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An exploration of the navigational behaviours of people who use wheeled mobility devices in unfamiliar pedestrian environments

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ABSTRACT

Purpose: This paper explores the challenges that people who use wheeled mobility devices face navigating unfamiliar pedestrian environments. The intent is to understand their decisions during the planning and travel phases and to compare these decisions and experiences between mobility device users.

Methods: Fourteen mobility device users (4 manual wheelchair, 6 power wheelchair, and 4 scooter users) completed surveys that captured data about socio-economic and disability status, mobility device skills and confidence, and wayfinding abilities. As part of a wheeling interview, participants planned trips to three destinations in an unfamiliar urban setting. They wore a GoPro camera affixed to their head and carried a global positioning system device as they wheeled to each destination. During each trip, participants answered questions regarding their decisions and experiences. At the end of each route, participants rated the physical and mental demand of the trip and rated their own performance using the NASA-TLX questionnaire. They also completed wayfinding skills tests of their spatial orientation and ability to estimate distance and slope. Transcripts of the videos were coded and analyzed using interpretive description. Spatial and qualitative data were then uploaded into a geographical information system to identify patterns in decision making and experiences and compare across mobility devices.

Results: The findings highlight the complex and dynamic challenges faced by wheeled mobility device users and the implications on their mobility. The findings emphasize the relationship between the individual, the mobility device, and the environment to shape navigational experiences. Manual wheelchair users appeared to struggle more with navigation because accessibility issues diverted their attention away from maintaining orientation and heading.

Conclusions: Wheeled mobility device users face challenges navigating unfamiliar environments that make reaching destinations difficult which may deter community participation. Environments that incorporate their diverse and unique requirements should be considered in urban design and research.

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1. Introduction

Transportation plays an important role in the ability of people who use wheeled mobility devices (PWMD) such as manual wheelchairs (MWC), power wheelchairs (PWC) and scooters, to participate in community activities (Lubin and Deka, 2012; Myers and Ravesloot, 2016; Páez and Farber, 2012; Schreuer et al., 2019; Sze and Christensen, 2017). Historically, transportation systems have not been built with the needs of PWMD in mind (Bascom and Christensen, 2017; Imrie, 1996; Park and Chowdhury, 2018). The pedestrian environment is an essential part of this system but its complex and dynamic network of sidewalks, crosswalks, and trails can be difficult to safely navigate (Atoyebi et al., 2019; Farr et al., 2012). This contributes to trips taking longer, PWMD travelling less (Church and Marston, 2003; Ferrari et al., 2014; Miller et al., 2006), and levels of overall participation dropping (Bascom and Christensen, 2017; Gray et al., 2003). Therefore, efforts should be made to develop a better understanding of the factors that influence navigation (Prescott et al., 2019).

Navigation is the process of planning routes to a destination, performing the planned route, and adapting to unexpected challenges along the way to reach a destination (Bovy and Stern, 2012; Seneviratne and Morrall, 1985). Route choices have wayfinding and wayfaring components that are influenced by topological, physical, social, cognitive, affective, temporal, and information factors (Wiener et al., 2009). Wayfinding involves finding a route through the pedestrian network of sidewalks, crosswalks, and pathways and wayfaring involves overcoming physical and social features in the pedestrian environment (Lanng and Jensen, 2016; Montello and Sas, 2006; Park and Chowdhury, 2018). Accessibility factors impacting wayfaring can result in barriers (i.e., obstacles that impede progress along a path) and burden (i.e., the increase in effort, time, or exposure to hazards that accumulate over the length of the journey). Temporal factors are changes in the physical and social environment resulting from human activities (e.g., sidewalk construction) or natural occurrences (e.g., snowfall). Information, including signs, maps, navigation applications, and environmental design can facilitate travel in unfamiliar environments or when unexpected barriers exist. As PWMD tend to rely on familiar routes to reach destinations, they may not have the navigational resilience to adapt when necessary (Brunyé et al., 2017). To improve our understanding of the challenges PWMD face navigating the pedestrian environment, we wanted to know:

- Which factors affect the route plans PWMD make to reach destinations in unfamiliar pedestrian environments? (Q1)
- Which factors influence the decisions PWMD make to follow their plans to reach destinations during travel? (Q2)
- How did PWMD feel trying to reach their destinations? (Q3)
- What differences exist between mobility device users? (Q4)

2. Materials and methods

2.1. Study design

Qualitative GIS, a mixed-methods approach, was used to explore how PWMD navigate unfamiliar pedestrian environments (Jones and Evans, 2012; Jung and Elwood, 2010). A wheeling interview was conducted to capture the navigational experiences of PWMD from their perspective in real-time. These data were incorporated into geographical information system (GIS) software to create a spatial transcript used to identify themes (Battista and Manaugh, 2019). The study was approved by the local university ethics board and followed COREQ guidelines for qualitative research (Tong et al., 2007). Prior to beginning, the research team met with participants to develop a relationship to minimize any power imbalances and ensure they felt comfortable with the study.

2.2. Study site and routes

The study took place on a university campus with a varied physical and social environment (e.g., hills, bumpy surfaces, construction hazards) over a period of a year (2018–2019). The topology varied from a typical grid pattern to complicated options such as criss-crossing trails and through buildings. Route origins and destinations were chosen to 1) maximize potential variation in topology and physical environment; 2) limit distance to under 800 m; and 3) minimize potential overlap of routes. Because participants planned their own routes, it was not possible to control for these variables entirely. The first route started with an elevated view of a large open space in the foreground and a clear view of the path in the distance. The second route had a complex set of trails that were more direct than the major routes. The third route started between buildings, limiting what could be seen ahead and construction was underway in two separate places along the route. Weather conditions were similar on days of data collection over the course of the study with moderate temperatures and negligible or no precipitation.

2.3. Eligibility and recruitment

To be eligible, participants had to use a wheeled mobility device such as a MWC, PWC, or scooter to get around their community. Participants had to be unfamiliar with the campus, which was determined by asking participants, prior to the study, if they had visited the campus fewer than 3 times in the previous year. Participants also had to be over 18 years of age, able to communicate in English, able to get to the study site, and be able to travel 2 km. A purposive sample was recruited with the goal of having an even number of people by sex and wheeled mobility device. Participants were recruited from multiple sources including a database of people that had agreed to volunteer in future studies, recruitment websites, and word-of-mouth.

2.4. Procedures

This study was conducted in two phases (Fig. 1). In the first phase, participants were sent information packages about the study and a consent form to complete prior to beginning the study. Those who agreed to participate provided demographic information and completed self-report measures using an online survey platform (Qualtrics, Provo, UT) before meeting with the researchers at the study site for the second phase. Information was collected about age, gender, education, employment, and income, mobility, and device type and use. Mobility device confidence was assessed using the short form the WheelCon-M, 2.1 (Sakakibara et al., 2018), a 101-point scale was used for 13 questions about physical confidence and eight question about social confidence. Participants completed the Wheelchair Skills Test – Questionnaire (WST-Q, version 4.3) to measure perceived ability to perform skills using their mobility device. The WST-Q has versions that are specific to the primary mobility device used in the community (WST-Q for MWC users, WST-Q for PWC users, and WST-Q for scooter users) (Rushton et al., 2016). There were 34 questions for MWC users, 30 for PWC users, and 29 for scooter users. Participants also completed the Wayfinding Questionnaire (Claessen et al., 2016) to test perceived spatial anxiety, navigation and orientation, and ability to estimate distances on a 7-point scale (from not applicable to fully applicable or not uncomfortable to very comfortable). Spatial anxiety scores that are high mean the individual feels they can adjust to difficult situations.

On the day of the study, researchers reviewed the purpose of the study and the activities that would take place with each participant. The main activity was planning and completing three consecutive wheeling interviews between pre-defined origins and destinations. Before each route, participants traced their intended route on a paper map that displayed streets, pedestrian paths, buildings, starting point, and destination (i.e., sketch map). Once they were satisfied with the route, they gave a reason for choosing that route (Wang and Worboys, 2017). The map could be referred to at any time, but the researcher would only intervene if the participant was in danger (e.g., about to enter vehicle traffic) or far off track. A GoPro camera was affixed to their head using a strap and the researcher carried a geographical positioning system (GPS) device as they followed the participant. A set of semi-structured questions (e.g., where are you, where are you headed, how does this route feel, why did you choose to … ?) were used to prompt participants to describe their decisions and experiences as they travelled to each destination using their mobility device (Parent, 2016).

At the end of each route, participants were asked to evaluate the perceived demands of the trip across six dimensions including physical, mental, temporal, performance, effort to achieve performance, and frustration, using the NASA-TLX questionnaire (Hart and Staveland, 1988). Participants rated these on a scale of 1 (low) to 20 (high) for all but performance which was on a scale of 1 (good) to 20 (poor). The NASA-TLX has been used to assess workload across a large variety of activities (Hart, 2006). Participants also completed three spatial skills tests: they 1) estimated the distance to a landmark 2) estimated slope to a landmark, and 3) pointed to the origin of

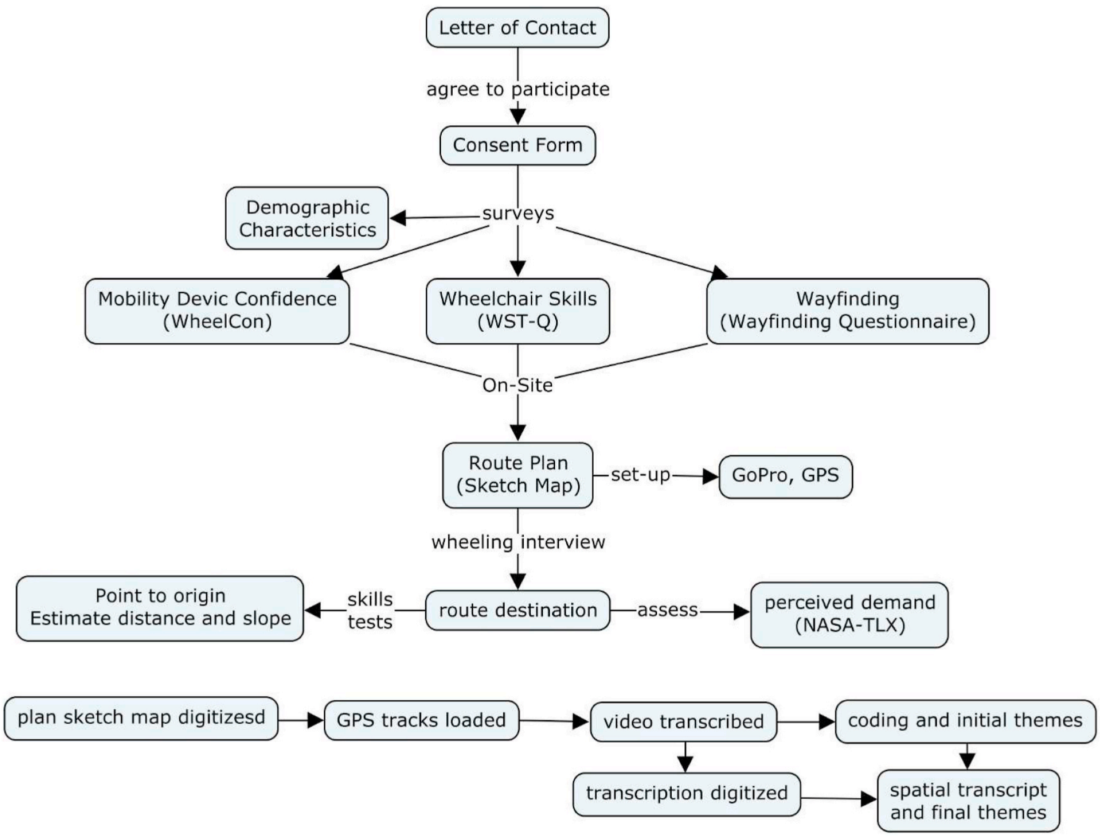

Fig. 1. Study protocol.

the trip using a compass.

2.5. Data analysis

Participant characteristics were reported as medians and ranges for the total sample and by device. Measures for PWC and scooter users were grouped as power users because they relied on motorized means of locomotion. Mobility device type was used as a filter in the GIS to conduct comparisons and identify patterns. Analysis was conducted before and after data was uploaded to the GIS software (QGIS). In the first stage, the main author transcribed the audio/video onto a spreadsheet. Researcher notes were added at this time to indicate participant actions (e.g., going in the wrong direction, looking at the map), and researcher insights (e.g., moves quickly and confidently, easy to see sign ahead). Two researchers reviewed the transcripts independently and created preliminary codes. A consensus on the textual transcript codes for the first stage was reached by all the authors after a final review.

The second stage involved creating a spatial transcript by linking the spreadsheet to the map in the GIS (Jones and Evans, 2012). Participants' routes were added to the map by uploading the tracks from GPS devices. The text and codes were reviewed again, within the GIS, to finalize the codes. This was done by looking at the spatial location and patterns of the codes (Battista and Manaugh, 2019). For example, the original code of being disoriented did not capture the difference disorientation made at the start of a trip compared to later in the journey. A spatial reference was added to the code indicating it was at the start of the trip. Broad categories were developed by organizing codes into groups (Morse and Field, 1995). Filters in the GIS were applied to the data to compare the experiences of mobility device users.

Trustworthiness strategies were used throughout this study. Researchers discussed preconceptions about the challenges that PWMD face during navigation and used journals to track insights and discussed how their preconceptions were being challenged. This was enriched by the fact that the research team included experts in rehabilitation sciences, new students to occupational therapy, and a MWC user. Member checking was done with two participants to see if their experiences aligned with the analysis This feedback was integrated into the spatial transcripts and used in the final analysis.

3. Results

3.1. Participant characteristics

Fourteen PWMD participated in this study including four MWC users (2 males and 2 females), six PWC users (3 males and 3 females), and four scooter users (2 men and 2 women). Ten participants (71.4%) had completed at least a university degree, four (28.6%) were working, and six (42.9%) had incomes less than $30,000 per year. Participants had been living with a disability for a median of 36.5 years (range = 2–76 years), accounting for a median of 66.4% of their lives (range = 3.2–100%). The median number of years using a mobility device was 24.4 years (range = 2.5–50 years) and 10 h using device per day (range = 2–16 h). Eight (51.4%) participants had received training to use their device, and three (21.4%) travelled with an attendant.

Table 1
Participant scores (in percent) for wheelchair skills (WST), mobility device confidence and physical and social environment sub-scores, and wayfinding skills and anxiety, orientation, estimation sub-scores, and perceived demand and performance.

	Total (n = 14)		Manual (n = 4)		Power (n = 10)		PWC (n = 6)		Scooter (n = 4)	
Measure	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
Age	53.5	32–90	41.5	32–50	58.5	41–90	58.5	41–63	71.5	53–90
Age at Onset	19.0	0–78	11.0	0–24	22.0	0–78	22	0–60	20.5	0–78
WST	78.0	63.3–94.8	80.1	75.0–88.2	76.7	63.3–94.8	76.7	63.3–86.7	77.4	69.9–94.8
Confidence	78.1	38.5–00.5	84.3	65.7–99.5	77.0	38.5–89.1	79.0	56.8–89.1	71.0	38.5–86.0
Physical	78.9	26.5–100	80.6	68.5–100	78.9	26.5–94.8	76.9	65.4–94.8	78.9	26.5–93.9
Social	73.3	42.3–100	94.4	61.3–98.8	69.8	42.3–100	70.9	42.9–100	65.4	42.3–73.8
Wayfinding	63.3	35.7–89.6	61.4	35.7–66.2	64.3	41.6–89.6	67.6	41.6–89.6	62.3	53.9–66.6
Anxiety[a]	59.8	35.7–85.7	50.9	42.9–73.2	61.6	35.7–85.7	59.8	35.7–85.7	61.6	58.9–62.5
Orientation	66.2	32.5–93.5	61.7	32.5–72.7	66.9	48.1–93.5	72.1	48.1–93.5	57.8	54.-66.26
Estimation	64.3	28.6–85.7	59.5	28.6–85.7	69.1	33.3–85.7	71.4	33.3 = 85.7	64.3	38.1–71.4
Navigational skills										
Pointing	22.8	8.5–44.6	20.4	12.6–27.2	22.8	8.5–44.6	24.0	8.5–44.6	16.9	10.4–27.4
Distance	70.2	27.7–3335.5	67.7	35.6–92	72.4	27.7–335.5	79.1	29.4–61.1	60.2	27.7–335.5
Slope	63.6	37.8	63.6	43.8–122.1	83.1	37.8–220.2	83.1	51.8–220.2	63.6	37.8–220.2
Demand (NASA-TLX)										
Physical	15.0	5.0–73.3	34.2	25.0–73.3	5.0	5.0–31.7	30.8	11.7–75.0	5.0	5.0–28.3
Mental	44.2	11.7–75.0	70.0	50.0–73.3	30.8	11.7–75.0	5.0	5.0–31.7	40.8	26.7–46.7
Effort	42.5	5.0–83.3	60.0	40.0–75.0	35.8	5.0–83.3	35.8	5.0–83.3	25.8	5.0–50.0
Temporal	25.8	5.0–56.7	44.2	25.0–56.7	14.2	5.0–38.3	14.2	5.0–33.3	18.3	8.3–33.3
Frustration	32.5	5.0–81.7	52.5	33.3–81.7	25.8	5.0–61.7	20.0	5.0–61.7	29.2	23.3–41.7
Performance	35.8	20.0–76.7	33.3	23.3–48.3	43.3	20.0–76.7	44.2	76.7–61.7	42.5	20.0–70,0

Age and Age at Onset are reported in years while all other scores are percent.
[a] Higher anxiety scores represent better ability to deal with spatial anxiety.

The main differences between groups reported in Table 1 were scooter users being older than MWC users though age at onset was similar to the other two groups. MWC users had higher perceived wheelchair skills and mobility device confidence but the lowest perceived wayfinding scores. MWC users performed better than others in slope estimation. Perceived demand was highest for MWC users in every category, though MWC users had the highest perceived performance.

3.2. Interview findings

An example of planned (thick, light grey line) and actual (narrow, black line) routes of a MWC participant is provided (Fig. 2). It shows how they had to backtrack in the north-west section of route 1 and how they missed a critical turn during route 2. In this example, poor signage (sign was too high or missing) played a role in difficulties following their plan.

Fig. 3 shows more detail for this route and the comments that were made by the participant and observations made by the researcher in square brackets. The results that follow are broken down by navigation phases (planning, travel decisions and experiences, and arrival at destination.

3.3. Planning the route

Overall, participants found the planning process to be challenging. Participants spoke in general terms about finding routes that were “better” or “more direct” for them. They spent 5–10 min to finalize their route choice. Two strategies were used for 39 of the 42 routes (92.7%) planned. The shortest route was chosen 22 times (52.4%), fewest turns 17 times (40.5%). Shortest route was also mentioned 11 times (26.2%) as a secondary reason. MWC users preferred the shortest route 7 times (58.3%), fewest turns 2 times (16.7%) and power users preferred the shortest and fewest turns 15 times each (50%). Regardless of strategy, participants struggled to sketch their plans onto the map, citing difficulties determining which paths were for pedestrians, estimating distances, and a general confusion using a map.

The most common planning approach was to rotate the map to try to align it with the world in front of the participant. For example, the elevated view from the start of the first route provided detailed information about the large, open space nearby as well as the steep

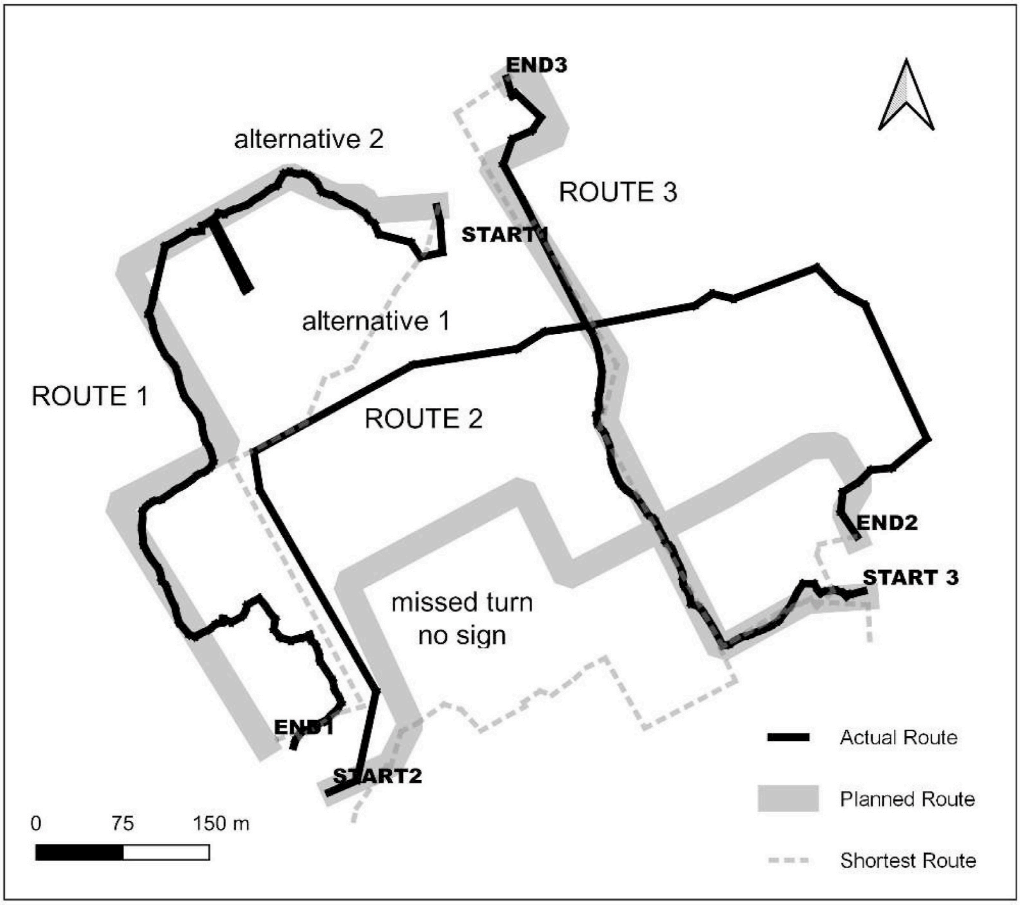

Fig. 2. Example of a participant’s planned and actual routes.

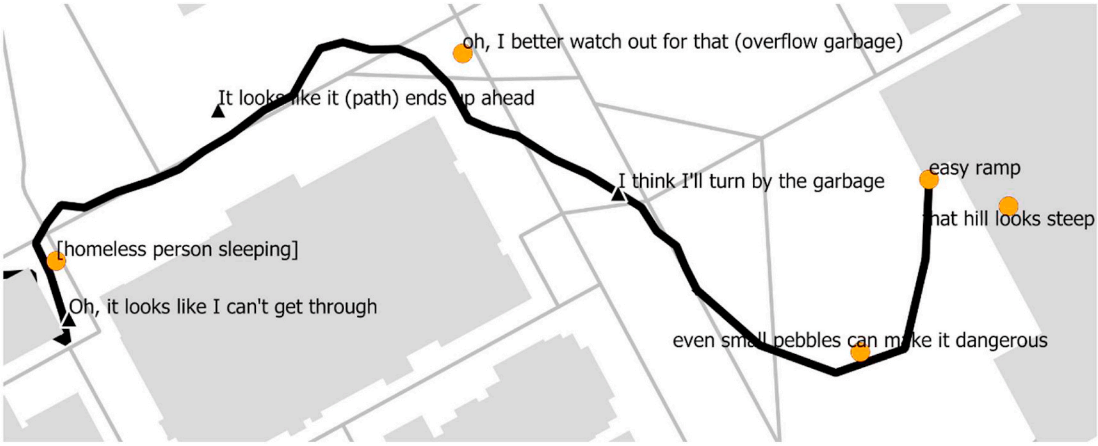

Fig. 3. Detailed map of wayfinding and wayfaring issues along the route.

slope of the path leading to the destination. Before starting, a scooter user pointed in the opposite direction of their plan and said, “I think we’re headed that way?” After a few minutes of hesitation, they decided to review the map again prior to embarking on the journey. This contrasts with the third route where the surrounding buildings limited what was visible ahead. They ended up going 100 m in the wrong direction before realizing, “I was oriented wrong, I thought I was by one building, but I was by another”. They had to retrace their steps to reorient themselves, adding 200 m to the total distance travelled.

3.4. Decisions and experiences during travel

Participant feedback and observations during the travel phase were broadly categorized as either wayfaring or wayfinding (Table 2) by mobility device. Of the 610 comments made during the interviews, 215 (35.2%) focused on wayfaring and 395 (64.8%) focused on wayfinding. Wayfinding issues were found throughout the study site but in high concentration at the start and end of routes and at key decision points. Wayfaring comments were found in high concentration along the main pedestrian paths where a bus loop

Table 2
Wheeling interview comments by code and primary mobility device.

WAYFARING	MWC		PWC		Scooter		TOTAL
	N	%	N	%	N	%	N
Hazards	19	24.1%	18	22.8%	13	22.8%	50
Uneven/bumpy surfaces	17	21.5%	15	19.0%	10	17.5%	42
Feeling uncertain	17	21.5%	15	19.0%	10	17.5%	42
Heuristics[a]	2	2.5%	15	19.0%	6	10.5%	23
Steep slope	15	19.0%	3	3.8%	2	3.5%	20
Crosswalks & ramps	2	2.5%	7	8.9%	9	15.8%	18
Obstacles	4	5.1%	2	2.5%	4	7.0%	10
Difficult cross slope	1	1.3%	3	3.8%	1	1.8%	5
Narrow path	2	2.5%	1	1.3%	2	3.5%	5
Subtotal	79	100%	79	36.7%	57	100%	215
WAYFINDING							
Needed map/directions	28	20.3%	30	19.5%	27	26.2%	85
Headed in wrong direction	24	17.4%	35	22.7%	20	19.4%	79
Orientation	19	13.8%	24	15.6%	21	20.4%	64
Poor signage	20	14.5%	20	13.0%	11	10.7%	51
Recognized destination	13	9.4%	15	9.7%	4	3.9%	32
Blocked/limited sightlines	15	10.9%	9	5.8%	7	6.8%	31
Used landmarks	11	8.0%	12	7.8%	5	4.9%	28
Took a shortcut	5	3.6%	5	3.2%	8	7.8%	18
Estimated distance	0	0.0%	1	0.6%	0	0.0%	1
Follow others	3	2.2%	3	1.9%	0	0.0%	6
Subtotal	138	100%	154	100%	103	100%	395

% is calculated as the proportion of times a code was identified for the mobility device user.

[a] Heuristics refers to decisions made to manoeuvre the mobility device to avoid obstacles and hazards unrelated to the broader goal of reaching the destination.

and obstructions from construction existed. Fewer comments were made along long straight sections of routes overall.

Wayfaring factors influenced the route experiences and wayfinding of participants. Route conditions that were of a more permanent nature, such as steep slopes and poor surfaces, presented some challenges for MWC users. For example, interlocked bricks and seams in the surface made travel difficult for some participants in the large open spaces at the start of the first route. Even small hazards could have an impact as a MWC user said, “whoops, the little bump just about wiped me out”. In fact, MWC users related that they spent much of their travel focusing on the ground where obstacles and hazards existed. A MWC user stated “… I always look down and I can sort of scan how level the ground is”. A PWC said, “sometimes I run over things I shouldn’t” but followed up by saying, “I’m not too worried with my tires”.

The experiences of power users were pronounced at crosswalks and where tipping hazards existed. Power users found some of the crosswalks challenging because of poor push button placement. In one instance, a scooter user was not able to cross the street until the light changed three times because of the location of the push button, crumbling sidewalk ramp, and presence of pedestrians, many of whom were looking at their cell phones. They said about the crosswalk button, “what a ridiculous place for controls”. As a result, they forgot that they were going to turn on the other side of the street. While power users did not feel curb ramps affected their travel, researchers noted the caution that was taken going up ramps that were not aligned with each other. When asked about this, a PWC user said, “I usually try to go fast” though they had slowed down and oriented their chair perpendicularly to the ramp. In another situation, broken glass forced a scooter user to change sides only to be confronted by a motor vehicle coming around a blind turn into their path. Tree roots under sidewalks were another hazard cited often. A PWC user said, “I have to slow down where there are tree roots or I’ll tip”, while a scooter user felt safe and said, “[my] safety wheels prevent me from tipping”.

Temporary environmental conditions also played a role in navigation. Construction zones forced participants to quickly adapt their plans. Near the end of one route, construction obscured the pathway and there were no signs directing pedestrians. Fig. 4 highlights the navigation challenge where sightlines are blocked and hazards along the path make finding a safe and effective route to the destination cumbersome. Some participants took the risk of going around the construction without looking at the map. They soon found that there was no reasonable alternative and had to backtrack. Upon returning to the construction site, participants followed the ambulatory pedestrians and discovered that access was not blocked. A scooter user said of the situation, “I just couldn’t see past the equipment”. A variety of heuristics were used to avoid obstacles and hazards including going to the other side of the street. Along one path, sidewalk construction reduced the width of the path which required being aware of people approaching and those behind. A PWC user said of this, “I’ll stay on this side because it looks more comfortable”. Pedestrians walking slowly were approached with caution by all participants, but powered users quickly increased their speeds as soon as they were not near other people.

Wayfinding challenges were experienced along all three routes. Participants missed built environment cues such as signs that were erected too high, buildings that were not labelled, construction fences that blocked sightlines, and hazards that diverted their attention. A MWC user headed in the wrong direction said,” this intuitively doesn’t feel right” while another MWC user decided against a shortcut saying, “hmm, I might regret taking that route.” The natural environment also influenced navigational performance. In one

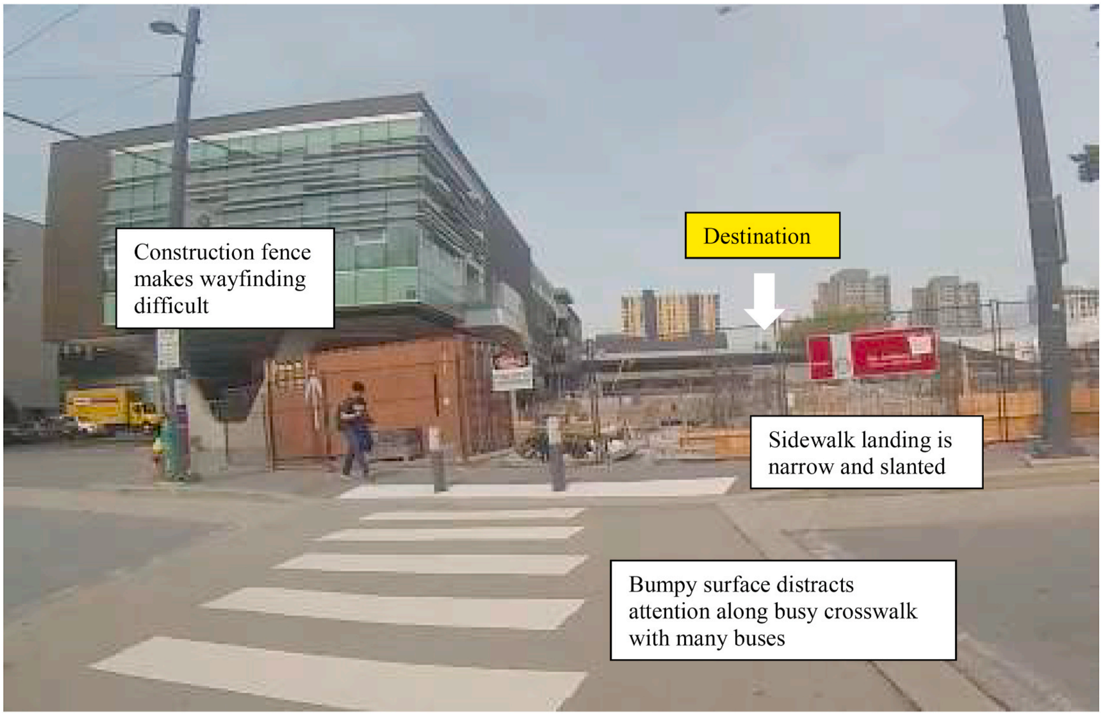

Fig. 4. Example of access challenge.

example, a MWC user cut their route short because they were not sure if there were stairs at the top of the hill. Their decision led them down a dead-end alley. It turned out that they had not noticed the sign to the destination well above her head. In another example, a PWC user could not tell if there was an accessible path through a construction site but decided that, “people are going this way so let’s be an optimist and go this way".

Because of these challenging conditions, participants tried to keep to their plans as much as possible. When asked about their plans *en route*, participants would try to recall the next turn or recite the entire remaining journey turn by turn (often with errors). One PWC user said, ‘I’m trying to remember that it’s the third turn” despite it being the second turn. This resulted in participants referring to their maps and map kiosks to re-orient themselves at intersections where route decisions were required. They struggled with this task and spent up to 10 min rotating the map in order to match their location on the map with their real-world location. A PWC said, “I’m just not good at reading the map and where I am”. Participants spent several minutes rotating the map and looking for environmental cues to orient themselves. On a few occasions, researchers had to assist because the participant was veering far off the route. This resulted in route travels that lasted for as long as 45 min, not including planning.

3.5. Arriving at the destination

At the end of routes, participants were not always certain they had reached their destination. Design issues such as stairs obscuring the view of ramp or a lack of signs made locating the accessible entrance difficult. At the end of one route, a PWC user said, “they should have more identifying signs not that fine print here”. They had arrived at the destination, but the lack of clear signage did not giver them an indication of this fact. In another situation, a scooter user sped passed their final turn along a route that they had performed perfectly up to that point. After completing each route, participants rated the perceived workloads using the NASA-TLX questionnaire with results reported as a percentage of maximum effort. The bottom of Table 1 reports the median scores and ranges for the six measures with lower scores indicating higher perceived performance and higher scores indicating greater demand for all other scores.

The key issues that arose planning and executing routes were tied to wayfaring and wayfinding issues. Table 3 highlights these challenges during the planning and travel phases. Issues are described as wayfaring (fare) or wayfinding (find). In some cases, the wayfinding and wayfaring aspects of a challenge are difficult to differentiate.

4. Discussion

This study sought to build on the limited research examining how PWMD navigate the pedestrian environment (Prescott et al., 2019). Planning a route (Q1) and executing this plan (Q2 3) are key tactical decisions for reaching destinations and participating in the community (Hoogendoorn et al., 2002). Navigating unfamiliar environments highlights how this difficult this challenge is and how it differs (Q4) between PWMD (Beale et al., 2006). However, previous studies have not examined the factors affecting the route choices of PWMD in a rigorous manner (Gharebaghi et al., 2017). Our study’s identification of the interplay between wayfaring and wayfinding factors (Lanng and Jensen, 2016; Vandenberg et al., 2016) is novel in this population. It also strengthens research that has identified the barriers and facilitators to travel for PWMD by situating it within the specific context of navigation (Gray et al., 2003; Hästbacka et al., 2016; Jeong et al., 2018; Longmuir et al., 2003). The findings of this exploratory study support the need for more research that informs urban design policies and practices, individualized navigation training by rehabilitation professionals, and the development of more inclusive navigation technologies.

Participants in this study were experienced mobility device users with wheelchair skill levels similar to those found in previous studies (Mortenson et al, 2014, 2018) but moderate mobility device confidence and poor wayfinding skills according to the skills tests. The contrast between strong physical skills and wide-ranging psychosocial abilities may have contributed to the diversity of experiences observed in addition to the type of mobility device used.

Table 3
Key navigational challenge at each stage.

Stage	Key Challenges (wayfaring and wayfinding)
Planning	• Understanding which lines were for pedestrians (find) • Figuring out the shortest path (find) • Figuring out current location on map and relating that to current position (find) • Trying to predict path conditions based on initial viewpoint (fare)
Travel	• Avoiding obstacles and hazards (fare) • Noticing signs (find) • Figuring out current location on map and relating that to current position (find) • Frustration (fare) • Lower height put them at a disadvantage of determining what lay up ahead (find and fare) • Maintaining heading
Arrival	• Knowing they were at the destination (find) • Finding the accessible entrance (fare)

Fare = wayfaring challenge find = wayfinding.

Based on the spatial transcripts from the wheeling interviews, four themes were identified that relate to the research questions. *Planning the way* identifies the factors that impact route choice at the planning phase (Q1). *Starting off right*, *Staying on track* and *Arriving at the destination* explore the factors that affect decision and experiences during travel (Q 2&3). Differences between mobility device users are described within each theme (Q4). We conclude by highlighting common and distinct elements across navigation.

4.1. Planning the way

People with disabilities struggle to plan routes through unfamiliar pedestrian environments. This differs from studies of those without disabilities, where route choice is reduced to a wayfinding exercise of topological optimization (Bovy, 2009). Those without disabilities can focus on the structure of the street network when planning because wayfaring conditions in urban and suburban environments tend to be predictable and of moderate difficulty because they have been built according to their needs (Duvall et al., 2013; Ishida et al., 2006). However, PWMD need information about slope, availability of curb ramps, and location of stairs to determine if it is accessible for them (Karimi et al., 2014; Kasemsuppakorn and Karimi, 2009). They also need to know if temporary activities such as construction or snow blocking sidewalks exist to reduce planning uncertainties (Burns et al., 2013; Kovacs Burns and Gordon, 2010; Prato, 2009). Research that does not include those with disabilities suggests factors such noise (Wang et al., 2020), pollution (Agrawal et al., 2008), aesthetics, and access to nature impact route choice (Sugiyama et al., 2012). These factors might influence PWMD if there was trust in the accessibility of the pedestrian network (Rosenberg et al., 2013).

Planning the best route with limited accessibility information may result in a strategy that marginally satisfies the preferences of PWMD. In this study, participants relied on the shortest or simplest route (fewest turns) to reach each destination, neither of which guarantee success (Jankowski, 2018). Currently, we cannot determine if this is due to poor map reading skills, map quality, or environmental uncertainties (Kässi et al., 2013). More research that focuses on the personalized navigational needs of PWMD is still required.

4.2. Starting off on the right track

Starting a journey in the right direction involves reconciling where people are on the map in relation to where they are going in the real-world through a process of mental rotation (Aretz and Wickens, 1992; Tversky, 2003). Participants exhibited difficulties identifying features such as buildings and streets in front of them with their location on the map and the direction of the destination. PWMD might find this task more difficult because of the increased cognitive load required to incorporate wayfinding and wayfaring information (Bunch and Lloyd, 2006). This time-consuming task may have contributed to uncertainty and erosion of confidence (Schmid et al., 2010). Therefore, clear and concise information is especially important for PWMD at the start of their journey to ensure they do not encounter unexpected barriers that add to the burden of their trip.

4.3. Making decisions along the way

Travel using a wheeled mobility device presents unique navigational challenges that affect orientation and heading. PWMD do not get the podokinetic feedback ambulatory people receive that is useful for orientation and heading (Chrastil and Warren, 2012). Differences between mobility device users exist such as MWC users getting proprioceptive feedback from actively propelling their wheelchair that someone in a PWC or scooter does not receive (Nicholls et al., 2010). PWMD may also have to deal with vestibular feedback that is overloaded because of changes in direction required to avoid obstacles and approach curb ramps (Pithon et al., 2009). These internal changes in direction may overwhelm their working memory and make path integration difficult (Bunch and Lloyd, 2006). As a result, PWMD have a more difficult time creating cognitive maps of their experiences that will help with future travel (Allen, 1999).

Visual information is usually cited as the most important environmental information sighted people use for navigation (Loomis et al., 2001; Philbeck and Sargent, 2013). PWMD rely on street signs, landmarks, building signs for orientation and heading. However, PWMD may miss important cues because of obstacles and hazards in their path and the positioning of signage, which is intended for people ambulating. Previous research has identified uneven terrain, icy surfaces, and curb ramps as hazards that may double the risk of collisions in the outdoor environment compared to indoors (Chen et al., 2011; Kirby et al., 1994). This can cause injuries, slow travel, divert attention away from wayfinding cues and safety hazards, and takes away from the enjoyment of the trip. MWC users must avoid hazards on the ground that might lodge under their front wheels and bring them to an abrupt stop and cause them to fall out of their wheelchair. Power users need to go slowly at curb ramps with severe cross slopes that may tip their devices.

Visual information can also be impacted by the fact that PWMD sit lower than ambulatory pedestrians (Steinfeld et al., 2010). An example of this is where a PWMD might not be able to see a car (and vice versa) as they cross the street because another parked vehicle is blocking their sightline. As a result, PWMD are forced to engage in unsafe practices that are danger to themselves and others (Pecchini and Giuliani, 2015). Sitting in a mobility device also delays access to visual cues such as what can be seen at the top of a hill because of the more acute angle (Fajen and Phillips, 2013). As they approach the top, they may realize that it is a dead-end which will force them to re-route. It is essential that wayfinding cues take into consideration accessibility factors. For example, pedestrian detours that are accessible should be planned when sidewalk construction blocks passage and placed in a location that allows a PWMD to make the best route choice possible. Websites and mobile applications that provide real-time notifications about pedestrian obstructions would be useful for ensuring information remains current.

4.4. Arriving at the destination

Completing a trip usually means recognizing the destination from signage and finding an accessible path to an accessible entrance. PWMD often use stairs as an indicator of where the ramp is because this is a common design feature. This becomes difficult when built and natural features block the view. When alternate entrances are required for access, PWMD must find and follow the appropriate route, adding to the burden of the journey which can draw unwanted attention and creating a feeling of being different (Williams et al., 2017).

5. Conclusion

This research builds on past research about the mobility of PWMD by examining the factors that affect their route choices in unfamiliar pedestrian environments (Bascom and Christensen, 2017). The findings highlight how the navigation process, from planning the trip to arrival at destination, involve wayfinding and wayfaring factors that uniquely affect the mobility of PWMD. However, not all experiences are the same as because obstacles, hazards, and overall path conditions impact mobility device users differently.

To build on this study, future research that includes people without disabilities will help bridge the large body of work with that exists for this population. Increasing sample sizes for each type of device would allow those developing innovative technologies to customize their solutions to meet the varied needs of PWMD. This would also be helpful to consider how PWMD navigate familiar environments to see how that impacts navigation. In addition to advancing research, transportation planners can start to use this information to design more inclusive pedestrian environments that embody the requirements of all travellers (Van Der Ham et al., 2013). This could also translate into mobile applications that can support *en route* wayfinding for PWMD. Lastly, rehabilitation specialists working with PWMD can help to improve their mobility in the community by including the development of spatial skills in their training.

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CRediT authorship contribution statement

Mike Prescott: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Project administration. **William C. Miller:** Conceptualization, Writing - review & editing, Supervision. **Jaimie Borisoff:** Conceptualization, Writing - review & editing, Supervision. **Polly Tan:** Data curation, Writing - review & editing. **Nova Garside:** Data curation, Writing - review & editing. **Robert Feick:** Conceptualization, Writing - review & editing, Supervision. **W. Ben Mortenson:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare no conflict of interest.

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