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Shedding light on cycling in the dark: Some evidence from Flanders (Belgium)

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ABSTRACT

Darkness is a barrier to cycling because the risk of an accident is higher and the feeling of social safety is lower. Factors influencing the choice to cycle (e.g., socio-demographic factors) have already been studied extensively, but rarely in relation to darkness. To implement strategies for increasing bicycle use (also when it is dark), we need to know what decision factors play a role for people to cycle or not when it is dark. A mixed method approach is adopted; applying a logistic regression using data of 842 surveyed cyclists in the province of East Flanders (Belgium), supplemented a qualitative analysis using 26 in-depth semi-structured interviews. Results show that knowing and using a route frequently has a positive effect on the likelihood of cycling in the dark. Elderly (and retirees) are less likely to cycle in the dark compared to youth and young adults. The latter group (ranging between 11 and 17 years old) often cycle to school while it is still dark (either or not accompanied by a parent). Whether or not one cycles alone or in group has a lower or higher propensity to cycle during the dark. People with a racing bike often cycle in groups and are less likely to cycle in the dark. Recreative and sportive cycle tours are mostly done during the day. Cyclists with an e-bike and speed pedelec have a higher likelihood to cycle in the dark compared to those who cycle on a regular bike. Women have 84% lower odds to cycle in the dark compared to men because they perceive darkness as less socially safe. Lastly, living in a rural environment has a positive impact on the odds to cycle in the dark compared to more urban environments. Establishing a cycling culture with inclusive infrastructure is essential for addressing the diverse needs of vulnerable groups and ensuring the provision of safe routes. A holistic approach is critical to effectively integrate these elements into urban planning and transport policies.

1. Introduction

Governments strive to enhance both the safety and utilization of cycling by adjusting land use and investing in cycling infrastructure (Heinen et al., 2010; Schepers et al., 2014). Promoting cycling stands as a central goal in transport planning due to its manifold environmental, social, and health advantages (Heinen et al., 2010). Cycling, being a sustainable mode of transport, mitigates congestion and enhances overall well-being. Moreover, cycling promotes physical activity, resulting in positive health outcomes (Lovelace et al., 2011; Marquart et al., 2020; Mueller et al., 2018). Additionally, cyclists report higher satisfaction levels with their trips compared to users of other modes such as private cars (De Vos et al., 2016). Bicycles occupy minimal parking space, thus requiring less public area than cars. Lastly, cycling fosters greater transport equity, with most cities offering convenient access to shared bicycles (Pucher and Buehler, 2008).

Despite the many improvements in cycling infrastructure in many European countries, there are still some bottlenecks and barriers that discourage people from using the bike. Barriers are diverse, ranging from the risk of having an accident to getting sweaty (Lois et al., 2015). Another barrier deals with level or lack of road illumination. Cyclists feel less safe in darkness than in daylight (Fotios et al., 2019; Kummeneje and Rundmo, 2019; Ravensbergen et al., 2020; Uttley and Fotios, 2017; Van Cauwenberg et al., 2012). The risk of a cycle accident during darkness is higher and the feeling of social safety is negatively affected (Wanvik, 2009). In winter, when darkness sets in early, bicycle commuting decreases, in part due to potential bad weather conditions and early darkness. Sears et al. (2012) found that “getting dark too early” is the third most frequently cited reason for using the bike to commute.

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As a case study, we have looked into cycling in the dark in the province of East Flanders in Belgium. The province of East Flanders wants to increase the share of cyclists in their modal split by building cycling infrastructure and bicycle highways. The bicycle highways form the backbone of the bicycle route network in Flanders and lie between important poles of attraction where high cycling intensities can be expected. Skov-Petersen et al. (2017) conclude that upgrading cycle infrastructure and investments in bicycle highways result in a higher cycle use. Furthermore, the investments result in a higher degree of satisfaction among active cyclists. Over a longer period, this could lead to a higher modal share due to a potential social advertising effect (Skov-Petersen et al., 2017). In Flanders, public lighting is present along most cycling infrastructure to facilitate cycling when there is no or insufficient daylight. The design of cycling infrastructure is however currently more focused on daytime cycling. To organize effective strategies for increasing overall bicycle use, we need to know what hampers people from cycling in the dark. To address this, we conducted an online survey in January and February 2022. Additionally, in April 2022, we interviewed a selected group of respondents to gain deeper insights into their needs and bottlenecks of cycling in the dark. To our knowledge, current research on the socio-demographic characteristics of people cycling in the dark is limited. Hence, more insights can lead to better policy recommendations to increase the use of bicycles and partly resolve the bottleneck of darkness.

The paper is structured as follows. First, we discuss how darkness has an impact on cycling and cycling safety. Next, we look into socio-demographic characteristics that have an influence on the choice to cycle. We use a logistic regression analysis to explain the odds that a person will or will not cycle in the dark. These results are compared with the responses of the interviewees. We end the paper with the main conclusions and formulate a number of policy recommendations.

2. Literature review

2.1. Impact of darkness on cycling and cycling safety

Darkness and safety seem to be intertwined. Generally, darkness makes people feel less at ease, secure, and often associate the dark with danger, low visibility and higher accident risks. This sense of insecurity is especially pronounced among women, limiting their mobility when it is dark (Farina et al., 2021). Winters et al. (2011) and Spencer et al. (2013) found that lighting conditions are often a decisive factor for commuting to work by bike. Compared to darkness, daylight causes a relative increase in cyclists by 29%, from 38% to 67%, at the same time of day (Uttley et al., 2020). This deterrent effect is also more significant among people who do not regularly cycle (Uttley et al., 2020; Winters et al., 2011).

After dark, there is an increased risk of serious injury or death compared to other periods (Johansson et al., 2009). The risk of an accident for cyclists increases by 55% at night compared to daytime (Wanvik, 2009). Most recent figures (although dating from 2010) indicate a higher risk of serious injuries in accidents when it is dark compared to daylight, despite lower cycling mobility (Reurings, 2010) (see Figs. 1 and 2). In addition, the probability of a fatal outcome doubles when it is dark or when there is no lighting (Wanvik, 2009). This is likely the result of reduced visibility, which in turn can lead to slower reaction times and a higher impact at the time of the crash. At night, obstacles on a cycle path seem less visible to cyclists, leading to higher risks of a single crash involving only the cyclist. Furthermore, the visibility of cyclists to car drivers at night diminishes significantly, especially if the cyclists are not wearing fluorescent clothing, which increases the chance of an accident involving a car and a cyclist (Reurings, 2010; Wanvik, 2009).

Installing public lighting not only enhances road safety but could also increases cyclists' feelings of social safety. Lighting has a significant effect on 'reassuring' people. This has been confirmed by several studies

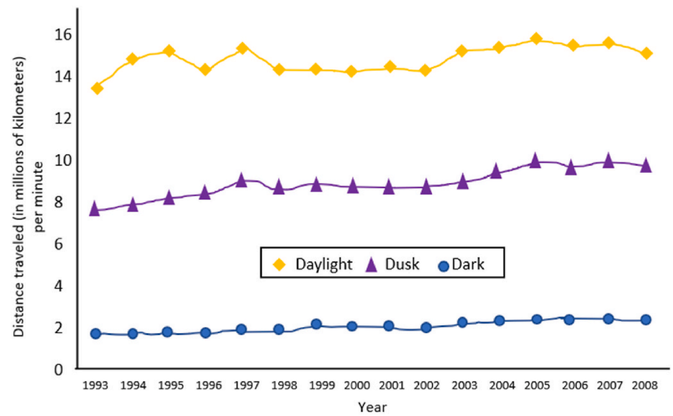

Fig. 1. Cycling mobility according to different light conditions (Adapted from Reurings, 2010).

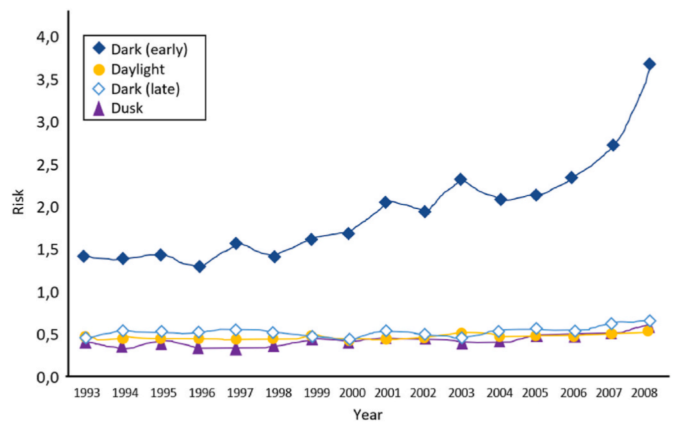

Fig. 2. The risk of cyclists in a non-motor vehicle crash (number of seriously injured cyclists divided by the distance traveled by cyclists in million km) according to different lighting conditions (fatalities not included) (Adapted from Reurings, 2010).

(Bernhof and Carstensen, 2008; Fotios and Gibbons, 2018; Hanyu, 1997; Kummeneje and Rundmo, 2019; Loewen et al., 1993; Nair et al., 1993; Okuda et al., 2007; Painter, 1994; Uttley and Fotios, 2017; van Cauwenberg et al., 2012). Street lighting reduces the fear of crime, assault, and intimidation (Fotios et al., 2019).

While public lighting is crucial, it is part of a broader array of strategies needed to enhance cycling safety. In exploring cycling safety in the dark, the discourse often gravitates towards the installation of public lighting. However, this focus might obscure other crucial elements that contribute to cycling accidents and general safety. A well-designed infrastructure that ensures visibility both during the day and at night is essential to provide safe cycling conditions. The vulnerability of cyclists is also seen as a direct result of societal choices in road design and traffic rules (te Brömmelstroet, 2020). A shift towards a cycling culture that prioritizes bicycles over motorized traffic is necessary (Braun and Randell, 2022). Cox (2020) states that cycling infrastructure should aim beyond merely a safe and comfortable means of travel. The dominance of car-based mobility practices should be challenged as well (Cox, 2020; Egan and Caulfield, 2024; Urry, 2004). Freudendal-Pedersen (2015) discusses the ongoing fight for mobility space between car drivers and cyclists, noting that the preference for motorized traffic in cities has marginalized cycling and led to conflicts over urban space (Koglin and Rye 2014; Koglin 2013, 2020). This comprehensive perspective highlights the need for a paradigm shift towards urban planning and policy-making that promotes cycling as a primary mode of transportation to make cycling safer both during the day and at night.

2.2. Socio-demographic factors influencing the choice to cycle

The modal choice to cycle depends on several factors (socio-demographic, environmental, psychological, economic, logistical and policy-related). These factors are not separate, but overlap and are intertwined. Some factors shape the general attitude towards cycling as a transport mode, while others have a greater influence on day-to-day decisions to use a bike. Although extensive literature on cycling exist (e.g. Baslington, 2009; Barberan et al., 2017; Dill and Voros, 2007; Hull and O'Holleran, 2014; Kim and Ulfarsson, 2008; Marquart et al., 2020; Motoaki and Daziano, 2015; Pucher and Buehler, 2006; Rérat, 2019; Sabir, 2011; Winters et al., 2007), factors related to cycling in the dark remain underexplored.

As individual socio-demographic factors are relevant in this study, some general findings are worth mentioning. According to Winters et al. (2007), elderly and women are associated with a lower likelihood of cycling compared to young adults and men. Farina et al. (2021) concluded that women feel less safe when it is dark. However, it is not clear to what extent this fear has an impact on the choice of cycling in the dark. Since women tend to be more risk averse than men, they often choose a 'safer' route (Edmond et al., 2009; Harms et al., 2007). Safer routes can have different meanings including cycling along a more lively route to reduce the risk of assault, cycling in groups, cycling in areas that are more secure and lit, etc. The effect of gender on cycling is however mixed and context-dependent. In low-cycling countries men cycle more frequently than women, while in high-cycling countries, no gender differences are found, or even women cycle more than men especially for trips to and from work and for trips related to shopping due to the present cycling culture (Aldred et al., 2016; Harms et al., 2014; Haustein et al., 2020).

Parents have a major influence on their children's (later) modal choice. When parents drive their children to school or other activities (i.e. children are used to getting around by car), once adults, they will mimic their parents' behaviour when they have children (Baslington, 2009). According to McDonald (2012), parents are often more concerned about letting their daughters cycle alone than their sons, and when parents choose to go to school by bike, they do this at a younger age with boys compared to girls (Aldred, 2015).

There has been an increase in e-bike use in European countries in the last decade (Casier and Witlox, 2022). Rising sales numbers plays a role in the more general acceptance of e-bikes as a functional mode of transport. E-bikes were primarily used by older adults. Now, recent Belgian data show that e-bike use spans all age groups, with the proportion of users over 46 years old decreasing from 96% in 2015 to 68% in 2020 (IMOB, 2020). Studies on the gender of e-cyclists suggest that most e-cyclists are predominantly male (Johnson and Rose, 2013; MacArthur et al., 2014). Fyhri and Fearnley (2015) concluded that although users are mostly male, e-bikes have a greater influence amongst women because women tend to make more and longer bicycle trips when changing to an e-bike compared to men. In a Chinese study, An et al. (2013) observed that there were no significant differences between genders. According to Ravensbergen et al. (2020) cyclists (and especially women) felt safer if they could get away faster from dangerous situations at night. The use of an e-bike could have a positive effect on the choice of cycling in the dark, but this is not discussed by Ravensbergen et al. (2020).

The intention to commute by bicycle is often associated with identifying oneself as 'a cyclist'. Interventions designed to encourage more people to cycle regularly should encourage them to identify themselves as cyclists (Lois et al., 2015). Besides intentions, habits and past use affect our mobility-related choices (Lanzini and Khan, 2017). Utility cyclists, who use bicycles primarily as a means of transport rather than for sport, perceive a lower risk of accidents due to their experience. This fear of accidents discourages people from cycling (Dill and Voros, 2007; Lois et al., 2015; Winters et al., 2011).

There exists a negative association between sport or leisure cycling and cycle commuting. These superficially similar behaviors have different underlying motivations (Lois et al., 2015). Cycle commuting is often seen as dangerous, demanding and stressful. Sport or leisure cycling is regarded as calm, peaceful and liberating. Sport or leisure cycling also often occurs during the day and not when it is dark. These conflicting images of cycling may discourage people who already cycle for sport from taking up cycle commuting (Gardner, 1998; Lois et al., 2015). Previous research suggests that cycling for leisure or sport can have a positive impact on commuting by bike, as those people have already cycling experience and are more familiar with the cycling environment (Kroesen and Handy, 2014; Lee et al., 2012; Park et al., 2011; Stinson and Bhat, 2004; Xing et al., 2010).

The results on the relationship between income and cycle use depends on how income is defined. Canadian research from Toronto (Decima Research, 2000) and Vancouver (Translink, 2004) show that a higher income per capita leads to a higher chance of using a bicycle. The Netherlands, Denmark and Germany are often cited as examples as relatively rich countries with high bicycle use (Pucher et al., 1999). Winters et al. (2007) and Sabir (2011) state that higher individual incomes lead to a lower probability of commuting by bike (i.e., income inelastic demand for cycling).

Also individual socio-demographic factors (among other factors) have an influence on the choice to cycle. However, research on socio-demographic characteristics of people cycling in the dark is limited and it is not known to what extent the darkness has an impact on the choice to cycle.

3. Methodology

3.1. Data

Data used for this analysis were collected using an online survey focused on cyclists in (East) Flanders (Belgium). Besides some general questions on cycling and cycling in the dark, four particular sections of bicycle highways in the province of East Flanders (Belgium) were examined. These bicycle highways, mainly used by commuters, were chosen due to recent modifications to the public lighting (such as the presence of spotlights in the ground (F400, F417 and F45) or dynamic lighting (F412)) (see Fig. 3). On these particular sections, public lighting is present during the whole night. The choice of cycling in the dark on these sections is therefore not affected by the absence of public lighting. The F400 runs through an urban area, while the other three sections are located in suburban or rural areas. For this study, we exclusively included people who cycle on the four aforementioned sections.

We recruited participants through social media, cycling organizations in Flanders, handing out flyers on the specific trajectories and contacting municipalities, schools and specific organizations. We obtained responses from 842 cyclists, predominantly using the F400 in Ghent, with the F45 being the least frequent used route (see Fig. 4).

After indicating if the respondent uses one of the selected sections of the bicycle highways, the respondent was asked if he/she used these trajectories when it is dark or only during the day. This is the input for the dependent variable. It is possible that some of the respondents cycle in the dark, but not along the bicycle highways. Furthermore, they were asked to answer some general socio-demographic questions.

In addition to the online survey, qualitative data were obtained through in-depth interviews. From those expressing interest, we selected a representative group for interviews based on gender, age, type of bike, work situation, and living environment. The number of interviewees per route was proportional to the distribution of respondents in the survey for each route. Although some participants did not attend the scheduled appointments, 26 interviews were ultimately conducted, predominantly men. We were unable to conduct an interview with any of the few respondents who used the F45. Table 1 gives an overview of the socio-demographic characteristics of the interviewees. Interviews were conducted either face-to-face or via the online platform Microsoft Teams,

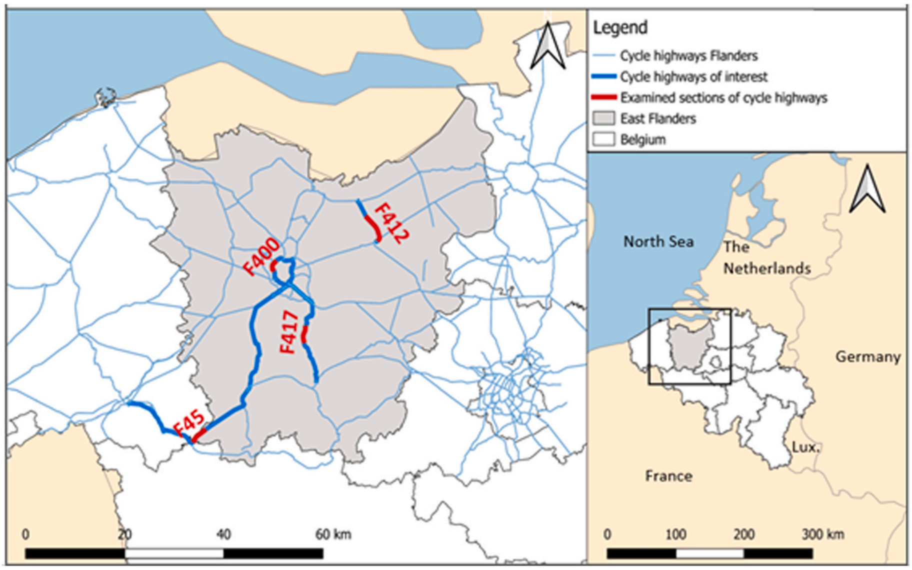

Fig. 3. Overview of examined sections of cycle highways in East Flanders (Belgium).

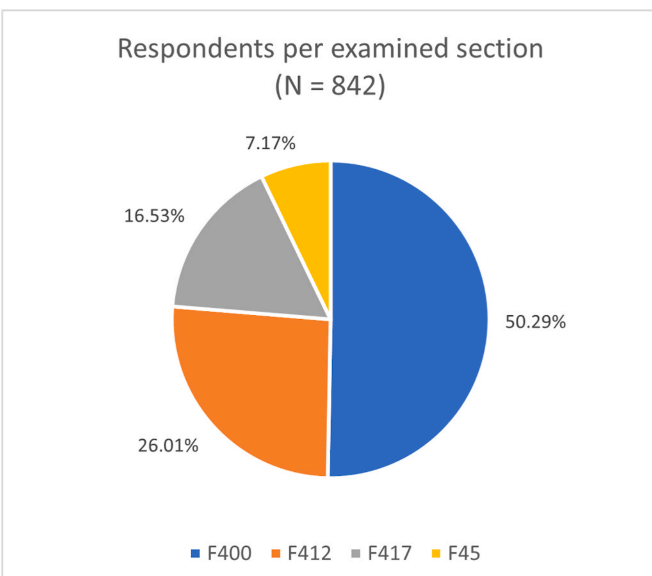

Fig. 4. Percentage of respondents per examined section.

Table 1
Profile interviewees (N = 26).

VARIABLE	CATEGORIES	NUMBER OF RESPONDENTS
USED SECTION OF CYCLE HIGHWAYS	F400	14
	F412	5
	F417	7
	F45	0
GENDER	Male	18
	Female	8
AGE	<25	1
	26–45	9
	46–65	13
	>65	3
TYPE OF BIKE	Regular bike	13
	Racing bike	4
	E-bike	5
	Speed pedelec	2
	Outsized bike	2
WORK SITUATION	Working	21
	Unemployed	1
	Pupil or student	1
	Retired	3
LIVING ENVIRONMENT	City center	7
	Suburban region	11
	Village center	5
	Rural environment	3

focusing on topics like cycling experiences in the dark, deterrents to cycling in the dark, preferred routes, and the effectiveness of different types of lighting and markings on cycling lanes. The semi-structured interview questions were based on the respondents' answers in the survey. Each interview lasted approximately half an hour.

3.2. Method of analysis

To determine which factors have an influence on whether or not a person cycles in the dark, a multiple logistic regression (Hosmer and Lemeshow, 2000; Kleinbaum and Klein, 2002) is performed using the statistical software IBM SPSS Statistics 27. The dependent binary variable is if a person cycles in the dark on one of the selected trajectories or not. The independent variables are a series of categorical variables (See Table 2). The general form of logistic regression is as follows:

$$y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

$$y_i = \ln\left(\frac{P}{1-P}\right)$$

$$P = \frac{e^{yi}}{1+e^{yi}} \text{ and } 1-P = \frac{1}{1+e^{yi}}$$

where X_1, X_2, …, X_n are the independent variables, y_i is the binary independent variable (per trajectory), β_1, β_2 to β_n are the regression coefficients to be estimated, and P is the probability of success (cycling in the dark), whereas (1 – P) the probability of failure (no cycling in the dark).

The results of the multiple logistic regression analysis are complemented by interview responses. The combination of the quantitative and qualitative analyses enhances the depth of understanding and allows for a nuanced interpretation of the result.

Table 2
Explanatory variables for cycling in the dark (N = 813 respondents) (reference categories in italic type).

Variable	Categories	Number of respondents	Percentage of respondents
Frequency	Daily	105	13%
	Multiple times a week	153	19%
	Weekly	82	10%
	Multiple times a month	129	16%
	Monthly	102	13%
	Multiple times a year	242	30%
Company	*Alone*	529	65%
	With child(ren)	72	9%
	With someone else (partner, friend, colleague …)	191	23%
	In group	21	3%
Bike	*Regular bike*	407	50%
	Racing bike	118	15%
	E-bike	220	27%
	Speed pedelec	35	4%
	Outsized bike	33	4%
Age	11–17	39	5%
	18–25	44	5%
	26–45	373	46%
	46–65	281	35%
	> 65	76	9%
Gender	*Male*	398	49%
	Female	411	51%
	X	4	0%
Diploma	None	5	1%
	Primary education	42	5%
	Secondary education	155	19%
	Bachelor or equivalent	281	35%
	Master/PhD or equivalent	330	41%
Work situation	*Working*	621	76%
	Unemployed	17	2%
	Pupil or student	75	9%
	Retired	100	12%
Living environment	City center	118	15%
	Suburban region	445	55%
	Village center	109	13%
	Rural environment	141	17%

4. Results

Table 2 presents an overview of the answers related to the used variables in the analysis. 29 outliers were detected and removed from the dataset based on the case wise list, leverage values and DFBETAS values. The remaining 813 cases had no missing values.

Table 3 consists of the regression coefficients of the independent variables after carrying out the multiple logistic regression. All variables are significant and exert a (positive or negative) influence on cycling in the dark with a significance level of 10%. As the variables are categorical variables, a reference category is chosen for each variable. The results need to be interpreted compared to this reference category (see Table 2). Based on goodness-of-fit (GoF) parameters, we can conclude that the logistic model is acceptable. There is no strong multicollinearity between the independent variables as the Variance Inflation Factors (VIF) are between 1 and 1.3.

4.1. Influence of socio-demographic characteristics on the choice to cycle in the dark

The analysis revealed that familiarity with a route has a strong positive effect on the likelihood of cycling in the dark. The more frequently a indicated route is used, the greater the chance that a person will cycle there when it is dark. Using a route daily increases the odds of cycling in the dark by 3.644 compared to those who only use it a few times a year. When commuting, people use a cycle path mostly on a daily or weekly basis so they know this route quite well. This supports the findings of Dill and Voros (2007), Winters et al. (2011) and Lois et al. (2015) which suggest that utility cyclists, who are familiar with their routes, perceive fewer risks and have less fear compared to less experienced cyclists.

Contrastingly, many interviewees (who are mainly utility cyclists) reveal that they change their routes as darkness falls. They often prefer routes that are livelier and offer more social control. Because cycle highways are typically underused at night and remote, routes along busier roads are favoured. One of the interviewees (male, student, regular bike, living in the countryside of Lokeren) stated: *"Cycling through a forest feels unsafe since someone can always be hiding in the bushes. Cycling through open fields feels abandoned and thereby unsafe."* Nonetheless, some respondents also noted that cycle highways feel safer in the dark due to the absence of motorized traffic, for example: *"I prefer to cycle in a pleasant, open, natural environment, which makes you cycle more relaxed and less stressed even when it is dark"* (male, average age, e-bike, living in the countryside of Oosterzele). Moreover, cycle highways can become more desirable during peak hours, such as commuting times, even when it is dark since they are more heavily trafficked by cyclists.

Cycling with children increases the likelihood of cycling in the dark compared to cycling alone. The odds increase by a factor of 1.720, or 72%. Parents often accompany their children when cycling to school. In winter, this often takes place in the dark which could explain why these odds are this high. One interviewee, who is a father, responded (male, average age, regular bike, living in the city of Ghent): *"I cycled with my children to school for a long time out of concern. There is a forest on this route and I prefer not to let my children cycle here alone in the dark."* If people cycle with someone else (e.g. friend, colleague, partner …), the odds to cycle in the dark decrease with 8.7% but the odds do not differ a lot compared to people who cycle alone. People who cycle in groups have the least chance to cycle in the dark on one of the chosen trajectories. Their odds are 1.108 times lower than people who cycle alone. The odds that people in groups cycle in the dark decrease with 67%. Those people are mostly recreational or sportive cyclists on these trajectories. Recreative and sportive cycle tours are mostly done during the day when there is still daylight. Obstacles or bad road surfaces are in addition more difficult to detect in group when it is dark as stated during the interviews.

Racing bike users have 70% lower odds of cycling in the dark compared to regular bike users, largely because racing bikes often lack proper lighting, and the reduced visibility at night makes fast cycling less appealing. This result confirms that recreational and sportive cyclists mostly cycle during the day and not when it is dark. It is also in line with the results of Lois et al. (2015) who say that there is a negative association between sport cycling and cycle commuting (which more frequently occurs in the dark). Cyclists with a racing bike tend to cycle faster than cyclists with a regular bike. Cyclists with an e-bike and a speed pedelec have higher chances to cycle in the dark (respectively with a factor of 1.24 and a factor of 17.437). People with an e-bike or a speed pedelec often use these types of bikes for commuting and will use those bikes during peak hours. Their bike lights are in general quite good and strong which makes cycling in the dark more comfortable. Using an e-bike or a speed pedelec can have an reassuring effect because, in case of danger, you could quickly cycle away. This is confirmed by a statement of one of our respondents (female, average age, speed pedelec, living in the countryside of Lokeren) who said: "*I prefer not to cycle in the dark on an abandoned cycle path with my regular bike. With my speed pedelec however, I would probably do*". Cycling with a high speed in the dark can however also be a disadvantage as reported by another respondent (male, average age, e-bike, living in the city of Ghent): "*The route through the Bourgoyen (nature reserve in Ghent) is a nice cycle path during the day, but in the dark the visibility is less because of the bushes and the bends, making it difficult to pick up speed*". Lastly, cyclists with an outsized (cargo) bike have lower chances to cycle in the dark. Their odds are 23.8% smaller than cyclists with a regular bike. Cargo bikes, being wider than regular bicycles, face increased danger due to road narrows

Table 3
Multiple logistic regression Logit Model Estimates and goodness-of-fit parameters.

	B	S.E.	Wald	df	Exp(B)	Sig.
Frequency			95.844	5		0[a]
Daily	3.644	0.541	45.303	1	38.237	0[a]
Multiple times a week	2.833	0.354	64.182	1	16.998	0[a]
Weekly	1.756	0.347	25.605	1	5.791	0[a]
Multiple times a month	1.769	0.305	33.753	1	5.867	0[a]
Monthly	0.963	0.289	11.119	1	2.621	0.001[a]
Company			6.318	3		0.097[c]
With child(ren)	0.542	0.395	1.881	1	1.72	0.17
With someone	−0.091	0.234	0.151	1	0.913	0.698
In group	−1.108	0.554	4.005	1	0.33	0.045[b]
Bike			28.628	4		0[a]
Racing bike	−1.205	0.293	16.901	1	0.3	0[a]
E-bike	0.216	0.247	0.764	1	1.241	0.382
Speed pedelec	2.859	1.081	6.997	1	17.436	0.008[a]
Outsized bike	−0.272	0.56	0.237	1	0.762	0.626
Age			11.941	4		0.018[b]
11-17	2.013	1.259	2.558	1	7.489	0.11
18-25	0.714	0.943	0.575	1	2.043	0.448
26-45	1.144	0.67	2.917	1	3.141	0.088[c]
46-65	0.444	0.63	0.496	1	1.558	0.481
Gender			58.545	2		0[a]
Female	−1.803	0.236	58.545	1	0.165	0[a]
X	19.356	18208.215	0	1	254819922	0.999
Diploma			12.93	4		0.012[b]
None	−0.973	1.882	0.267	1	0.378	0.605
Primary education	−2.983	0.854	12.209	1	0.051	0[a]
Secondary education	−0.131	0.29	0.204	1	0.877	0.652
Bachelor or equivalent	−0.289	0.231	1.571	1	0.749	0.21
Work situation			6.958	3		0.073[c]
Unemployed	0.523	0.828	0.399	1	1.687	0.527
Pupil or student	0.556	0.76	0.535	1	1.744	0.465
Retired	−1.453	0.602	5.815	1	0.234	0.016[b]
Living environment			8.461	3		0.037[b]
City center	−0.19	0.353	0.29	1	0.827	0.59
Suburban region	−0.727	0.287	6.433	1	0.483	0.011[b]
Village center	−0.633	0.367	2.976	1	0.531	0.084[c]
Constant	0.868	0.728	1.422	1	2.382	0.233
Goodness-of-fit parameters						
R^2	80.6%					
Adjusted R^2	32.8%					
−2 Log likelihood	674.788					
Chi^2	302.928[a]					
Cox & Snell R^2	31.1%					
Nagelkerke R^2	44.5%					

Note.
B = logistic coefficient; S.E. = standard error of estimate: Wald = Wald Chi-square values; df = degree of freedom, Sig. = significance; Exp(B) = exponentiated coefficient.
[a] Represents the significance levels of 1%.
[b] Represents the significance levels of 5%.
[c] Represents the significance levels of 10%;

and poles, which are particularly challenging to navigate in the dark as reported by a respondent using a cargo bike (male, average age, cargo bike, living in the city of Ghent): "*You have to be more alert and focused in this area (where the cycle highway narrows near the station). It is often difficult to pass, especially with a cargo bike, and the poles on the side are poorly lit*".

All age groups have higher odds to cycle in the dark than seniors over 65 years old. Seniors have less need to go out in the evening or at night when it is dark. Since the studied sections of the bicycle highways are mostly used by commuters, it seems logical that seniors use these routes less. It also confirms that elderly are associated with a lower likelihood of cycling compared to young adults (Winters et al., 2007). One of the senior respondents (female, senior, regular bike, living in the city of Ghent) stated: "*An area in the dark is not inviting. I only cycle in the dark out of necessity*". The odds of young people between 11 and 17 years old have the highest odds to cycle in the dark. Those odds are higher with a factor of 7.489 compared to seniors. They could cycle to school which in the winter often takes place in the dark. This age group also has less access to possible alternatives than adults (e.g. a car). The odds of the other age groups are respectively higher with a factor of 2.043 (18–25), 3.141 (26–45) and 1.558 (46–65) compared to seniors.

Women have 84% lower odds to cycle in the dark compared to men. This is in line with previous findings on the impact of darkness on women and men. Women feel less safe in the dark than men because of the fear of possible assaults and robberies (Farina et al., 2021). Besides, there are noticeable gender differences in the answers given on other questions of the survey. Women cycle less in general and cycle less in the dark. When it is dark, they prefer not to cycle alone and they choose more often to cycle along lively routes. A female respondent (female, average age, regular bike, living in the countryside of Lokeren) mentioned: "*If there is enough light, in built-up areas where there is enough life, I would use my bike. On a route where there are many other cyclists when it is dark, I would cycle in the dark*". Male respondents even stated that they would have answered the questionnaire differently if they would be a woman. There are less pronounced differences between other target groups (e.g., based on age, working situation, type of bike).

Level of education also has an impact. Having a master diploma, a PhD or an equivalent diploma increases the odds of cycling in the dark compared to other diplomas. The odds of cycling in the dark of people with only a diploma of primary education decrease 95% compared to people with university college or university degree. Based on the cycle research of the province of Antwerp, most cyclists are typically higher educated people (iVOX, 2018). Note that older generations had fewer opportunities to pursue higher education, which confirms the conclusions made about the age groups. However, no significant differences were observed among interviewees with different education levels.

The results about the different work situations also confirm previous results of the age groups. Retirees are less likely to cycle in the dark, with their odds of doing so 25% lower than those of the working class. In addition, pupils and students have higher odds and these increase with 74% compared to the working class. Since the number of unemployed people in our sample is relatively small, we are not able to draw meaningful conclusions.

Lastly, living in a rural environment has a positive impact on the odds of cycling in the dark. When living in a city center, the odds of cycling in the dark decreases with 17% compared to a rural environment. People living in a suburban region or a village center have respectively 52% and 47% less chance to cycle in the dark compared to a rural environment. Three of the four trajectories are located in a rural environment. If people live nearby in a rural environment, it is normal to use those trajectories more, even in the dark. In a city and village center, there are possibly more other alternatives to a bike when it is dark such as public transport. For instance, one of the respondents (male, average age, regular bike, living in the city of Ghent) mentioned preferring the bus over cycling when the weather is bad and it is dark, especially since a bus stop is conveniently located near his home.

4.2. Relative importance of the variables

Fig. 5 illustrates the relative importance of the different variables based on the Wald statistics. This is done by dividing each variable's Wald score by the total of all Wald scores.The variables 'Frequency', 'Gender' and 'Bike' have the highest impact on whether a person cycles in the dark. Together, these factors determine almost 80% if a person cycles in the dark. Therefore, if policymakers aim to increase cycling frequency, including during dark hours, they should focus on specific demographic groups: those who already frequently use bicycles for commuting, address gender differences, and consider the type of bicycle used.

5. Discussion and conclusion

Darkness remains a barrier to cycling and commuting by bike, especially during the winter. It is often associated with danger such as higher risks of an accident or a lower feeling of social safety. Since there is significant investment in cycling infrastructure and highways to increase bicycle use in the dark, it is important to know who is cycling in the dark and who is not. This knowledge helps target promotional campaigns and government interventions to enhance the attractiveness of cycling in the dark.

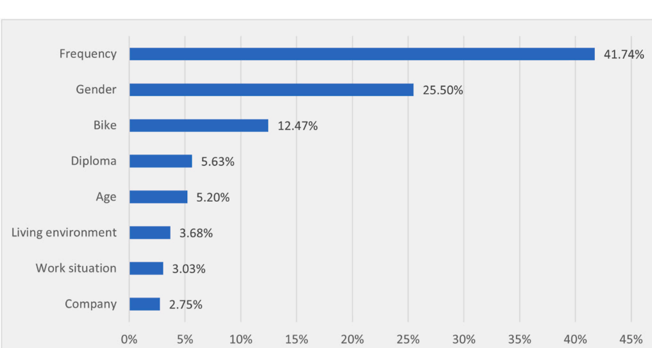

Fig. 5. Relative importance of variables.

The socio-demographic factors influencing the choice to cycle in the dark have not received much attention in previous research. We provide more insights. Our results align with known socio-demographic factors influencing the choice to cycle, but with specific differences when cycling in the dark. Combining quantitative and qualitative research enables a more comprehensive understanding of cycling in the dark. The interviews offered deeper insights into the thoughts, feelings and behaviours of cyclists. The responses of the interviewees mostly confirmed the results of the multiple logistic regression analysis and helped understanding the mechanisms behind the different odds of cycling in the dark. Combining these insights can lead to a more advanced understanding of the issue.

Knowing and using a route frequently has a positive impact on the likelihood of cycling in the dark. Encouraging daily cycling can positively affect cycling frequency when it is dark because people would be more familiar with the cycled routes. By encouraging people to cycle in general, it creates a cycling culture. Habits and past use have an impact on the mode choice and leads to an increased cycling. Secondly, age also has an impact on the choice to cycle in the dark. Adolescents or students have higher odds of cycling in the dark compared to elderly or retirees. Younger adults often have fewer mode alternatives to travel than adults. It is important to further investigate how (social) safety can be increased for this age group.

The cycling infrastructure should also be well adapted to cyclists with an e-bike or speed pedelec. Those cyclists have higher chances to cycle in the dark compared to cyclists with a regular bike. As most people still have access to a regular bike, this group of cyclists should not be ignored. The average speed of a regular bike is lower. This can have an impact on the social safety feelings of cyclists. In future research, we should look at how cyclists with a regular bike perceive darkness and how cycling in the dark could be made more attractive (e.g., by improving infrastructure). Furthermore, given the significant speed differences between regular bikes and e-bikes or speed pedelecs, cycling infrastructure should be designed to facilitate safe passing (both during the day and at night). This can include removing obstacles, designing wider cycling lanes, and providing clear ground markings.

Lastly, women feel less safe by bike, especially when it is dark. Promotion campaigns should also focus on how feelings of social safety of women can be increased and how cycling in the dark could be made more appealing. Some female interviewees suggested the development of a smartphone application for use in emergencies, which could facilitate quick contact with emergency services or offer safer cycling route options.

Some of the other suggestions to improve cycling safety were related to improve the lighting. As public lighting can have a positive impact on the feeling of social safety, it is also relevant to know the impact of possible modifications to the public lighting (e.g., installing dynamic lighting or ground spots). Since public lighting also has negative side effects such as light pollution, impact on fauna and flora (Hölker et al., 2010; Longcore and Riche, 2004), it is important to know if the installation of lighting could result in a higher modal share of cyclists. However, it is important to note that numerous factors contribute to enhancing both the perceived safety and actual traffic safety, including a clear view of the route, route liveliness, and good orientation. While lighting improves visibility for cyclists and is often mentioned by respondents as a solution to make cycling in the dark more appealing, it is not the only method. Interviewees frequently emphasized the significance of ground markings (such as those indicating the edges or centre of cycling lanes), maintenance of surrounding bushes and trees, and the removal of obstacles to enhance visibility along the route as well. Public lighting should be installed only where necessary, ensuring the right lighting (e.g., lampposts, ground spots, dynamic lighting etc.) is used in the appropriate locations. Furthermore, by providing a clear motivation, most respondents are open to alternatives of classic public lighting (lampposts). Additionally, transport policies and planning should prioritise the needs of cyclists, making cycling a core element of transport planning (equal to motorized counterparts).

During the day, most interviewees prefer cycling in remote, natural or rural areas due to the ample space, reduced risk of collisions with motorized traffic, and a less congested environment. However, as it gets dark, they often favor city areas over remote locations. During the interviews, many participants expressed a willingness to deviate from the shortest route in favor of one that is livelier and has safer infrastructure (e.g., separated cycling lanes or presence of public lighting), provided the detour does not exceed 5–10 min. Possible solutions include providing signage for alternative routes and developing a route planner tailored to cyclists' needs.

There are however still other important variables that have an impact on the choice to cycle when it is dark, which were not included in our study. To propose effective strategies and policies to make cycling in the dark more attractive, it is important to look at the specific context of cycling infrastructure. One of the respondents (male, average age, sports bike, living in the city of Ghent) stated: "*The most pleasant route during the day is not always the most pleasant route in the dark*". The socio-demographic characteristics of the cyclists, the main use and trip purposes of a route, the (perceived) social and road safety, the public lighting, the type of cycling infrastructure, the activity along the cycle route, cycling planning and policies etc. have an impact on the attractiveness of a cycle route and hence the choice to cycle in the dark. In future research, it is of interest to include those variables and the specific context to achieve a more holistic approach.

Another limitation of this study is the underrepresentation of younger people and older adults in the sample, with only 5% and 9% respectively. Given that the logistic regression analysis identified age as a significant factor influencing the decision to cycle in the dark, these findings may not accurately reflect broader trends. Further research targeting these specific age groups is needed to better understand age-related influences on cycling behaviour in dark conditions.

Additionally, the use of a cross-sectional design limits our ability to establish causal relationships between socio-demographic characteristics and cycling choices in the dark. This study design only allows for identifying associations and cannot track changes in cycling behaviour over time or in response to modifications in cycling infrastructure. Conducting follow-up studies or natural experiments as infrastructure evolves could provide valuable insights into the dynamics of cycling preferences and safety perceptions.

Besides, this study is geographically limited to one province in Belgium, where cycling infrastructure and habits are relatively advanced. While there are similar conditions in other Belgian provinces, the findings and recommendations may not directly apply to regions with less developed cycling cultures. Consequently, while the insights gained from this research are valuable for similar contexts, they should be adapted with caution when applied to areas where cycling as a mode of transport is still emerging or underfunded.

In conclusion, it is important that cycle routes are attractive and safe for everyone. Gender differences need to be reduced, and all age groups should feel comfortable to cycle in the dark. By prioritizing cycling over motorized traffic and considering the varied needs of different (vulnerable) groups in bicycle planning and policies, we can create more equitable urban spaces. Everyone experiences cycling in the dark differently. Some choose to cycle along other more vibrant routes, and others focus on road safety. Note that in our sample, people who do not cycle at all are not included. Insights in why they do not cycle and their potential to cycle, could lead to interventions to increase the modal share of cyclists. So for policy-making the first priority should go to how to get people to cycle, and then, how to keep them cycling, even when it is dark. Policy interventions should focus on the actual needs of the intended target groups. Further sociological, behavioral and traffic research is therefore required.

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Declarations of interest

None.

CRediT authorship contribution statement

Caroline Beckers: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Corneel Casier:** Visualization, Writing – review & editing. **Frank Witlox:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tranpol.2024.05.030.

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