Transportation Research Interdisciplinary Perspectives 22 (2023) 100921

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.sciencedirect.com/journal/transportation-research-interdisciplinary-perspectives

Transforming bicycle market: Assessing cyclists route preferences on different bike types in a choice experiment

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ARTICLE INFO

Keywords:
Bike infrastructure
Route preferences
Discrete choice experiment
Cargo bike
e-bike

ABSTRACT

Cycling is an environmentally friendly and healthy mode of transport that can be supported by appropriate road infrastructure. Most recently, the bike market is being differentiated and sales of innovative bike types such as cargo bikes and e-bikes are growing rapidly. Even though the importance of these particular vehicles is increasing greatly, little is known about specific route preferences applicable. Hence, we evaluate a graphically assisted online discrete choice experiment. We investigate the route preferences of users of different types of bikes. By applying mixed logit models, we estimate the differences in the valuation of infrastructure characteristics between users of regular bikes, cargo bikes and e-bikes. Results show that users of both, cargo bikes and e-bikes value a high-quality infrastructure even higher than users of regular bikes do. Higher route requirements of users of innovative bike types strengthen the importance of upgrading the infrastructure as these vehicles are becoming increasingly popular.

Introduction

Choosing bicycle as mode of transport in cities shows several positive impacts on both, the society and the environment (Gössling et al., 2019; Makarova et al., 2019; Raustorp and Koglin, 2019; Watts et al., 2020). Cycling rates are rising in many cities and a growing number of municipalities aim to support the uptake of cycling (Lanzendorf and Busch-Geertsema, 2014). Thereby adapting the road infrastructure to current and future needs is major challenge in cities. Hence, knowing about these needs is of major importance. Regarding the technological development of bicycles, we experience a differentiation amongst various bike types. Innovative vehicle concepts gain more and more importance. Especially the sales volume of e-bikes and cargo bikes show strong growth rates (Brust, 2021; Eisenberger, 2020; Stork, 2022). In Germany the share of e-bikes in all sold bikes reached 48 percent in 2022 (Stork, 2023). These types of bikes allow for longer trips, more luggage and as a consequence enable users for other trip purposes. At the same time, different acceleration behaviour and another track width can be observed. To date, the share of cargo bikes is much smaller. But the increase in sales was almost 2/3 in 2021 compared to 2020 (Stork, 2022). When looking at the infrastructure or dedicate cycle routes, many different options are possible in terms of which roads are being used and which type of infrastructure is being built. For example, along main streets protected bike lanes, as rather new type of infrastructure in Europe, compete with cycle paths on the pavement or with marked bike lanes. Alternatively, cycling in mixed traffic along roads with low volume of car traffic of different type seems desirable to cyclists. Cycle streets explicitly prioritize cyclists. These roads without through traffic are a rather new achievement in many countries and are still used rarely. In Germany, motorized traffic is only allowed in a cycle street when additional signs state so (often residents are permitted). Cyclists are allowed to cycle side by side. Cars are allowed to drive up to 30 km/h and must not endanger or hinder bicycle traffic.

There is a long history of investigating cyclists route choice behaviour using different methodologies (Aultmann-Hall, 1996; Broach et al., 2012; Buehler and Dill, 2016; Caulfield et al., 2012; Krizek et al., 2009; Nelson and Allen, 1997). Even though there is a large body of studies investigating cyclist's route choice behaviour using stated preference approaches (Clark et al., 2019; Hardinghaus and Papantoniou, 2020; Mertens et al., 2016; Tilahun et al., 2007; Vedel et al., 2017), most of them focusses on route choice behaviour of users of conventional bikes or does not differentiate between bike types. Existing research on new bike types such as e-bikes or cargo bikes usually deals with one specific bike type and therefore does not allow for direct comparisons.

Regarding cargo bikes, previous research proves that infrastructure is of major importance (Liu et al., 2020; Nürnberg, 2019; Thoma and

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https://doi.org/10.1016/j.trip.2023.100921
Received 20 March 2023; Received in revised form 10 July 2023; Accepted 12 September 2023
Available online 15 September 2023

Gruber, 2020). Thereby, several prior studies investigate the commercial use of cargo bikes in delivery. Often a comparison between cars or trucks and cargo bikes is aimed at. Route choice is only of minor importance in current research. Gruber and Narayanan (2019) investigate travel time differences in commercial transport and compare cargo bike and cars. The authors find that commercial users of cargo bike choose routes through parks and via one-way streets where contraflow is permitted for bicycles. These shortcuts result in time advantages compared to cars (Gruber and Narayanan, 2019). Related research conclude that delivery cargo bikes are more cost effective than delivery trucks in close proximity (Sheth et al., 2019) and a significant share of deliveries can be substituted (Yang et al., 2023). One reason for this is that cargo bikes have route options like bike lane, sidewalks, and may access car-free areas (Sheth et al., 2019). Liu et al. (2020) address the question of cargo bike route preferences. The authors develop a qualitative approach and interview both planners and users of cargo bikes. The study finds that traffic volume of trucks is most important to how routes are perceived. Also parked vehicles and the type of the bike infrastructure play a role in route choice (Liu et al., 2020). Dybdakeb and Ryeng (2021) combine GPS tracking and qualitative interviews to draw conclusion regarding cargo bike usage in winter. Regarding route choice, the authors state that volume and velocity of motorized transport as well as pedestrians are crucial factors (Dybdalen and Ryeng, 2021).

The state of research on e-bikes appears diverse. There are several studies broadly assessing various aspects of e-bike usage (Almannaa et al., 2021; Plazier et al., 2017; Sun et al., 2020; Wild and Woodward, 2019). A lot of research addresses the potential of e-bikes to substitute cars (Lopez et al., 2017; McQueen et al., 2020; Winslott Hiselius and Svensson, 2017). In addition, Plazier et al. (2017) perform a comprehensive analysis of e-bike commuters. Further studies explicitly investigate route choice of e-bike users (Dane et al., 2020; Lopez et al., 2017). Dane et al. (2020) analyse GPS tracks of e-bike users and estimate a mixed logit model comparing influence of sociodemographic attributes on route choice between regular bikes and e-bikes. Differences between bikes and e-bikes based on GPS data were also analyzed by Allemann and Raubal (2015). In addition, Lux et al. (2018) compared users of both bike types. Resulting route preferences appear inconsistent across prior studies. Plazier et al. (2017) state the rather qualitative finding that users of e-bikes "generally preferred enjoyable and quiet routes over faster and more direct ones" (Plazier et al., 2017). The authors conclude that electric assistance allows for choosing more enjoyable routes. On the contrary, Allemann and Raubal (2015) find that e-bike users choose routes with higher exposure to motorized traffic more often and value traffic volume as less important than users of regular bikes while the importance of trip length is similar across both groups.

In summary, knowledge of route preferences in terms of the type of bike that was used is not sufficient to date. In prior research, authors miss a systematic comparison between the infrastructure needs of users of cargo bikes and regular bikes (Liu et al., 2020). Comparing individual results based on studies using different methodologies does not allow for drawing conclusions regarding differences in route preferences.

In addition, it is criticised that results regarding differences between route choices of bike and e-bikes are based on small sample sizes (Allemann and Raubal, 2015) which means that the reliability of results is limited. Accordingly, authors of prior studies see the need to verify the results by large samples of quantitative data (stated or revealed preference) (Allemann and Raubal, 2015). Thus, there is limited empirical knowledge on differences in route choice behaviour under joint consideration of the influence of bike types and comprehensive route attributes. Hence, in this study, a choice experiment is performed to evaluate route preferences of users of different bike types. We aim to investigate differences in route preferences of cargo and e-bike users compared to usual bike users. Since the share of these innovative bike types is raising, meeting the demand of their users is crucial when aiming for a future-proof adaptation of the urban road infrastructure.

Materials and methods

The data used originate from a large online survey on bike route choice (Hardinghaus and Papantoniou, 2020). In a graphically supported stated choice experiment different route characteristics were presented to and evaluated by participants. Table 1 displays the attributes and levels of the experiment with the respective reference alternatives marked in bold. These were based on the literature and selected in an expert workshop. In addition, information on characteristics of the person travelling and the trip itself were collected. Thereby, the participant was asked before the experiment which type of bike he or she would be using.

For the experiment, a Bayesian efficient design was developed based on a pre-test using Ngene (Bliemer and Rose, 2006). It consisted of eight choice situations with three alternatives (and a no-choice option), varied in three blocks. Fig. 1 displays an exemplary choice situation.

Detailed information about considerations when designing the experiment as well as recruitment and the sample description can be found in the original resource (Hardinghaus and Papantoniou, 2020).

Sample and subsampling

The participants were recruited in multiple countries in autumn 2018 using social media and newsletters. For the analysis the data on participants from Germany was used in order to reduce bias from different state of infrastructure experiences in different countries. The dataset for participants in Germany consists of 4,463 individuals. With eight choice situations per individual, this leads to 35,704 observations. In addition to the choice experiment, some information on user characteristics were collected. Those include, sociodemographics like age, gender, education and occupation, riding with children, the frequency of bike riding as well as the used bike type.

Due to the self-selective sampling method, the sample shows some bias in terms of sociodemographics. Male participants are overrepresented with almost 72%. The age distribution of the sample shows differences to the German population as a whole. Children and adolescents under the age of 18 are not addressed in this survey. At the same time, these groups make up around 16% of the German population. In addition, only 2.5% of the subjects are 65 years or older - compared to 20.6% in the total German population (Zensus 2016: Vielfältiges Deutschland, 2016). The formal level of education is significantly higher than the German average: 67% of the participants in the sample compared to 15% in the population have a college or university degree (Zensus 2016: Vielfältiges Deutschland, 2016). Mostly cyclists took part in the survey. Three quarters of the participants use the bicycle daily or almost daily. In a nationwide study with representative sampling, this is only nine percent (Borgstedt, 2017).

When separating the sample by the used bike type sociodemographic distributions differ greatly between the groups. As we are interested in differences in preferences for the infrastructure attributes depending on

Table 1
Attributes and levels of the experiment.

Attribute	Levels
Street type	**Arterial road** | Side street
Cycle infrastructure	**No cycle infrastructure** | Bike lane | Cycle path | Protected bike lane
Street Regulation	**Maximum speed for cars: 50 km/h** | Maximum speed for cars: 30 km/h | Cycle street (no through traffic, residents only) | Living street (max. speed cars 7 km/h)
Surface	**Cobblestones** | Asphalt
Parking	**No on-street parking** | On-street parking
Trees	**No trees** | Trees
Travel time [minutes]	8 | 10 | 12 | 15

Bold indicates the reference scenarios. Source (Hardinghaus and Papantoniou, 2020).

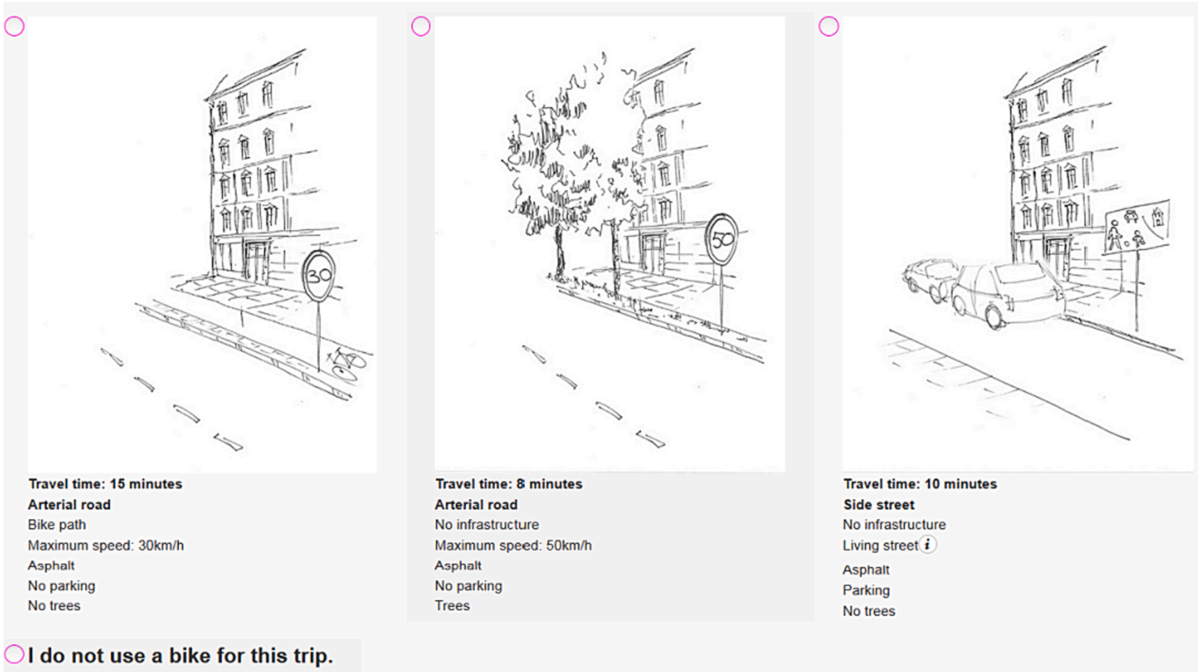

Fig. 1. Exemplary choice situation (Hardinghaus and Papantoniou, 2020).

the bike type used, controlling for these sociodemographic attributes is necessary. This is to make sure that the estimated differences do not arise from the different sociodemographic distributions but rather from the different bike type used. Therefore, we decided to follow the approach to draw a subsample from the data using stratified sampling while controlling for age, gender and frequency of cycling. This aims at having similar sociodemographic distributions of each bike type user group and allows therefore to compare preferences for infrastructure by the bike type used independent from sociodemographic characteristics. To do so, the original sample were split up into the groups e-bike, cargo bike and regular bike (trekking, Dutch style, city bike) users. From each group, a subsample aiming at matching the distribution of the overall sample was drawn. This results in a sample of 687 users from which 271 uses e-bikes, 166 use cargo bikes and 250 use regular bikes. The age, gender and frequency distribution of each group is shown in Table 2. The sample matches closely for most characteristics regarding frequency and gender, with the majority are daily male riders. The age distributions don't match as precisely as the other both characteristics. However, in all groups, the majority of participants is between 25 and 54 years old.

The employment status and educational level is displayed in Fig. 1. It is seen, that the majority of respondents work full time and obtain a higher education degree. The distributions among the three groups are very comparable. Nevertheless, it needs to be mentioned, that the analyzed sample is not representative for the average German population. However, as we are interested in the perception of bicyclists on different bike infrastructure elements, the results benefit from the large proportion of regular cyclists in the sample.

Table 2
Sample characteristics.

Characteristic	Regular Bike	Cargo Bike	E-Bike
Age			
Up to 17 years	0.4 %	0 %	0 %
18 – 24 years	10.4 %	1.2 %	2.2 %
25 – 34 years	31.6 %	31.3 %	14.4 %
35 – 44 years	20 %	50 %	25.1 %
45 – 54 years	24 %	12.1 %	30.6 %
55 – 64 years	9.6 %	4.8 %	18.8 %
65 and older	3.2 %	0.6 %	8.5 %
No answer	0.8 %	0 %	0.4 %
Gender			
Male	72 %	66.3 %	69.8 %
Female	26.4 %	31.9 %	29.5 %
No answer	1.6 %	1.8 %	0.7 %
Frequency			
Daily	75.6 %	89.8 %	70.1 %
1 to 3 days a week	17.2 %	7.8 %	24.4 %
1 to 3 days a month	4.8 %	1.8 %	4.1 %
Less than once a month	0.8 %	0.6 %	1.0 %
Never or almost never	1.6 %	0 %	0.4 %
No answer	0 %	0 %	0 %

Model

The data from the stated choice experiment is analyzed using a logit model. The multinomial logit model is based on random utility theory assuming that the utility U of an alternative consists of a deterministic term V and a stochastic term ε and each individual choses the alternative with highest utility (McFadden, 1973). To account for repeated choices by the same individuals as well as choice heterogeneity between respondents a mixed logit model with random parameters is used in this paper (Train, 2009). The choice probabilities in the mixed logit model are the weighted mean of the multinomial logit probabilities over a distribution $f(\eta)$.

$$P_{n,i} = \int L_{n,i}(\beta,\eta)f(\eta)d\eta$$

To estimate the differences between the three bike types, the model is specified with joint parameters (β) based on all considered bike types (regular, cargo bike and e-bike) and additional interaction terms (β_{ebike}, β_{cargo}) between the both bike types focused in this paper (I_{ebike},I_{cargo}) and each covariate (X_{iqt}). The formal model formulation of utility for alternative i, individual q and choice task t is then specified as follows:

$$U_{iqt} + U_{iqt,ebike} + U_{iqt,cargo} = ASC_{iq} + (\beta + \eta_{iq})X_{iqt} + [(\beta_{ebike} + \eta_{iq,ebike})X_{iqt}]I_{ebike} + [(\beta_{cargo} + \eta_{iq,cargo})X_{iqt}]I_{cargo} + \epsilon_{iqt}$$

with coefficients ASC and β common to all bike types and β_{ebike} as well as β_{cargo} representing the difference in the respective parameter compared to the regular bike types. Parameters η_{iq} equals the estimated standard deviation of the estimated parameter means β. I_{ebike} and I_{cargo} are dummy variables indicating if the respondent is an e-bike or cargo bike user. Error term ϵ_{iqt} is iid extreme value 1 distributed. We assume that due to the previous sampling method the influence of sociodemographic attributes does not differ between the groups and therefore no individual specific variables were included in the estimated model. Consequently, we assume that estimated differences between the groups arise from the different bike type used and not by any selection bias. The parameters were then estimated with the software Biogeme (Bierlaire, 2018) using 2,000 MLHS draws (Hess et al., 2006). No parameter restrictions were imposed.

In addition to the estimation of the model, to do a comparison on the preferences of different infrastructures by different bike type users, we perform another analysis using the estimated parameters. Dividing the parameter estimate of an infrastructure by the travel time parameter leads to the marginal rate of substitution between the infrastructure element and travel time. This indicates how much extra travel time an average user within a given subsample is willing to accept to ride on the given infrastructure instead on the reference alternative. We organize the willingness for detour for the combined utilities with regard to their appearance on main streets, side streets or irrespective of street type. Therefore, for the case of side streets, the utilities for the side street itself and the according regulations are summed up. These analyses allow for a better practical understanding of the results gathered.

Results

The results from the estimated model are shown in Table 3. The differences between cargo and e-bikes compared to regular bikes were tested for all infrastructure variables first and only maintained in the model when the estimated parameter was significant at least at the 10% level. This is the same for parameter standard deviations, which were introduced for all infrastructure variables in the first place and removed for those parameters not significant at 10% level.

Generally, the model performs good with a rho square of 0.342. All joint parameters are with the expected sign and significant at 5 % level. All three ASCs are positive indicating, that all alternatives are preferred over the no choice option with no significant difference between the alternatives, which is expected in an unlabelled choice experiment. Regarding the infrastructure attributes, preferences for protected bike lanes are nearly twice as strong as for bike paths and bike lanes, while both are still significantly preferred to no infrastructure. Similarly, living streets and those with a speed limit of 30 km/h are perceived better than streets with a speed limit of 50 km/h while dedicated cycle streets are valuated even three times higher than living streets. Regarding street characteristics, side streets are preferred over main roads, asphalt is clearly favoured compared to cobblestones and on-street parking comes with a negative utility. The presence of trees leads to slightly higher utility; however, the magnitude is much smaller compared to the other characteristics. The travel time parameter is negative as expected, showing that each additional minute travel time reduces the utility of the alternative.

Table 3
Estimation Results.

	All Biketypes (Joint Parameter)		Cargo Bike (Δ Regular Bike)		E-Bike (Δ Regular Bike)	
Attribute	Estimate (std. error)	*t*-test	Estimate (std. error)	*t*-test	Estimate (std. error)	*t*-test
ASC 1	4.49 (0.239)	18.8				
ASC 2	4.36 (0.236)	18.4				
ASC 3	4.64 (0.239)	19.4				
ASC 4 (no choice)	***0***	***fixed***				
Travel time	−0.319 (0.0186)	−17.2				
σ Travel time	0.227 (0.0169)	13.5				
Bike lane	1.57 (0.142)	11.2			0.409 (0.232)	1.76
σ Bike lane					0.761 (0.239)	3.19
Bike path	1.75 (0.191)	9.15	0.626 (0.21)	2.98	1.05 (0.263)	4
σ Bike path	0.952 (0.133)	7.17				
Protected bike lane	3.04 (0.187)	16.2	0.6 (0.2)	2.99	1.18 (0.265)	4.46
σ Protected bike lane	1.13 (0.119)	9.53			1.07 (0.238)	4.49
No infrastructure	***0***	***fixed***				
Living street	0.991 (0.125)	7.93				
σ Living street	1.83 (0.14)	13.1				
Cycle street	2.89 (0.162)	17.8			0.607 (0.233)	2.61
σ Cycle street					1.44 (0.336)	4.3
Speed limit 30 km/h	0.693 (0.0588)	11.8				
Speed limit 50 km/h	***0***	***fixed***				
Side street	1.01 (0.166)	6.05	0.559 (0.185)	3.02	0.447 (0.241)	1.85
σ Side street	0.803 (0.112)	7.19				
Main street	***0***	***fixed***				
Asphalt	4.2 (0.228)	18.4	0.665 (0.351)	1.9		
σ Asphalt	2.4 (0.179)	13.4				
Cobblestone	***0***	***fixed***				
On-street parking	−0.908 (0.0787)	−11.5	0.188 (0.114)	1.64	−0.384 (0.121)	−3.18
σ On-street parking	0.434 (0.111)	3.9			0.849 (0.144)	5.89
No parking	***0***	***fixed***				
Trees	0.308 (0.0468)	6.59				
σ Trees	0.413 (0.0913)	4.52				
No trees	***0***	***fixed***				
Respondents	*687*					
Observations	*5,496*					
Log Likelihood	*−5014.04*					
Rho square	*0.342*					

For cargo bike users, the five characteristics bike path, protected bike lane, side street, asphalt and on-street parking differ compared to the joint parameters for all users, while e-bike users value bike lanes, bike paths, protected bike lanes as well as cycle streets, side streets and on-street parking differently. Those estimated parameters are presented in the two rightmost columns in Table 3. Protected bike lanes for example are valued about 20 % higher by cargo bike users and even nearly 40 % higher by e-bike users than by users of regular bike types. In the same way, bike paths, side streets and asphalt as smooth surface are valued between 15 % and 60 % higher by cargo bike users while e-bike users have higher preferences for bike lanes, bike paths, cycle street and side streets in the range between + 20 % and + 60 % compared to regular bike users. The presence of on-street parking is perceived differently by both bike type users. While the general utility of on-street parking is negative, e-bike riders experience an even higher disutility from it, while cargo bike users perceive parked cars less negative compared to regular users.

For the variables travel time, living street, speed limit 30 km/h and trees along the street, no differences were found between the analysed groups. Furthermore, attributes bike lane as well as cycle street are perceived no different by cargo bike users compared to regular users. This is the same for the attribute asphalt for e-bike riders.

The subsequent analyses relating the utilities from the infrastructure attributes to the marginal utility of travel time result in a value describing the willingness for detour in minutes for other route characteristics compared to the reference. For regular bike users this leads e. g. to willingness to detour for around 10 min, to ride on a protected bike lane instead of a main street without cycling infrastructure or 5:30 min for a bike path. The relation of all infrastructure characteristics to travel time is shown in Fig. 2 separated by the three analysed bike types. There it can be seen, that the willingness to travel longer to ride on better infrastructure is almost always higher for the analysed bike types cargo bike and e-bike. This amounts up to nearly 16 min for cargo bikes having an asphalt street instead of cobblestones. The least preferences exist for trees along the route, with not even 1 min willingness to detour for all bike types.Fig. 3..

Discussion

First, it can be concluded that the estimated effects of route characteristics ‘protected bike lane’ and ‘cycle street’ are among the most important considering all attributes. These types of infrastructure seem to have an extremely high value for the whole group of cyclists. This finding was similarly delivered by an initial evaluation of a different subsample derived from the same poll (Hardinghaus and Papantoniou, 2020). Furthermore, the general direction and relative magnitude of the other characteristics is also comparable with the earlier analyses (Hardinghaus and Papantoniou, 2020).

Looking at the differences in utility of attributes between users of regular bikes and those of cargo and e-bikes, we see several particularities. Overall, it can be observed, that e-bike riders and cargo bike riders’ value better conditions for bicyclists more than those with regular bikes. It is striking, that for all characteristics where differences exist, except for parking, the magnitude of the estimated parameter is stronger than for regular bikes. This indicates, that preferred infrastructure characteristics are valued more by riders of e-bikes and cargo bikes. The parameter estimates show, that the value of single characteristics is 60 % higher compared to users of regular bikes. Only for on-street car parking, there is a difference between the sign for cargo bike and e-bike, with cargo bike riders have lower preferences for streets without parking. This may arise from the fact, that many cargo bikes have three wheels and are therefore more stable and not in danger of dooring, while e-bikes ride at higher speeds and therefore suffer harder from dooring accidents. For the infrastructure variables bike path, bike lane, protected bike lane and cycle street, the additional utility for e-bike riders is higher than for cargo bikes. This may be due to the fact, that e-bike riders tend to ride faster and therefore require even more qualitative dedicated infrastructure. In contrast, asphalt as surface is much more valued by cargo bike users, which may be explained by heavier weight and loads that makes riding on cobblestones even more complicated.

The subsequent estimation of willingness for additional travel time uses the utilities from the infrastructure attributes together with utility of travel time. Because the utilities for travel time do not differ across bike types under consideration, the differences result from the infrastructure utilities only. These calculations quantify the model results defining a practical value and therefore allow for an apparent understanding of the results gathered.

In context to recent literature, this study adds important results for the perception of infrastructure elements by different bike type users. Our results show, that many infrastructure attributes are valued higher by e-bike and cargo bike users and therefore a higher willingness to make a detour exists. This is in line with the results of Allemann and Raubal (2015) and Campbell et al. (2016), stating, that for e-bike users, taking the shortest route is less important than for users of regular bikes. This is also the case for the route environment which was found not important by Allemann and Raubal (2015) and shows the least importance in this present study when looking at street greenery. For other analysed infrastructure characteristics, like traffic lights, low traffic volume or the share of bike lanes and paths, Allemann and Raubal (2015) did not find significant differences between the two groups, which is in contrast to our findings that show significant differences. This is also confirmed by an analysis from Chavis and Frias-Martinez (2021) showing that e-bike users ride to a significantly higher share on streets with cycleways (Chavis and Martinez, 2021). One route

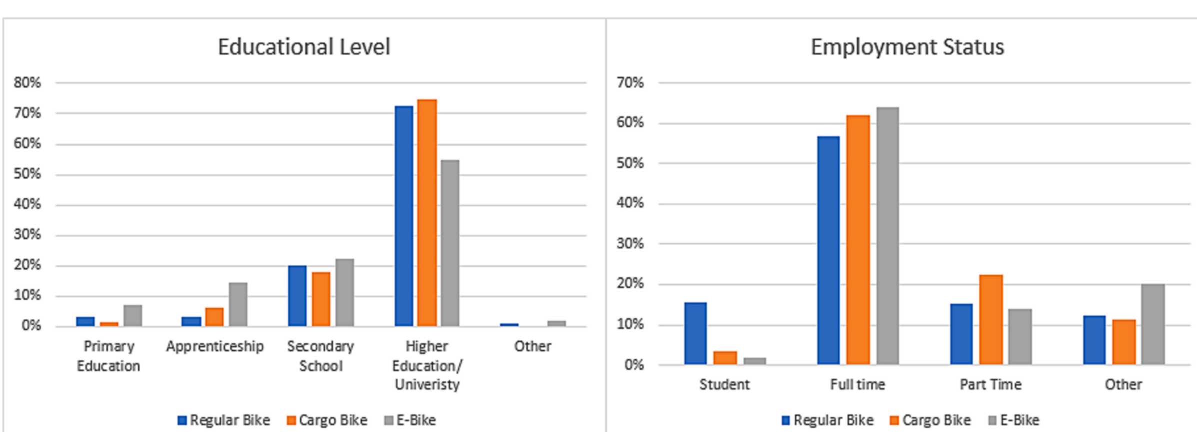

Fig. 2. Employment and Education of Sample.

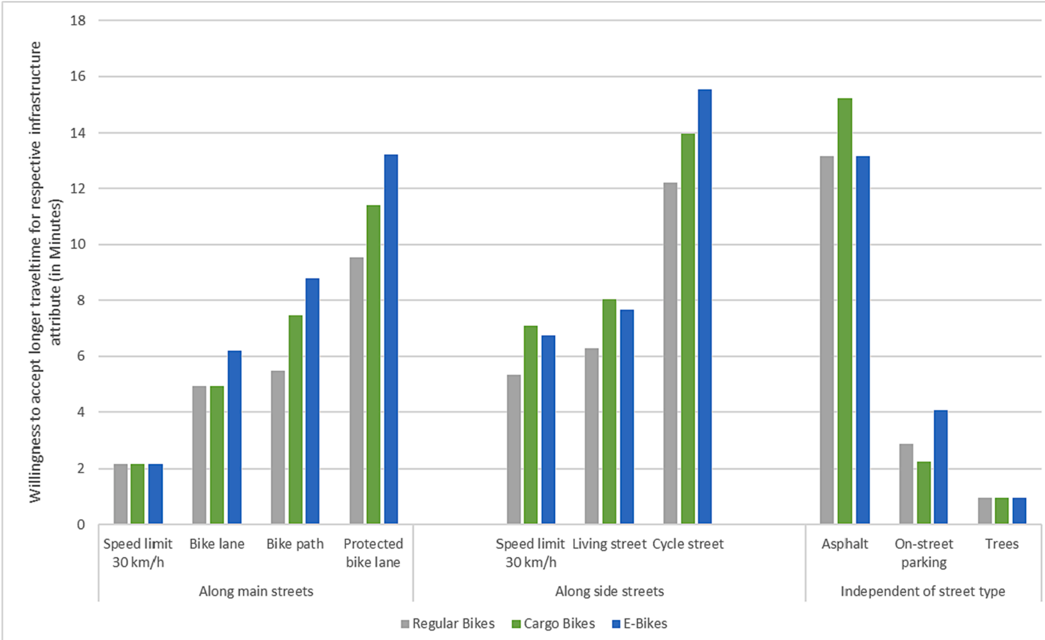

Fig. 3. Valuation of infrastructure attributes in relation to travel time.

characteristic, which was not considered in this study, is the elevation gain and presence of steep road segments. While Allemann and Raubal (2015) found that there is a significant difference between e-bike and regular bike users in the avoidance of steep road segments, Chavis and Frias-Martinez (2021) could not find any significant difference in the route choice. Comparing the results of cargo bikes to regular bikes with existing literature, our results show similar to Liu et al. (2020), that the speed limit for cars is no important factor for route choice. Only when further regulations which prioritize bikes over cars in side streets are proposed together with lower speed limits the utility for cyclists rises significantly. For on-street parking cars, we found this less important for cargo bikes than for regular bikes, while the results from Liu et al. (2020) differ between Stockholm and Amsterdam with high importance in the first city and low importance in the latter. Further, our results show, that cargo bike users prefer bike paths and protected bike lanes even more than regular users, while there is no difference for regular bike lanes. This may be explained by the width of bike paths, which are often narrower (at least in Germany, where the study took place) and therefore less comfortable for cargo bikes (Liu et al., 2020). A general preference of cargo bike users to cycle outside of potentially narrow separated infrastructures as concluded by Liu et al. (2020) can clearly not be seen in the present study. Contradicting, across all groups, both separated infrastructures are valued highest by users of cargo bikes. Other important factors found by Liu et al. (2020) are the smoothness of the route and the number of vehicles along, this is reflected in our findings that show cargo users prefer even more riding in side streets and on asphalt.

As pointed out, this study shows, that there exist significant differences in the perception of several infrastructure elements in route choice between users of different bike types. However, these findings are to some extend limited by the self-selective sample, which may be biased due to recruiting in social media and cycling groups. As described there are strong distortions compared to the whole German population. With the weighted subsample, we converge different populations of respondents and can therefore investigate different preferences caused by bike types but do not evaluate potentially different user groups. The approach used also does not elicit different preferences resulting from sociodemographic variables. Further, we can only determine route preferences according to attributes used in the experiment. There might be more influencing factors which were not considered, like route elevations (Allemann and Raubal, 2015) or the importance of seasons (Dybdalen and Ryeng, 2021). As described, we do not consider weather influences and base the findings on a hypothetical day under good weather conditions. Lastly, we do not recognize typical spatial characteristics (urban, suburban, rural) or the place of living of the respondents which may affect the results due to different experiences.

Based on the discussed findings of the present study, we draw recommendations for planning and practice. In general, desirable road properties appear similar for the entire cyclists' population. For riders of cargo bikes and e-bikes the according characteristics are even more important. Consequently, all cyclists and potential cyclists benefit from the transformation of the road infrastructure according to the discusses findings. More precisely, building a network of protected bike lanes along main streets and dedicated cycle streets in side roads as well as ensuring smooth surfaces are key interventions to satisfy cyclists. This transformation seems even more crucial as those bike types with higher requirements are increasingly popular.

Conclusion

This contribution investigates the route preferences of users of new bike types (cargo bike and e-bike) based on a nationwide discrete choice experiment. Using mixed logit models, the effect of several route characteristics on route choice is evaluated and compared to such of users of regular bikes.

In conclusion, the research proves that route requirements of users of innovative bike types such as cargo bike and e-bike are generally higher than those of users of regular bikes. Given the increasing importance of the innovative bike types researched, the importance of a high-quality bike infrastructure seems even more important than under consistent conditions regarding the bicycle stock. Thereby, physically separated infrastructures along main streets such as bike paths and protected bike lanes are of major importance for the specific user group. In addition, routes through side streets in general and cycle streets with priority for cyclists in particular fulfil user needs.

Hence the research delivers arguments for designing a future-proof bike friendly city. It also may give decision support for planners when various routing or design variants are discussed.

Funding

The research was funded by the German Federal Ministry of Transport and Digital Infrastructure.

CRediT authorship contribution statement

Michael Hardinghaus: Conceptualization, Investigation, Resources, Writing – original draft, Project administration, Funding acquisition. **Jan Weschke:** Writing – original draft, Data curation, Formal analysis, Methodology, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

References

Allemann, D., Raubal, M., 2015. Usage Differences Between Bikes and E-Bikes. In: Bacao, F., Santos, M.Y., Painho, M. (Eds.), AGILE 2015: Geographic Information Science as an Enabler of Smarter Cities and Communities. Springer International Publishing, Cham, pp. 201–217.

Almannaa, M.H., Ashqar, H.I., Elhenawy, M., Masoud, M., Rakotonirainy, A., Rakha, H., 2021. A comparative analysis of e-scooter and e-bike usage patterns: Findings from the City of Austin, TX. Int. J. Sustain. Transp. 15 (7), 571–579. https://doi.org/10.1080/15568318.2020.1833117.

Aultmann-Hall, L. (1996). *Commuter bicycle route choice: analysis of major determinants and safety implications.* (PHD-Thesis). McMaster University, Hamilton, Ontario.

Bierlaire, M. (2018). *PandasBiogeme: a short introduction.* Retrieved from Lausanne, Switzerland.

M. Bliemer J. Rose Designing Stated Choice Experiments: State-of-the-art 2006 ETH Zürich Zürich, Switzerland.

Borgstedt, S. H., Jan; Jurczok, Franziska. (2017). Fahrrad-Monitor Deutschland 2017.

Broach, J., Dill, J., Gliebe, J., 2012. Where do cyclists ride? A route choice model developed with revealed preference GPS data. Transp. Res. A Policy Pract. 46 (10), 1730–1740. https://doi.org/10.1016/j.tra.2012.07.005.

Brust, E. (2021). *Zahlen - Daten - Fakten zum Fahrradmarkt in Deutschland 2020.* Retrieved from https://www.ziv-zweirad.de/fileadmin/redakteure/Downloads/Marktdaten/PM_2021_10.03._ZIV-Praesentation_10.03.2021_mit_Text.pdf.

Buehler, R., Dill, J., 2016. Bikeway Networks: A Review of Effects on Cycling. Transp. Rev. 36 (1), 9–27. https://doi.org/10.1080/01441647.2015.1069908.

Campbell, A.A., Cherry, C.R., Ryerson, M.S., Yang, X., 2016. Factors influencing the choice of shared bicycles and shared electric bikes in Beijing. Transp. Res. Part C: Emerg. Technol. 67, 399–414. https://doi.org/10.1016/j.trc.2016.03.004.

Caulfield, B., Brick, E., McCarthy, O.T., 2012. Determining bicycle infrastructure preferences – A case study of Dublin. Transp. Res. Part D: Transp. Environ. 17 (5), 413–417. https://doi.org/10.1016/j.trd.2012.04.001.

Chavis, C., & Martinez, V. F. (2021). *E-bikes' Effect on Mode and Route Choice: A Case Study of Richmond, VA Bike Share.* Retrieved from.

Clark, C., Mokhtarian, P., Circella, G., Watkins, K., 2019. User Preferences for Bicycle Infrastructure in Communities with Emerging Cycling Cultures. Transp. Res. Rec. 2673 (12), 89–102.

Dane, G., Feng, T., Luub, F., & Arentze, T. (2020, 2020//). *Route Choice Decisions of E-bike Users: Analysis of GPS Tracking Data in the Netherlands.* Paper presented at the Geospatial Technologies for Local and Regional Development, Cham.

Dybdalen, Å., Ryeng, E.O., 2022. Understanding how to ensure efficient operation of cargo bikes on winter roads. Res. Transp. Bus. Manag. 44, 100652.

Eisenberger, D. (2020). Zahlen - Daten - Fakten zum Deutschen Fahrrad- und E-Bike Markt 2019 - Dynamischer Wachstumskurs der Fahrradindustrie setzt sich ungebremst fort [Press release]. Retrieved from https://www.ziv-zweirad.de/fileadmin/redakteure/Downloads/PDFs/PM_2020_11.03._Fahrrad-_und_E-Bike_Markt_2019.pdf.

Gössling, S., Choi, A., Dekker, K., Metzler, D., 2019. The Social Cost of Automobility, Cycling and Walking in the European Union. Ecol. Econ. 158, 65–74. https://doi.org/10.1016/j.ecolecon.2018.12.016.

Gruber, J., Narayanan, S., 2019. Travel Time Differences between Cargo Cycles and Cars in Commercial Transport Operations. Transp. Res. Rec. 2673 (8), 623–637. https://doi.org/10.1177/0361198119843088.

Hardinghaus, M., Papantoniou, P., 2020. Evaluating Cyclists' Route Preferences with Respect to Infrastructure. Sustainability 12 (8), 3375. https://doi.org/10.3390/su12083375.

Hess, S., Train, K.E., Polak, J.W., 2006. On the use of a Modified Latin Hypercube Sampling (MLHS) method in the estimation of a Mixed Logit Model for vehicle choice. Transp. Res. B Methodol. 40 (2), 147–163. https://doi.org/10.1016/j.trb.2004.10.005.

Krizek, K., Forsyth, A., & Baum, L. (2009). *Walking and Cycling International Literature Review.* Retrieved from Melbourne.

Lanzendorf, M., Busch-Geertsema, A., 2014. The cycling boom in large German cities—Empirical evidence for successful cycling campaigns. Transp. Policy 36, 26–33. https://doi.org/10.1016/j.tranpol.2014.07.003.

Liu, G., Nello-Deakin, S., te Brömmelstroet, M., Yamamoto, Y., 2020. What Makes a Good Cargo Bike Route? Perspectives from Users and Planners. Am. J. of Econ. Sociol. 79 (3), 941–965. https://doi.org/10.1111/ajes.12332.

Lopez, A. J., Astegiano, P., Gautama, S., Ochoa, D., Tampère, C. M. J., & Beckx, C. (2017). Unveiling E-Bike Potential for Commuting Trips from GPS Traces. *6*(7), 190. Retrieved from https://www.mdpi.com/2220-9964/6/7/190.

Lux, S., Schleinitz, K., & Krems, J. (2018). *Developing a method to examine the route choice of conventional cyclists and e-bike riders in a naturalistic cycling study.*

Makarova, I., Mavrin, V., Magdin, K., Shubenkova, K., Boyko, A., 2019. Evaluation of Sustainability of the Transport System of Urbanized Areas Considering the Development of Bicycle Transport. Transportation Science and Technology, Vilnius, Lithuania, Paper presented at the TRANSBALTICA XI.

McFadden, D., 1973. Conditional logit analysis of qualitative choice behavior. Academic Press, New York.

McQueen, M., MacArthur, J., Cherry, C., 2020. The E-Bike Potential: Estimating regional e-bike impacts on greenhouse gas emissions. Transp. Res. Part D: Transp. Environ. 87, 102482 https://doi.org/10.1016/j.trd.2020.102482.

Mertens, L., Van Dyck, D., Ghekiere, A., De Bourdeaudhuij, I., Deforche, B., Van de Weghe, N., Van Cauwenberg, J., 2016. Which environmental factors most strongly influence a street's appeal for bicycle transport among adults? A conjoint study using manipulated photographs. Int. J. Health Geogr. 15 (1), 1–14. https://doi.org/10.1186/s12942-016-0058-4.

Nelson, A., Allen, D., 1997. If You Build Them, Commuters Will Use Them: Association Between Bicycle Facilities and Bicycle Commuting. Transp. Res. Rec. 1578 (1), 79–83. https://doi.org/10.3141/1578-10.

Nürnberg, M., 2019. Analysis of using cargo bikes in urban logistics on the example of Stargard. Transp. Res. Procedia 39, 360–369. https://doi.org/10.1016/j.trpro.2019.06.038.

Plazier, P.A., Weitkamp, G., van den Berg, A.E., 2017. "Cycling was never so easy!" An analysis of e-bike commuters' motives, travel behaviour and experiences using GPS-tracking and interviews. J. Transp. Geogr. 65, 25–34. https://doi.org/10.1016/j.jtrangeo.2017.09.017.

Raustorp, J., Koglin, T., 2019. The potential for active commuting by bicycle and its possible effects on public health. J. Transp. Health 13, 72–77. https://doi.org/10.1016/j.jth.2019.03.012.

Sheth, M., Butrina, P., Goodchild, A., McCormack, E., 2019. Measuring delivery route cost trade-offs between electric-assist cargo bicycles and delivery trucks in dense urban areas. Eur. Transp. Res. Rev. 11 (1), 11. https://doi.org/10.1186/s12544-019-0349-5.

Stork, B. (2022). Marktdaten Fahrräder und E-Bikes 2021 [Press release].

Stork, B. (2023). ZIV and VDZ: Associations present figures for Bicycle and E-Bike Market 2022 [Press release]. Retrieved from https://www.ziv-zweirad.de/fileadmin/redakteure/Downloads/PDFs/PresseRelease_ZIV_MarketData_230315.pdf.

Sun, Q., Feng, T., Kemperman, A., Spahn, A., 2020. Modal shift implications of e-bike use in the Netherlands: Moving towards sustainability? Transp. Res. Part D: Transp. Environ. 78, 102202 https://doi.org/10.1016/j.trd.2019.102202.

Thoma, L., Gruber, J., 2020. Drivers and barriers for the adoption of cargo cycles: An exploratory factor analysis. Transp. Res. Procedia 46, 197–203. https://doi.org/10.1016/j.trpro.2020.03.181.

Tilahun, N.Y., Levinson, D.M., Krizek, K.J., 2007. Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. Transp. Res. A Policy Pract. 41 (4), 287–301. https://doi.org/10.1016/j.tra.2006.09.007.

Train, K.E., 2009. Discrete choice methods with simulation. Cambridge University Press.

Vedel, S.E., Jacobsen, J.B., Skov-Petersen, H., 2017. Bicyclists' preferences for route characteristics and crowding in Copenhagen – A choice experiment study of commuters. Transp. Res. A Policy Pract. 100, 53–64. https://doi.org/10.1016/j.tra.2017.04.006.

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Beagley, J., Belesova, K., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Capstick, S., Chambers, J., Coleman, S., Dalin, C., Daly, M., Dasandi, N., Dasgupta, S., Davies, M., Di Napoli, C., Dominguez-Salas, P., Drummond, P., Dubrow, R., Ebi, K.L., Eckelman, M., Ekins, P., Escobar, L.E., Georgeson, L., Golder, S.u., Grace, D., Graham, H., Haggar, P., Hamilton, I., Hartinger, S., Hess, J., Hsu, S.-C., Hughes, N., Jankin Mikhaylov, S., Jimenez, M.P., Kelman, I., Kennard, H., Kiesewetter, G., Kinney, P.L., Kjellstrom, T., Kniveton, D., Lampard, P., Lemke, B., Liu, Y., Liu, Z., Lott, M., Lowe, R., Martinez-Urtaza, J., Maslin, M., McAllister, L., McGushin, A., McMichael, C., Milner, J., Moradi-Lakeh, M., Morrissey, K., Munzert, S., Murray, K.A., Neville, T., Nilsson, M., Sewe, M.O., Oreszczyn, T., Otto, M., Owfi, F., Pearman, O., Pencheon, D., Quinn, R., Rabbaniha, M., Robinson, E., Rocklöv, J., Romanello, M., Semenza, J.C., Sherman, J., Shi, L., Springmann, M., Tabatabaei, M., Taylor, J., Triñanes, J., Shumake-Guillemot, J., Vu, B., Wilkinson, P., Winning, M., Gong, P., Montgomery, H., Costello, A., 2021. The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. Lancet 397 (10269), 129–170.

Wild, K., Woodward, A., 2019. Why are cyclists the happiest commuters? Health, pleasure and the e-bike. J. Transp. Health 14, 100569. https://doi.org/10.1016/j.jth.2019.05.008.

Winslott Hiselius, L., Svensson, Å., 2017. E-bike use in Sweden – CO2 effects due to modal change and municipal promotion strategies. J. Clean. Prod. 141, 818–824. https://doi.org/10.1016/j.jclepro.2016.09.141.
Yang, H., Landes, H., & Chow, J. Y. J. (2023). A large-scale analytical residential parcel delivery model evaluating greenhouse gas emissions, COVID-19 impact, and cargo bikes. *International Journal of Transportation Science and Technology*. https://doi.org/10.1016/j.ijtst.2023.08.002.
Zensus (2016). *Zensus 2011: Vielfältiges Deutschland*. Retrieved from: https://www.statistikportal.de/sites/default/files/2017-06/zensus_ergebnisse.pdf.