

1 Using environmental audits and photo-journeys to compare objective attributes  
2 and cyclists' perceptions along cycling routes

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7 **Abstract**

8 **Background:** Cycling is known to have many health benefits. For this reason, transport planners and public  
9 health officials in Canada increasingly aim to encourage cycling for transport. On- and off-street infrastructure is  
10 often implemented to facilitate cycling and planners rely on a range of tools for informing the design of the  
11 network of facilities. This mixed methods study compares objectively measured attributes and cyclists'  
12 perceptions of the built environment along inferred cycling routes in Hamilton, Ontario.

13 **Methods:** Environmental audits were conducted along six cycling routes in Hamilton to document the attributes  
14 that might support or hinder cycling. The routes were inferred based on the output of a model of cycling flows.  
15 Cyclists, 9 male and 5 female, then participated in semi-structured interviews where a form of photo elicitation,  
16 which we call photo-journeys, was used to explore their perceptions and preferences. Interview data were  
17 analyzed using both inductive and deductive thematic analysis based on the categories of the audit instrument.

18 **Results:** Cyclists prefer routes that have dedicated cycling infrastructure, or residential streets with low volumes  
19 of traffic even if they lack infrastructure. They dislike routes with busy arterial roads or that lack cycling  
20 infrastructure. Their experience and knowledge of cycling in a city transitioning to be more bicycle-friendly  
21 revealed preferences that can help to improve existing infrastructure and cycling routes, which may also help to  
22 reduce barriers for non-cyclists.

23 **Conclusions:** Photo-journeys are an innovative and practical approach to explore perceptions of regular cyclists,  
24 which can be leveraged to inform policies and interventions to make cycling routes and infrastructure safer and  
25 more attractive. Transport planners in developing cycling cities should pay attention to both the objective  
26 attributes of the built environment and how it is perceived by the public.

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27 **1. Introduction**

28 Many Canadian cities have adopted pro-cycling policies and programs in recent years to support the uptake of  
29 cycling for transport, including a range of interventions from investments in infrastructure to educational  
30 programs or promotional events (Assunçao-Denis and Tomalty, 2019). Large population health gains  
31 (Celis-Morales et al., 2017) and improved environmental conditions in urban areas (Zahabi et al., 2016) could be  
32 achieved if cycling became more mainstream. For instance, Raustrop and Koglin (2019) estimated that if nearly  
33 half of the residents in Scania county, Sweden cycled to work, almost 20 percent would meet physical activity  
34 guidelines from utilitarian travel alone. The challenge, however, is how to successfully transition from commonly  
35 car-centric North American cities to bicycle-friendly cities with larger shares of active travel.

36 Active travelers seem to derive intrinsic value from their travel experience (Whalen et al., 2013). In addition,  
37 travelers also tend to associate values such as freedom, enjoyment, and happiness with active travel, even if their  
38 regular mode of travel is not active (Mella Lira and Paez, 2021). However, to convince people to cycle it is  
39 necessary to create social and built environments that are bicycle-friendly, and also to improve the public's  
40 perception of those environments (Jamal et al., 2020). Short distances are ideal for cycle trips, which makes  
41 compact mixed-used areas attractive and supportive for cycling where people can reach a variety of destinations  
42 (Handy, 2020; Heinen et al., 2010; Pucher and Buehler, 2008). Streets with slow traffic and traffic calming can  
43 also encourage people to use the bicycle for transport (Mertens et al., 2017). Other features such as routes with  
44 aesthetic views have been found to motivate cycling (Winters et al., 2011). Cyclists also report that factors  
45 relating to traffic and route conditions, as well as aggression from people who drive, which influence safety are  
46 constraints or deterrents for cycling (Heesch et al., 2012; Winters et al., 2011). Furthermore, cycling experts from  
47 both The Netherlands and New Zealand agree that cycling infrastructure is a universal prerequisite in countries  
48 with an established culture of cycling for transport and in countries with low levels of cycling (Adam et al., 2020).  
49 Likely for this reason, cities where cycling is less mainstream have started building infrastructure to encourage  
50 more cycling. The case of Seville, Spain is a great example of the success that can be achieved by implementing a  
51 network of connected facilities at a rapid pace (Marqués et al., 2015).

52 Revealed and stated preference studies have been further informative about the types of environments that  
53 cyclists prefer and have reinforced that cycling infrastructure is fundamentally important. Using global  
54 positioning system (GPS) data, several studies have found that cyclists travel routes that have on-street and  
55 off-path cycling facilities and streets with low volumes of traffic (Broach et al., 2012; Dill, 2009; Lu et al., 2018;  
56 Misra and Watkins, 2018; Scott et al., 2021). Stated preference studies also indicate that cyclists dislike mixing  
57 with traffic and prefer separated and protected infrastructure (*inter alia*, see Clark et al., 2019; Caulfield et al.,  
58 2012; Stinson and Bhat, 2003; Veillette et al., 2019; Winters et al., 2011).

59 Cities with low but growing levels of cycling have been called “developing cycling cities” (Liu et al., 2020), “low

60 cycling maturity” cities (Félix et al., 2019), “emerging cycling cultures” (Clark et al., 2019), or “starter cycling  
61 cities” (Meireles and Ribeiro, 2020). People who currently cycle in these settings are in the unique position of  
62 observing and experiencing how the city changes over time to become more bicycle-friendly. Their experiences  
63 can highlight the extent to which a city’s current efforts support or hinder cycling. A few studies in cities with  
64 lower cycling levels have found a similarity in route preferences and barriers to cycling between cyclists and  
65 non-cyclists (see Félix et al., 2019; Clark et al., 2019; Winters and Teschke, 2010) which also suggests that the  
66 perspectives of regular cyclists may be informative about what could be improved to encourage more people to  
67 cycle. Tools and approaches for doing local research in developing cycling cities are needed because, as Meireles  
68 and Ribeiro (2020) note, cities have unique conditions and constraints that influence their efforts and success in  
69 promoting cycling.

70 A variety of qualitative methods that examine the experience and perceptions of cycling in such settings can help  
71 to centre these components in route and infrastructure design in developing cycling cities. For example,  
72 interviews or mapping exercises (see Manton et al., 2016; Marquart et al., 2020) and ride-alongs (van Duppen  
73 and Spierings, 2013) may shed more light on reasons for where people cycle and how cycling is experienced.  
74 Other methods that hold promise for cycling research are photovoice and photo elicitation, techniques that have  
75 been used to explore the link between transportation and well-being (Guell and Ogilvie, 2015; Ward et al., 2015)  
76 and perceptions of the built environment (Alexander, 2013; Bornioli et al., 2018). These approaches involve the  
77 use of images or photographs in qualitative interviews, usually taken by participants, to evoke memories, feelings,  
78 and experiences about a research phenomenon (Harper, 2002). Photo elicitation is well-suited for prompting  
79 discussion and developing a comprehensive understanding and description of cycling issues, and builds upon the  
80 use of photos in stated preference surveys (see Clark et al., 2019) by enabling participants to recall and share  
81 perceptions or experiences that influence travel preferences. Environmental audits can also be a useful tool to  
82 document how the built environment supports active travel (Moudon and Lee, 2003), and have been used in  
83 studies to explore walkability. Qualitative evidence captured from photo elicitation or interviews can thus  
84 complement objective assessments of the physical environment studied through methods like environmental  
85 audits or GIS (see Lee and Dean, 2018). Perceptions of the built environment have been found to influence active  
86 travel behaviour (Grabow et al., 2019; Guell et al., 2013; Jamal et al., 2020; Ma et al., 2014), which highlights the  
87 importance of alignment between these two constructs and using qualitative data to improve the objective  
88 attributes.

89 In this paper, a sequential explanatory mixed methods approach compares objectively measured attributes and  
90 cyclists’ perceptions of the built environment along inferred cycling routes in Hamilton, Ontario. This project  
91 explored the influence of the built environment on cycling in a mid-sized Canadian city with low but growing  
92 cycling levels. We previously estimated a spatial interaction model to investigate the correlates of cycling in  
93 Hamilton and found that the *quietest* distance route between cycling trip zones of origin and destination inferred

94 by *CycleStreets* best explained cyclist travel in Hamilton and led to the most parsimonious model [paper  
95 submitted to *Transportation*]. Given that the routes were inferred, we did not know the quality of their built  
96 environment or how well they match where cyclists actually travel in Hamilton. To further explore these  
97 objectives, we audited 6 inferred routes to document attributes that might influence cycling. We then used  
98 photos of the routes, or photo-journeys, in 14 semi-structured interviews with regular cyclists to examine their  
99 perceptions of the routes.

100 **2. Methods, Research Setting, and Materials**

101 *2.1. Research Setting*

102 Hamilton is a mid-sized city located in Ontario, Canada with a population of roughly 540,000 according to the  
103 2016 Canadian Census (Statistics Canada, 2017). The city is relatively flat but is separated by the Niagara  
104 Escarpment, referred to locally as “the mountain”, which can be as high as 100m in many places. The rural and  
105 suburban parts of the city are on top of the Escarpment and the lower city and downtown core are below [see  
106 Figure 1 for reference]. Similar to other Canadian cities, cycling levels have grown in recent years; the mode share  
107 of cycling for transport doubled from 0.6% in 2011 to 1.2% according to the 2016 *Transportation Tomorrow*  
108 *Survey (TTS)* (Data Management Group, 2018). This voluntary travel survey is conducted every 5 years to  
109 collect information about urban travel for commuting purposes in Southern Ontario (Data Management Group,  
110 2018). Between the 2011 and 2016 surveys, the City of Hamilton implemented a public bicycle share program  
111 (PBSP) and added 85 kilometres of bicycle lanes. Hamilton is the only mid-sized city in Canada with a PBSP  
112 which reflects that the City has invested a lot of effort in the potential for Hamilton to become a mid-sized  
113 cycling city in North America. As of 2019, approximately 46% of the cycling network has been built and  
114 approximately 15 to 20 km of new facilities are added each year. The City’s current Cycling Master Plan states  
115 that the goal is to implement all proposed infrastructure by 2029 (City of Hamilton, 2018a), but the City’s  
116 typical annual investment in cycling infrastructure falls short of what is needed to meet this goal. Therefore, it is  
117 suggested that Hamilton is a developing cycling city because it is currently in a state of transition and has  
118 growing cycling levels. The City is at the mid-way point in the development of its planned cycle infrastructure  
119 network. Other interventions have been implemented to increase cycling levels, but the cycling culture is still  
120 growing and the network is currently fragmented.

121 This paper contributes to the growing body of research on cycling and active travel in mid-sized Canadian cities  
122 in recent years (Fischer et al., 2020; Klicnik and Dogra, 2019; Mayers and Glover, 2020; Winters et al., 2018).  
123 Mid-sized cities in Ontario offer unique opportunities for future growth and development despite but face existing  
124 challenges to transportation and land use planning (Evergreen, 2017). In the case of Hamilton, efforts to increase  
125 pedestrian and cyclist-friendly spaces are constrained by the city’s efforts in the mid-1900s to prioritize



Figure 1: The number of cycle trips reported for each traffic analysis zones in the city of Hamilton that produced cycle trips. The number of cycle trips (ranging from more than 1 to over 1097) are shown by the colour gradient. Most cycle trips reported occur around the University.

automobile traffic on arterial roads (Leanage and Filion, 2017). Despite the legacy of Hamilton’s car-oriented streets, building a cycling network in mid-sized cities is promising because of shorter trip distances (Winters et al., 2018), which can make cycling appealing given the proper investment in supportive infrastructure. Indeed, further analysis of the 2016 *TTS* data revealed that 35% of all current trips in Hamilton are 5 km or less (Mitra et al., 2016), which means that these trips could be cycled. The City of Hamilton also aims to have 15% of the mode share be comprised of walking and cycling trips by 2031 (City of Hamilton, 2018b). In this stage of transition, there is the potential to incentivize modal shifts that specifically increase opportunities for physical activity.

## 2.2. Previous Research

In the first phase of this project, [paper submitted to *Transportation*], we used bicycle trip data from the 2016 *TTS* to develop a spatial interaction model that investigated the built environment correlates of cycling flows in Hamilton. While the *TTS* is informative about the traffic zones of origin and destination of cycling trips, it does not reveal the route choice of respondents. Thanks to the growth in open source resources for transportation analysis (Lovelace, 2021), a novel feature of this model was the use of a cycle routing algorithm to infer different types of cycle routes between zones of origins and destinations (Lovelace and Lucas-Smith, 2018). The centroid of each traffic analysis zone, the geographical unit of analysis used by the *TTS*, serves as the start and end point for these inferred routes. The distance and time of three different types of routes, characterized as *fastest*, *quietest*, or *balanced* by the *CycleStreets* algorithm, were used as measures of impedance in the model. Briefly, the R package states, “These represent routes taken to minimize time, avoid traffic, and compromise between the two, respectively” (Lovelace and Lucas-Smith, 2018, p. 1). Additional details about the algorithm are available online. The model revealed that inferred *quietest* routes that allow cyclists to minimize distance and interactions with

147 other road users best explain the pattern of travel by bicycle in Hamilton [paper submitted to *Transportation*].  
148 The *quietness* score takes into account attributes of the road, mainly the presence or absence of cycle  
149 infrastructure. Our findings suggests that cyclists in Hamilton are seeking out routes that enable them to avoid  
150 traffic while potentially maximizing the use of residential streets over arterial roads. We then used the model to  
151 identify trip flows where there was more or less cycling than expected (i.e., reported number vs. predicted number  
152 of cycle trips). The model did not capture any route-level characteristics beyond the data available for Hamilton  
153 through *OpenStreetMap* that was used by the algorithm. Therefore (see Moniruzzaman and Páez, 2012), it was  
154 hypothesized that more cycling occurred between zones of origin and destination that were under-estimated  
155 because the inferred routes facilitate cycling (meaning that there was *more* cycling between the zones than  
156 predicted by the model), for example through the provision of infrastructure. Conversely, cycling trips may have  
157 been over-estimated if routes between zones of origin and destination are less supportive of cycling (meaning that  
158 there was *less* cycling between zones than predicted by the model).

159 *2.3. Methods*

160 *2.3.1. Environmental Audits*

161 We conducted environmental audits along 6 inferred routes that were most substantially over- or under-estimated  
162 by the model. The *Systematic Pedestrian and Cycling Environmental Scan (SPACES)*<sup>1</sup> (Pikora et al., 2002) was  
163 selected because it documents the presence or absence of observable characteristics that are potential influences of  
164 walking and cycling. The framework describes four domains of the built environment that influence physical  
165 activity: functional, safety, aesthetic, and destination (Pikora et al., 2003). The instrument was developed for use  
166 along street segments within neighbourhoods around a residential location. While the cycling trip flows in  
167 Hamilton occur beyond the 400 m neighbourhood range, our unit of analysis, namely segments of a street, is the  
168 same as the *SPACES Instrument*. The instrument also includes an extensive range of measurable features that  
169 have been identified in the literature which meet our objective in conducting an exploratory and descriptive  
170 analysis of attributes along the inferred cycling routes. For these reasons, we determined that the *SPACES*  
171 *Instrument* was suitable for our purposes. This instrument was also selected because it is relatively simple to use  
172 and developed for research purposes (Moudon and Lee, 2003). The instrument comes from the field of health and  
173 the factors included in the audit were guided by stakeholder interviews and a Delphi study (Pikora et al., 2003).  
174 The *SPACES Instrument* was adapted to the local context in Hamilton. Cycling was the primary focus of this  
175 study; accordingly, some factors that were less influential on cycling, according to the literature, were removed for  
176 ease of data collection. The features that were removed from the instrument used in this study include:  
177 *permanent path obstructions, pedestrian crossing aids, surveillance, building design, and driveway crossovers.*

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<sup>1</sup>SPACES Audit Instrument

Table 1: Demographics of participants (age, gender, self-reported frequency of cycling, and self-reported confidence level).

Participant	Age	Gender	Frequency	Confidence
1	18-24	Male	Every day	Excellent
2	25-44	Male	Multiple times a week	Excellent
3	25-44	Female	Multiple times a week	Excellent
4	25-44	Male	Multiple times a week	Excellent
5	45-64	Male	Multiple times a week	Good
6	45-64	Male	Every day	Excellent
7	45-64	Male	Multiple times a week	Excellent
8	45-64	Male	Multiple times a week	Good
9	25-44	Female	Multiple times a week	Excellent
10	25-44	Male	Every day	Excellent
11	25-44	Female	Multiple times a week	Good
12	25-44	Female	Every day	Excellent
13	25-44	Male	Every day	Excellent
14	25-44	Female	Multiple times a week	Excellent

178 Other features were combined: all types of maintenance instead of specific categories, and the types of paths. A  
 179 broader range of cycling facilities, buildings, and traffic calming measures that are found in Hamilton were also  
 180 added. The modified *SPACES Instrument* is shown in Appendix A and the Hamilton cycling guide added to the  
 181 *SPACES Observation Manual* is found in Appendix B. The first author and three research assistants conducted  
 182 the audits during October and November 2019. The first author was the only auditor who has cycling experience  
 183 in Hamilton. Each auditor participated in a training exercise led by the first author to become familiar with the  
 184 *SPACES Instrument* and the *SPACES Observation Manual*<sup>2</sup> (Pikora et al., 2002), and to standardize the way in  
 185 which the audits were carried out. The majority of routes ( $n = 4/6$ ) were audited by a pair of research assistants  
 186 who filled out the instrument together. Two routes ( $n = 2/6$ ) were audited by the first author alone. The  
 187 auditors were instructed to discuss any disagreements and reach consensus before filling out the instrument. Once  
 188 the audits were completed, the features of each route segment were manually recorded in an Excel sheet by the  
 189 first author. Any perceived errors in data collection were reviewed using Google Street View and were corrected  
 190 by the first author. A descriptive analysis of each route was performed to determine the presence and frequency  
 191 of features along each route.

### 192 2.3.2. Interviews

193 Following the audits, 14 cyclists in Hamilton were recruited to participate in a 90-minute semi-structured  
 194 interview [see Table 1 for demographics of participants]. We employed a convenience sampling strategy to recruit  
 195 participants using posters in local bike stores and coffee shops in Hamilton and a social media post on Twitter. A  
 196 total of 28 people responded to the recruitment notice, and the first 14 who met the inclusion criteria were  
 197 recruited to the study. Inclusion criteria were as follows: age (18 years of age or older) and regular travel by  
 198 bicycle for transport in Hamilton. The latter was defined as cycling for transport at least once per week.

<sup>2</sup>SPACES Observation Manual

199 The first author conducted the interviews, ranging in time from 60 to 90 minutes, between November 2019 and  
200 January 2020 at either the institution, a local coffee shop, or local library. Participants were presented with three  
201 packages of photos that each contained two routes (i.e., the first package contained routes 1A and 1B; the second  
202 contained routes 2A and 2B; and the third contained routes 3A and 3B). Table 2 provides a description of the  
203 routes. This approach can be considered a form of photo elicitation (see Harper, 2002), whereby images are used  
204 in interviews to prompt memory, emotions, and experience of a particular research phenomenon (e.g., identity,  
205 culture, place, etc.). The photos of the routes audited were taken from Google Street View, using the most recent  
206 photos available to ensure that they matched the current streetscape as much as possible. As such, the time of  
207 day or day of the week that the photos were taken may not reflect prime cycling times and likely traffic volumes  
208 expected at those times. We used photos to understand how these routes were perceived or experienced based on  
209 cyclists' knowledge or history of traveling through these spaces. In contrast to photo elicitation, which typically  
210 uses standalone photos of a particular item of interest, a novel aspect of our approach is the sequential nature of  
211 the photos presented in the interviews. Therefore, these photo-journeys include a more dynamic, temporal  
212 element that allow participants to follow the route, and see and comment on the changes that they perceive. This  
213 enables us to capture both perceptions of specific attributes of the routes as well as the experiences or  
214 impressions of the journey as a whole.

215 The first two photo packages each had one route where cycling was over-estimated by the original model (i.e.,  
216 1A and 2A), and one route where cycling was under-estimated by the original model (i.e., 1B and 2B). The final  
217 photo package had two routes where cycling was under-estimated (i.e., 3A and 3B). The routes in each package  
218 were paired according to their length and number of segments [see Table 2]. Participants did not know which  
219 routes were over- and under-estimated. The photos for each route were numbered to make it easier to transcribe  
220 and ensure that participants' comments could be attributed to the appropriate segment. Segments that were  
221 long or that had changing attributes in the same segment were depicted through multiple photos. Participants  
222 were asked to look through the photos of each route from start to finish and then to share their perceptions by  
223 commenting on what they liked and disliked about the route. However, some participants preferred to make  
224 comments as they looked through the photos. After commenting on both routes in one package, participants were  
225 asked which route they preferred. Additional questions were asked if a participant reported having cycled part of  
226 a route or if they described taking a different route than the one inferred. Other follow-up probing questions were  
227 asked to better understand participants' perceptions or experiences of the route.

228 The interviews were audio recorded and later transcribed using Temi, an online AI-based transcription software.  
229 The first author then reviewed and proofread each transcript. The first author coded all of the interviews and  
230 conducted a thematic analysis using both inductive and deductive approaches (Braun and Clarke, 2006). Themes  
231 were determined by the frequency of codes (Braun and Clarke, 2006), meaning the number of different  
232 participants who expressed a similar like, dislike, or perception for each route. Themes identified using a

Table 2: Description of inferred routes that were audited using the SPACES Instrument.

Route	Origin	Destination	Distance	Number of Segments	Number of Photos
1A	Dundas	West Hamilton	2.3 km	13	19
1B	East Mountain	East Mountain	1.3 km	10	17
2A	Downtown Hamilton	West Hamilton	5.3 km	27	34
2B	East Hamilton	East Hamilton	4.7 km	31	36
3A	Stoney Creek	Stoney Creek	3.6 km	19	23
3B	Downtown Hamilton	Downtown Hamilton	2.5 km	20	25

233 deductive approach aligned with the attribute categories from the *SPACES Instrument*, while other themes were  
 234 identified using an inductive approach based on perceptions and experiences that emerged in the interviews.  
 235 Themes were identified for each individual route and not for the collective of six routes.

236 *2.3.3. Ethics*

237 This study was approved by the institution's research ethics board in September 2019.

238 **3. Findings**

239 *3.1. Observable Route Attributes Measured using the SPACES Instrument*

240 A total of 6 inferred routes were reviewed by 14 cyclists [see Table 2]. The results of select objective route  
 241 attributes are presented in Table 3. The characteristics documented from the *SPACES Instrument* are presented  
 242 only for the right side of the street where cyclists would typically travel. It is important to note that attributes  
 243 are only documented in one direction along the routes, therefore the presence of attributes in the other direction  
 244 may be different. Each route is accompanied by a map of the street network from origin to destination and by  
 245 one or more photos to illustrate segments with attributes that elicited comments from many participants. The  
 246 full results of the audits are available in a Google Drive folder:

247 [https://drive.google.com/drive/folders/1tYFPrlNgsF\\_LffzZferBMeMQOcUu3MIH?usp=sharing](https://drive.google.com/drive/folders/1tYFPrlNgsF_LffzZferBMeMQOcUu3MIH?usp=sharing)

248 *3.2. Cyclists' Perceptions of the Cycling Routes*

249 *3.2.1. Package 3*

250 *3.2.1.1. Route 1A*<sup>3</sup>. Most participants reported being familiar with this route; they had previously cycled at  
 251 least part of the route or in this general area. The majority of participants disliked the segments with a four-  
 252 lane arterial road that lacked infrastructure, and more than half stated that they would not cycle this part of

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<sup>3</sup>This route was slightly adjusted for the audit. Rather than starting midblock, the audit started one block south at the commercial plaza. Recall that the origin of each inferred route is the centroid of the traffic analysis zone, so this is not the true origin of this cycling flow.

Table 3: Results of the objectively measured attributes by percentage of segments along the inferred cycle routes.

Attribute	Route.1A	Route.1B	Route.2A	Route.2B	Route.3A	Route.3B
<i>Predominant buildings/features</i>						
<i>Transport infrastructure</i>	0	0	3.7	3	0	5
<i>Housing</i>	69	80	63	58	63	40
<i>Office</i>	0	0	0	0	0	10
<i>Food (grocery, restaurant)</i>	8	0	0	3	0	0
<i>Retail</i>	8	0	3.7	0	5	5
<i>Other retail (gas station, etc.)</i>	0	0	0	0	0	0
<i>Industrial</i>	0	0	3.7	0	21	0
<i>Educational</i>	8	0	11.1	7	0	5
<i>Service</i>	8	0	3.7	26	5	30
<i>Natural features</i>						
<i>Cycling facilities</i>	0	20	11.1	3	5	5
<i>Sharrows</i>	0	0	4	0	0	0
<i>Signed route</i>	8	80	7	55	0	10
<i>Bicycle lane - marked</i>	54	0	26	0	0	5
<i>Buffered bicycle lane</i>	0	0	4	0	0	10
<i>Protected bicycle lane</i>	0	0	0	0	0	10
<i>Two-way cycle track</i>	0	0	0	0	0	60
<i>Multi-use trail</i>	0	0	15	3	0	0
<i>Bike path</i>	0	0	0	0	0	0
<i>Paved shoulder</i>	0	0	0	0	0	0
<i>No facilities</i>	38	20	44	42	100	5
<i>Cycling facility has flat or gentle slope</i>	100	88	93	100	N/A	84
<i>Cycling facility has moderate slope</i>	0	12	7	0	N/A	11
<i>Cycling facility has steep slope</i>	0	0	0	0	N/A	5
<i>Road condition is good</i>	92	100	63	55	68	90
<i>Road condition is moderate</i>	8	0	22	29	32	10
<i>Road condition is poor</i>	0	0	0	0	0	0
<i>Road is under repair</i>	0	0	0	16	0	0
<i>1 traffic lane</i>	77	100	63	55	79	30
<i>2 or 3 traffic lanes</i>	23	0	19	42	21	70
<i>4 or 5 traffic lanes</i>	0	0	0	3	0	0
<i>6 or more lanes</i>	0	0	0	0	0	0
<i>Traffic calming devices</i>	0	0	7	0	0	0
<i>Traffic signal</i>	23	10	22	13	11	80
<i>Bike signal</i>	0	0	0	0	0	10
<i>Bike box</i>	0	0	0	0	0	15
<i>Bridge or overpass</i>	0	0	4	3	0	0
<i>Streetlights are present</i>	31	60	59	19	21	50
<i>Over 75% of street is well maintained</i>	100	100	88	81	95	100
<i>Street is clean (no litter, graffiti, etc.)</i>	100	100	100	97	84	100
<i>1 or more trees per block</i>	100	80	66	19	89	80
<i>Approx 1 tree for every 2 blocks</i>	0	0	4	20	0	0
<i>No trees at all</i>	0	20	30	61	11	20
<i>Very attractive for cycling</i>	54	10	11	3	0	20
<i>Attractive for cycling</i>	23	70	52	36	58	55
<i>Not attractive at all for cycling</i>	23	20	37	61	42	25
<i>Easy to cycle</i>	62	10	37	3	0	60
<i>Moderately difficult to cycle</i>	15	70	48	61	53	25
<i>Very difficult to cycle</i>	23	20	15	36	47	15

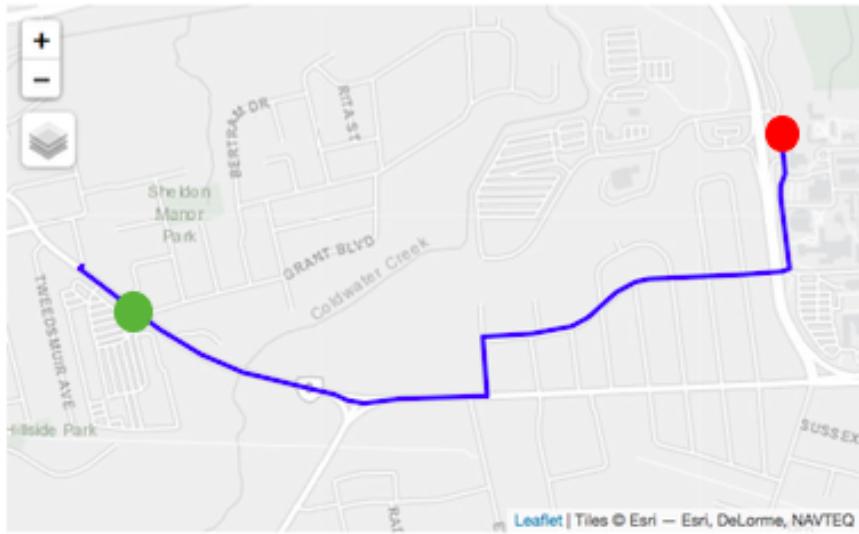


Figure 2: Map of route 1A.

253 the route. Factors that made them dislike these segments include the lack of cycling facilities, number of traffic  
 254 lanes, the width of the lanes, and the hilliness (see Figures 3 and 4). Most participants expected car traffic to be  
 255 moving faster on these segments.

256 A few participants who were familiar with the area reported that they would have cycled the Hamilton-Brantford  
 257 Rail Trail instead, an off-street multi-use trail parallel to the arterial road. Some cyclists noted that there was no  
 258 sidewalk or shoulder on the right side of the roadway where they would be cycling, with some describing that it  
 259 would make them feel “*uncomfortable*” or “*anxious*” without that space. In general, the arterial road without  
 260 infrastructure was perceived to be too busy and not designed for cycling. The left turn at an unsignalized  
 261 intersection was also noted as difficult by a few participants (see Figure 5).

262 However, the route was generally perceived positively once it entered a residential area. The majority of  
 263 participants reported liking or had positive comments of the segments that had an on-street marked bicycle lane  
 264 (see Figure 6). Most participants also liked these segments because they were perceived to be “*residential*” or  
 265 “*quiet*”, and not as busy in terms of car volume. Some participants reported liking the green space and nature  
 266 along the on-street marked bicycle lane. In addition, half of the participants stated that they liked the  
 267 pedestrian-activated traffic signal because it enabled them to cross the arterial road promptly and safely (see  
 268 Figure 7).

269 3.2.1.2. *Route 1B.* While none of the participants were familiar with this route, this route received overall  
 270 positive comments. Cyclists primarily liked the route because it was perceived to have low traffic, fewer cars, and  
 271 was quiet or residential. Some words used to describe the route include “*nice*”, “*lots of trees*”, and “*not busy*”  
 272 (see Figure 9). The lack of infrastructure was noted by some participants but only two reported that they disliked  
 273 this aspect of the route. Only one participant noticed that it was a signed route, but participants reported that



Figure 3: Segment 2 of route 1A depicting two or three lanes in each direction and no cycling facilities on the roadway. Lighting and natural views are present. (Source: Google Street View)



Figure 4: Segment 2 of route 1A depicting the uphill section on a 2 lane arterial road with no on-street cycling infrastructure. (Source: Google Street View)



Figure 5: Segment 4 of route 1A depicting the urban design of the street when making a left turn to follow the City's signed bicycle route. (Source: Google Street View)



Figure 6: Segment 9 of route 1A depicting the on-street marked bicycle lane in a residential neighbourhood. (Source: Google Street View)



Figure 7: Segment 13 of Route 1A depicting a pedestrian-activated signal to cross a an arterial road. (Source: Google Street View)

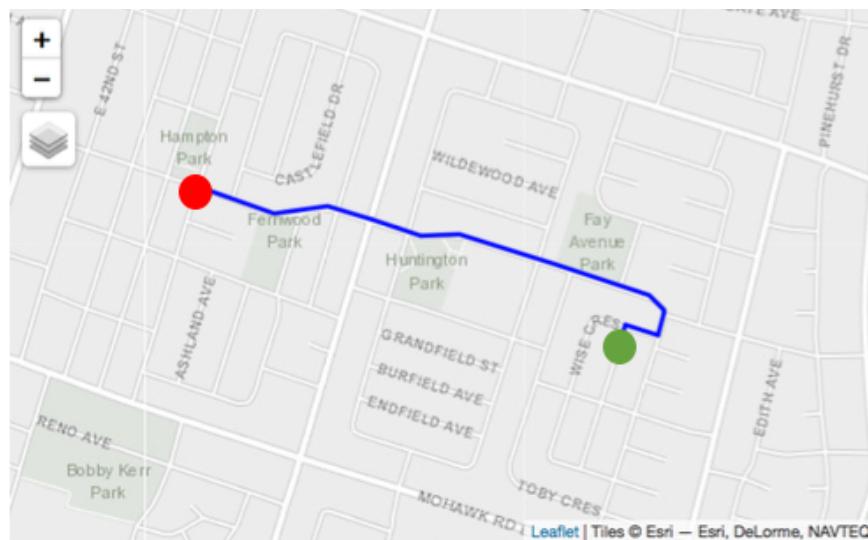


Figure 8: Map of route 1B.

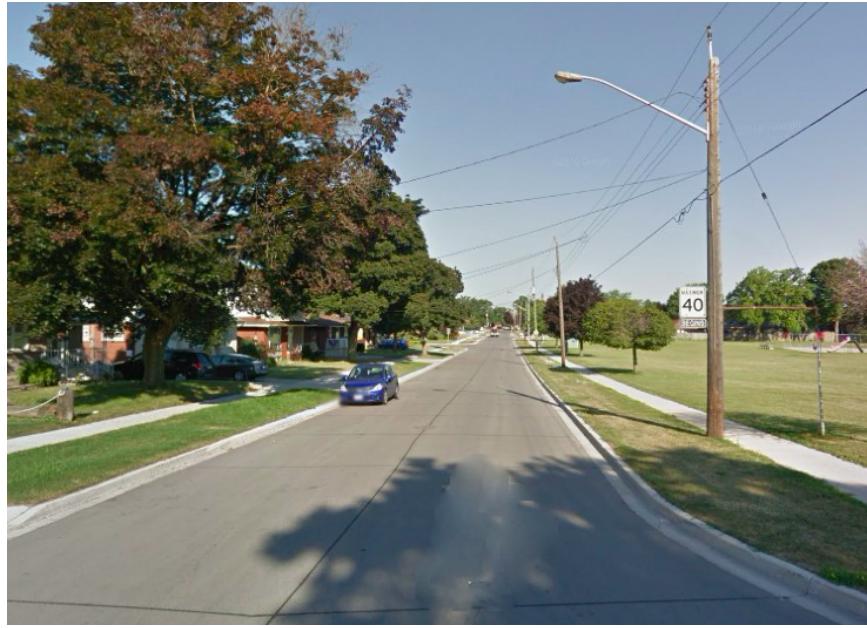


Figure 9: Segment 4 of route 1B depicting the streetscape on a signed route in a residential area. (Source: Google Street View)

274 they would generally feel comfortable cycling this route. A few participants commented on the good quality of  
275 the pavement. Although the route was perceived to be low traffic and residential, some cyclists would still have  
276 preferred if the route had a dedicated cycling facility. Four participants noticed or liked the 40 kilometres/hour  
277 speed limit on the route.

278 *3.2.2. Package 2*

279 *3.2.2.1. Route 2A<sup>4</sup>.* Participants were familiar with this route and had previously cycled the entire route or parts  
280 of it. Cyclists reported liking the infrastructure, particularly the on-street marked bicycle and the Hamilton-  
281 Brantford Rail Trail, which is an off-street multi-use path (see Figure 11 and Figure 12). The Rail Trail was  
282 perceived to be ideal for cycling: one participant called it a “*superhighway for bicycles*”, another described it as  
283 a fundamental “*arterial route*” for cyclists in Hamilton. Most participants also liked that many sections of the  
284 route that did not have dedicated infrastructure were on residential streets. Several cyclists liked or noticed that  
285 the route connected them to or passed by key destinations.

286 There were four areas or features along the route that participants disliked or that were more poorly perceived.  
287 First, several participants disliked or expressed concern about turning left at an intersection without a signal  
288 after the bike lane ends. Cyclists who disliked this feature reported often waiting a while to turn left, that it was  
289 challenging for them that motorists did not always anticipate their need to transition lanes like other road users,  
290 or that they were not given enough space (see Figure 13).

---

<sup>4</sup>This route was slightly adjusted for the audit. CycleStreets inferred that cyclists would cross midblock at an unsignalized intersection towards the end of the route. Cyclists have been found to be sensitive to intersections Broach et al. (2012). Therefore, the audited route was adjusted to a parallel street one block east that would enable a cyclist to cross at a signalized intersection.

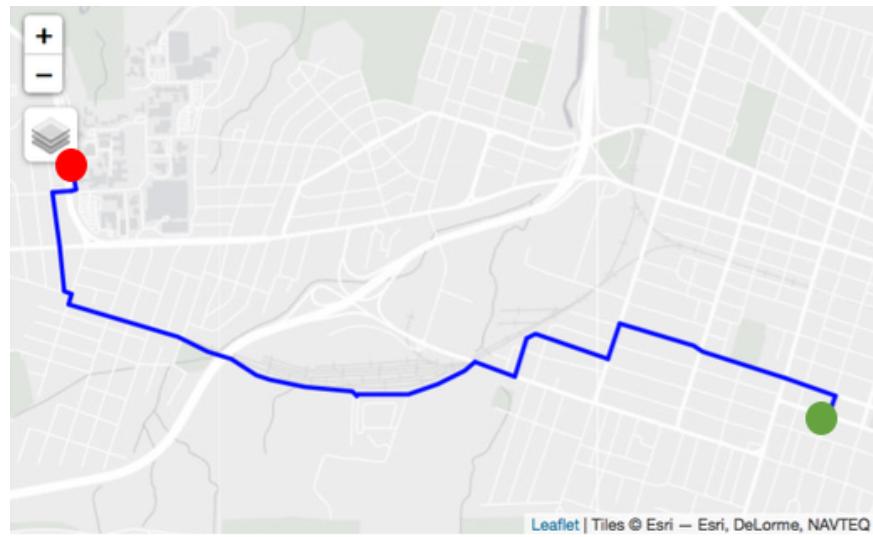


Figure 10: Map of route 2A.



Figure 11: Segment 5 on route 2A depicting an on-street marked bicycle lane on a one-way street with one lane going westward.  
(Source: Google Street View)



Figure 12: Segment 18 of route 2A depicting the off-street multi-use path called the Hamilton Brantford Rail Trail. (Source: Google Street View)



Figure 13: Segment 8 of route 2A depicting the buffered bicycle lane ending and the transition that a cyclist would have to make to get into the left-turn lane. (Source: Google Street View)



Figure 14: Segment 14 of route 2A depicting an arterial road without on-street cycling infrastructure. (Source: Google Street View)

291 Second, the short stretch along an arterial road with two traffic lanes in each direction and no dedicated cycling  
292 infrastructure (see Figure 14) was strongly disliked by most participants. Others had mixed perceptions or  
293 experiences or reported being fine cycling on a short stretch of this road. Those who strongly disliked the arterial  
294 road reported avoiding this street as much as possible or preferred to cycle on the sidewalk instead. For example,  
295 the arterial road was perceived to be a “*speedway*” and an area that had “*a lot of car entitlement*”. Next, the left  
296 turn at a signalized intersection from an arterial road to a street with sharrows was disliked or concerning for  
297 some participants (see Figure 15). Many participants noted that they used an alternate route to get to the Rail  
298 Trail to avoid this arterial road and intersection entirely.

299 Finally, most cyclists stated that they disliked an intersection at the end of the route that would require them  
300 to transition from a residential to arterial road (see Figure 16). The area was viewed as very busy or “*not fluid*”  
301 by some participants because there was an off-street multi-use path parallel to the road on the left side of the  
302 roadway that could not be accessed swiftly from the right side. However, several participants reported that they  
303 would have taken an alternate route to access the university campus from another entrance.

304 *3.2.2.2. Route 2B.* Some cyclists reported that they were familiar with this route or that they had previously  
305 cycled part of the route. The participants commented that there was a mix of features of the route that they  
306 liked and disliked. The segments along the route that were perceived to be “*quiet*” or “*residential*” were liked by  
307 most participants because car volume and speed were perceived to be lower (see Figure 18). The protected off-  
308 street multi-use trail over the highway was another feature that most participants liked or that elicited positive  
309 comments (see Figure 19). In general, the segments that were perceived to not be busy with traffic were liked  
310 or participants reported feeling comfortable cycling there, but the segments where car volume or speed were  
311 perceived to be higher were disliked.



Figure 15: Segment 14 of route 2A depicting a signalized intersection where a cyclist would turn left on to a street with sharrows to travel to the Hamilton-Brantford Rail Trail. (Source: Google Street View)



Figure 16: Segment 29 of route 2A depicting the intersection of a residential road and two arterial roads. (Source: Google Street View)

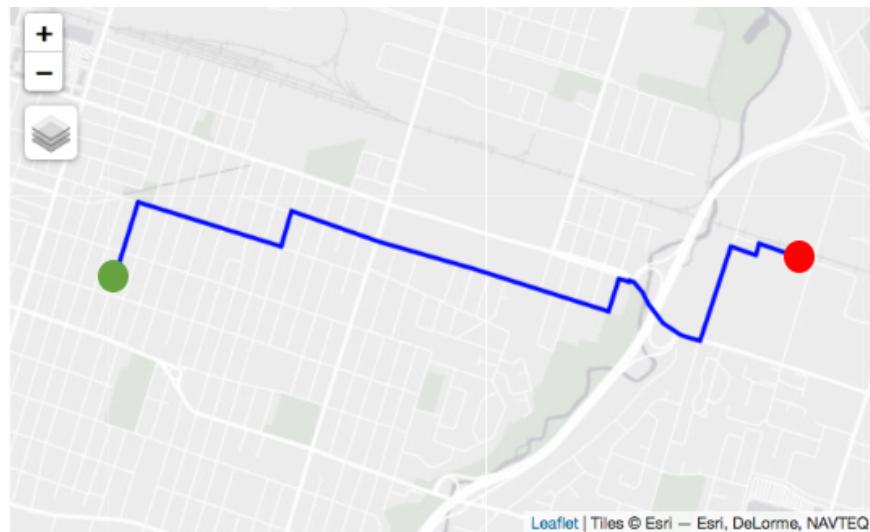


Figure 17: Map of route 2B.



Figure 18: Segment 11 of route 2B depicting a residential area. (Source: Google Street View)



Figure 19: Segment 30 of route 2B depicting the protected multi-use trail on the right side of the roadway on an arterial road over the Red Hill Valley Parkway. (Source: Google Street View)



Figure 20: Segment 14 on route 2B depicting a two-lane arterial road with on-street parking. (Source: Google Street View)

312 Some cyclists had mixed perceptions about the width of some of the segments (see Figure 20 and Figure 21). A  
313 few participants commented that at times there appeared to be enough space for motorists to safely pass cyclists,  
314 while others perceived the wide streets to potentially invite speeding. Anticipated car volume and the presence  
315 of on-street parking along these segments seemed to influence perceptions about the width of the street and  
316 comfortability. Cyclists preferred to have space for a motorist to safely pass. Most participants noticed or disliked  
317 the poor condition of the road along parts of the route. Finally, participants reported that they disliked the end  
318 of the multi-use trail or having to cycle on an arterial road and cross four lanes to make a left turn (see Figure  
319 22).

### 320 3.2.3. Package 3

321 3.2.3.1. *Route 3A*<sup>5</sup>. None of the participants had cycled in this area or were familiar with this route. The  
322 opposite to Route 1A, participants liked the first half of the route and generally disliked features of the second  
323 half. The beginning of the route was in a residential area; most cyclists reported that they liked the quiet streets  
324 and good road condition (See Figure 24). The lower speed limit of 40 kilometres/hour was noticed by several  
325 participants and some commented that they like travelling on streets with this speed limit. Once the route left  
326 the residential area about mid-way, most participants disliked turning to or cycling on a two-lane arterial road  
327 without infrastructure. The arterial road leading towards the industrial was perceived by some cyclists to be  
328 designed for cars (see Figure 25 and Figure 26). One participant described this as, “*you’re just out on a bike in*  
329 *the middle of the highway*”. The route ended in an industrial area which received mixed perceptions; some cyclists  
330 commented that traffic volume did not appear to be too heavy in the photos while many others reported feeling

<sup>5</sup>This route was slightly adjusted for the audit. The starting point was midblock on a residential street. The audit started instead at the nearest intersection along the route.



Figure 21: Segment 20 on route 2B depicting a two-lane arterial road with no on-street parking and a wide grassy verge on the right side of the roadway. (Source: Google Street View)



Figure 22: Segment 31 of route 2B depicting a lane change from the far right side of the roadway to the left-turn lane on a four-lane arterial road. (Source: Google Street View)



Figure 23: Map of route 3A.

331 less comfortable cycling in an area where they could expect a lot of trucks.

332 *3.2.3.2. Route 3B*<sup>6</sup>. This route was familiar to the participants and the majority had cycled at least part of  
 333 it. Cyclists liked that the majority of the route had cycling infrastructure (see Figure 28 and 29). The first few  
 334 segments at the beginning of the route were perceived to be busy in terms of traffic by several participants, but  
 335 many noted that people drive slower near the hospital.

336 The two-way cycle track (see Figure 29) was generally perceived well and elicited a lot of comments from  
 337 participants, likely because they reported using it. However, participants expressed a mix of appreciation and  
 338 frustration about this “*major cycling infrastructure*”. Several participants reported that they had witnessed  
 339 people drive or park in the lanes, as well as drift into them to avoid passing closely to the parked cars in the  
 340 outer right lane. Many participants expressed a desire to have enhanced protection along these facilities. Three  
 341 participants, one travelling with a young child, reporting being hit by a motorist who was turning left across the  
 342 cycle track. Others reported being vigilant when using this infrastructure because it is a two-way facility on a  
 343 one-way street. Despite it being a relatively new and important North-South route in the city’s cycling network,  
 344 cyclists described that it needed improvements in particular areas that were conflict points with other road users.  
 345 There were also mixed comments about a few intersections along the route that had bike boxes. Most cyclists  
 346 reported that this infrastructure could be confusing, both for them and for motorists, and that sometimes  
 347 motorists park in them if the light is red (see Figure 30). However, others reported that they liked the bike boxes  
 348 and find them useful for transition points. The route was also perceived to be disconnected or disjointed by some

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<sup>6</sup>This route was slightly adjusted for the audit. Rather than starting midblock on an uphill access to the escarpment, which would be an unlikely origin, the audit started two blocks south. Recall that the origin of each inferred route is the centroid of the traffic analysis zone, so this is not the true origin of this cycling flow.

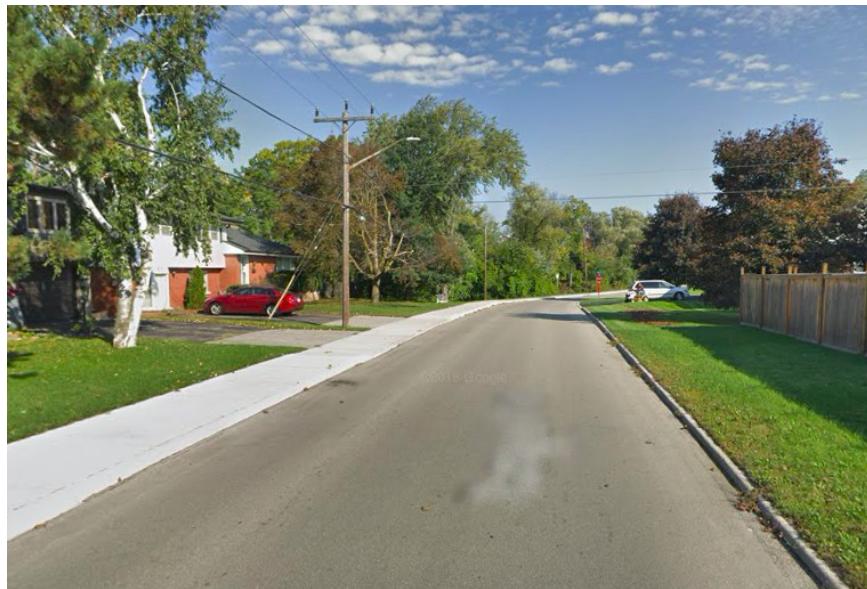


Figure 24: Segment 2 of route 3A depicting a residential street. (Source: Google Street View)



Figure 25: Segment 13 of route 3A depicting a two-lane arterial road without cycling facilities in a residential area. (Source: Google Street View)



Figure 26: Segment 15 of route 3A depicting a two-lane arterial road without cycling facilities or a sidewalk leading to a more industrial area. (Source: Google Street View)

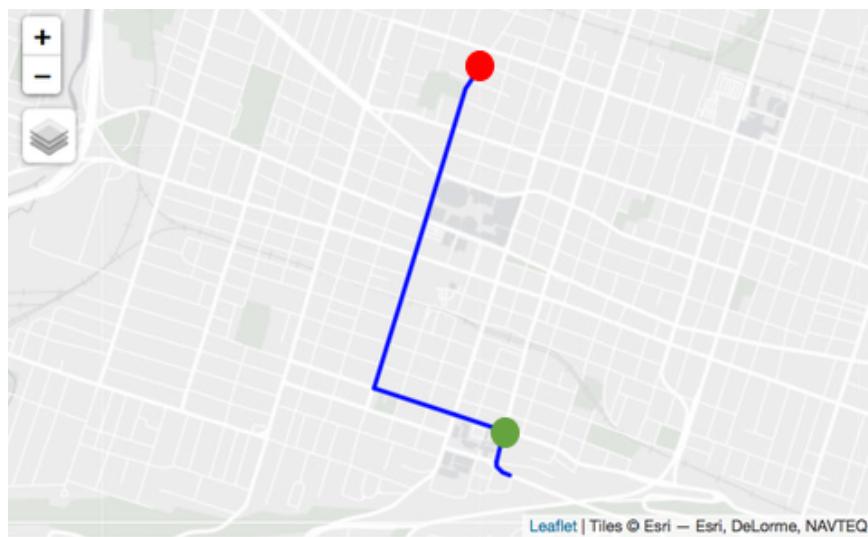


Figure 27: Map of route 3B.



Figure 28: Segment 4 on route 3B with a buffered on-street bicycle lane on a one-way street. (Source: Google Street View)

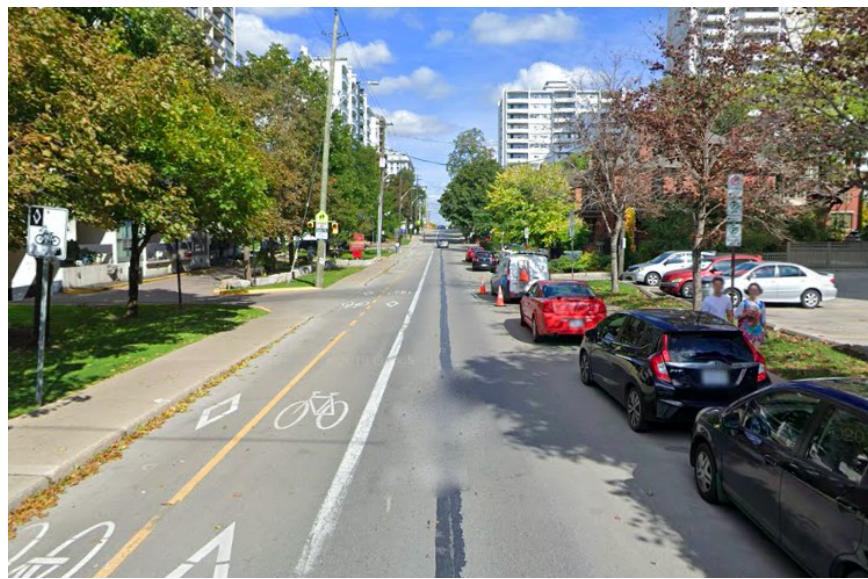


Figure 29: Segment 8 on route 3B depicting a two-way cycle track on a one-way arterial road. (Source: Google Street View)



Figure 30: Segment 20 of route 3B depicting the bike box at the intersection of two cycling facilities. After the intersection, the two-way cycle track on the left side of the roadway splits to on-street bicycle lanes on both sides of the road. (Source: Google Street View)

349 participants; these comments were in reference to the different or inconsistent types of infrastructure along the  
 350 route and because the infrastructure ends or is missing at certain spots.

351 *3.3. Preferred Routes*

352 After reviewing each of the three packages of photos, participants were asked to select which of the two routes  
 353 in each package they preferred. All participants consistently selected the same routes: 1B was preferred over 1A,  
 354 2A over 2B, and 3B over 3A. In the first package, cyclists preferred route 1B because they disliked the first three  
 355 segments of 1A. Cycling on route 1B on residential streets was preferred over negotiating shared space on a busy  
 356 four-lane arterial road even though there were dedicated cycling facilities later in the route. It is worth noting  
 357 that a few participants commented that they most preferred the second half of 1A because it had an on-street  
 358 marked bicycle lane, but that 1B was a better route overall. In the second package, participants preferred 2A  
 359 because it had cycling infrastructure throughout compared to 2B which had a signed route only for part of it. 2A  
 360 was also familiar to most participants. Finally, 3B was preferred for similar reasons that 2A was preferred; there  
 361 were on-street cycling facilities for most of the route and it was familiar to most participants.

362 **4. Discussion**

363 The environmental audits revealed that each of the routes had a mix of attributes that support or hinder cycling.  
 364 This can be expected in a city with a cycling network under development. The audits helped to explain why  
 365 certain trip flows were over- or under-estimated by the model [paper submitted to *Transportation*]. All inferred  
 366 routes included residential streets with lower volumes of cars or cycling infrastructure. With respect to the routes  
 367 that were under-estimated (i.e., 1B, 2B, 3A, and 3B), there were many features that might influence cycling. For

368 instance, two of the four (i.e., 2B and 3B) had some type of separated cycling facility. Three of the four routes  
369 (i.e., 1B, 2B, and 3A) included residential streets. Based on the routes audited, we observed that the *CycleStreets*  
370 algorithm makes sensible recommendations that a knowledgeable cyclist could take. Indeed, three of the six  
371 routes (1A, 2A, and 3B) were familiar to or had been previously cycled by many participants. This suggests that  
372 the inferred routes do match where cyclists actually travel in Hamilton.

373 However, the photo-journeys revealed how objective attributes that are thought to support cycling are actually  
374 perceived and experienced by regular cyclists. Participants preferred routes that visibly accommodate cycling,  
375 and their route and infrastructure preferences align with previous literature. They preferred cycling facilities  
376 and streets with lower levels of traffic, which has been found in many other studies (*inter alia*, see Buehler and  
377 Dill, 2016; Clark et al., 2019; Mertens et al., 2017; Scott et al., 2021; Winters et al., 2011). Participants were  
378 also sensitive to traveling through intersections (Broach et al., 2012) and many enjoyed routes that had natural  
379 features (Marquart et al., 2020; Winters et al., 2011). Perceived car volume was another factor that participants  
380 frequently commented on as they reviewed photos, likely because cyclists are known to be sensitive to busy traffic  
381 (Segadilha and Sanches, 2014) and are motivated to cycle if there are routes away from cars (Winters et al., 2011).  
382 Cyclists in Hamilton describe similar experiences to those who cycle in Waterloo, Ontario (Mayers and Glover,  
383 2020), which suggests that a pattern of exclusion may currently exist in mid-sized cities as they grapple with a  
384 tension between transport culture and new interventions. Finally, participants also considered a range of factors  
385 beyond infrastructure to determine whether a street or route sufficiently meets their needs and preferences, which  
386 is useful information for policy-makers and transport planners. Many participants reported that they like to  
387 cycle on roads with smooth or good conditions, which has previously been reported in the literature (Stinson  
388 and Bhat, 2003). Some cyclists also preferred to have lateral space to their right, like a sidewalk or some other  
389 “escape zone”, in the event that they needed to quickly move out of the way. These attributes may be overlooked  
390 by transport planners but should be considered when planning cycling networks and routes.

391 The temporal aspect of our photo elicitation approach also revealed that there is a threshold of unpleasantness  
392 that cyclists are willing to tolerate along a route. In the case of route 1A, where the second half of the route  
393 was perceived to be pleasant, the first segments along the arterial road without infrastructure were such strong  
394 deterrents that cyclists preferred the other unfamiliar residential route. Although 1A was inferred and not one  
395 that participants reported using, someone who is new to cycling but unfamiliar with other routes could likely  
396 consider this to be the most direct route. The photo activity underscored that the fragmented nature of the  
397 cycling network in a developing cycling city can create barriers for accessing bikeable streets. This reinforces  
398 the importance of connected facilities in encouraging cycling (Buehler and Dill, 2016; Handy, 2020; Yang et al.,  
399 2019) and that navigating mixed traffic in cities where there is less infrastructure is perceived to be less safe  
400 (Chataway et al., 2014) or a major barrier for non-cyclists (Félix et al., 2019). More importantly, these streets are  
401 not separate from the rest of the transport system and the ability to reach this infrastructure matters. If getting

402 to on-street cycling facilities is perceived to be challenging or too dangerous, then regular and even potential  
403 cyclists may be unwilling to use existing infrastructure or avoid routes that incorporate these streets altogether.  
404 Studies have provided strong evidence that cities that are most successful in increasing their cycling trips and  
405 levels have implemented a suite of interventions to change behaviour and the built environment (Pucher et al.,  
406 2011, 2010). Transport planners in developing cycling cities, like Hamilton, should make every effort to focus  
407 beyond infrastructure and seek to better integrate these individual links within a transport system that is  
408 designed with pro-cycling policies in mind. Integration is fundamentally important for becoming a  
409 bicycle-friendly city (Handy, 2020), as are infrastructure improvement for facilitating modal shifts for multi-modal  
410 trips (Cervero et al., 2013). The City of Hamilton has several off-road paved urban trails that are ideal for  
411 cycling (see Agarwal et al., 2020), which one participant described as a “*superhighway for bicycles*”, that could be  
412 better integrated with on-road infrastructure and improved traffic conditions to encourage more cycling.  
413 Therefore, our findings support the recommendation that the City of Hamilton explore and implement bolder  
414 policies to encourage modal shifts. There is strong incentive for prioritizing cycling more: 35% of all current trips  
415 in Hamilton could be cycled (Mitra et al., 2016). More people could benefit from increased physical activity,  
416 which in turn could help the City meet its climate action goals.

#### 417 4.1. Policy Implications

418 There are three important implications of this study for developing cycling cities: i) using photo elicitation is  
419 an innovative and practical approach for cycling planning practice; and ii) the perceptions of cyclists should be  
420 regularly explored and incorporated in route design through local data collection.  
421 Although our approach differed from other studies where participants took photos themselves (Bornioli et al.,  
422 2018; Guell and Ogilvie, 2015; Ward et al., 2015), the use of photo journeys was illuminating because it helped  
423 participants recall their experiences and revealed rich insights about cycling behaviours and perceptions. This  
424 evidence could not have been derived from a travel survey or cycle routing algorithm. This is one of the benefits  
425 of using photos to elicit dialogue because they “evoke deeper elements of human consciousness than do words”  
426 (Harper, 2002). Therefore, it is recommended that developing cycling cities routinely examine cycling perceptions  
427 through qualitative data like photo elicitation to centre the experience of cycling in the design of infrastructure  
428 and routes. Local data is also relevant to the development of mobile applications or platforms which have the  
429 potential to inform planning, route choice, and promotional efforts to induce cycling (see Meireles and Ribeiro,  
430 2020). Users can describe how particular routes or types of infrastructure are actually experienced and travelled,  
431 both to communicate preferred routes to other cyclists and to highlight necessary improvements to planners. The  
432 use of photos can extend current planning practices beyond simple identification of problem areas by describing  
433 how cyclists navigate these spaces. Meireles and Ribeiro (2020) found that both regular cyclists and non-cyclists  
434 have been found to view mobile apps as valuable for cycling, particularly for deriving routes.

435 Furthermore, inviting cyclists to have a more regular participatory role in route design and planning as the  
436 cycling network develops is an important practice for developing cycling cities. Failing to collect and use local  
437 data to inform planning early on in a city's cycling network development can negatively impact efforts to increase  
438 cycling; resources could be spent on facilities that are fundamentally unappealing to cyclists or other barriers can  
439 be ignored. Taking advantage of cyclists' expertise in developing cycling cities can help to overcome the barrier of  
440 a lack of safe cycling routes, a barrier identified in another "low cycling maturity" city by Félix et al. (2019).  
441 Marquart et al.'s (2020) study also highlights that planners "are determining the characteristics of routes in  
442 urban areas", which supports our recommendation that more opportunities be created for cyclists to share  
443 feedback to inform route design. Without such opportunities, tools can be developed that only reflect the  
444 designers' perceptions and that fail to account for the needs of other cyclists like women (Xie and Spinney, 2018).  
445 Participants' comments about the bike boxes, a relatively new cycling intervention in Hamilton, is one example of  
446 how the use of photos and detailed feedback can be informative for transport planners. Likewise, new or potential  
447 cyclists also have specific preferences and their perceptions should be explored through similar approaches. In  
448 addition to our methods, other mapping techniques (see Manton et al., 2016; Marquart et al., 2020), ride-along  
449 activities (see van Duppen and Spierings, 2013), and frequent audits before and after next infrastructure is built  
450 are other useful methods may for understanding how cyclists navigate developing cycling cities. Cyclists' input  
451 can also be used to inform temporary changes to the streetscape to improve active travel conditions (see Carlson  
452 et al., 2019) or to gauge receptiveness to different types of route improvements.

## 453 5. Study Limitations

454 There are some instances where the *CycleStreets* algorithm failed to include some of the city's off-street cycle  
455 infrastructure or signed routes. Some participants noted these situations and described alternate detours that are  
456 more locally known. This highlights that a routing algorithm may not reflect the extent or range of behaviours  
457 of cyclists. However, many routes were familiar to participants so we find that the algorithm makes sensible  
458 recommendations. Although the photos of the routes were taken from Google Street View and may not reflect  
459 prime cycling times and likely traffic volumes expected at those times, there were no errors or differences pointed  
460 out by participants along routes familiar to them.  
461 Furthermore, several cyclists noted that the routes they preferred were familiar to them, which suggests that  
462 familiarity played a role in their decision. This makes sense because it affords them more intimate knowledge of  
463 the route. Therefore, our findings could have been different if the participants were familiar with all of the routes  
464 or if they were familiar with none. However, their familiarity offered insightful information about how these road  
465 spaces are actually experienced which is useful for transport planners in Hamilton. Our findings would also likely  
466 have been different if the participants were new or occasional cyclists. Less experienced cyclists are likely to have  
467 even stronger preferences for protected infrastructure and be more averse to mixing with traffic (Félix et al., 2019;

468 Winters et al., 2011). The findings may not match the preferences or experiences of other cyclists such as older  
469 adults, women who are more conscious of traffic risks, children, or marginalized groups. These individuals have  
470 unique needs with respect to separation from traffic and perceptions of the built environment, as well as different  
471 trip patterns (*inter alia* see Aldred, 2015; Black and Street, 2014; Emond et al., 2009).

472 Finally, some photos taken from Google Street View were darker or cloudier than others. This was noticed by  
473 some participants, suggesting that it may have subconsciously influenced participants' perceptions. However,  
474 there was similarity in participants' stated preferences and all selected the same preferred routes. This suggests  
475 the weather depicted in the photos likely had less of an influence on individual perceptions and preferences, and  
476 that attributes of the routes and familiarity were more important.

## 477 6. Conclusion

478 Through environmental audits and photo elicitation in semi-structured interviews, we demonstrated the  
479 importance of considering both objective and perceived attributes of the built environment in cycle planning.  
480 Cycling routes in Hamilton have a mix of attributes that support and hinder cycling, while the photo journeys  
481 revealed that regular cyclists prefer routes that have dedicated cycling infrastructure or streets with low volumes  
482 of traffic, and that existing infrastructure needs to be adapted to better align with cyclists' needs and preferences.  
483 As a developing cycling city with 46% of the cycling network completed, the findings from this study will be  
484 useful to policy-makers and transport planners in Hamilton, and other mid-sized cities with growing cycling  
485 levels, to design more bicycle-friendly streets and facilitate more trips that enable people to be physically active.  
486 Our findings support the recommendation that other developing cycling cities involve local cyclists to inform  
487 infrastructure design and location and pay attention to a broad range of built environment factors that influence  
488 where people choose to cycle. The use of photo elicitation to explore cyclists' perceptions and experiences is a  
489 promising participatory approach that can be incorporated into planning practice to complement travel survey  
490 data and better centre the cycling experience in cycle infrastructure and route design.

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498 **ggplot2** (H. Wickham, W. Chang, et al., 2020), **ggthemes** (Arnold, 2019), **kableExtra** (Zhu, 2020), **knitr** (Xie,

499 2020), `ngram` (Schmidt and Heckendorf, 2017), `purrr` (Henry and Wickham, 2020), `readr` (Wickham and Hester,  
500 2020), `rticles` (Allaire et al., 2020), `sf` (Pebesma, 2020), `sp` (Pebesma and Bivand, 2020), and `spdep` (Bivand,  
501 2020).

## 502 8. CRediT Statement

503 **First author:** conceptualization, methodology, investigation, formal analysis, data curation, writing - original  
504 draft, writing - review & editing. **Second author:** conceptualization, writing - original draft, writing - review &  
505 editing. **Third author:** conceptualization, writing - original draft, writing - review & editing. **Fourth author:**  
506 conceptualization, methodology, writing - original draft, writing - review & editing. **Fifth author:**  
507 conceptualization, methodology, writing - original draft, writing - review & editing, supervision.

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