerhedskommissionen, 2007). Following this, the increase in helmet use that took place over the years in the absence of legislation most likely facilitated the stakeholders to retain the consensus on increasing helmets through voluntary means. This consensus among key stakeholders has probably meant that there has not been any strong or vocal anti-helmet voices questioning the effectiveness of helmets or questioning the promotion of bicycle helmets as one of the important and effective means for increasing cyclist safety. The agreement among stakeholders has also been reflected in the politically agreed road safety action plans over the years, all of which have highlighted the need for campaigns to encourage bicycle helmet use (Danish Road Safety Commission, 2000; Danish Road Safety Commission, 2013; Danish Road Safety Commission, 2021). This in turn has probably also meant that such campaigns have been able to secure funding.

The enduring consensus among stakeholders and largely absence of anti-helmet voices in Denmark differs from some of the other countries in Europe where cycling is popular. Most noticeably the Netherlands, where there has been substantial resistance toward promoting helmets through legislative as well as non-legislative means[6] (Van den Brand et al., 2020). The use of bicycle helmets among cyclists in The Netherlands is also a contrasting case to Denmark. In an observational study conducted in 2021/2022, bicycle helmet use in the Netherlands was estimated to be at 1.0% (Rijkswaterstaat, 2022).

4.3. Secular trends: More Safety-oriented behavior in road traffic in general

Increased bicycle helmet use might also be part of a long-term secular trend in which the population over time in general displays more safety-oriented and risk-reducing behaviors in road traffic as well as in other areas. Regarding road safety behavior, the Danish population has steadily exhibited safer behavior in road traffic, spanning from lower levels of speeding (Olsson et al., 2023), a lower level of drunk driving (Reiff, 2021), and increased seat belt use (Kany & Olsson, 2023). Thus, the upward trend in the use of bicycle helmets could partially be rooted in a more general secular trend in which the population gradually develops higher preferences for safety in road traffic.

[6] While there does not seem to be published research on the effect of consensus among stakeholders on bicycle helmet use, research in other areas indicates that consensus among stakeholders matters for behavioral outcomes. Research on how public health messaging for managing and preventing infectious diseases shows that unifying messages from different sources that are consistent and do not conflict tend to have a larger behavioral impact than messages that are not (Ghio et al., 2021).

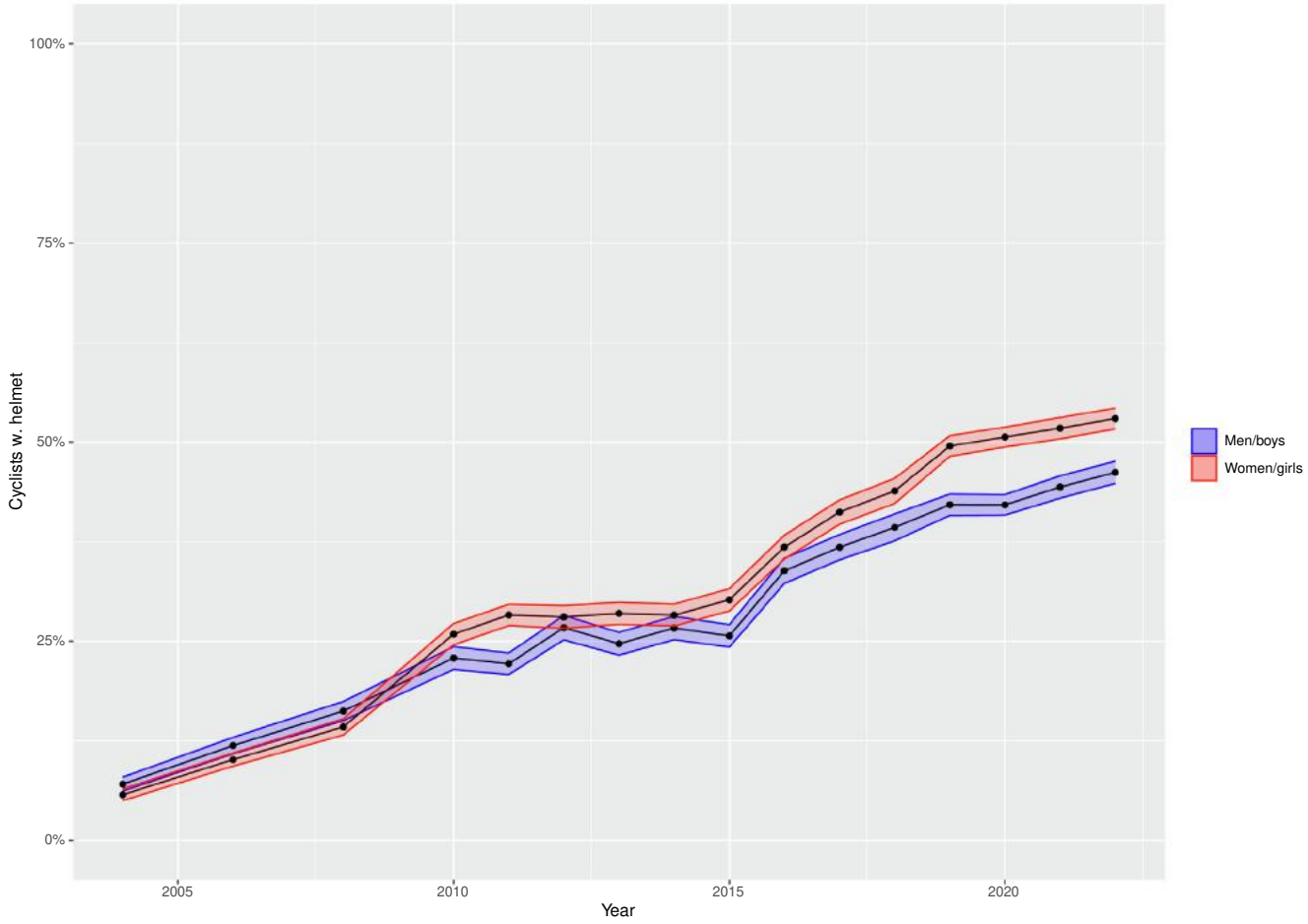

Fig. 4. Bicycle helmet use in city traffic across gender.

4.4. Self-reinforcing processes

As more people start using bicycle helmets, the increase could in itself have a positive effect on helmet use. Such self-reinforcing mechanisms could potentially play out in multiple ways.

Some of these mechanisms could occur through behavioral spill-over via social influence. Behavioral spill-over effects take place when some individuals are not directly affected by a campaign or intervention but are indirectly affected by interacting with people who have been directly affected by a given campaign or intervention (Schimmelpfennig, et al., 2021). Such behavioral spill-over effects could take place on both the interpersonal level as well as at a higher level through norms.

On the interpersonal level, cyclists not wearing a helmet could be affected by what close ties in their network (family, close friends, and colleagues) do and say. For instance, people who start wearing a bicycle helmet might either explicitly recommend or tell close ties to use a bicycle helmet. In a survey among Danish cyclists from 2017, those who "sometimes" or more often used a bicycle helmet when cycling, were asked why they used a helmet. 7% gave the answer "Because someone else has asked me to" (Epinion, 2017b). Furthermore, people who start wearing a helmet might implicitly inspire behavior change among others by being a role model. Networks can thus act as multipliers for behavioral change (VanderWeele & Christakis, 2019).

The other plausible mechanism for behavioral spill-over via social influence is at a higher level through broader norms and experiences. As using a helmet becomes more common, fewer cyclists most likely feel that they stand out by wearing a helmet. Surveys also highlight the potential for increasing helmet use among adults further through making it the norm. In a survey in 2021, Danish cyclists were asked if they used a bicycle helmet. Those who said that they never wore a helmet were asked what could make them start using a helmet. 14% gave the answer "If most other cyclists used a helmet" (Epinion, 2021).[7] Furthermore, as wearing a bicycle helmet indeed has become the dominating norm among young school children, it might also have started being perceived as socially unacceptable for parents not having their young cycling school children wear a helmet.

Another potential self-reinforcing mechanism for increased bicycle helmet use relates to market dynamics. As more people started buying and demanding bicycle helmets, the other side of the market of bicycle helmets – the supply side – most likely

[7] In the same survey, cyclists never wearing a helmet (n=435) were asked why they did not use a helmet. The most common responses (close-ended) were as follows: I am not used to wearing a bicycle helmet (33%), it is uncomfortable to wear (24%), it is difficult to bring it with me when I have arrived at my destination (23%), I do not bother to use the helmet if I am only going for a short trip (18%), I would like to use a helmet, but I have not bought a helmet yet (17%), it ruins my hair (14%) (Epinion, 2021). These barriers, which have also been assessed in previous surveys and qualitative interviews (Olsson & Ehlers, 2021), have actively been targeted in national behavior change campaigns, interventions, and general communication on bicycle helmet use.

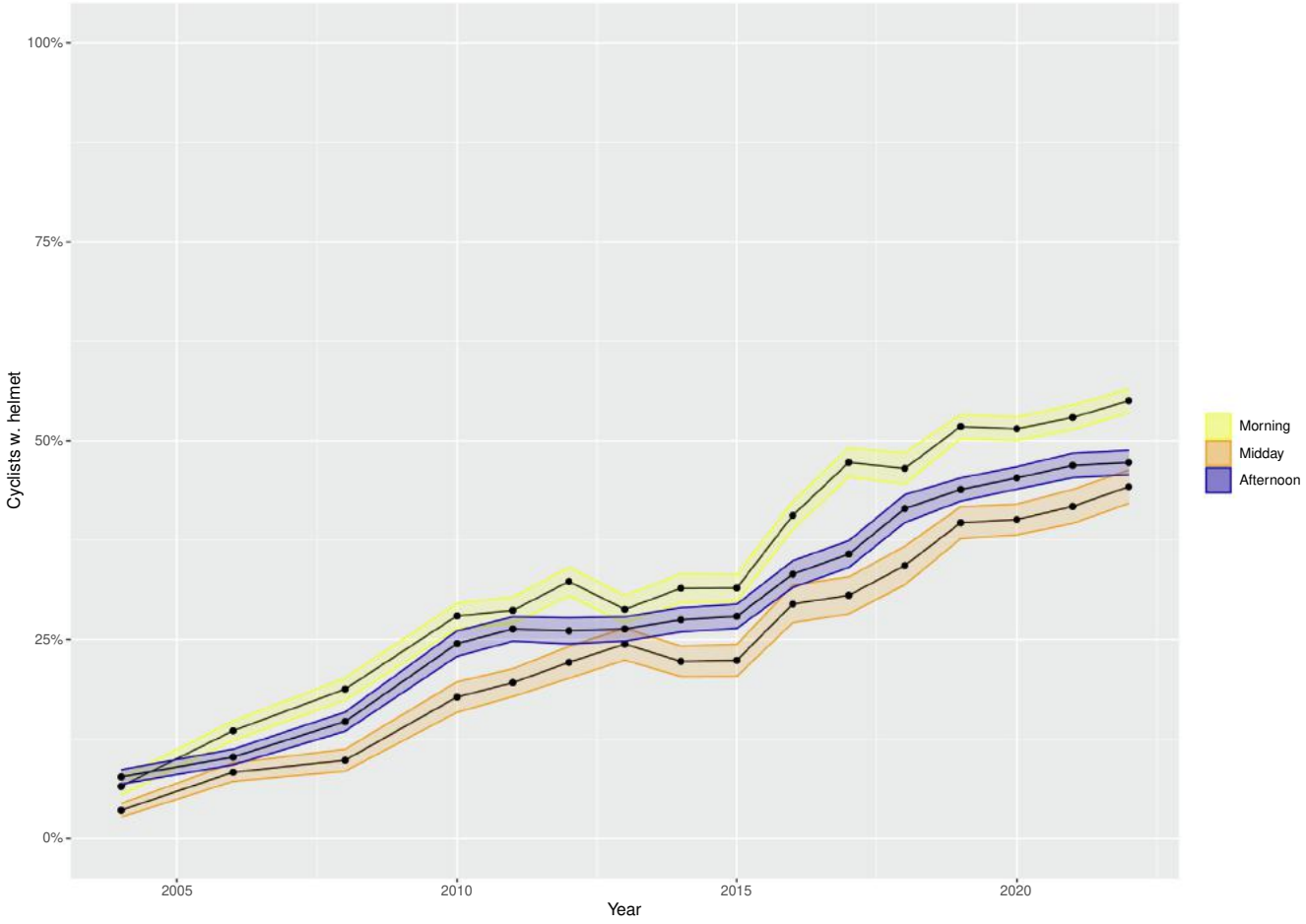

Fig. 5. Bicycle helmet use in city traffic across time of day.

reacted by increased efforts to sell helmets by boosting the availability of helmets and the availability of more different types of helmets in different designs.[8]

Finally, an adverse self-reinforcing process that could be hypothesized to have taken place is that helmet-wearing might be detrimental to bicycle use. According to such a hypothesis, cyclists who do not use a helmet and do not want to wear a helmet might feel that they go against the norms by not using a helmet and therefore cycle less or stop cycling. As such, helmet use could have been increasing because the absolute numbers of cyclists decrease. In Denmark, there has indeed been a small decrease in cycled kilometers per capita (Schepers et al., 2021), bicycle modal share (Nielsen et al., 2016), and the probability of cycling (Rich et al., 2023). However, the hypothesis is unlikely to hold given existing evidence. The decrease in cycling began in the 1990 s, long before bicycle helmets started becoming prevalent. Furthermore, analyses of why people do not cycle or only cycle very little do not point to bicycle helmets as a barrier, but rather factors as long travel distances, busy day-to-day life, not feeling safe as a cyclist, the convenience of the car, and forgetting to consider the bicycle as an option for transportation (Vejdirektoratet, 2018).

5. Strengths and limitations

One key strength of the time series data on bicycle helmet use is the consistency in methodology over a long period of time. Combined with a relatively large number of observations across different age groups and gender, this makes for data sets that can be used to evaluate trends over time and across groups in detail.

The presented time series have some weaknesses as well. First, they are not necessarily strictly representative of the general cycling population in Denmark. However, representative surveys among cyclists conducted in 2008, 2013, 2017, and 2021 (Epinion, 2008; Epinion, 2013; Epinion, 2017; Kantar Public, 2021) have shown prevalence and trends of bicycle helmet use that are generally in line with the observational time series.

Second, the observational study only takes place in city traffic at weekdays in the morning, midday, and afternoon. Therefore, one cannot infer the prevalence of bicycle helmet use in the weekends, evenings, nights, and in rural areas. A study conducted in the university city of Aarhus did indeed find that helmet use was significantly lower during the evening, nights, and weekends (Jensen & Kallesen, 2018). As to bicycle helmet use outside cities, there are no data on helmet use in rural areas in Denmark. However, it should also be noted that cycling is less common in rural areas compared to larger cities (Malmgren & Christiansen, 2022).

A third limitation is that there are probably some errors in the assessments of the age of the observed cyclists. These errors are most likely to be random and should be roughly constant over time. The random errors in the assessments of age groups have

[8] This dynamic could probably also go in the other direction. An increased supply of different types of helmets (greater product variety and better designs of helmets) could have convinced some people to buy a helmet.

the effect that the estimated differences in helmet use among different age groups are underestimated, implying that the real differences might be somewhat larger than what is estimated (King et al., 1994).

Finally, while not a limitation in the time series data in itself, but rather of the present paper, is the hypothetical nature of the potential factors that could help explain the increase in bicycle helmet use in Denmark. While the non-experimental data implies that no study cannot without substantial risk of bias estimate the causal effects of the different factors, further research should – where existing high-quality longitudinal data on such potential factors exist – estimate the effects of such factors.

6. Conclusions

In Denmark, the use of bicycle helmets has changed from being a relatively rare sight in city traffic to being widely used. In 2004, 6.3% [5.8, 6.9] of the observed cyclists across all age groups in city traffic used bicycle helmets. The proportion increased to 27.6% [26.6, 28.6] in 2014 and to 49.8% [48.8, 50.8] in 2022. In school traffic, helmet use among cycling school children (aged 6–16) increased from 33.4% [32.2, 34.6] in 2004 to 59.5% [58.4, 60.7] in 2014 and to 78.5% [77.6, 79.4] in 2022. There are many potential factors behind the increase in helmet use. These factors range from traffic safety education in primary and lower secondary schools and national behavior change campaigns promoting bicycle helmets, stakeholder agreement on recommending and promoting helmets, broader secular trends of more safety-oriented behavior in road traffic in general, and self-reinforcing processes.

7. Practical applications

Increasing bicycle helmet use in a country where cycling is popular is possible in the absence of mandatory bicycle helmet legislation. A persistent focus on traffic safety education in primary and lower secondary schools, national behavior change campaigns, consensus among stakeholders on recommending cyclists to wear a bicycle helmet, broader secular trends of higher levels of safety-oriented behavior in road traffic in general, and self-reinforcing processes have been potential factors enabling increased bicycle helmet use among cyclists in the case of Denmark. Even with these factors present, it should also be noted that it takes time to increase bicycle helmet in the absence of legislative means.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The author of the study works at the Documentation Office at the Danish Road Safety Council. The data for the study has been gathered and analysed by the author and other employees and former employees at the Documentation Office. The Documentation Office serves as the independent monitoring and evaluation unit at the Danish Road Safety Council.

Acknowledgements

The author expresses his gratitude to those who have been involved in the design and execution of the bicycle helmet study over the years - including, but not limited to Mathilde Strunge Kany, Jesper Sølund, Søren Troels Berg, Lise Heiner Schmidt, and all the local observers. The author would also like to thank Henrik Vaerø, consultant at Trafiktastatoriet, who has conducted quality assurance of the annual technical reports on bicycle helmet use. Finally, Paul Schepers offered advice on the writing of the article, while Lise Heiner Schmidt, Pernille Ehlers, Lars Bo Pedersen, and Lukas Beraki provided valuable feedback on draft versions of the article, and Julian Umbhau Jensen assisted significantly in visualization of the data.

Funding

The philanthropic foundation, TrygFonden, partly funded the Danish Road Safety Council's nationwide bicycle helmet campaign from 2014 to 2020 targeting parents with school children. TrygFonden also partly funded the Danish Road Safety Council's traffic safety education to primary and lower secondary schools, including on cycling safety. The present research in itself did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. TrygFonden had no role in the study design, in the collection, analysis and interpretation of data, nor in the writing of this paper or the decision to submit this article for publication.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsr.2023.09.003.

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