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Practical urban planning for winter cycling; lessons from a Swedish pilot study

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ABSTRACT

Introduction: A detailed understanding of how the weather affects cycling is lacking. Where research has been carried out, the focus has often been on temperate and hotter climates; little research has been carried out regarding cycling in colder climate communities. This study therefore investigated the lived experience of winter-season cycling to provide empirical data for planning winter cycling in cold-climate communities.
Methods: Between 1 December 2017 and 30 April 2018, the activities of 13 cyclists (eight female and five male, mean age 42 years, age range 11–74 years) in Luleå, Sweden, were surveyed. Methods: Structured questionnaires, individual travel diaries, and recorded data for outdoor temperature, precipitation type, and snow cover were used.
Results: 1) Cycle level and frequency could be maintained during the winter season; 2) in winter, participants were more likely to use their bicycles for commuting than other activities, 3) electric bicycles helped winter cycling significantly; 4) the quality of the cycling infrastructure is critical to making winter cycling attractive.
Conclusion: For winter cycling to be successful, town planners need to consider winter cycling as a specific activity with its own design, policy and management requirements. This study has shown that year-round cycling can be achieved in cold-climate communities, with all its attendant potential health benefits.

1. Introduction

Creating attractive, safe and well-maintained built environments with connected networks of streets and spaces is an established prerequisite for soft mobility in the form of walking and cycling as active modes of transport (Carmona et al., 2010; Cowan et al., 2010; Marshall, 2005). Urban environments that are compact, mixed-use and diverse in function are seen as conducive to cycling, while single-use areas and urban sprawl are unattractive to cyclists (Cabral et al., 2018). Equally, it has been shown that providing an efficient cycling infrastructure (cycle paths) can mitigate adverse weather conditions and influence people's decisions on bicycle (bike) usage (Hong et al., 2020). The characteristics of the cycling infrastructure influence cyclist speeds (Clarry et al., 2019), which in turn influence decisions about daily usage.

Cycling for transport and leisure has grown significantly over the last few decades and has been the subject of many research studies. Cycling has the potential to deliver a range of town planning outcomes that can be linked to the UN's Sustainable Development

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Goals, the Paris Agreement targets for global warming and the WHO's targets for health (UNFCCC, 2018a; 2018b; WHO; 2006; 2018). Overall, cycling is described as a positive enabler and can have an impact on diverse issues such as social and physical health and well-being and cohesion. Cycling can also reduce energy demand and pollution, and in so-doing help slow climate change. Cycling requires minimal space and facilities (Amiri et al., 2015; Rekila, 2016) compared with the car. However, while the space required for cycling may be minimal, the quality of the facilities is critical to encouraging people to travel by bike. High-quality cycle lanes and special cycle junctions, as well as destination facilities such as storage, changing and maintenance areas, are all important considerations (Frasier, 2011; Rekila, 2016; Cass et al., 2016; Damant-Sirois, 2015; de Sousa et al., 2014).

Electrically assisted bicycles (e-bikes) are also becoming a significant part of the cycle industry, and this sector is seeing rapid growth (Sun et al., 2020). It appears that people will cycle more if bikes are electrically aided, and that e-bikes can replace a substantial proportion of car journeys, especially short ones. However, many factors associated with e-bike usage and travel behaviour need to be considered in campaigns to promote e-cycling as a mode of transport (for an overview, see Bourne et al., 2020). The benefits of using e-bikes as an active form of transport include people following health and physical activity guidelines (Nematchoua et al., 2019), and e-bikes can help people overcome common barriers to cycling, such as distance, topography and sweaty/uncomfortable personal hygiene (Dill and Rose, 2012; MacArthur et al., 2017). Importantly, research has shown that people have a positive attitude towards e−bikes, based on functionality, health benefits and image (Simsekoglu and Klöckner, 2019). E-bikes do, however, need battery charging or swapping facilities, which in the future may require publicly accessible charging stations within the built environment to facilitate the growth of this mode of transport (Dill and Rose, 2012). Encouraging a greater shift to e-bike use would also benefit from specific e-bike policies (Sun et al., 2020), such as planning policies for charging and storage of e-bikes within the public realm and transport policies for e-biking as a mode of transport.

While there are many studies on cycling behaviour (Heinen et al., 2010; Cabral et al., 2018), less research is available on the effects of weather and climate on cycling (Böcker et al., 2013; Wadud 2014; Mathisen et al., 2015). Such research is often focused on temperate and hotter climates, and little information is available about cold-climate communities during the winter season. Studies have established weather as an important consideration in deciding whether to travel by bike or not, and have shown that, in cold-climate communities, cycling rates decline significantly in winter (Bergström, 2003; Nahal et al., 2018). In cold-climate settlements, cycling is viewed by many as a seasonal, summer, activity (Spencer et al., 2013).

This suggests the need for a better understanding of how weather conditions in the cold winter season affect cyclists in cold-climate communities. However, it is not just the daily weather that affects a decision to cycle. Research has shown that during the winter layers of snow and ice can build-up and alter the basic form and layouts of streets and pathways within the built environment (Chapman et al., 2017, 2018, 2019). This affects the cycle-ability of a local area, and presents challenges to delivering good, functional cycle networks (Rekila, 2016). Underutilisation of the cycle infrastructure because of winter conditions is therefore a town planning concern (Nahal et al., 2018).

Studies on the impact of weather conditions on cycling commonly focus on rain, temperature, snow, wind speed, sunshine hours, humidity, fog and thunderstorms (Wadud, 2014). The studies available of cold-climate areas show the importance of weather conditions such as precipitation (especially as snow rather than rain), wind and temperature (Nankervis, 1998; Flynn et al., 2012; Mathisen et al., 2015; Sears et al., 2012; Winters et al., 2007, Spencer et al., 2013). The impact of temperature is, however, contested. Some research suggests that cold is a barrier to cycling, while elsewhere temperature is shown to have little effect on cycling behaviour (Amiri and Sadeghpour 2015; Ebrahimabadi et al., 2015). Research carried out in hotter climates indicates that, while heat waves discourage people from cycling because of the discomfort, there is threshold before a negative impact is seen (Rabassa et al., 2020). Wind speed is generally shown to impact cycling negatively, but the effects are non-linear (Wadud, 2014). Sunshine hours are perceived as having a positive effect; however, in cold-climate settlements with limited sunlight hours in winter, artificial lightning along roadways can compensate for the darkness (Spencer et al., 2013). Conflicting results about the relative importance of different weather variables on cycling can therefore potentially be explained by geographical location. The cycling culture, experience and resilience to various weather conditions among communities can all affect the decision-making process, as well as climate (Goldmann and Wessel, 2020).

On-going climate change is a double-edged sword for cycling in cold-climate communities. On the one hand, global warming is likely to shorten the periods of harsh winter conditions and extend the periods when it is easier to travel by bike. Some estimate that the winter season could be reduced by up to 2–3 months a year (Mathisen et al., 2015), while others suggest that good design and planning could also extend the accessible period for outdoor activities in winter (Pressman, 1985). On the other hand, warmer temperatures may create longer periods with temperatures around 0 °C, resulting in more ice and/or standing water in the public realm, and more slush and rain, which are all major barriers to outdoor activities and cycling (Chapman and Larsson, 2019).

In this context, research into cycling in cold-climate settlements during the winter season is important. The aim of this study was therefore to gain insight into cycling behaviour by addressing the research question: *What is the lived experience of cycling in the winter season and how can this knowledge be used to better enable year-round cycling in cold-climate settlements?*

2. Materials and methods

The study followed the cycling activity of 13 cyclists who committed to becoming 'winter cyclists' between 1 December 2017 and 30 April 2018, in a winter-cycling project run by Luleå Municipality, Sweden. This initiative was part of a wider winter-cycling campaign. Winter cyclists are defined as people who consciously adapt their equipment for cold-climate conditions. These adaptations can include having a second bike for winter, changing summer tires to winter tires (which have spikes), using additional lighting, and having appropriate clothing.

The city of Luleå, latitude 65.5848° N, is characterised as a winter city, and has a sub-arctic (Group D) climate belonging to the Dfc subcategory according to the Köppen-Geiger Climate Classification system. During the winter, the city experiences limited hours of sunshine and daylight; there is significant seasonal climatic variation, but temperatures are typically below zero during the winter and regularly fall to −20 to −30 °C. Winter precipitation is usually in the form of snow (Pressman, 1985). In the summer, high-latitude cities can experience extended periods of 24-h sunlight, when the sun stays near the horizon, an effect commonly called a 'midnight sun'. In cities such as Luleå, the winter season can last for up to 6 months a year (Mathisen et al., 2015).

2.1. Study design

A concurrent embedded mixed methods design (Creswell and Clark, 2011) was used to answer the research question, by combing data from surveys, diaries and a climate database. Data was gathered on people's perceptions of winter cycling using two structured questionnaires. Travel diaries of daily cycling behaviour between December 2017 and April 2018 were used to capture the lived experience of winter cycling. Details of the weather conditions during this period were collected from the Swedish Meteorological and Hydrological Institute (SMHI).

2.2. Study participants and procedure

Cyclists for the winter-cycling project were strategically selected. The municipality wanted to include people that others could relate to, to facilitate a "That could be me" response. The municipality was searching for cyclists with limited experience of cycling in winter conditions who wanted to challenge themselves by becoming committed winter cyclists. Each participant was expected to comply with the project's objective of using a bike for at least half of the daily journeys made during the winter. The aim was to include women and men of all ages, with varying lifestyles and needs, from different parts of Luleå.

To achieve this, an open invitation was sent to Luleå residents to apply to be a winter cyclist in the project. The application process was open from 16 October to 8 November 2017. Applicants were asked to write a personal letter explaining why they wanted to be a winter cyclist, and these applications were then judged by municipality staff. The successful applicants were announced at the municipality's Bicycle Conference, held on 18 November 2017. The actual winter cycling project ran from 1 December 2017 to 30 April 2018.

To raise awareness of the winter cycling campaign and recruit participants to the project, information was posted on the municipality website and video clips were posted on its Facebook account during the application period. The project was also covered by local newspapers and featured on Swedish television. The municipality presented the project on two public video screens, one on the wall of a shopping centre in a central city location and one on a screen close to a bridge on a major route into and out of Luleå.

Thirteen winter cyclists took part in the study. The participants, eight female and five male, had a mean age of 42 (±17.6, range 11–74) years. Three of the participants were excluded during the travel diary analyses because they did not usually commute to work. This was done so that necessary and optional activities could be compared. The remaining ten participants, six female and four male, had a mean age of 42 (±13.7, range 21–61) years.

Each of the successful applicants was then randomly assigned a bike for the project (13 bikes was the limit of the project's budget). Four of the bikes were city bikes, two were electric city bikes, two were electric cargo bikes, one was a fat bike, one was a tandem, one was a tricycle, one was a folding bike, and one was a mountain bike.

During the five-month project, a number of meetings were held with the participants. Later in the project the meeting agendas were based on subjects the participants wanted to learn more about. The agendas included:

- A start-up meeting so that everyone could get to know each other
- How to dress for winter cycling, with an invited speaker from one of Luleå's adventure stores providing an overview
- How to maintain a bike in winter, with a visit to a local bike store and an explanation of general and winter bike maintenance
- How snow clearance and gritting works are undertaken, and what could be expected from the municipality
- A final meeting to sum up the project.

2.3. Data collection and analysis

2.3.1. Structured questionnaire

Participants completed a structured questionnaire at the beginning and at the end of the project. The questionnaire explored the participants' travel behaviours and perception of winter cycling. A mixture of multiple choice, yes/no and descriptive (free comments) questions was used.

The outcomes of the before and after questionnaires were descriptions of the primary patterns in the data, i.e., the content, number of comments, and key quotations. For this analysis, data from all thirteen participants was used.

2.3.2. Travel diaries

The journeys undertaken, their purpose, distance (km) and whether using a bike replaced a car journey were recorded during the five-month period. The results were divided into commuting to and from work and leisure trips. For this analysis, data from only the 10 participants who commuted to work was used.

Data from the travel diaries was compared with meteorological data sets to identify trends in travel behaviour during winter cycling. The descriptive data was analysed using mean, SD, median and maximum and minimum values. Between-group comparisons were analysed using the T-Test and Wilcoxon Signed Ranks Test, and related samples were analysed using Friedman's two-way analysis of variance. The significance level was set to 0.05. Separate analyses were made for journeys related to commuting to work compared with journeys for leisure activities, and for e-bikes compared with other bike designs.

2.3.3. Climate data

Data sets were downloaded from the SMHI to analyse the meteorological conditions between 1 December 2017 and 30 April 2018. The specific sets obtained were: temperature (degrees Celsius), sun minutes, snow cover and precipitation type.

2.3.4. Research ethics

The study was performed in compliance with the ethical principles for good research practice (World Medical Association, 2013), and informed consent was obtained from all participants. Protective equipment, i.e. a helmet, was provided, and the participants were encouraged not to exceed their ability or expose themselves to unnecessary risks. Information on appropriate clothing and bike maintenance was offered.

3. Results

3.1. Structured questionnaires

3.1.1. Frequency of cycling

During the project, the frequency of bike use increased significantly, to the level of summer season usage, i.e. when it is warmer, lighter and the streets and spaces in the public realm are free of snow, ice, or slush (Table 1).

3.1.2. At the outset of the study

Nine of the thirteen participants stated that the car was their main form of transport during winter. Six owned a car, while the others had the opportunity to use a car when they needed one. Their most common daily journey distance was on average 5.9 (range 2–12) km.

Modal choice: The majority of participants thought it would be quite hard to achieve the objective of using the bike for at least half of their daily journeys during winter.
Experience of (winter) cycling: Eleven participants had often cycled during bare ground conditions (summer), but only five had some experience of winter cycling. The five who had winter cycled before reported using their bikes less from December to February because of cold temperatures and snow obstacles on the streets, or because it entailed too much effort to use a bike.
Anticipated barriers to winter cycling: The main reasons given for not cycling more frequently during winter were related to travel distance (2 comments), coldness (2 comments), fear of falling (3 comments), inappropriate clothing/sweating (3 comments), having accompanying children (2 comments), snow management (2 comments), and not having a bike appropriate for winter conditions (2 comments).

3.1.3. At the end of the study

Barriers to winter cycling: Five important factors were identified from the free comments: coldness, snow management, bike management, psychosocial concerns, and risk of falling.

Cold temperatures was the most mentioned factor (8 comments). The participants questioned the appropriateness of cycling as the main choice of transport during the coldest periods of winter, but acknowledged that the aim of the journey and personal capability had a bearing on the relative impact of coldness: *' … especially when my kids cycled with me, then we had -15 degrees Celsius as cold limit'*. Snow management in the public realm was also a significant concern (7 comments); aspects of information about and the timing of snow clearance on roads as well as coverage were mentioned: '*faster snow clearing in the event of heavy snowfall' 'better snow clearing along with all networks of roads, at cycle paths, streets through the neighbourhood, between the city centre and an out of town retail park'*.

The participants also mentioned practical issues such as bike management (5 comments). Problems of storage at home and at the work place, and cycle parking in public spaces, were highlighted, e.g. *'There is no way to arrange a simpler storage where I live', 'If the*

Table 1
Bike usage at baseline(s) and during the study (n = 13).

Summer conditions (baseline)	Winter (baseline)	Winter (during project)	*p1*	*p2*	*p3*
4.1 (1.6)	1.8 (1.3)	4.2 (1.2)	0.001	0.805	<0.001

P1 = summer season (baseline) – winter (baseline), p2 = summer season – winter (during project),
p3 = winter (baseline) – winter (during project).
T-Test, paired samples
Scale 1–6 (1 = never/seldom, 2 = once a month, 3 = 1 day/week, 4 = 2–3 days/week, 5 = 3–4 days/week, 6 = 6–7 days/week.

weather-protected bicycle garage at work had been easier to use', and also a lack of facilities for maintaining the bikes, such as somewhere to pump up tires. The general usability of bikes as a means of transport was addressed in terms of work and social contextual factors (5 comments), such as work schedules and demands: *'Unless I travelled between different places during the workday',* and social support from family units: *'If my partner would have cycled on our weekend adventures, but instead we used the car'*.

Four participants had experienced *adverse incidents*, i.e. falling with the bike, but no severe injuries were reported. Reasons for the falls included snow cover and hitting the edge of a sidewalk, turning the bike too quickly and instability of the cargo bike.

Motivations for winter cycling: The majority of the participants predicted that they would cycle next winter, and all would recommend winter cycling to others. Five main themes emerged from the free comments: personal health & wellbeing, cost-effectiveness, environment, e-bike, general inspiration and support.

Ten comments acknowledged the health and well-being benefits of cycling: '*feeling more alert during the day, daily exercise*', *'cycling to work is more fun than driving'*. The environmental benefits of reduced car usage (4 comments) were also perceived as a motivating factor; *'contributing to a better environment is a positive side effect'*. At a personal level, cycling was perceived as time- and cost-effective and flexible (3 comments): *'more flexible than having to wait for the bus', 'It was easier than I thought and it goes faster'.*

Using an e-bike (4 comments) was a deciding factor: *'It will depend on whether I have purchased an electric bike or not', 'I realised that I do not want to ride a regular bike when it is too cold. So if I had had the electric bike before … '*

Other motivations included cycling in general and for the wider population (to promote it to other residents), and the importance of, and a need for, good planning and management of paths to cycle along, during both summer and winter seasons, was highlighted. It was suggested that creating more public opportunities to test winter bikes and rent an *e*-bike, or get a discount on purchasing winter tires, would increase the attraction of winter cycling in the wider population. Creating challenges, such as competitions between companies or on social media, or arranging group activities and setting up bike clubs, were recommended. Dissemination of information about good practice and winter cycling via media channels and within schools and workplaces was also suggested.

In summary, the qualitative comments provided a deeper insight into the topic of winter cycling, revealing a wide variety of perceived barriers and motivations that all need to be addressed. The issues could be divided into four broad groups:

1) weather-related obstacles, such as coldness (ambient) and snow on cycle lanes and connected routes (terrain & urban form)
2) practicalities in terms of bike storage and clothing, including the 'role' of e-bikes
3) personal circumstances and capabilities, working conditions and social pressures
4) personal health & wellbeing benefits and cost effectiveness (time, expenses).

3.2. Travel diaries

Over the five months, the 10 participants who used the bike for commuting travelled a total distance of 5935 km. Of those, 5098 km represented journeys where cycling replaced transportation by car. These journeys reduced the amount of carbon dioxide released by 663 kilos.

The monthly values for kilometres cycled did not differ significantly. A sub-analysis showed that slightly more kilometres were cycled for work commutes than for leisure activities, but there were no statistically significant differences (Table 2).

Table 2
Data from participants' (n = 10) travel diaries showing the accumulated and average distances (kilometres) cycled per month, for commuting and leisure activities.

	December	January	February	March	April	*Sum*	*p1*
All winter cycling							
Accumulated distance (km)	903	1196	1264	1398	1173	5934	
Average (km) Md (min-max)	86 (34–198)	96 (18–393)	86 (0–418)	94 (42–385)	94 (0–413)	455 (203–1807)	0.439
Commuting to work							
Accumulated distance (km)	716	1040	1085	1143	869	4853	
Replaced car (km)	648	940	995	1000	753	4336 (*89.4 %*)	
Average (km) Md (min-max)	69 (6–175)	78 (8–350)	68 (0–379)	78 (27–325)	58 (0–396)	316 (166–1625)	0.166
Leisure transport							
Cycling distance (km)	187	157	179	255	304	1081	
Replaced car (km)	148	149	156	168	141	762 (*70.5 %*)	
Average (km) Md (min-max)	15 (0–54)	5 (0–52)	15 (0–43)	25 (0–60)	26 (0–94)	96.5 (22–224)	0.833
p2	0.017	0.017	0.008	0.007	0.043		

p1 Difference over time. Related Samples Friedman's two-way analysis of variance, 0.05.
p2 Comparison between Commuting versus Optional cycling per month. Wilcoxon Signed Ranks Test, 0.05.

3.2.1. Winter cycling to commute to work or for leisure activities

Winter cycling replaced a high proportion of previous work-related car journeys (89%). For leisure travel, cycling replaced car usage for 70% of the journeys. One explanation of this lower percentage is that exercise was one of the reported reasons for leisure cycling. Cycling for exercise is an activity that does not replace car usage.

The monthly reports showed that participants used bikes for journeys to and from work to a greater extent than for transportation to and during other activities (such a shopping, visiting friends, exercise and recreation). This difference between commuting to work and for leisure activities was statistically significant for all five months.

3.2.2. Bike type

An analysis of bike type showed that the participants (two men and two female) who had been allocated e-bikes accumulated more kilometres cycled per month for both commuting and leisure, than participants (two men and four female) with other bike types, but the differences were not statistically significant (Fig. 1). Regarding daily usage, the distance travelled by participants with e-bikes was on average 10 km (ranging from 3.7 to 20.1), while participants using non e-bikes travelled on average 6.4 km (ranging from 3.9 to 11.1).

For participants with e-bikes, monthly variables, such as weather conditions, did not significantly influence the accumulated kilometres travelled for either commuting to work ($p = 0.267$) or leisure activities ($p = 0.831$). There were no monthly differences in accumulated kilometres between work commutes and leisure cycling, apart from minor differences in March (December $p = 0.273$, January $p = 0.273$, February $p = 0.109$, March $p = 0.068$, April $p = 0.144$).

Participants using other types of bike showed significant monthly differences in kilometres travelled to work ($p = 0.036$) but not for leisure cycling ($p = 0.553$). There were significantly fewer kilometres per month cycled for leisure activities compared with commuting for all months except for April, when commuting distances also declined (December $p = 0.028$, January $p = 0.046$, February $p = 0.028$, March $p = 0.046$, April $p = 0.109$).

3.3. Climate data

The number of sun minutes per month increased from 298 in December to 16271 in April. January was the coldest month, and April the warmest, with only 2 days with temperatures below zero. From January to March the precipitation fell in the form of snow, while in December and April rainfall and sleet also occurred (Table 3).

4. Discussion

4.1. The outcomes

The objective of this study was to gain insight into the environmental factors influencing winter cycling behaviour. During the project, participants increased their bike usage and began to use their bikes in winter as much as they had done during the previous summer season. The participants' daily distances travelled by bike were relatively high compared with other studies (Bourne et al.,

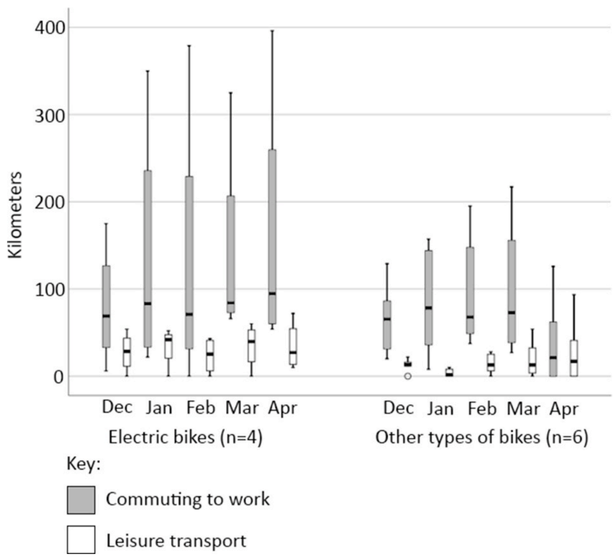

Fig. 1. The distances cycled for leisure activities and commuting are illustrated separately for participants with e-bikes and participants with other types of bike. The data distribution is displayed as a box and whiskers diagram, showing the minimum, first quartile, median, third quartile, and maximum values.

Table 3
Average monthly outdoor temperatures, sun minutes, snow cover and precipitation.

	December	January	February	March	April
Temperature	*Mean (low/high)*	*Mean (low/high)*	*Mean (low/high)*	*Mean (low/high)*	*Mean (low/high)*
Degrees Celsius	−7.2 (−20.7/3.3)	−9.8 (−30.0/1.5)	−12.6 (−28.9/0.1)	−7.5 (−22.5/6.0)	0.4 (−16.2/12.7)
No. days below 0 °C	21 (of 31) days	21 (of 31) days	27 (of 28) days	21 (of 31 days)	2 (of 30) days
Sun minutes					
Accumulated min	298	708	5758	8875	16271
Mean min/day	10 (0.2 h)	23 (0.4 h)	206 (3.4 h)	286 (4.8 h)	543 (8.7 h)
Snow cover					
Mean, metre	0.48	0.88	0.95	1.07	0.95
Precipitation type					
Snowfall/rain or sleet (No. days)	7/4	13/0	11/0	8/0	7/5

2020), which is important for two reasons. Firstly, regular cycling has been shown prospectively to provide important cardiovascular health benefits (Grøntved et al., 2016). Secondly, winter has previously been shown to be an inhibiting factor for cycling (Bergström, 2003; Sears et al., 2012; Nahal et al., 2018). Although cycling in the winter presents particular challenges, our research suggests that approaches can be made to overcome these barriers and facilitate more winter cycling. Participants mentioned the time saving and economic benefits of cycling for transport, and valued the physical exercise and resulting well-being. Interestingly, while environmental benefits such as reduced carbon dioxide pollution were acknowledged, these were often seen as a spin-off. This is in line with earlier findings regarding e-bikes, that the health benefits and enjoyable journeys are the most frequent motivating factors (Plazier et al., 2017).

At the start of the project, participants saw the goal of using the bike for at least half of their journeys as challenging. Thus, replacing car transportation by up to 89% and 70%, respectively, for work-related journeys and leisure activities is a good outcome. Considering the monthly distance travelled, these results indicate that people are more likely to replace commutes than leisure journeys with cycling. This supports earlier findings on conventional cycling in colder climates (Amiri and Sadeghpour, 2015) and e-bikes (Bourne et al., 2020). The rationale for utilitarian bike usage can be understood by applying the first of Gehls' (2011) concept of three types of activities. Of which the first, denotes compulsory activities that would take place in any weather condition. Regarding bike type, participants, including those who had not been allocated one, noted the benefits of having an e-bike. As in other studies, e-bikes were seen as attractive and enabling for winter cycling ((MacArthur et al., 2017); Simsekoglu and Klöckner, 2019). The results from the travel diaries also showed that some of the participants with an e-bike covered considerably more kilometres each month than those using a non-e-bike. Which corresponds to Dill and Rose (2012) and MacArthur et al. (2017) finding that e-bikes enabled people to travel greater distances and made terrain that is challenging for conventional bikes more accessible. In this study, the terrain was affected by the presence of snow, ice and slush in the public realm. This is interesting, as the interaction of people's capacity, clothing and cycling speed, with wind chill temperature, and demanding terrain, etc., together form thermal stress and metabolic demands (Petersson et al., 2019). Which inevitability have an impact on the motivation to cycle in winter. In these situations, use of an e-bike can here act as a moderating factor. This highlights the importance of finding a balance between using the assistance of an e-bike and pedalling enough for comfortable thermoregulation, enhancing personal performance and conferring health benefits as a result of regular physical activity.

Additional data on cycling speed and trips would have been valuable, in order to relate speed to weather conditions, terrain and the cyclists' own perceptions. Using GPS devices or smartphone tracking as sources of data on travel behaviours could widen our understanding of the impact of weather on cycling (Hong et al., 2020; Plazier et al., 2017; Goldmann and Wessel 2020).

Our results show that the requirements of winter cycling do have much in common with more general non-winter cycling. Attractive, safe and well-maintained built environments are important prerequisites (Carmona et al., 2010; Cowan et al., 2010; Marshall, 2005), and the quality of the routes and facilities such as storage are also important considerations (Rekila, 2016; Cass et al., 2016; Damant-Sirois, 2015; de Sousa et al., 2014). These apply to both e-bikes and non-e-bikes.

However, the participants did perceive winter cycling to be different from non-winter cycling. This suggests that specific interventions, designs and policies are needed to enable and enhance people's perception of winter cycling (Ma and Dill, 2015). While all the participants were experienced summer cyclists, they expressed limited knowledge of winter cycling, and questioned how safe it was, how difficult it would be and whether they had the right equipment for cycling, in relation to both the bike and clothing. This is important, as it illustrates that the perception and needs of winter cycling, for example metal-studded tires, are not the same as summer cycling (Rekilä and Klein-Paste, 2016). All participants acknowledged the importance of having the right clothing and equipment, such as studded tyres to enhance grip and friction on snow and ice (Rekilä and Klein-Paste, 2016). In accordance with earlier findings by Bergstrom (2003), the participants considered winter pathway maintenance to be critical in delivering a useable cycle infrastructure across the winter season.

The only complaint made by the participants about the bikes was about the large cargo e-bikes, which were found to be unstable and heavy to manoeuvre in winter conditions. Issues related to battery life or charging were not mentioned in the questionnaire responses, which suggests that currently this is not an issue. However, as e-bikes grow in popularity the need for such facilities may increase (Dill and Rose, 2012).

This study also confirms that coldness can be both a perceived and an actual barrier to winter cycling (Nankervis, 1999; Flynn et al., 2012; Mathisen et al., 2015). However, it was unclear how 'cold' was defined by the participants. One highlighted −15 °C as a threshold for winter cycling, and the mean temperatures during the study period were between −12.6 and 0.4 °C, suggesting that much of the winter season was cycle-able. However, there were days with temperatures as low as −30 °C.

Issues with snow centred around its build-up on the ground rather than in terms of its precipitation. It was notable that cycling was less frequent in December and April, when precipitation occurred in the form of rain or sleet, particularly in April when temperatures fluctuated around zero °C. This suggests that for cycling it is the form of precipitation combined with temperature, and its effect on the terrain, that is problematic. This could also explain conflicting results on the negative impacts of both rain and snowfall reported in earlier studies (Sears et al., 2012; Winters et al., 2011; Larsson and Chapman, 2020), and highlights the importance of defining and measuring the different qualities of precipitation as well as the lived experiences of the population. Darkness, in January and February, did not reduce the amount of cycling to work.

The participants stressed personal capabilities and psychosocial influences on their cycling behaviour. Such results are supported by earlier research (Goldmann and Wessel, 2020) and can be explained by, for example, Chapman & Larsson's soft mobility model (2019). The soft mobility model explains how the interplay between the individual, built infrastructure and seasonal climate and weather affect the decisions made about the mode of transport to use.

4.2. The methodology

While the strategic selection of the winter cyclists was to form a representative sample of the study area, it should be borne in mind that the volunteers were self-selecting in putting themselves forward. Equally, the study sample was small at only 13 people. Overall, the sample cannot be seen as representative of all the residents in the study location. For example, no participant had a particular aversion to cycling or physical activity. There were also officials from the municipality who supported and promoted the winter cycling campaign. The strength of the data collection relied on motivated participants: documenting all their cycling activities over five months required commitment. However, an advantage of the mixed methods design was the option to include data on people's perceptions of facilitators and barriers to their winter cycling activities. Hence a deeper understanding of what factors need to be tackled was attained, which is important for public planning strategies to engage with winter cyclists in general.

The small sample size also suggests that large distances were cycled by a few committed cyclists. This influenced the accumulated total time spent cycling by the group, indicated by the wide range in variation seen in the graphs. So that optional and work-related winter cycling could be compared, for the analysis of the travel diaries three participants' data were excluded because they did not commute to work. However, the survey reports from all 13 participants are valuable for planning purposes, because their reported experiences describe both 'good' practices and barriers.

The use of a range of bikes within the study was both a strength and a weakness methodologically. The range allowed the advantages and disadvantages of different types of bike to be explored. For example, the capacity of the e-bikes was seen as a great asset by the group, but some of the larger cargo bikes were considered to be cumbersome and hard to manoeuvre in winter conditions. However, because the characteristics of the different bikes varied, different outcomes could not be compared directly.

The main weakness of the study design was that the travel diaries did not correspond with exact dates, so daily weather conditions could not be analysed against frequency and distance travelled. For this reason, the climatic variables are presented as monthly values.

4.3. Recommendations for practice

The results and discussion lend themselves to a range of conclusions and town planning-related recommendations. By far the most important and striking finding is that winter cycling and the variable ground conditions caused by snow, ice, and slush need special consideration within urban design and community maintenance. Regarding town planning, we cannot expect a cycle infrastructure designed for summer (bare ground conditions) to operate successfully in the winter. Town planners and urban designers need to provide clear design guidance on how the cycle infrastructure can be adapted for winter. This could include specific design/planning guidance for winter cycling or seasonal alterations to the cycle networks and their management.

Equally, the study shows that, in cold-climate communities, summer cycling is perceived to be a different activity to winter cycling. Softer, capacity-building strategies are needed to complement infrastructure-based adjustments. These should promote and build confidence in winter cycling and make people aware of the risks but also the benefits, allowing them to make informed decisions on the suitability of this form of transport for them. Training on winter cycling and bike maintenance should be provided. Many people may be prevented from becoming a winter cyclist just because they do not have the skills or tools to change a bike's summer tyres to winter tyres.

This study also shows that e-bikes have a positive effect on people's motivation and confidence in winter cycling. E-bikes are seen as an attractive and positive enabler for cycling. To maximise the benefits of this type of bike, consideration should be given to how green energy production and consumption can be integrated into the public realm and cycle parking areas, at all levels, both public and private, from town centre to neighbourhood and street.

5. Conclusion

This study indicates that if people are supported and well equipped, committed year-round cycling can be achieved in cold-climate communities, with its attendant potential health benefits. However, compared with summer cycling, there are more barriers to overcome. For winter cycling to be successful, planning needs to view winter cycling as a particular activity with its own design, policy and management requirements. Implementing such planning recommendations would make it significantly easier for summer cyclists to extend their soft-mobility period into and across winter and thus help achieve the UN Sustainable Development Goals and Paris Agreement to tackle global warming.

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Declaration of competing interest

The authors declare that they have no competing interests.

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References

Amiri, M., Sadeghpour, F., 2015. Cycling characteristics in cities with cold weather. Sustain. Cities Soc. 14, 397–403. https://doi.org/10.1016/j.scs.2013.11.009.
Bergstrom, A., Magnusson, R., 2003. Potential of transferring car trips to bicycle during winter. Transport. Res. part A - Policy and practice 8, 649.
Bergstrom, A., 2003. More effective winter maintenance method for cycleways. Transport. Res. Rec. 1824, 115.
Bourne, J.E., Cooper, A.R., Kelly, P., Kinnear, F.J., England, C., Leary, S., Page, A., 2020. The impact of e-cycling on travel behaviour: a scoping review. J. Transp. Health 19, 100910.
Böcker, L., Dijst, M., Prillwitz, J., 2013. Impact of everyday weather on individual daily travel behaviours in perspective: a literature review. Transport Rev. 1, 71.
Cabral, L., Kim, A.M., Parkins, J.R., 2018. Bicycle ridership and intention in a northern, low-cycling city. Travel Behav. Soc. 13, 165–173. https://doi-org.proxy.lib.ltu.se/10.1016/j.tbs.2018.08.005.
Carmona, M., Tiesdell, S., Heath, T., Oc, T., 2010. Public Places - Urban Spaces: the Dimensions of Urban Design, vol. 2. Architectural Press/Elsevier, Oxford.
Cass, N., Faulconbridge, J., 2016. Commuting practices: new insights into modal shift from theories of social practice. Transport Pol. 45, 1–14. https://doi.org/10.1016/j.tranpol.2015.08.002.
Chapman, D., Larsson, A., 2019. Toward an integrated model for soft-mobility. Int. J. Environ. Res. Publ. Health 16, 3669.
Chapman, D., Nilsson, K., Larsson, A., Rizzo, A., 2017. Climatic barriers to soft-mobility in winter: luleå, Sweden as case study. Sustain. Cities Soc. 35, 574–580. https://doi.org/10.1016/j.scs.2017.09.003.
Chapman, D., Nilsson, K., Rizzo, A., Larsson, A., 2018. Updating winter: the importance of climate-sensitive urban design for winter settlements. In: Arctic Yearbook. Northern Research Forum: Akureyri, Iceland, pp. 86–105.
Chapman, D., Nilsson, K.L., Rizzo, A., Larsson, A., 2019. Winter city urbanism: enabling all year connectivity for soft mobility. Int. J. Environ. Res. Publ. Health 16, 1820. https://doi.org/10.3390/ijerph16101820.
Clarry, A., Imani, A.F., Miller, E.J., 2019. Where we ride faster? Examining cycling speed using smartphone GPS data. Sustain. Cities Soc. 49, 101594.
Cowan, R., Adams, S., Chapman, D., 2010. Quality Reviewer: Appraising the Design Quality of Development Proposals. Thomas Telford.
Creswell, J.W., Clark, V.L.P., 2011. Designing and Conducting Mixed Methods Research. Sage, Thousand Oaks, CA, USA.
Damant-Sirois, G., El-Geneidy, A.M., 2015. Who cycles more? Determining cycling frequency through a segmentation approach in Montreal, Canada. Transport. Res. Part A 77, 113–125. https://doi-org.proxy.lib.ltu.se/10.1016/j.tra.2015.03.028.
Dill, J., Rose, G., 2012. Electric bikes and transportation policy: insights from early adopters. Transport. Res. Rec. 2314, 1.
Ebrahimabadi, S., 2015. Outdoor comfort in cold climates: integrating microclimate factors in urban design (Lic-dissertation). Luleå University of Technology, Luleå.
Flynn, B.S., Dana, G.S., Sears, J., Aultman-Hall, L., 2012. Weather factor impacts on commuting to work by bicycle. Prev. Med.: Int. J. Devoted Pract. Theory 54 (2), 122–124. https://doi.org/10.1016/j.ypmed.2011.11.002.
Fraser, S.D.S., Lock, K., 2011. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. Eur. J. Publ. Health 21 (6), 738–743. https://doi.org/10.1093/eurpub/ckq145.
Gehl, J., 2011. Life between Buildings: Using Public Space. Island Press, Washington, DC.
Goldmann, K., Wessel, J., 2020. Some people feel the rain, others just get wet: an analysis of regional differences in the effects of weather on cycling. Res. Transport. Bus. Manag. 100541.
Grøntved, A., Koivula, R.W., Johansson, I., Wennberg, P., Østergaard, L., Hallmans, G., et al., 2016. Bicycling to work and primordial prevention of cardiovascular risk: a cohort study among Swedish men and women. J. Am. Heart Assoc. 5 (11), e004413.
Heinen, E., van Wee, B., Maat, K., 2010. Commuting by bicycle: an overview of the literature. Transport Rev. 30 (1), 59–96. https://doi.org/10.1080/01441640903187001.
Hong, J., McArthur, D.P., Stewart, J.L., 2020. Can providing safe cycling infrastructure encourage people to cycle more when it rains? The use of crowdsourced cycling data (Strava). Transport. Res. Pol. Pract. 133, 109–121.
Larsson, A., Chapman, D., 2020. Perceived impact of meteorological conditions on the use of public space in winter settlements. Int. J. Biometeorol. 64 (4), 631–642. https://doi.org/10.1007/s00484-019-01852-5.
Ma, L., Dill, J., 2015. Associations between the objective and perceived built environment and bicycling for transportation. J. Transp. Health 2 (2), 248–255. https://doi.org/10.1016/j.jth.2015.03.002.
MacArthur, J., Kobel, N., Dill, J., Mumuni, Z., 2017. Evaluation of an Electric Bike Pilot Project at Three Employment Campuses in Portland, Oregon. TREC Final Reports.
Marshall, S., 2005. Streets & Patterns: the Structure of Urban Geometry. Taylor & Francis Group/Books.
Mathisen, T.A., Annema, J.A., Kroesen, M., 2015. The effects of weather and climate change on cycling in northern Norway. Eur. J. Transport Infrastruct. Res. 15 (2). http://doi-org.proxy.lib.ltu.se/10.18757/ejtir.2015.15.2.3072.
Nahal, T., Mitra, R., 2018. Facilitators and barriers to winter cycling: case study of a downtown university in Toronto, Canada. J. Transp. Health 10, 262–271. https://doi-org.proxy.lib.ltu.se/10.1016/j.jth.2018.05.012.
Nankervis, M., 1999. The effect of weather and climate on bicycle commuting. Transport. Res. part A – Policy and practice 6, 417.

Nematchoua, M., Deuse, C., Cools, M., Reiter, S., 2019. Evaluation of the potential of classic and electric bicycle commuting as an impetus for the transition towards environmentally sustainable cities: a case study of the university campuses in Liege, Belgium. Renew. Sustain. Energy Rev. 119, 109544.

Petersson, J., Kuklane, K., Gao, C., 2019. Is there a need to integrate human thermal models with weather forecasts to predict thermal stress? Int. J. Environ. Res. Publ. Health 16 (22), 4586.

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. Transport Geogr. 65, 25–34.

Pressman, N. (Ed.), 1985. Reshaping Winter Cities: Concepts, Strategies and Trends. Waterloo. Univ. of Waterloo Press, Ontario.

Rabassa, M.J., Grand, M.C., García-Witulski, C.M., 2020. Heat warnings and avoidance behavior: evidence from a bike-sharing system. Environ. Econ. Pol. Stud. 1–28.

Rekilä, K.-P., Klein-Paste, A., 2016. Measuring bicycle braking friction in winter conditions. Cold Reg. Sci. Technol. 125, 108–116. https://doi.org/10.1016/j.coldregions.2016.02.005.

Sears, J., Flynn, B.S., Aultman-Hall, L., Dana, G.S., 2012. To bike or not to bike: seasonal factors for bicycle commuting. Transport. Res. Rec. 2314, 105.

Simsekoglu, Ö., Klöckner, C.A., 2019. The role of psychological and socio-demographical factors for electric bike use in Norway. Int. J. Sustain. Transp. 5, 315.

de Sousa, A.A., Sanches, S.P., Ferreira, M.A.G., 2014. Perception of barriers for the use of bicycles. Procedia - Soc. Behav. Sci. 160, 304–313. https://doi-org.proxy.lib.ltu.se/10.1016/j.sbspro.2014.12.142.

Spencer, P., Watts, R., Vivanco, L., Flynn, B., 2013. The effect of environmental factors on bicycle commuters in Vermont: influences of a northern climate. J. Transport Geogr. 31, 11–17. https://doi.org/10.1016/j.jtrangeo.2013.05.003.

Sun, Q., Feng, T., Kemperman, A., Spahn, A., 2020. Modal shift implications of e-bike use in The Netherlands: moving towards sustainability? Transport. Res. Transport Environ. 78 https://doi.org/10.1016/j.trd.2019.102202.

UNFCCC, 2018a. 2015 Paris Agreement. Retrieved 2018-08-08. https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

UNFCCC, 2018b. United Nations, Climate Change. Retrieved 2018-08-08. https://unfccc.int/.

Wadud, Z., 2014. Cycling in a changed climate. J. Transport Geogr. 35, 12–20.

WHO, 2006. Promoting Physical Activity and Active Living in Urban Environments. The Role of Local Governments. WHO.

WHO, 2018. Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World. WHO.

Winters, M., Davidson, G., Kao, D., Teschke, K., 2011. Motivators and Deterrents of Bicycling: Comparing Influences on Decisions to Ride, vol. 1. Transportation, Amsterdam, p. 153.

Winters, M., Friesen, M.C., Koehoorn, M., Teschke, K., 2007. Utilitarian bicycling: a multilevel analysis of climate and personal influences. Am. J. Prev. Med. 32 (1), 52–58. https://doi.org/10.1016/j.amepre.2006.08.027.

World Medical Association, 2013. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. Jama 310 (20), 2191–2194.