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Implementing bicycle-friendly transport policies: Examining the effect of an infrastructural intervention on residents' perceived quality of urban life in Frankfurt, Germany

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ABSTRACT

In recent years, many European cities have developed strategies to improve the quality of urban life by reducing car traffic and increasing the attractiveness of alternative modes and the built environment for residents. Frequently, at least in German cities, improvements to the cycling infrastructures play a key role in this transformation of urban spaces. One of those transformative interventions took place in 2020 in Frankfurt am Main (Germany). The city redesigned an arterial road close to the city centre, the Friedberger Landstrasse, by converting two car lanes to bicycle lanes. It is the aim of this study to analyse the effects of this change on the quality of urban life of its residents using a quantitative before-and-after study. The results demonstrate the expected improvements in the perceived quality of urban life for residents after the intervention. A more detailed analysis, however, shows that the residents' perceptions vary according to their own mode use on the Friedberger Landstrasse and other sociodemographic characteristics. Thus, better cycling infrastructure does not only improve conditions for cyclists, but also contributes to a higher quality of urban life for residents and, therefore, improves the liveability of a city in two ways. We conclude that local transport policies are not only relevant for a modal shift, but also for the quality of urban life and, thus, related urban development strategies.

1. Introduction

The 'success story' and dominance of the automobile system has shaped societies for decades (Urry, 2004, Manderscheid, 2012). Daily travel practices emerged with the interaction of car- oriented materialities, competences and symbols (Shove et al., 2012). Most obviously, large parts of urban areas are dominated today by car-related infrastructures, like roads and parking facilities. In the car-oriented city (Buchanan, 1964), streets are an almost exclusive place for the automobile to which other modes of transportation have to be subordinated (Hebsaker, 2018: 89). Thus, walking and cycling have become increasingly unattractive and unsafe, and public life was banished from the streets for the most part resulting in a decline in the quality of urban life (Gehl, 2015: 14 et seqq.; Wilde, 2015: 22). For example, increased volumes of car traffic reduce the quality of stay and air as well as safety and increase noise (Appleyard et al., 1981; Elsawy et al., 2017; Hart & Parkhurst, 2011).

However, in recent decades, more and more cities worldwide, like Copenhagen and Vienna (e.g., Gehl, 2010, Buehler et al., 2017, Knoflacher et al., 2018), have adopted measures to improve the quality of urban life by reducing car traffic and infrastructures and promoting alternative modes of transport. European and national authorities have developed strategies to stimulate a new 'urban mobility culture' (e.g. European Commission, 2007, German Federal Environment Agency, 2017). In 45 German cities, citizens' initiatives for improving cycling, known as 'Radentscheide', call for a redesign of the urban traffic infrastructure towards cycling-friendly cities with a higher walkability and quality of life (Changing Cities, 2021). These grassroots movements gathered overwhelming local support for their respective cycling referendums and then gained political momentum when some local authorities (e.g., Berlin, Frankfurt am Main, Hamburg) and many political parties agreed to the most important demands of the 'Radentscheide'. In 2019, the city of Frankfurt implemented the action plan *Fahrradstadt Frankfurt* (Bicycle City Frankfurt) as a result of negotiations with the local citizens' initiative 'Radentscheid' (Fraktion von CDU, SPD, GRÜNEN, 2019). The overall aim of this plan is to improve the quality of urban life for residents. Specifically, it aims to increase the quality of stay in public spaces and the safety of all cyclists (e.g., children and the

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elderly) as well as to reduce the negative impact of traffic on health.

Currently, there is only a limited number of studies examining the impact of a street conversion on residents' quality of life (e.g. Aldred et al., 2019; Blechschmidt, 2015; Blitz et al., 2020). Therefore, in this paper, we ask how the conversion of two car lanes to bike lanes on a four-lane main road, the Friedberger Landstrasse (Frankfurt am Main), affects the residents' quality of urban life. Thus, the focus of this study is not on people using the road section exclusively as a traffic space, but on the residents who also live on site. Furthermore, we analyse how the changes in the perception of local traffic and quality of urban life depend on the residents' own travel practices and related factors. For the purpose of our study, we surveyed households on the Friedberger Landstrasse before and after the intervention using a standardized questionnaire. 169 residents completed the first survey before the intervention and 114 residents completed the second survey after the intervention. Our questionnaire measured each respondent's daily travel practices, perceptions of local traffic and quality of urban life. Conceptually, we focus on the link between the objective urban environment and its subjective evaluation and understand quality of urban life as derived from the urban environment (McCrea et al., 2011: 59).

In section 2, we discuss earlier studies on the influence of new traffic infrastructures on residents' quality of urban life. Section 3 describes the case study of Friedberger Landstrasse and our survey methods. Subsequently, section 4 presents the survey results with a focus on the residents' perception of the traffic situation before and after the intervention. Next, section 5 shows the multivariate results, which are discussed in section 6. The paper ends with some conclusions (section 7).

2. Quality of urban life and infrastructural interventions for cycling

In transport-related literature, several concepts are used to measure the impact of the increased dominance of the car and the creation of new infrastructures on the people affected by these changes to the built environment. For example, Steg and Gifford (2005: 63) examine its impact on quality of life and conceptualize it as "the extent to which important values and needs of people are fulfilled". With this, they ask how the promises of the individual car on the one hand increase these values and needs, but on the other hand also threaten them. Santos and Martins (2007) analyse people's satisfaction or happiness with their perceived local environment. They argue that mobility conditions and environmental quality are decisive factors for urban quality of life. With the concept of 'satisfaction with life' (SWL), Cao (2013: 922) employs another approach to measure quality of life or 'subjective well-being' (SWB). He concludes in his study that new light rail developments may improve SWL by providing better access to destinations and increased travel satisfaction. High car traffic volumes are frequently reported as a major factor threatening the quality of life in urban areas. Appleyard et al. (1981) show, in an often-referenced study, that high car traffic volumes in San Francisco (USA) increase traffic hazards, stress, noise and air pollution, while social interactions in the neighbourhood and individual privacy decline. More recently, Hart and Parkhurst (2011) show similar results for Bristol (UK). In comparison to other streets, residents of streets with moderate to heavy car use report relatively low amounts of neighbourly interaction and a widespread dissatisfaction with the health and safety impacts of car use. Similarly, Flade (2013: 115) notes that main roads are frequently major obstacles to active travel modes and limit the activity spaces of people, and especially children, significantly (e.g., for recreational purposes).

Road traffic is one of the most important sources of noise and air pollution in urban areas (European Environment Agency, 2020). In addition to short-term effects, such as stress or sleep disturbances, long-term health impairments can result from noise pollution (Babisch, 2011; Brüning, 2013; Christ & Loose, 2000; Flade, 2013; Gather et al., 2008). Also, in a more general way, traffic has been found to have a negative impact on overall health status and triggers depressive symptoms (Song et al., 2007).

Numerous studies show the increasing number of cyclists on new or improved cycling infrastructure, sometimes even in the surrounding neighbourhood (Hong et al., 2020, Parker et al., 2013). Despite, in a review study, Aldred et al. (2019) concluding that structural interventions in the built environment may increase the frequency of walking or cycling, she emphasizes a lack of empirical evidence. Similarly, Scheepers et al. (2014) argue from existing literature that legal, economic, communicative and built environment measures may promote a shift to active transport modes. Ma et al. (2014) emphasizes the importance of intervention programmes which improve the environmental perception of cyclists to use this transport mode.

Some studies analyse the effects of built environment interventions for cycling on traffic volume, mode choice and health in more detail. Aldred et al. (2019) examine the impact of the 'Mini-Holland Programme' to improve the local environment for walking and cycling in three outer London boroughs using a longitudinal study. They report improved perceptions of the local environment as well as more cycling and walking in the intervention areas after cycling facilities and footpaths have been improved. However, despite a reduced car infrastructure, they do not observe less car traffic one year after the intervention. With a quasi-experimental design, Rissel et al. (2015) observed more biking and walking as well as an improved perception of the neighbourhood after the implementation of a new cycling infrastructure in Sydney (Australia). From an empirical study in the UK, Panter and Ogilvie (2015) report improved perceptions of safety after the implementation of new walking and cycling infrastructures.

In summary, car traffic and its infrastructures are decisive factors influencing the perceived quality of urban life (Appleyard et al., 1981; Santos & Martins, 2007). Traffic conditions and volume impact on noise, air quality, social and neighbourly interactions, stress, health, safety and especially safety of children (Appleyard et al., 1981; Hart & Parkhurst, 2011; Flade, 2013). Infrastructural changes that reduce the proportion of space dedicated to car traffic and increase the space for active modes of transport, such as cycling, can improve residents' perceptions of the neighbourhood and increase the use of active travel modes (Aldred et al., 2019; Rissel et al., 2015; Panter & Ogilvie, 2015).

3. Methods

3.1. Case study of Friedberger Landstrasse, Frankfurt am Main, Germany

For more than three decades, political initiatives and practitioners aimed to improve cycling conditions in the city of Frankfurt am Main. In the 1990s, pilot projects tested a bicycle street and the enabling of contra-flow cycling on one-way roads. However, it took until 2003, when the city government defined a quantitative objective, to increase the modal share of cycling from 6% in 1998 to 15% in 2012 (Busch-Geertsema & Lanzendorf, 2014). Indeed, the cycling share has tripled since 1998 to 20% in 2018 with car use at 33%, public transport at 21% and walking at 26% (TU Dresden, 2018).

Despite the growth in cycling, city infrastructural conditions developed around the car and motorized traffic for decades with a lack of adaptation to the needs of cyclists. For example, in 2019, almost 1,200 cyclists had an accident and four cyclists died (Polizei Hessen, 2020). The '*Radentscheid Frankfurt'*, a citizens' initiative for a cycling referendum in 2018, challenged this mismatch of infrastructural conditions with the needs of cyclists in Frankfurt. The initiative's objective was to transform the traffic space into a safer environment for cycling and walking and, thus, improve the overall quality of life. The '*Radentscheid Frankfurt*' collected 34,000 verified signatures of Frankfurt citizens within 4 months and influenced the agenda setting of local politicians considerably (Frankfurter Allgemeine Zeitung, 2018).

In 2019, after negotiations with the '*Radentscheid Frankfurt'*, the local government presented an action plan "Bicycle City Frankfurt am Main" with a set of infrastructural measures to improve cycling and walking

conditions in Frankfurt, mainly focused on the inner-city areas within three kilometres of the city centre.

The Friedberger Landstrasse is in parts a four-lane arterial road from the north to Frankfurt's city centre (Fig. 1). With an average daily traffic volume of almost 40,000 motorized vehicles, it is one of the most frequented roads in the inner-city area (Hessen Mobil Straßen- und Verkehrsmanagement, 2017: 16). Thus, exposure to noise and air pollution (e.g., NOx) is high for the local population and consistently exceeds thresholds for health risks (HLNUG, 2017).

In the summer of 2020, the Friedberger Landstrasse was one of the first areas to have implementations from the action plan "Bicycle City Frankfurt am Main'' and led to controversial public discussions. At this time, the city administration of Frankfurt designed new cycling lanes in both directions on an approximately-one-kilometre section of the southern part of the Friedberger Landstrasse close to the city centre (between Hessendenkmal and Friedberger Platz, see Fig. 1). For this purpose, they reduced the two car lanes in each direction to just one. The two outer tracks were painted red with bicycle pictograms. There is no physical separation between bike and car lanes (see Fig. 2). Before this change to the street layout, there were almost no cycling lanes on this section of the Friedberger Landstrasse with the only exception being a short part suddenly ending in the direction of the inner city. In this paper, we use the term 'Friedberger Landstrasse' only for the redesigned section of the road. It should be noted that several tram and bus lines go through this section as well. Since the end of 2020, the cycling lanes have also been shared with bus routes, which was not the case at the time we conducted our survey after the redesign. Furthermore, the buildings along the Friedberger Landstrasse are mainly residential, but there are also some retail and commercial properties.

3.2. Survey methods

The term 'quality of urban life' can refer to external, objective circumstances measured by spatially aggregated secondary data. Also, it can relate to subjective perceptions and evaluations of these circumstances by individuals (von Wirth et al., 2015; Marans and Stimson, 2011). To analyse the effects of the described infrastructural change on the quality of urban life of residents in our case study, we focus on the latter approach. Since, to the best of our knowledge, there was no other suitable index available for our purpose, we derived a quality of urban life index for the residents of Friedberger Landstrasse from the assumption that satisfaction in urban life domains is interrelated with urban sub-domains such as traffic and infrastructural conditions in the neighbourhood (McCrea et al., 2011). Moreover, environmental quality and mobility conditions are crucial for the quality of urban life (Santos & Martins, 2007).

To assess the impact of the intervention on the quality of urban life and travel patterns, we conducted a survey of local residents in a quasi-experimental design. The first survey took place in July 2020 (pre-survey) and the second in August 2020 about three weeks after the intervention (post-survey). In both surveys, we distributed the questionnaire to all households located on the Friedberger Landstrasse, in total 445 households. Each household received one questionnaire with a return envelope free of charge and, additionally, with online access options to the questionnaire for those who preferred to submit their answers digitally (for details, Scheffler et al., 2021). Even though the households surveyed were identical in both surveys, a panel data set could not be created because a large proportion of respondents varied between the surveys.

The survey questionnaires were almost identical. We asked for the frequency of travel and mode use on the Friedberger Landstrasse, the perceived quality of stay, noise and air quality as well as safety. Additionally, we collected the socio-demographic data of the respondents. In the pre-survey, the response rate was 36% (N = 169). The rate was lower in the post-survey, but still 26% (N = 114). In our sample, women and multi-occupancy households are overrepresented both in the pre- and post-surveys compared to the population register from the City of Frankfurt while the age distribution is relatively good (Table 1). This is not surprising compared to other household-based surveys (e.g. Kirschner & Lanzendorf, 2020).

For the analysis, we redefined the age groups as a dummy variable. People over the age of 50 were grouped together because the proportion of older residents in Friedberger Landstrasse, and in our sample in particular, is relatively small. The education of the respondents was also queried and transformed into a dummy variable with a university degree as the criterion. For more details, see Scheffler et al. (2021).

Furthermore, we defined a regular mode use type for the Friedberger Landstrasse by the respondent's regular use of car, bicycle and public transport on that particular road section (at least once per week). Walking was not used, since virtually all respondents reported walking

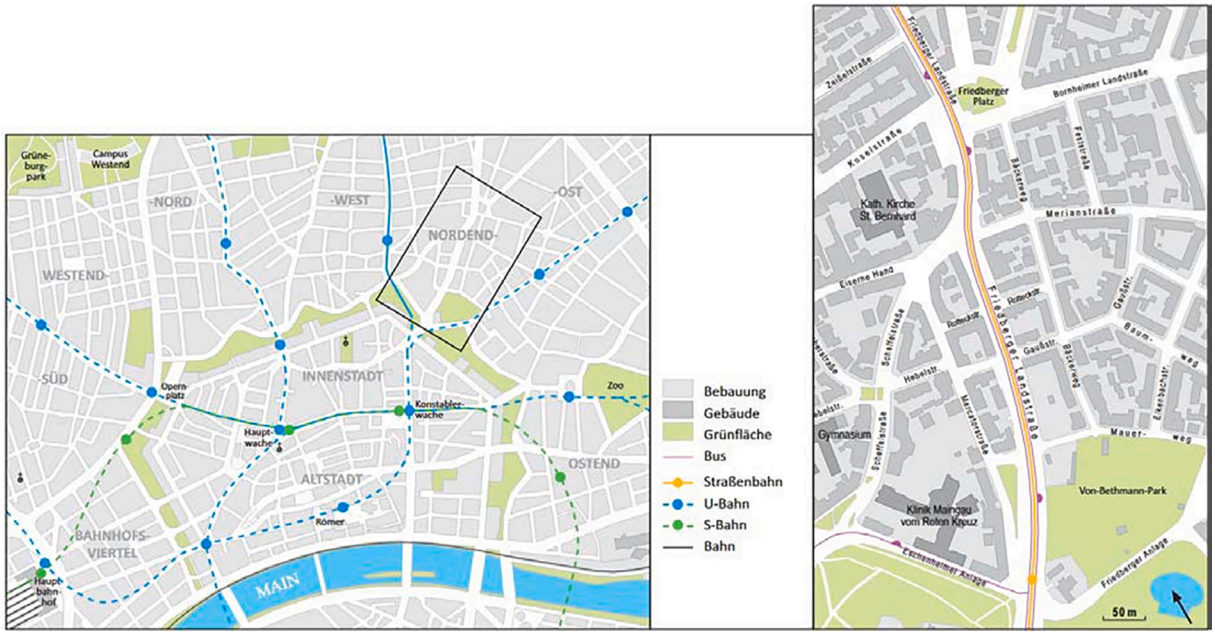

Fig. 1. Section of Friedberger Landstrasse from Hessendenkmal to Friedberger Platz. Source: own illustration.

Fig. 2. Situation before (left) and after (right) the intervention. Source: Drei Eins // Stadt Freiraum Architektur, Rebecca Faller (2020).

Table 1
Sample composition and representativeness in comparison with the population register.

	Population register	Pre-survey (N = 169)	Post-survey (N = 114)
Gender			
Women	52.8%	59.4% (N = 98)	62.7%* (N = 69)
Men	47.2%	40.6% (N = 67)	37.3%* (N = 41)
Age			
18 – 34	43.2%	41.9% (N = 70)	39.3% (N = 44)
35 – 49	25.2%	32.9%* (N = 55)	30.4% (N = 34)
50 – 64	18.7%	16.8% (N = 28)	20.5% (N = 23)
65 and older	12.9%	8.4%* (N = 14)	9.8% (N = 11)
Education			
No university degree	n/a**	39.0% (N = 64)	39.8% (N = 43)
With a university degree	n/a**	61.0% (N = 100)	60.2% (N = 65)
Type of household			
Single-person households	63.2%	47.6%* (N = 79)	52.3%* (N = 57)
With children (under 14 years of age)	14.4%	18.4% (N = 29)	15.7% (N = 17)

* Statistically significant difference between survey and population register (*t*-test, $p < 0.05$).
** Education of the residents is not included in the population register. The differences between *N*-values and summed values are missing values.
An excerpt of the population register was provided after a request to the Residents' Registration Office. The population register only provided information for households with postal addresses on the Friedberger Landstrasse. Households living in buildings facing the Friedberger Landstrasse but whose postal address was in one of the side streets were not included in the data provided by the city of Frankfurt. Thus, our statistical tests of representativeness assume that this difference is not important for the social structure of people living on the Frankfurter Landstrasse.

regularly. The variable is not significantly differently distributed in the pre and post survey according to the Chi-Square Test (Table 2). About 10% of the respondents regularly only use their car on Friedberger Landstrasse. 21% are multi-modal with a car (they drive by car and use at least one other mode of transport, e.g. a bicycle or public transport). Of the remaining approximately-two thirds of non-car drivers, most respondents regularly ride their bicycles (38%) and nearly-one third of all respondents use neither cars nor bicycles on a regular basis. They use either public transport, only walk or do not travel regularly at all.

Table 2
Multimodal travel type on Friedberger Landstrasse.

	Pre-survey	Post-survey	Total
Car only	8.9% (N = 15)	12.3% (N = 14)	10.3% (N = 29)
Multimodal with car	21.9% (N = 37)	20.2% (N = 23)	21.2% (N = 60)
Bicycle, no car	37.9% (N = 64)	39.5% (N = 45)	38.5% (N = 109)
No car, no bicycle	31.4% (N = 53)	28.1% (N = 32)	30.0% (N = 85)
Total	100% (N = 169)	100% (N = 114)	100% (N = 293)
Pearson $\chi^2(3) = 1.1559$; $P = 0.764$			

4. Travel mode use and the traffic situation in Friedberger Landstrasse

After the implementation of the cycling paths on Friedberger Landstrasse, there were no significant changes in the residents' regular mode use frequency. The share of regular car users stayed almost the same as before and the share of regular public transport users decreased slightly (Fig. 3). Compared to the pre-survey, the share of regular bicycle users increased from 57% to 65%. However, due to the small sample size, the increase is not statistically significant. Walking is the most frequently used regular mode both before and after the intervention.

Residents perceive the transformation of the Friedberger Landstrasse as an improvement for cyclists, pedestrians and also for the overall traffic situation (Fig. 4). Before the changes, only a quarter of the residents assessed the latter as good or very good, a figure that increased to 42% afterwards. 82% of cyclists perceive the situation afterwards as good or very good (compared to 10% before) and only 7% of pedestrians state that it is bad or very bad (compared to 23% before). In contrast, residents assess the conditions for cars and public transport as worse than before the redesign.

Similar to the overall assessment of the traffic situation, the subjectively perceived lack of safety and endangerment on the Friedberger Landstrasse decreased for cyclists and pedestrians but tended to increase for car drivers (Table 3). Most clearly, cyclists perceived the road as having improved after the implementation of the bicycle lane: While it was dangerous and unsafe before, it is safer and with fewer risks afterwards. Pedestrians perceived a reduction in threats, but still feel unsafe. Ultimately, car drivers did not perceive significant increases in risks, but feel significantly less safe than before the redesign.

5. Residents' quality of urban life before and after the redesign

5.1. Quality of urban life index

To compare the situation before and after the implementation of the cycling lane, we calculated a quality of urban life index as the mean value of six perceptions by residents: quality of stay, lingering, air

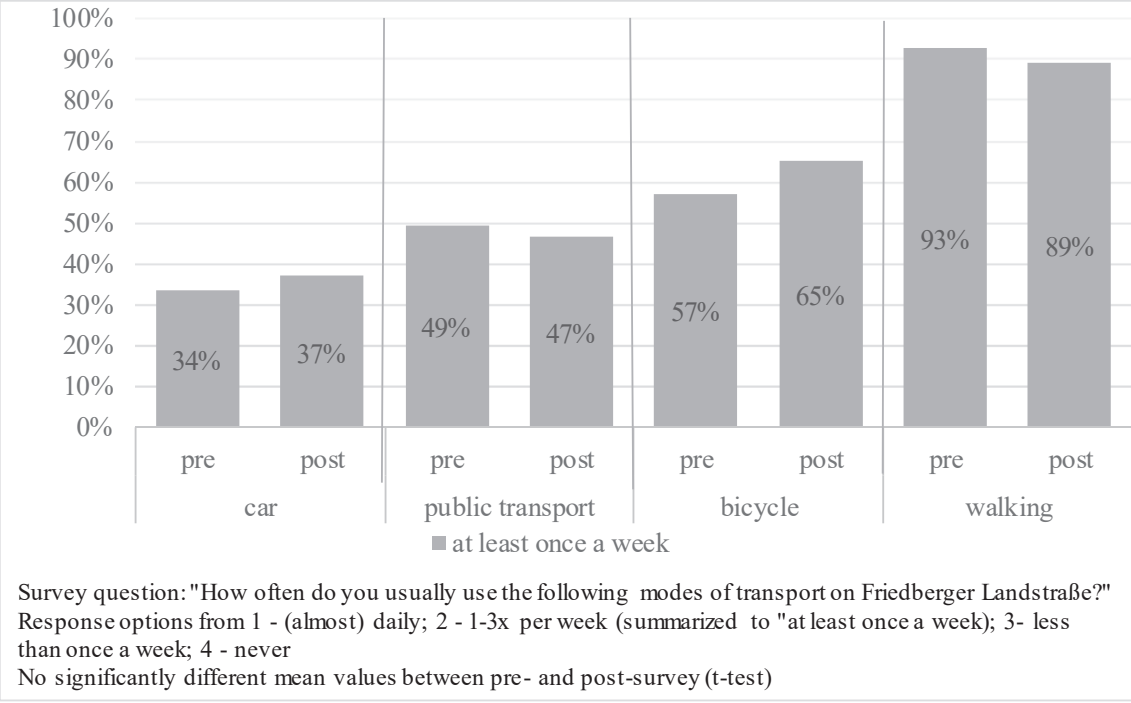

Fig. 3. Share of regular mode users (at least once per week) on Friedberger Landstrasse before and after the implementation of the cycling paths (Pre-Survey N = 164; Post-Survey N = 110).

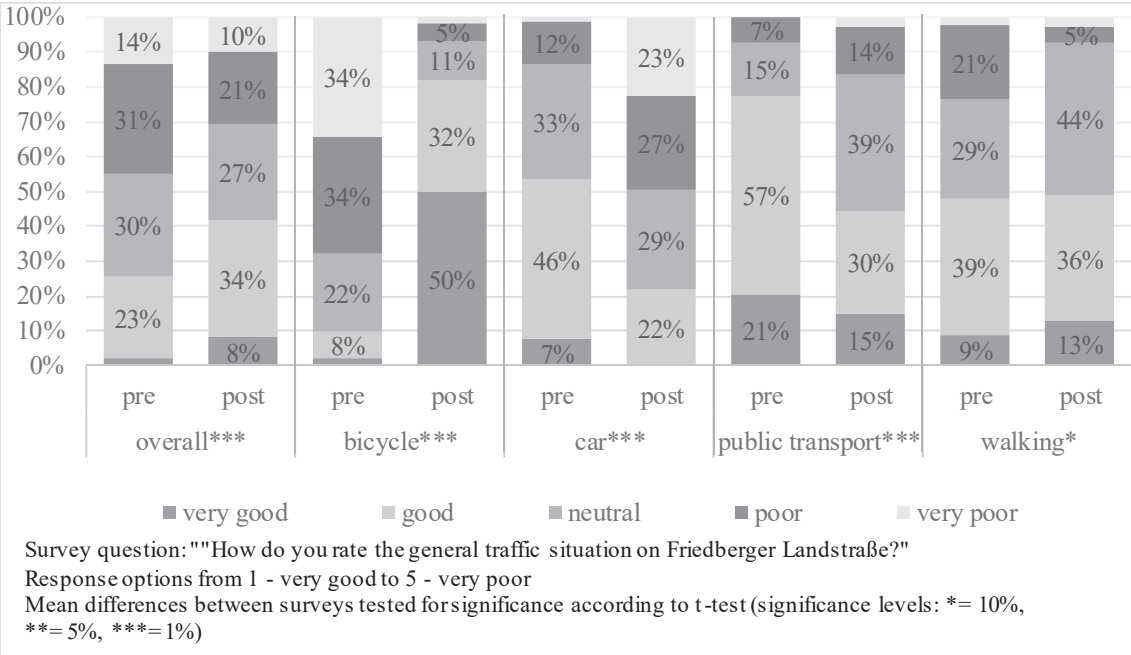

Fig. 4. Perception of the traffic situation on Friedberger Landstrasse before and after the implementation of the cycling paths for various modes of transport (Pre-Survey N = 168; Post- Survey N = 111).

quality, traffic noise, traffic volume and safety of children (Table 4).

On average, the residents assessed the quality of urban life as well as the underlying six dimensions as rather negative on the Friedberger Landstrasse (Table 5). This is not surprising for a heavily used trunk road. However, we observed significant improvements in the perception from the pre- to the post-survey. In particular, the perception of children's safety increased and of traffic noise decreased with the new cycling lanes. These perceptions are also shared by different sexes, ages and educational backgrounds (Table 5).

Nevertheless, some differences between social groups and their perception of the changes remain. Unlike men, women do not perceive the quality of stay and lingering as significantly improved. Surprisingly, and in contrast to younger respondents, the residents aged 50 and above do not perceive improvements in the quality of urban life overall nor any of the dimensions, except for the safety of children. In contrast to that, residents with children below the age of 14 perceive the improvements

Table 3
Assessment of safety and endangerment according to mode of transport use in the pre- and post-survey.

		Safety	Endangerment
Travelling by car	pre (N = 120)	2.28 (0.09)	3.81 (0.09)
	post (N = 64)	2.74 (0.15)	3.59 (0.15)
	Difference	0.46***	$-0.21^{n.s.}$
Walking	pre (N = 161)	2.60 (0.09)	3.16 (0.08)
	post (N = 105)	2.53 (0.11)	3.48 (0.11)
	Difference	$-0.07^{n.s.}$	0.32**
Cycling	pre (N = 120)	4.01 (0.09)	2.07 (0.09)
	post (N = 76)	1.96 (0.11)	3.74 (0.10)
	Difference	−2.05***	1.67***

Only respondents who already used the respective mode of transport on Friedberger Landstrasse answered the associated statements (overall number of participants: pre N = 169 and post N = 114).
Safety: "I feel safe"
Endangerment: "I feel endangered"
Response options from 1 - Agree to 5 - Disagree
Mean differences tested for significance according to *t*-test (Significance levels: *= 10%, **= 5%, ***= 1%)

Table 4
Six dimensions of the quality of urban life index.

Indicator	Question	Answer (five-point Likert scales)
Quality of stay	How do you perceive the quality of stay in Friedberger Landstrasse?	very bad (1) to very good (5)
Lingering	Do you enjoy lingering in Friedberger Landstrasse?	very bad (1) to very good (5)
Air quality	How do you perceive the air quality on Friedberger Landstrasse?	very bad (1) to very good (5)
Traffic noise	How do you perceive the noise of the traffic on Friedberger Landstrasse?	very loud (1) to very quiet (5)
Traffic volume	How do you assess the traffic volume on Friedberger Landstrasse?	very disturbing (1) to pleasant (5)
Safety of children	How do you rate the safety of children on Friedberger Landstrasse?	very unsafe (1) to very safe (5)

strongly, particularly regarding lingering, traffic volume and the safety of children.

One major factor for the perception of improved quality of urban life is the residents' own regular use of travel modes on the Friedberger Landstrasse. Unsurprisingly, those who only use their bicycle on that road perceive the redesign as an improvement in almost all dimensions of quality of urban life. Similarly, but not as pronounced, the user groups "no car, no bicycle" and "multimodal with car" appreciated the changes. Finally, the residents who use the road only by car, albeit being low in number (Table 5), assessed the changes completely differently. It should be noted that for them the quality of urban life was lower after the redesign as well as the air quality and quality of stay, while the perceived traffic volume increased. Even the safety for children did not improve, despite this being consistently reported by all other social groups analysed.

5.2. *Multivariate models for quality of urban life*

Our multivariate analyses included 14 OLS regression models: seven dependent variables for the quality of urban life index and its six underlying factors calculated both with pre and post data. Thus, we compared the contribution of factors affecting the dependent variables to assess changes from the intervention. After initial calculations with five independent variables (mode use on Friedberger Landstrasse, gender, age group, children in household and level of education), we omitted the education variable, since it did not contribute significantly to the models. In most cases, this delivered a significant outcome despite the non-significant models for air quality and for the pre-intervention model for safety of children (F-Test, see Table 6). The assumptions of multicollinearity and heteroscedasticity for linear regression models are met in the models. Only the Cook-Weisberg test showed heteroscedasticity in the traffic noise model 'pre'. Thus, the validity of this specific model is limited. Furthermore, the assumption of residuals' normality was not met. However, for models with a relatively large N, the violation of this assumption does not necessarily lead to a bias of the results (Schmidt & Finan, 2018).

As shown above, the regular use of transport modes on the

Table 5
Quality of urban life index and indicators by sociodemographic characteristics.

		Quality of urban life	Quality of stay	Lingering	Air quality	Traffic noise	Traffic volume	Safety of children
Overall	**pre (N = 169)**	**2.101**	**2.533**	**2.385**	**2.189**	**1.527**	**2.059**	**1.910**
	post (N = 114)	**2.556*****	**2.876*****	**2.623***	**2.395***	**2.246*****	**2.395****	**2.804*****
Female	pre (N = 98)	**2.112**	2.622	2.408	2.184	1.459	2.051	1.938
	post (N = 69)	**2.476*****	2.735	2.478	2.377	2.188*****	2.363*	2.735*****
Male	pre (N = 67)	**2.085**	2.388	2.343	2.179	1.627	2.060	1.910
	post (N = 41)	**2.663*****	3.073*****	2.829****	2.439	2.317*****	2.390	2.9*****
Under 50 years old	pre (N = 125)	**2.115**	2.592	2.432	2.200	1.488	2.024	1.952
	post (N = 78)	**2.652*****	2.949****	2.705*	2.462****	2.41*****	2.538*****	2.846*****
50 and older	pre (N = 42)	**2.063**	2.357	2.238	2.143	1.643	2.143	1.829
	post (N = 34)	**2.315**	2.667	2.412	2.206	1.882	2.029	2.688*****
Without a university degree	pre (N = 64)	**2.169**	2.563	2.391	2.281	1.672	2.188	1.922
	post (N = 43)	**2.531****	2.814	2.628	2.442	2.047****	2.326	2.93*****
With a university degree	pre (N = 100)	**2.046**	2.500	2.360	2.130	1.430	1.950	1.898
	post (N = 65)	**2.579*****	2.923*****	2.615	2.354	2.4*****	2.446*****	2.75*****
No children under 14 years old in household	pre (N = 140)	**2.157**	2.557	2.500	2.229	1.571	2.100	1.978
	post (N = 97)	**2.548*****	2.865****	2.629	2.392	2.216*****	2.371*	2.821*****
Children under 14 years old in household	pre (N = 29)	**1.833**	2.414	1.828	2.000	1.310	1.862	1.571
	post (N = 17)	**2.598*****	2.941	2.588****	2.412	2.412*****	2.529****	2.706*****
Car only	pre (N = 15)	**2.511**	3.067	2.733	2.600	1.733	2.667	2.267
	post (N = 14)	**2.036***	2.286*	2.143	1.857****	1.857	1.571*****	2.385
Multimodal with car	pre (N = 37)	**2.094**	2.595	2.324	2.162	1.622	1.973	1.861
	post (N = 23)	**2.493****	2.783	2.478	2.522	2.087	2.348	2.739*****
Bicycle, no car	pre (N = 64)	**1.911**	2.234	2.188	2.016	1.375	1.813	1.844
	post (N = 45)	**2.778*****	3.13*****	2.822	2.422****	2.489*****	2.733*****	3.091*****
No car, no bicycle	pre (N = 53)	**2.220**	2.698	2.566	2.302	1.585	2.245	1.923
	post (N = 32)	**2.517***	2.839	2.656*****	2.500	2.188*****	2.313	2.625*****

Significance levels for the differences between the surveys according to *t*-test: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6
Multi Regression Model of the quality of urban life index and indicators.

	Quality of urban life		Quality of stay		Lingering		Air quality		Traffic noise		Traffic volume		Safety of children	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Gender (1 = Female)	−0.001	0.209	−0.253	0.386*	−0.044	0.390**	0.001	0.127	0.211*	0.125	0.074	0.040	0.014	0.142
Age_dummy (1 = over 50)	−0.131	−0.273*	−0.331*	−0.187	−0.369*	−0.230	−0.126	−0.189	0.163	−0.475**	0.054	−0.428*	−0.203	−0.128
Children_dummy (1 = childrenin household)	−0.376**	0.000	−0.240	0.078	−0.789***	−0.030	−0.269	−0.020	−0.285*	0.102	−0.233	0.036	−0.448**	−0.166
Multimodal travel type														
car only	0.590***	−0.729***	0.821***	−0.890***	0.528*	−0.715**	0.580**	−0.553*	0.353	−0.557*	0.847***	−1.080***	0.415	−0.708**
multimodal with car	0.230	−0.333*	0.382*	−0.411	0.227	−0.398*	0.174	0.070	0.300*	−0.477*	0.204	−0.442	0.063	−0.358
bicycle, no car	0 (reference group)		0 (reference group)		0 (reference group)		0 (reference group)		0 (reference group)		0 (reference group)		0 (reference group)	
no car, no bicycle	0.339**	−0.226	0.457**	−0.237	0.437**	−0.110	0.309*	0.098	0.254*	−0.264	0.459**	−0.402*	0.111	−0.456**
Constant	1.990***	2.782***	2.457***	3.038***	2.395***	2.755***	2.077***	2.435***	1.275***	2.566***	1.793***	2.837***	1.944***	3.100***
Observations	N = 169	N = 114	N = 169	N = 113	N = 169	N = 114	N = 169	N = 114	N = 169	N = 114	N = 169	N = 114	N = 167	N = 112
R-squared	0.101	0.151	0.089	0.116	0.104	0.111	0.049	0.064	0.065	0.106	0.066	0.145	0.052	0.099
Prob > F	0.008	0.007	0.018	0.039	0.006	0.046	0.221	0.298	0.086	0.057	0.084	0.009	0.198	0.084
Cook-Weisberg test	0.698	0.264	0.883	0.259	0.387	0.715	0.306	0.340	0.000	0.956	0.335	0.971	0.285	0.971
Shapiro-Wilk W test	0.001	0.005	0.002	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Significance levels on *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Variance Inflation Factor (VIF) = 1.16

Friedberger Landstrasse affects the residents' assessment of the quality of urban life. In almost all models, the "car only" and "no car, no bicycle" users assessed the situation before the intervention as better than the reference group "bicycle, no car". However, after the intervention, the "car only" users assessed the quality of urban life as worse. In contrast, the residents without car and bicycle use only assessed the traffic volume and the safety for children as having worsened. However, in other dimensions and in the overall index, they do not differ from the "bicycle, no car" residents. Ultimately, the multimodal residents with car use are similar to the "bicycle, no car" residents, but slightly more content with the situation before the intervention and slightly less content afterwards.

The contribution of social group variables in the multivariate models remains limited. For example, after the intervention, women rated the quality of stay and lingering as being better than men did. As already suggested by the bivariate models, respondents above the age of 50 reported a significantly lower quality of urban life than those below that age. This is mainly due to their perception of increased traffic noise and traffic volume. Ultimately, respondents with children below the age of 14 rated the overall quality of urban life, lingering, the safety of children and traffic noise as worse than others in the pre-survey. These differences in perception are not apparent in the post-intervention survey.

6. Discussion

This study investigated the ways in which the removal of a lane for car traffic and the simultaneous introduction of a bicycle lane on Friedberger Landstrasse in Frankfurt am Main changed the quality of urban life for local residents. We investigated how perceptions of local transportation and quality of urban life depend on travel habits and sociodemographic patterns. Therefore, the focus of this study was not to examine a direct causal effect of the intervention on travel mode change as suggested by previous research (Aldred et al., 2019; Parker et al., 2013; Rissel et al., 2015). Despite its non-significance, the increase in residents' bicycle use on Friedberger Landstraβe by eight percentage points tends to show a modal shift towards more bicycle travel. Moreover, it is important to keep in mind that travel behaviour changes usually take place slowly and, thus, could take place in the medium term.

As many other studies (e.g., Appleyard et al., 1981; Brüning, 2013; Christ & Loose, 2000; Flade, 2013; Hart & Parkhurst, 2011; Santos & Martins, 2007; Song et al., 2007, Steg & Gifford, 2005), our study confirms that the high car volumes on main roads in urban areas severely affect the quality of urban life for residents, especially due to noise and unsafe traffic conditions for children. The study by Aldred et al. (2019) also confirms that the redesign of the road examined towards less space for cars and more for bikes has changed the perception of the local environment in a positive way.

Residents who participated in our study perceive the transformation of the street as an improvement for the overall traffic situation as well as for bicycling and walking, specifically. Moreover, cyclists report an improvement in the subjectively perceived endangerment and safety in the Friedberger Landstrasse. Evidently, they benefit from the clearly visible markings of the new cycling facility as suggested by the literature (e.g., Hunter et al., 2000). In our study pedestrians, on the other hand, perceive a reduction in threats but not an increase in safety. Even though the pavement is now further away from the car traffic, it is still narrow in places; there are only a few crossing points; and there are obstacles, such as poles, recycling containers and parked e-scooters.

The participating residents perceive the traffic conditions as having worsened for cars and public transport. This was expected for cars, since the number of car lanes decreased. However, car drivers' decreased perception of safety in traffic after the redesign was surprising at first glance. Car drivers have to adapt to a new, reduced car infrastructure. While pedestrians and cyclists are accustomed to very limited infrastructures, this may be a new experience for car drivers for whom public space has primarily been designed for decades. The increased lack

of safety by designing roads not exclusively for car users may help to slow cars down and increase safety for other mode users (Flade, 2013: 225). The more negative evaluation of public transport can be explained by the fact that, at the time of the second survey, bus traffic shared a lane with cars, so it was possibly slower. Later, however, the bicycle lane was opened to bus traffic so that this situation changed again. This development could not be mapped due to the time period of the survey. Moreover, the perception of worsening traffic conditions for public transport was surprising and can be attributed to the congestion reported on the remaining car lanes affecting the tram and bus lines as well (newspaper articles, e.g., Frankfurter Rundschau, 2020; Leclerc, 2020; Pfeiffer-Goldmann, 2020). Interestingly, despite the alarming reports by critics of the intervention about traffic jams and gridlock, the traffic volume is perceived as less disturbing in the post-survey.

Overall, the quality of urban life in the road section analysed increased after the redesign. As suggested by Brüning (2013: 90), residents who participated in our survey perceive less traffic noise with the increased distance between the front of the residential buildings and the car lanes. Similarly, our results are consistent with Christ & Loose (2000: 105), who indicate that reduced car infrastructures lower the emission of traffic-related pollutants and improve air quality. Moreover, the perceived safety of children increases as already suggested by Flade (1994, 2013) and others (Funk & Faβmann, 2002; Hüttenmoser, 1994).

Interestingly, participants above the age of 50 are less likely to perceive improvements in quality of urban life after the transformation with the only exception of child safety. As Amann et al. (2016: 141) argue, the frequency of daily travel in one's own neighbourhood increases with age, which is why this group of people may be more out and about in their neighbourhood. Thus, although the lane was modified in favour of cycling, additional improvements to the built environment, like high quality footpaths, crossing facilities, benches and greenery, were still missing. As White et al. (2013) note, greenery along streets leads to direct increases in life satisfaction and lowers physical stress. This is an overall assessment that still remains missing in the Friedberger Landstrasse.

Female respondents perceive quality of stay and lingering as better than men do. Previous research shows that women's daily activity spaces are closer to home and involve more complex trip chains than men's due to their greater share of household-related care work (de Madariaga, 2013; Flade, 2013: 162; infas, 2018: 64; Parker et al., 2013). Women are more attentive of and dependent on their neighbourhood's built environment. This could explain the more positive perception of the quality of stay after the measure compared to male respondents.

Unlike elderly people, participating residents living in households with children below the age of 14 perceive improvements after the transformation for lingering, traffic volume and children's safety. This is surprising, as all three groups of residents spend an above-average amount of time in the neighbourhood each day. Unfortunately, the limited number of residents on the road section does not allow us to analyse these differences in further detail. This could be a task for further research.

In our study, the perception of the road transformation was different depending on regular mode use. We found that participants who regularly only use cars on the Friedberger Landstrasse perceive the quality of urban life, air quality and quality of stay as worse and the traffic volume as higher after the transformation than before. This contrasts sharply with the residents who do not drive a car but regularly cycle on that road section. They value and benefit from the advantages of the transformation most when compared to other mode user groups. Steg and Gifford (2005) furthermore found that car-limiting traffic interventions often conflict with the routine behaviour of daily car drivers. With their study on road pricing, Schade and Baum (2007) discovered that the strength of belief in the implementation of a transport measure strongly influences the attitudinal evaluation by individuals. In addition, the evaluation of sustainable transport measures as well as the use of them is strongly influenced by personal involvement with environmental issues or the marketing of the measure by the municipal government (Eliasson & Jonsson, 2011; Hamilton & Eliasson, 2012).

In our case, this could also contribute to the fact that those who ride bicycles but do not drive a car are more likely to see their own benefits than those who drive cars and who were already hesitant in advance. Moreover, this may be related to the concept of group-serving bias, which states that people observe the conflicts they do not cause the most (Kirschner & Lanzendorf, 2020).

The main strength of this study is the evaluation of the effects of a transport-related built environment intervention on local residents in a before-and-after study to assess the changes in quality of urban life for the residents living along that specific road section. Furthermore, this study analysed how people's perceptions of local traffic and quality of urban life changed depending on their regular daily mode use and sociodemographic patterns. Given the uncertainties of this type of infrastructural project with frequently changing time plans, depending on financial sources, planning needs and political discussions, we succeeded in assessing the effects using a quantitative survey.

Nevertheless, the study has a number of limitations. First of all, we were not able to use panel data or control group design due to the limited number of people living close to the road section and due to the limited resources available to set up the survey. Thus, we cannot be completely certain that the main effect analysis is free of unobserved confounding variables. The household survey method used is not free of potential participation bias either. Residents who have a strong opinion on the topic are more likely to participate in the study and express their views (Singer, 2006). Furthermore, an assessment of medium- and long-term travel behaviour changes was not feasible within the short time period between the intervention and the post survey stage. As mentioned above, changes in mode use may require more time to occur. Therefore, another follow-up survey in the future might provide additional insights into these types of effect. By contrast, however, within the short survey period of our study, some external factors remained controlled and allow for a better understanding of the changes observed. For example, the summer weather conditions remained unchanged, and no local public discussions emerged around the topic of transport in that time period.

Despite some limitations, the results of this study could support Frankfurt and other municipalities in continuing their path to transform road space towards more liveable environments.

7. Conclusion

This study addressed the question of the extent to which changes toward sustainable infrastructure measures, such as bicycle lanes, contribute to improvements in the perceived quality of urban life by residents living on a major road. With a pre- and post-survey on the conversion of two car lanes to bike lanes on a four-lane main road in Frankfurt, Germany, we found that residents were generally more dissatisfied with the impact of traffic on their quality of urban life before the intervention than afterwards. Furthermore, residents who participated in our study perceived safety, quality of stay, noise levels and air quality more positively after the intervention than before. This suggests that reduced infrastructures for cars and the parallel introduction of bicycle lanes have a positive impact on the quality of urban life for residents. The results underscore the importance of further research on the impact of infrastructural interventions on individual travel behaviour as well as on the quality of urban life.

Our analyses showed, however, that the needs of some social groups were not met by the measure to the same extent as others. For example, frequent car users did not perceive improvements in most quality of urban life indicators even though these improvements affect their neighbourhood. Thus, our results suggest that individual's perceptions of the local traffic situation and the quality of urban life depend on their own travel routines that in turn may be affected by key events, such as the built environment intervention, or daily events, such as traffic jams

(Müggenburg et al., 2015). Further research could provide more detailed insights into the interaction between travel patterns and routines, on the one hand, and subjective quality of urban life perceptions, on the other.

Decision-makers and planners may benefit from the empirical results of our study. We showed that, in our case study, by converting car lanes to bicycle lanes, the quality of urban life for residents as well as their overall assessment of the traffic situation improved. The benefits of new cycling-friendly transport infrastructures are, thus, not limited to the objectives of traditional transport planning but rather to elements of urban planning and development objectives. This might be at least one reason why transport research and practice ignored these types of benefit for a long time.

CRediT authorship contribution statement

Martin Lanzendorf: Conceptualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Clara Scheffler:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Laura Trost:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Simon Werschmöller:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration.

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.

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