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The Impact of Design Elements on the Street Crossing Experience for Individuals with Disabilities at a Complete Street Intersection

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Abstract

Street intersections in busy urban environments may contain several key infrastructure elements specifically designed to facilitate the efficient flow of movement. A complete streets (CS) design approach attempts to balance the needs of all users, while supporting the simultaneous movement of multiple modes of transportation. Although the benefits of CS have been well documented, people with disabilities often experience difficulty with the use of this approach as a whole and when interacting with individual design elements. The objective of this study was to assess how CS design features affect the street crossing experience for people with various types of disabilities. A total of 24 participants completed the study at one of two CS intersections in downtown Toronto, Canada. A go-along interview method was employed, with probing questions used to understand the full experience of the street crossing and interaction with design elements. Qualitative, thematic analysis of the data revealed four major themes related to experiences with the design infrastructure, consistent across all participants: (1) reliance on maintenance, (2) importance of design consistency, (3) opportunities and challenges of transportation modes, and (4) influence of inclement weather. Across all themes, a greater number of individuals reported more negative experiences than positive ones. Results support the need for the inclusion of people with disabilities in the design of future major intersections to ensure streets are safe for all using them.

Keywords

complete street, intersection, navigation, mobility, accessibility

Introduction

Disability encompasses more than just physical or cognitive limitations; it affects all aspects of daily life and health behaviors (*1*). According to the 2017 Canadian Survey on Disability, approximately 6.2 million Canadian adults face barriers in their daily activities as a result of one or multiple disabilities (*2*). For people with disabilities, design and conditions of pedestrian infrastructure have considerable impacts on access and safety when traveling outdoors. As disability prevalence rises (*2*), the population increasingly depend on public community infrastructure to address daily needs (*3*), leaving individuals especially vulnerable to limitations within the built environment (*4–6*).

Previous literature suggests that streets, sidewalks, and street crossings can be significant barriers for individuals with disabilities. Street intersections are common locations for injuries and accessibility difficulties for all pedestrians, even when excluding vehicle collision (*7–9*). Since an intersection is a critical point of an accessible route, an inaccessible intersection may require additional

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effort and present as a substantial barrier for those with disabilities. Street crossing barriers may include a lack of working signals or insufficient time to cross the street for those who require extra time (*10*). Streets may also contain physical obstructions, street furniture, or suboptimal level changes that make traveling/navigating/maneuvering difficult for people with disabilities (*10*).

According to the Public Health Agency of Canada (2023), implementing barrier-free infrastructure promotes age-friendly communities, while promoting safe and accessible outdoor environments for all types of users. To implement these priorities, a complete streets (CS) design strategy may serve to support improved participation of individuals and more accessible street crossing design (*11*). CS are defined as "streets that are designed to be safe for all users: people who walk, bicycle, take transit or drive, and people of varying ages and levels of ability" (*12*). The goal of CS aims to integrate street space for a multimodal transportation system, accommodating separate traffic modes (e.g., pedestrians, motor vehicles, and bicycles), with a unified control system (*11*, *13*, *14*). CS projects have increased in popularity and this strategy has already been adopted in numerous cities across North America because of several beneficial outcomes regarding social inclusion (*11*, *15*). While the design of CS may vary, common CS features for pedestrian users include dedicated on-road bicycle lanes, limited maximum curb height, stable and slip-resistant sidewalk pavement, and gradual crosswalk slopes (*16*).

To date, there is limited research considering the perspectives of people with disabilities regarding CS designs, including at the street intersection specifically. Much literature has focused on individual design elements and considered single disability types, rather than the end-to-end experience of CS intersections across multiple disability types (*17*). For example, several studies have examined the effect of accessible pedestrian signals (APS) cues on street crossing navigation for people with visual disabilities (*18–20*). While important for guiding design of APS, consideration of similar, individual features as part of a larger experience as a pedestrian is explored to a lesser extent, and certainly not so considering a CS design. Evaluating the overall impact of the combined design features of CS intersections for pedestrians with disabilities is crucial in assessing the effectiveness of the CS design strategy. Further research should assess the level of complexity of intersections with a system that supports multiple modes of transportation, as it can change the overall experience for pedestrians with disabilities. There is also limited knowledge on the intersectionality of disability and general experiences with CS design features. However, as highlighted by McCann and Rynne (*21*), evaluating the effectiveness of CS design approaches can be accomplished by considering the outcome concept, which involves assessing its impact on users in relation to health and satisfaction. There is a need to include perspectives of people with varying disabilities in the design and implementation of street crossings to ensure accessibility.

In summary, important knowledge gaps remain in relation to CS design. In particular, little is known about the experiences of people with disabilities and how design features at street intersections influence these experiences across disability types. This study seeks to address these gaps by examining how specific design elements of a CS-designated intersection shape the overall end-to-end street-crossing experience for individuals with disabilities.

Methods

This study is a companion paper to a larger project that analyzes the broader experiences of people with disabilities crossing CS in an urban setting in downtown Toronto, Canada. The focus of this study is on how street crossing design elements impact experience, while companion work will investigate other aspects of one's lived experiences. All study components were approved by our institutional research ethics board and participants provided informed consent before study participation.

Participants

Participants were recruited over a four-month period using purposive sampling to identify individuals with characteristics relevant to the study aims. Recruitment occurred through community advertisements (printed and digital) and outreach via community-based disability organizations. Eligible participants were adults 18 years or older who identified with having at least one of a mobility (including flexibility, pain), visual, or hearing-related disability, or having a health condition affecting one of these areas.

Data Collection

Data were collected at one of two locations in Downtown Toronto, representing busy urban intersections (Intersection A (Bay St. & College St.) and Intersection B (Huron St. and College St.), as shown in Table 1). Intersections were selected because they were signalized intersections, designed using a CS approach (*22*, *23*). Two intersections were used to better generalize the findings of this study, which allows for comparative insight, adds to depth and complexity of data, supports transferability of findings and helps to capture a fuller picture of experience. Sixteen participants completed the study at Intersection A and eight participants at

Table 1. Detailed Design Features of Each Intersection and How They Compare

Intersection A (n = 16)	Intersection B (n = 8)
• Four-legged intersection • Larger & busy • Four automotive lanes in the East/West direction • Four automotive lanes in the North/South direction • Two bike lanes in the North/South direction • Two bike lanes only on the West side of College Street • Two parallel streetcar tracks in the East/West direction • Two parallel streetcar tracks only in the South direction • Four intersecting curved streetcar tracks from the East/West direction into the South direction • All automotive, streetcar, and bike lanes are controlled with overhead traffic lights in all four directions • Pedestrian traffic is controlled via pedestrian walking signals and APS systems at each corner • Zebra lines for pedestrian crossings in the North/South and East/West directions • Tactile Indicators—truncated domes at all corners	• Four-legged intersection • Smaller & less busy • Four automotive lanes in the East/West direction • One automotive lane in the North/South direction • Two bike lanes in the East/West direction, flowing in the same traffic direction as the automotive lane and separated by paint markings • No bike lanes in the North/South direction • Two parallel streetcar tracks on automotive lanes in the East/West direction • No streetcar tracks in the North/South direction • All automotive, streetcar, and bike lanes are controlled with overhead traffic lights in only three directions (no traffic lights on Huron Street in the West direction) • Pedestrian traffic is controlled via pedestrian walking signals and APS systems at each corner • Zebra lines for pedestrian crossings in the North/South direction • Tactile Indicators—truncated domes at three corners and grooved lines at the Northwest corner

Note: APS = accessible pedestrian signals.

Intersection B. Testing took place in dry weather conditions with no accumulation of rain, snow, or ice on the streets and sidewalks. The characteristics contributing to the CS designation of both intersections are outlined in Table 1.

Participants were asked to answer questions about their previous experience using CS before the testing session began. The testing session then included four sets of crossings and interview questions before and after each crossing. Participants were not required to cross or answer any questions if they felt unsafe or uncomfortable. The four street crossings started from the southeast corner, proceeding to the northeast corner, the northwest corner, and finally to the southwest corner where the interview concluded. One member of the research team waited at the preceding corner and another researcher followed (at a distance) the participant as they crossed. The researchers did not interfere with the participants as they crossed the street, unless the safety of the participant was threatened and assistance was requested (e.g., wheelchair stuck in the pavement, severe unsteady balance of the participant, or at risk of a fall). Intersection A is shown in Figure 1 and Intersection B is shown in Figure 2. A bird's-eye schematic of each intersection is provided in Figure 3.

Qualitative Interview Method

Using a go-along interview methodology (*24*, *25*), questions were asked in real-time after each individual crossing within the intersection to explore individual experiences and how they interacted with specific design elements. All interview questions were audio-recorded by a research assistant. Interviews were then analyzed to represent major commonalities across the data and generate themes. The go-along interview method was chosen because it integrates focused interviewing with participant observation, to observe the participant's physical and social interactions (*24*). Guiding, open-ended interview questions relating to the design elements of the intersection included:

- What was your experience with the crossing?
- How easy was it to cross the street? Why is this crossing easy or challenging?
- How safe did you feel when you crossed the street? Why did you feel safe or unsafe?
- What are some key features about this intersection that enable you to cross in a safe and easy manner?
- Is there anything that you would like to see/add to an intersection to make it more accessible for yourself?
- Imagine you just crossed this street in wet weather conditions. What would your experience of crossing the street at this intersection be like in wet weather conditions?
- This is a CS designed to accommodate many modes of transportation including cyclists, pedestrians, and streetcars. How does having all of



Figure 1. Participants crossing at each corner of Intersection A: (*a*) northwest corner, (*b*) northeast corner, (*c*) southwest corner, and (*d*) southeast corner.
Note: All participants were wearing a fluorescent vest with symbol X.

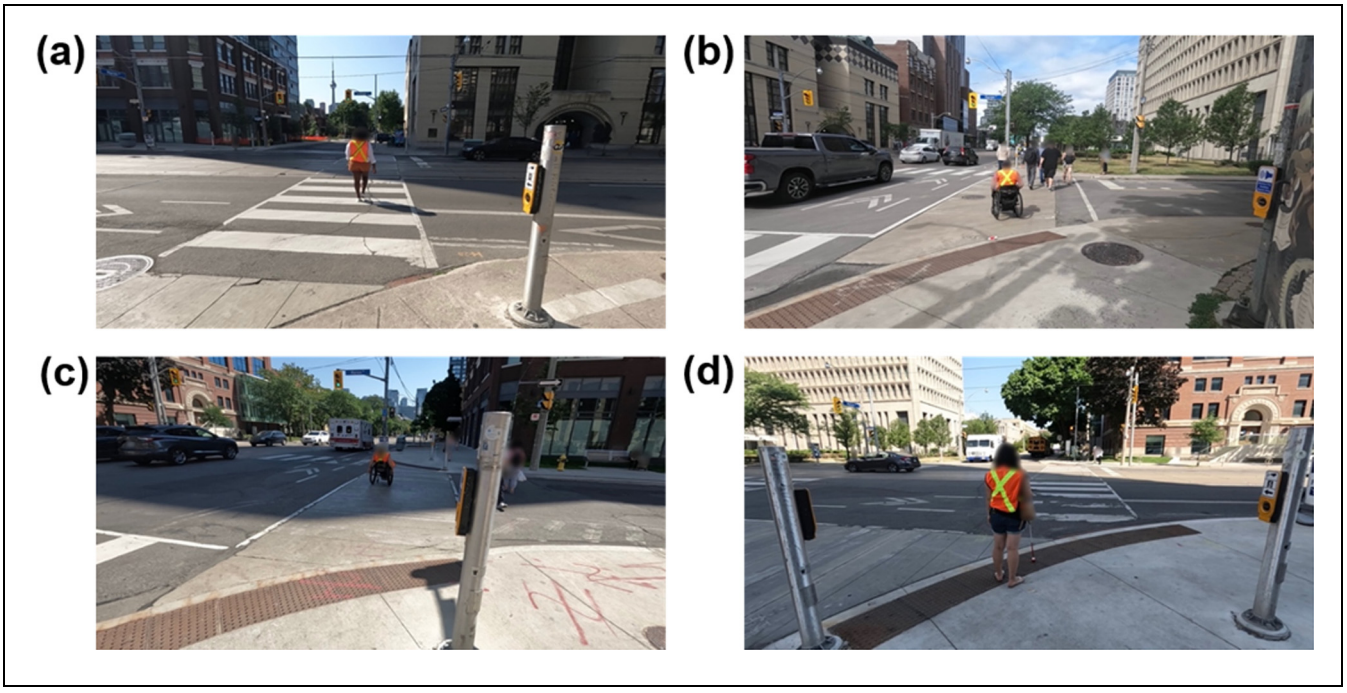

Figure 2. Participants crossing at each corner of Intersection B: (*a*) northwest corner, (*b*) northeast corner, (*c*) southwest corner, and (*d*) southeast corner.
Note: All participants were wearing a fluorescent vest with symbol X.

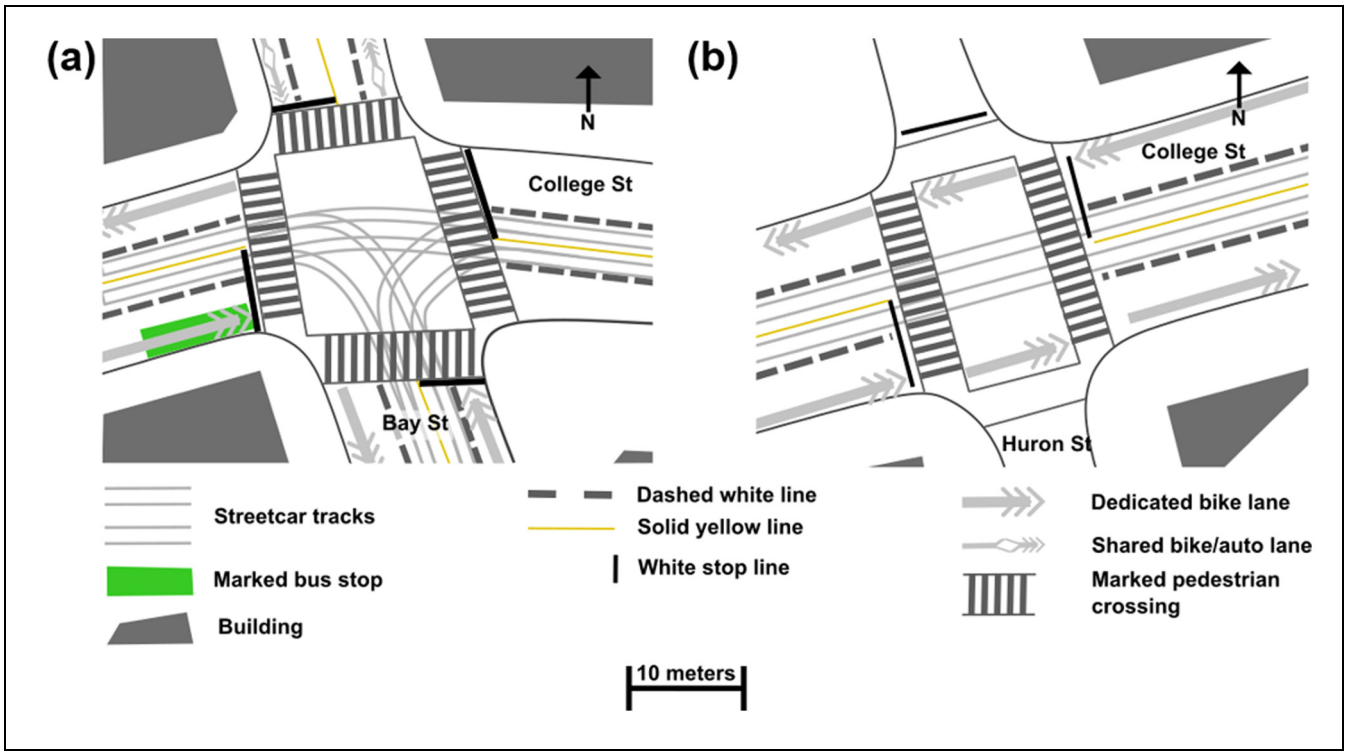

Figure 3. A bird's-eye schematic of (*a*) Intersection A, and (*b*) Intersection B, including the multimodes of traffic and pedestrian crossings (color online only).

these modes of transportation around you affect your mobility?

Qualitative Data Analysis

Qualitative interviews were transcribed and coded with a focus on design elements and user experience using an inductive, thematic analysis approach. All interviews were recorded and transcribed by a research assistant (MP) into a Microsoft Word document, then input into NVivo 12 (Lumivero Software Company, Colorado, 2018). The initial coding process began with three transcripts that were randomly selected and independently coded by two team members (MP & ST). After completion, the two researchers discussed their codes and developed a consensus table of shared codes. Transcripts were then divided between both team members for coding. If new codes emerged after the codebook was established, team members met to discuss and assess whether these new codes should be integrated based on insights from subsequent interviews. After examining the data independently by team members, and then together as a group, key themes were identified. Quotes relating to each theme were identified, analyzed, and sorted into positive and negative experiences; the frequency of reported positive and negative experiences is presented in the results along with verbatim quotes relating to each theme.

Results

A total of 24 participants completed the study (10 men, 14 women; mean age: 52 $\pm$ 15.2 years). Detailed participant demographics are provided in Table 2.

All participants' (n = 24) experiences were analyzed to identify and understand the benefits and challenges of street crossing design elements for people with disabilities at the CS intersections evaluated in our study. Across these CS intersections, the primary design elements impacting participant experiences mentioned in the qualitative interviews were APS, curb cuts, tactile warning systems, cycling lanes, street crossing length time, width of zebra lines, and inconsistent pavement. These elements were identified based on participants' verbal descriptions, whether they used technical terms described earlier or provided a description interpreted by the researcher to align with the terms above.

Characteristics of Experiences

Representing the impact of the various design elements of CS intersections on participant's street crossing experience, four main themes emerged: (1) reliance on maintenance, (2) importance of design consistency, (3) opportunities and challenges of transportation modes, and (4) influence of inclement weather. The themes are discussed in detail in the following subsections.

Table 2. Participant Demographic Data (n = 24)

Participant ID	Age	Gender	Type(s) of disability	Assistive aids
P01	37	Woman	Mobility	Mobility cane
P02	53	Woman	Visual	Guide/service dog
P03	30	Man	Visual	Guide/service dog
P04	71	Woman	Mobility, Visual, Hearing	Manual wheelchair
P05	45	Man	Visual	White cane
P06	70	Woman	Mobility, Visual	Mobility cane
P07	82	Woman	Mobility	Mobility cane
P08	41	Man	Mobility	Power wheelchair
P09	57	Man	Mobility	Power wheelchair
P10	74	Man	Mobility	Mobility cane
P11	55	Man	Visual, Hearing	White cane, support person
P12	28	Man	Visual	White cane
P13	68	Man	Visual	None
P14	45	Woman	Visual	White cane
P15	46	Man	Visual	White cane
P16	47	Woman	Visual	Guide/service dog
P17	39	Woman	Visual	White cane
P18	60	Woman	Visual	White cane
P20	51	Man	Mobility	Manual wheelchair
P21	70	Woman	Visual	White cane
P22	56	Woman	Hearing, Visual	Support person
P23	39	Woman	Visual	White cane
P24	57	Woman	Mobility	Manual wheelchair
P25	27	Woman	Mobility	Manual wheelchair

The Reliance on Maintenance. More than half of our participants (58.3%; n = 14) reported negative experiences when relying on street crossing elements such as pavement/road surfaces, paint markings, and APS systems, which were not well maintained. These elements are examples of general design features used to assist people with disabilities when crossing an intersection, which may pose an important mobility constraint for people with disabilities when not functioning as expected. When one participant was asked about their crossing experience, they replied "I had to go slower than I normally go because it's extremely uneven, especially with the streetcar tracks and the pavement is really bad" (P08, mobility disability, manual wheelchair user). Another participant offered similar insights into the impact of a lack of pavement maintenance: "So often, sidewalks are not well maintained, so there are cracks. And if I'm just using my cane, the cane gets caught in those cracks" (P16, visual disability, guide dog user). Alternative perspectives were shared, reflecting positive street crossing experiences when pavement at the intersection was well maintained, further emphasizing the reliance on street crossing maintenance for people with disabilities. When discussing safety concerns, one participant indicated "I stayed within the lines, the lines were easy to see, the white lines" (P13, visual disability). Another participant with a visual disability further shared that well-maintained pavement features were beneficial to their ability to navigate. This participant explained that white lines present before streetcar tracks: "They go, white line, white line, and as soon as the streetcar tracks, there's nothing there. So, you have to kind of guess where they would be with the white lines because it makes it just easier if you can see the white lines. When the white lines are new, you can actually feel them. Once they have been used for a while, they become worn out and you know" (P14, visual disability, white cane user). In addition to pavement, reliance on functioning APS systems was also highlighted by our participants (particularly those with vision disabilities), as features impacting their street crossing experience. Several participants remarked about their inability to hear the available system, impacting their effective use of the system. During one participant crossing, the research assistant (MP) directed the participant to the APS because the participant could not locate the tone themselves. When the participant was asked how their experience of that specific crossing was, the response was: "Um, it was good, I actually didn't hear the APS system. She told me there was one and so I looked, she directed me, but the volume on it, the locator tone, is very, very low" (P02, visual disability, guide dog user). Another participant also addressed this challenge with the APS: "The volume of the locators they have on the pole can be difficult, so I knew it was there, but with all

the traffic at first, I was having trouble finding it because they have turned it down to a volume that you can't really hear" (P03, visual disability, guide dog user).

The Importance of Design Consistency. Many participants commented on the importance of consistent design elements throughout a single intersection, which created a better, overall experience for them when crossing busy streets. More than half of the participants (58.3%; $n = 14$) discussed positive experiences with consistency in design elements associated with the crossing experience, particularly so for individuals with visual disabilities. As noted by one participant, "To line myself, I can also use the button where the pole is. There's a little arrow and I know if my arm is flush with that, I'm pointing straight to the other side" (P03, visual disability, guide dog user). Another participant remarked on the positive use of tactile domes in street crossing design for their safety and experience, "I can tell if I hit these bumps or domes, I know where the curb is. That helps because I know there's no step there. Or otherwise I have to step off the curb or up the curb on the other side" (P10, mobility disability, mobility cane user). In contrast, when design elements were inconsistent participants reported more challenges and feeling unsafe (62.5%; $n = 15$). This was evident through discussion related to presence versus absence of the accessible design element more generally, and specifically when discussing placement of curb cuts/poles/sound cueing systems and related spatial awareness. When asked about approaching a new intersection and elements to look out for, one participant noted, "A lot of times they put the curb cut right on the corner instead of going straight across the street. And if it's on the corner, that means you go out into the traffic to cross the road which we hate, yes, so I look for where the curb cut is and how steep it is" (P04, mobility, visual, hearing disability, manual wheelchair user). Having consistent presence of the accessibility design element at busy intersections was also discussed, "[specific intersection] is overrun by traffic … they are not adhering to the traffic lights, so they block the pedestrian walkway. So, often, my dog and I, if I can figure out how to cross because there is no through traffic, so I don't have an APS, I don't have through traffic, I try to stop people to ask them, but people are in a hurry … So I often have difficulty crossing" (P02, visual disability, guide dog user).

Participants expect consistent elements across intersections; inconsistencies create safety concerns, such as: "the curb cut [that goes East West, meeting the North South] … there's an unnecessary little bump in between those two separate curb cuts, that's not necessary, so, and it's because the sidewalk is the same color as the pavement. If you're leaving the sidewalk to cross the intersection, you can trip, the wheelchair could like fall off or the same coming the other way, is like my front tire, 'cause you know it's very difficult to gauge perception 'cause you're not expecting that, that little lip" (P08, mobility disability, power wheelchair user). Offering additional thoughts related to consistency in curb cut design, P08 stated: "you are hopefully paying attention, but if you are walking and talking to somebody or most of us are on our phones, and you are expecting that intersection that you're approaching to be similar than the one you are leaving, then that's a problem" (P08, mobility disability, power wheelchair user). Inconsistencies also raise questions for the pedestrian such as: "I guess another little thing that I sometimes wonder, it's a pretty wide intersection, so I'm sometimes halfway through and thinking, shouldn't I be across now or when am I actually going to hit the next curb? And do I have enough time to get across before the light changes?" (P03, visual disability, guide dog user).

The Opportunities and Challenges of Transportation Modes. While examining the effects of multiple modes of transportation (e.g., vehicles, cyclists, public transportation) at major intersections, almost all participants (87.5%; $n = 21$) reported negative outcomes associated with the CS design incorporating multiple transportation modes as a pedestrian. Most of the challenges discussed arise specifically from cyclists, bike lanes, and streetcar tracks. More individuals had trouble navigating these different transport modes than benefiting from them. The nature of these transportation modes themselves poses issues such as, "Cyclists can sometimes be an issue for someone who's blind, like if they are passing too close to you. I've been wacked by a few handle bars because I didn't know they were coming" (P03, visual disability, guide dog user). Another participant, when discussing interactions with cyclists, explained, "Um, I just worry about the bikes. The cars and the vehicular traffic and the streetcars are 99.9% follow the signals to stop. But, with e-scooters and bikes, and these bike lanes, there's, that I mean is 50/50. So I always try to keep that in mind when I see bike lanes" (P08, mobility disability, power wheelchair user). In relation to navigating traffic and streetcars concurrently, another participant stated, "I guess another whole thing that comes up too now is streetcars … it's really hard to know if I can actually safely get to the doors without a car coming in front of me, because you still have that lane of traffic that you have to go through to get to this required door" (P03, visual disability, guide dog user).

In comparison, a few participants (20.8%; $n = 5$) concluded that many transportation modes were favorably manageable, rather than difficult. Depending on the nature of an individual's disability, certain transportation modes may serve as a means of providing guidance

and safety when navigating crossings, or may be perceived more broadly as enhancing convenience, both for pedestrians and for users of the transportation system. When one participant with a visual disability was asked about how different types of transportation affected their mobility and experience when crossing, the participant reflected more broadly on the availability of different transportation modes, not just as a pedestrian: "It positively affects it [their experience] … Sometimes, I come here for a walk, sometimes I'm coming for some work, so I take the bus. Sometimes, the streetcar is not going in my direction. So, if there's multiple transport modes, it's easier and more convenient" (P05, visual disability, while cane user). In addition to the benefit of convenience, a participant noted how the variety of transportation modes can help individuals with disabilities integrate and connect to the community, "It's a positive thing because it gets you out and about. It gets you as part of the community, the only way people with disabilities, whether it's sight loss or being in a wheelchair, are going to feel included, is if we include ourselves. So yeah, I think it's a positive thing" (P17, visual disability, white cane user).

The Interaction of Inclement Weather with Intersection Design. Weather was a notable concern for a majority of participants (87.5%; $n = 21$). No participants stated that the interaction of inclement weather with intersection design could be a possible benefit. Although the study was conducted in dry conditions, questions were probed for insight into the impact of mobility in wet conditions. Many participants commented on the difficult and unsafe conditions of intersections during winter, for example, "If there's too much snow, it's very dangerous because I can't figure out the tactile bar and where there's street level. Even sometimes, I don't know where there is sidewalk, where the finished sidewalk border is" (P05). Another participant stated, "I could say more about intersections with snow. It's probably more lining up, so when I get to the intersection, if they've kind of piled the snow right in front of the curb or the pole, I'm left kind of having to figure out where to stand and how to line up, and then not being able to get the audible signal activated" (P03, visual disability, guide dog user). With an increased amount of snow on the ground, navigating to find important landmarks and features that allow for mobility in people with disabilities was a challenge. Participants also incorporated their personal recommendations for safety when speaking about their experiences, "Maybe the paintings of the zebra lines can be with a different material or with different painting stuff, so it is not very slippery. Because, sometimes when it's wet and where there is snow and ice, it can be very slippery when you are crossing" (P01, mobility disability, mobility cane user). Put simply, "The winter is always worse than the summer" (P21, visual disability, white cane user).

Discussion

The current study explored CS challenges and opportunities derived from the diverse experiences of individuals with disabilities utilizing the CS design. Qualitative interviews were conducted with all participants, allowing for increased knowledge and new insights on how accessibility and transportation design features at an intersection play a key role in shaping their experiences. Overall, a greater number of participants reported negative experiences associated with maintenance by the City of Toronto, multiple transportation modes creating difficulty when navigating, and winter weather creating obstacles to navigate seamlessly across a CS. Positive experiences were associated with consistent intersection design, providing familiarity for people with disabilities when crossing at different intersections.

Theme 1 noted that intersection design elements require regular and timely city maintenance to ensure safety among individuals at CS, a finding which has been previously shown to not be exclusive to those with disabilities (*8*). The results derived from our study indicate that poor city maintenance can negatively affect a user's confidence when navigating through structural barriers. Current intersection design features intended to support people with disabilities are generally perceived as helpful; however, ongoing maintenance and periodic upgrading of materials and technical systems are essential to ensure safety and sustain positive user experiences (*26*). A previous study researching the street crossing behaviors of individuals with disabilities found that inconsistent pavement and physical items located on streets caused significant safety issues affecting accessibility (*27*). In addition, Pecchini and Giuliani (*27*) demonstrate that intersection features are not always physical obstacles; rather, design-related challenges can also adversely affect individuals with disabilities. Consistent with this past work, our findings reveal that interactions with, or reliance on, certain design elements created difficulties for some participants when not properly maintained, contributing to the broader understanding of the complexities involved in intersection design and impact on pedestrians. Addressing identified issues through improved maintenance policies can create increased safety and perception of safety for those with disabilities (*27*).

Consistent pedestrian infrastructure design is shown to be essential for supporting safe, predictable navigation for people with disabilities (*28*, *29*). Aligning with this previous work, the experiences captured by Theme 2 highlight challenges for people with disabilities when experiencing inconsistencies in street crossing elements, a

finding consistent with our two intersections evaluated. Design consistency can refer to uniformity in how elements at an intersection are constructed, but it can also refer simply to whether the element is present at all to support safe pedestrian navigation. When considering the latter, Routhier et al. (*28*) have discussed that the presence versus absence of the design element (in this case APS cueing system) is a greater benefit than uniformity of the system. This was an insight that was also reflected among the visually impaired participants in our study. Design consistency is also necessary for individuals with disabilities to minimize physical and cognitive effort when crossing pavement, navigating raised curbs, and sidewalks (*29*). For example, people need to be able to anticipate where streetcar tracks begin to ensure a safe crossing over them. Inconsistency in design elements creates several barriers for individuals, ultimately shaping a negative experience when crossing an intersection. This can lead to disorientation and confusion, creating unsafe circumstances and a lack of confidence when navigating a busy intersection on their own (*29*). Our study shows that if intersections are designed consistently, even if the individual with a disability does not have previous experience navigating that specific intersection, it will result in a positive and safer experience.

As captured in Theme 3, CS that incorporate many types of transportation can present numerous difficulties for all individuals. For those with visual impairment, managing multiple transportation modes can create heightened anxiety (*30*, *31*). This concern of multitransportation modes was not exclusive to those with visual impairment, and was a shared sentiment for wheeled mobility device users as well. The experiences recorded in this study display how managing potentially cars, streetcars, bicycles, pedestrians, buses at once can pose safety threats while at an intersection (*30*). Our findings also underscore the challenges streetcar tracks pose for individuals using mobility aids such as white canes or wheelchairs. Similar to our findings, Buliung et al. (*32*) identified streets, intersections, crosswalks, and bike lanes as moderate barriers. Conversely, multimodal transportation can enhance confidence when crossing by offering directional cues from vehicles and auditory signals. However, as highlighted by previous work, this potential benefit may be offset by the increased use of hybrid or electric vehicles, which are typically quieter than their gas-powered counterparts (*33*) and should be investigated further.

Lastly, the evidence derived from Theme 4 amplifies the need for maintenance in winter conditions, as we highlight reliance on street crossing design elements for individuals with disabilities and negative experiences in inclement weather conditions. Although the study was conducted under dry conditions, participants were queried about their experience with similar intersection features under wet, snowy, or icy conditions. While not exclusive to CS design, physical barriers are present at street crossings throughout the city during winter months, which impede mobility for individuals using mobility devices and contribute to unsafe travel conditions (*34–37*). Participants in our current study also emphasized the challenges posed by snow piles and wet or slippery surfaces, supporting existing literature that winter conditions create barriers and compromise safety. As such, enhanced pedestrian safety measures and improved winter maintenance practices should be prioritized in cities where adverse weather substantially deteriorates road and sidewalk conditions.

A CS design should follow a "nothing about us without us" approach, as outlined in the Accessible Canada Act, which emphasizes the active involvement of people with disabilities in identifying, preventing, and removing barriers (*38*). This study contributes to the identification process, with participants serving as unique experts in how they navigate intersections. Therefore, CS design requires a collaborative approach to effectively design accessible intersections in the future that consider the user's experience.

Limitations

This study has several limitations, which may have contributed to the experiences that were recorded. First, all participants volunteered for the study and may reflect a certain type of person (e.g., outspoken, confident) and not representative of all people with disabilities. Second, this study only assessed two major CS intersections in Downtown Toronto. No formal comparison between Intersection A and B was completed to confirm that the two crossings were not significantly different from each other in relation to experiences reported. However, features included at both intersections were notably similar. Third, key participant characteristics such as disability type, age, aid/device use, and other demographic or contextual factors were not systematically considered in the analyses, which may have influenced the findings. Fourth, participants were asked to recall their experiences of wet or winter conditions, limiting the ability to fully apply a "go-along interview" approach for those themes. Finally, as the intersections were active, variability in environmental factors (e.g., vehicle and pedestrian traffic density, time of day, ambient sound, and lighting levels) likely influenced participant experiences in ways that could not be standardized.

Implications and Future Directions

Similar to other cities worldwide, the City of Toronto has developed CS guidelines, outlining their general

approach to street design and creating accessible environments for those who require them (*26*). Within these guidelines, several design elements, including curb ramps, tactile surface indicators, and APS signals, were mentioned to provide overall safety while using intersections (*26*). However, recommendations to ensure these elements are maintained over time and under varying weather conditions were not addressed. To support long-term accessibility, maintenance guidelines should be developed. In alignment with this study's findings, the City of Toronto should then adopt such guidelines to enhance accessibility for people with disabilities. These recommendations could then inform similar efforts across other cities in Ontario, Canada, and North America. A valuable future direction would be to replicate the current study under rainy or snowy conditions, to understand the full scope of the experiences in wet weather conditions. This study provides critical insights for improving CS intersection design by directly incorporating the perspectives of people with disabilities. Embedding these findings into design guidelines and urban planning practices can enhance safety and accessibility during street crossings. Moreover, the results can inform future legislation to ensure disability perspectives are systematically integrated into policy and decision-making.

Conclusions

This is the first study to consider the lived experiences of people with disabilities and design of street crossing features at CS intersections. Understanding the connection between intersection design and the lived experiences of people with disabilities is essential to informing inclusive urban planning. The influence of street crossing design on mobility highlights the urgent need for urban designers and city officials to implement inclusive design and maintenance practices. Accommodating the needs of people with disabilities will allow for the extension of accessible public spaces throughout Canada.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: all authors; data collection: Mara Primucci and Sin-Tung Lau; analysis and interpretation of results: Mara Primucci, Sin-Tung Lau, Pauli Gardner, Jordana Maisel, and Alison Novak; draft manuscript preparation: Mara Primucci, Iris Levine, and Alison Novak. All authors reviewed the results and approved the final version of the manuscript.

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References

1. Forster, G. K., L. E. Aarø, M. N. Alme, T. Hansen, T. S. Nilsen, and Ø. Vedaa. Built Environment Accessibility and Disability as Predictors of Well-Being among Older Adults: A Norwegian Cross-Sectional Study. *International Journal of Environmental Research and Public Health*, Vol. 20, No. 10, 2023, p. 5898. https://doi.org/10.3390/ijerph20105898
2. Statistics Canada. The Accessibility Experiences of Canadians with Disabilities, 2017. https://www150.statcan.gc.ca/n1/daily-quotidien/211027/dq211027d-eng.htm. Accessed September 29, 2025.
3. Clarke, P., J. A. Ailshire, M. Bader, J. D. Morenoff, and J. S. House. Mobility Disability and the Urban Built Environment. *American Journal of Epidemiology*, Vol. 168, No. 5, 2008, pp. 506–513. https://doi.org/10.1093/aje/kwn185
4. Baernholdt, M., I. Hinton, G. Yan, K. Rose, and M. Mattos. Factors Associated with Quality of Life in Older Adults in the United States. *Quality of Life Research: An International Journal of Quality of Life Aspects of Treatment, Care and Rehabilitation*, Vol. 21, No. 3, 2012, pp. 527–534. https://doi.org/10.1007/s11136-011-9954-z
5. Baernholdt, M., G. Yan, I. Hinton, K. Rose, and M. Mattos. Quality of Life in Rural and Urban Adults 65 Years and Older: Findings from the National Health and Nutrition Examination Survey. *The Journal of Rural Health*, Vol. 28, No. 4, 2012, pp. 339–347. https://doi.org/10.1111/j.1748-0361.2011.00403.x
6. Glass, T. A., and J. L. Balfour. Neighborhoods, Aging, and Functional Limitations. In *Neighborhoods and Health* (I. Kawachi and L. F. Berkman, eds), Oxford University Press, New York, NY, 2003, pp. 303–334.
7. Li, Y., and G. Fernie. Pedestrian Behavior and Safety on a Two-Stage Crossing with a Center Refuge Island and the Effect of Winter Weather on Pedestrian Compliance Rate. *Accident Analysis & Prevention*, Vol. 42, No. 4, 2010, pp. 1156–1163. https://doi.org/10.1016/j.aap.2010.01.004
8. Li, Y., J. A. Hsu, and G. Fernie. Aging and the Use of Pedestrian Facilities in Winter—The Need for Improved Design and Better Technology. *Journal of Urban Health*, Vol. 90, No. 4, 2013, pp. 602–617. https://doi.org/10.1007/s11524-012-9779-2
9. Ytterstad, B. The Harstad Injury Prevention Study: The Characteristics and Distribution of Fractures Amongst

Elders–An Eight Year Study. *International Journal of Circumpolar Health*, Vol. 58, No. 2, 1999, pp. 84–95.
10. Seetharaman, K., A. Mahmood, F. Rikhtehgaran, G. Akbarnejad, F. Chishtie, M. Prescott, A. Chung, and W. B. Mortenson. Influence of the Built Environment on Community Mobility of People Living with Visual Disabilities: A Scoping Review. *Urban Planning and Transport Research*, Vol. 12, No. 1, 2024, p. 2296891. https://doi.org/10.1080/21650020.2023.2296891
11. Bas, J., M. B. Al-Khasawneh, S. Erdoğan, and C. Cirillo. How the Design of Complete Streets Affects Mode Choice: Understanding the Behavioral Responses to the Level of Traffic Stress. *Transportation Research Part A Policy and Practice*, Vol. 173, 2023, p. 103698. https://doi.org/10.1016/j.tra.2023.103698
12. City of Toronto. Complete Streets Overview. https://www.toronto.ca/services-payments/streets-parking-transportation/enhancing-our-streets-and-public-realm/complete-streets/overview/. Accessed September 29, 2025.
13. Curtis, C. Completing Our Streets: The Transition to Safe and Inclusive Transportation Networks. *Urban Policy and Research*, Vol. 33, No. 1, 2015, pp. 120–122. https://doi.org/10.1080/08111146.2014.967442
14. McCann, B. *Completing Our Streets: The Transition to Safe and Inclusive Transportation Networks*. Island Press/Center for Resource Economics, Washington, D.C., 2013.
15. Donais, F. M., I. Abi-Zeid, E. O. D. Waygood, and R. Lavoie. Assessing and Ranking the Potential of a Street to be Redesigned as a Complete Street: A Multi-Criteria Decision Aiding Approach. *Transportation Research Part A: Policy and Practice*, Vol. 124, 2019, pp. 1–19. https://doi.org/10.1016/j.tra.2019.02.006
16. Gamache, S., F. Routhier, E. Morales, M.-H. Vandersmissen, N. Boucher, B. J. McFadyen, and L. Noreau. Methodological Insights into the Scientific Development of Design Guidelines for Accessible Urban Pedestrian Infrastructure. *Journal of Urban Technology*, Vol. 27, No. 1, 2020, pp. 87–105. https://doi.org/10.1080/10630732.2019.1632677
17. Deliali, A., N. Campbell, M. Knodler, and E. Christofa. Understanding the Safety Impact of Protected Intersection Design Elements: A Driving Simulation Approach. *Transportation Research Record: Journal of the Transportation Research Board*, 2020. 2674(3): 179–188. https://doi.org/10.1177/0361198120909382
18. Scott, A. C., K. N. Atkins, B. L. Bentzen, and J. Barlow. Perception of Pedestrian Signals by Pedestrians with Varying Levels of Vision. *Transportation Research Record: Journal of the Transportation Research Board*, 2012. 2299: 57–64.
19. Wall, R. S., D. H. Ashmead, B. L. Bentzen, and J. Barlow. Directional Guidance from Audible Pedestrian Signals for Street Crossing. *Ergonomics*, Vol. 47, 2004, pp. 1318–1338.
20. Bentzen, B. L., J. Barlow, and D. Gubbe. Locator Tones for Pedestrian Signals. *Transportation Research Record: Journal of the Transportation Research Board*, 2000. 1705: 40–42.
21. McCann, B., and S. Rynne. Complete Streets: Best Policy and Implementation Practices. *Planning Advisory Service Report Number 559*, American Planning Association, Chicago, IL. 2010.
22. Smith Lea, N., R. Mitra, P. Hess, B. Quigley, and N. Loewen. *Complete Street Transformations in the Greater Golden Horsehoe Region*. Clean Air Partnership, Toronto. https://www.completestreetsforcanada.ca/wp-content/uploads/2019/01/CompleteStreetTransformations_web-1.pdf. Accessed September 29, 2025.
23. Toronto Centre for Active Transportation. Understanding Complete Streets in the Greater Golden Horseshoe | 2014–2015. https://tcat.ca/project/understand-complete-streets-in-the-greater-golden-horseshoe/. Accessed September 29, 2025.
24. Gardner, P. The Role of Social Engagement and Identity in Community Mobility Among Older Adults Aging in Place. *Disability and Rehabilitation*, Vol. 36, No. 15, 2014, pp. 1249–1257. https://doi.org/10.3109/09638288.2013.837970
25. Gardner, P. MAPx (Mobility Aid Personalization): Examining Why Older Adults 'Pimp Their Ride' and the Impact of Doing So. *Disability and Rehabilitation. Assistive Technology*, Vol. 12, No. 5, 2017, pp. 512–518. https://doi.org/10.3109/17483107.2016.1158327
26. City of Toronto. *Toronto Complete Streets Guidelines*, 1st ed., Vol. 1.City of Toronto, Toronto, ON, 2017.
27. Pecchini, D., and F. Giuliani. Street-Crossing Behavior of People with Disabilities. *Journal of Transportation Engineering*, Vol. 141, No. 10, 2015, p. 04015022. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000782
28. Routhier, F., J. Lettre, C. Pigeon, D. Fiset, V. Martel, R. Binet, V. Vézina, et al. Evaluation of Three Pedestrian Phasing with Audible Pedestrian Signals Configurations in Quebec City (Canada): An Exploratory Study of Blind or Visually Impaired Persons' Sense of Safety, Preferences, and Expectations. *Disability and Rehabilitation*, Vol. 46, No. 8, 2024, pp. 1534–1546. https://doi.org/10.1080/09638288.2023.2200260
29. Hatzakis, T., L. Alčiauskaitė, and A. König. The Needs and Requirements of People with Disabilities for Frequent Movement in Cities: Insights from Qualitative and Quantitative Data of the TRIPS Project. *Urban Science*, Vol. 8, No. 1, 2024, p. 12. https://doi.org/10.3390/urbansci8010012
30. Cushley, L., N. Galway, and T. Peto. The Unseen Barriers of the Built Environment: Navigation for People with Visual Impairment. *Town Planning Review*, Vol. 94, No. 1, 2023, pp. 11–35. https://doi.org/10.3828/tpr.2022.4
31. Gustafson-Pearce, O., E. Billett, and F. Cecelja. Perceptual Impact of Environmental Factors in Sighted and Visually Impaired Individuals. https://journals.sagepub.com/doi/10.1177/0264619605051720. Accessed September 29, 2025.
32. Buliung, R., J. Niece, and R. Solomon. Toward an Understanding of Disabled Persons' Satisfaction with Pedestrian Infrastructure in Toronto, Canada. *Transport Findings*, September 2024.
33. Lakoud, M., E. Morales, A. Ruiz-Rodrigo, I. Feillou, S. Mathieu, and F. Routhier. Enhancing Shared Street Accessibility in Heritage Sites for Individuals with Visual Disabilities: A Canadian Perspective. *Frontiers in Rehabilitation Sciences*, Vol. 5, 2024, p. 1419446. https://doi.org/10.3389/fresc.2024.1419446

34. Morales, E., S. Gamache, and G. Edwards. Winter: Public Enemy #1 for Accessibility Exploring New Solutions. *Journal of Accessibility and Design for All*, Vol. 4, No. 1, 2014, pp. 30–52. https://doi.org/10.17411/jacces.v4i1.57
35. Morales, E., S. Lindsay, G. Edwards, L. Howell, C. Vincent, N. Yantzi, and V. Gauthier. Addressing Challenges for Youths with Mobility Devices in Winter Conditions. *Disability and Rehabilitation*, Vol. 40, No. 1, 2018, pp. 21–27. https://doi.org/10.1080/09638288.2016.1239768
36. Ripat, J., and A. Colatruglio. Exploring Winter Community Participation Among Wheelchair Users: An Online Focus Group. *Occupational Therapy in Health Care*, Vol. 30, No. 1, 2016, pp. 95–106. https://doi.org/10.3109/07380577.2015.1057669
37. Ripat, J., C. L. Brown, and K. D. Ethans. Barriers to Wheelchair Use in the Winter. *Archives of Physical Medicine and Rehabilitation*, Vol. 96, No. 6, 2015, pp. 1117–1122. https://doi.org/10.1016/j.apmr.2015.01.020
38. Parliament of Canada. Accessibility at the Office of the Conflict of Interest and Ethics Commissioner. https://ciec-ccie.parl.gc.ca/en/About-APropos/Pages/Accessible.aspx. Accessed September 29, 2025.