Perceptions of Comfort and Safety for Non-Motorized Road User Interactions in Vancouver

Report prepared for City of Vancouver

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Executive Summary

Background and objectives

The City of Vancouver recently completed the implementation of Phase 1 of the 10th Avenue Health Precinct Street Improvements. City staff held meetings with the 10th Avenue Evaluation Committee members to establish the scope of follow up analysis to evaluate the project's impacts. During these meetings, several Committee members raised the issue of interactions between people walking and people using different modes of transportation, particularly seniors and persons with disabilities, while navigating the recently rebuilt portion of 10th Ave. between Willow Street and Oak Street. City staff partnered with local researchers with expertise in this field to investigate those interactions. This project's objectives were to (a) determine the frequency of road user interactions in the 10th Ave. project area and at other sites in the city with similar characteristics; (b) investigate the perceptions of different groups of stakeholders on non-compliant, uncomfortable, and unsafe interactions; and (c) examine systematic differences in perceptions of interactions among stakeholders.

Overview of methods

The study framework is summarized in Figure 1. Video data, collected between September and December of 2019, were used to capture road user volumes and interactions between road users at 7 crosswalks along 10th Ave, and at 4 comparison sites. Video clips of 84 sample pedestrian crossings were rated in a web survey by three pools of participants: the general public, 10th Avenue Evaluation Committee members, and traffic safety experts. Video data and survey results were combined to understand broad perceptions of typical crossing experiences. On-site interviews with Committee members were used to qualitatively characterize perceptions of safety in further depth and inform the rating scales used in the web survey.

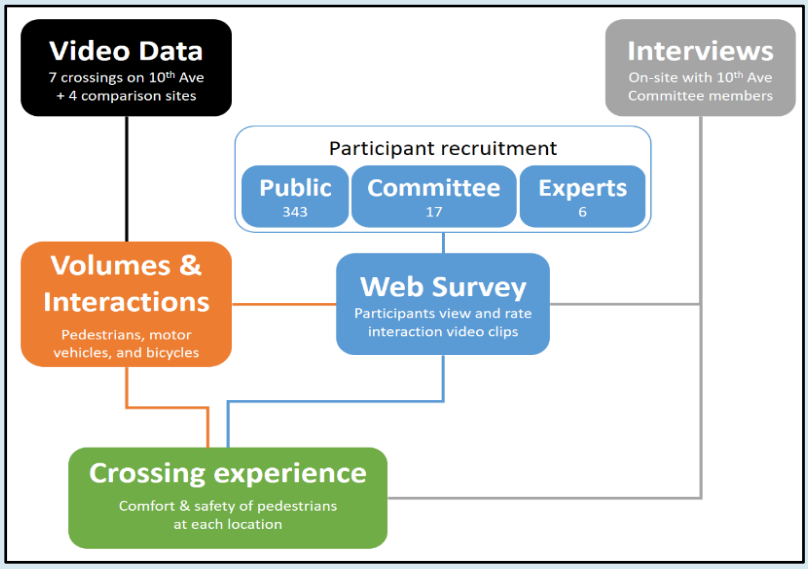

Figure 1. Study methods

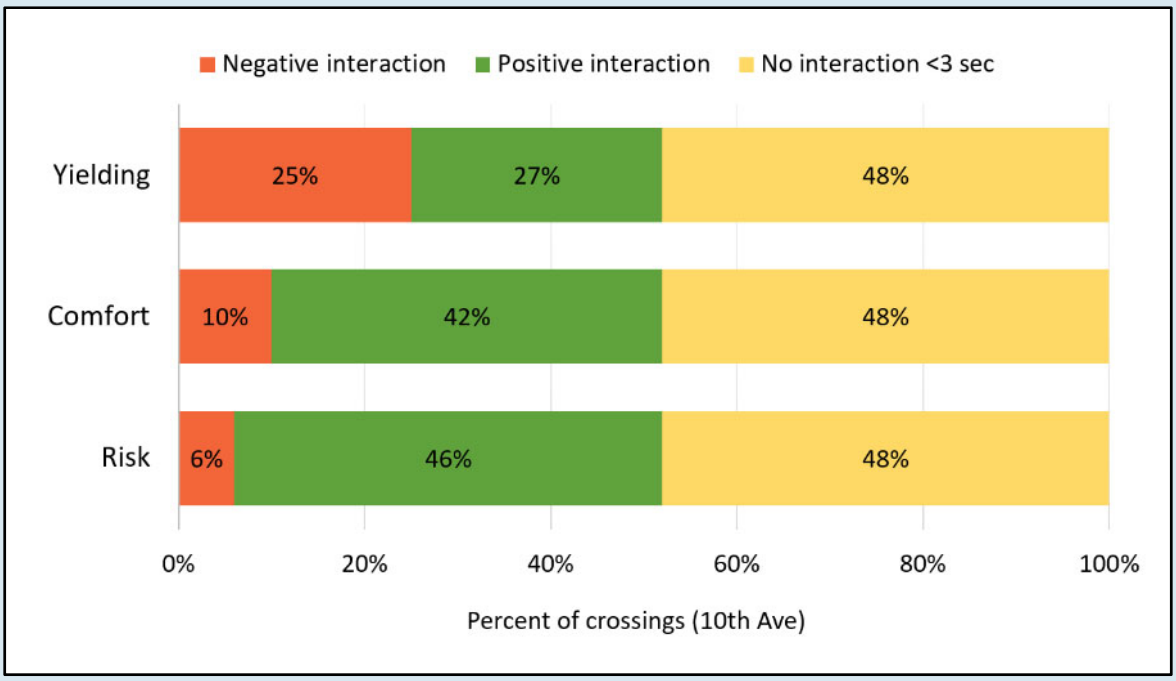

Figure 2. Overall pedestrian crossing experience at 10th Ave. crosswalks (negative/positive interactions indicate predicted disagreement/agreement that there was adequate yielding, that the pedestrian was comfortable, and that there was low risk of injury for the pedestrian);
A quarter of crossing pedestrians experience a negative interaction from the perspective of yielding, while 10% experience an interaction that was not comfortable and 6% that was not low risk.

Key findings

- **Most crossings were perceived as "low risk" (94%) and "comfortable" (90%)**, although 25% of crossings involved inadequate yielding (rated as "should have yielded", but did not) – see Figure 2.
- Pedestrian **interactions with bicycles are more comfortable and lower risk** than interactions with motor vehicles. This finding may be explained by the size difference between bicycles and motor vehicles and easier visual communication between pedestrians and cyclists. Rates of inadequate yielding are similar in pedestrian interactions with either motor vehicles or bicycles. In otherwise similar interactions, cyclists are much more likely to be perceived as not needing to yield than drivers.
- With high volumes of people walking, driving, and cycling, 10th Ave has **high interaction rates** during weekdays. Just over half of pedestrian crossings involved an interaction (defined from the survey results as another road user passing within 3 seconds before or after a crossing pedestrian).

- The observation sites along 10th Ave. have **higher yielding rates and lower risk** than the comparison sites. However, these effects are partially offset by longer crossings, higher volumes, and closer interactions along 10th Ave.
- Perceptions of yielding, comfort, and safety **do not vary significantly with a rater's socio-demographics** (age, gender, income, education), but perceptions do vary with a rater's travel habits. People who walk more frequently rate pedestrian comfort as lower. People who cycle more frequently rate risk as lower (including for pedestrian interactions with motor vehicles).
- There are no significant differences in perceptions of yielding, comfort, and safety between members of the public and Committee members who participated in the survey. The traffic safety experts have similar views of yielding and comfort to the Public and Committee pools, but a consistently **lower assessment of risk for pedestrians** in interactions with motor vehicles and bicycles.
- Interactions involving **more vulnerable pedestrians (children, mobility impaired) are perceived as higher risk** but there were no significant differences for the other severity outcomes of comfort or yielding. This finding is supported by the interview result that comfort and safety are distinct constructs and mobility aids may not affect assessed comfort.
- Perceptions of yielding are most strongly based on whether the pedestrian passed first, rather than specific manoeuvres by the other road user (i.e., visible slowing). Legal definitions of right-of-way and yielding are neither well-known nor considered of main importance, based on the interview results.

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1 Introduction

1.1 Background

The City of Vancouver recently completed the implementation of Phase 1 of the 10th Avenue Health Precinct Street Improvements (see Council report[1] for full background). Based on significant public and stakeholder feedback since the project began, City staff are confident that the final recommended design is a significant improvement over existing conditions. However, given the scale of changes being made to the street, it is difficult to predict all possible outcomes and inevitably some adjustments may be required. As part of the execution of the 10th Avenue Health Precinct Street Improvements, City of Vancouver staff committed before Council to "ongoing improvements and issue resolution, including establishing a 10th Avenue Evaluation Committee to evaluate the project's impact following implementation and recommend spot improvements" (identified as "Action 10" in the Council report). Following Council approval of the project, staff finalized Terms of Reference for an Evaluation Committee and held meetings with Committee members to establish the scope of follow up analysis. Through this engagement with Committee members, several raised the issue of interactions between people walking and cycling as a particular concern. As such, City staff sought to give special attention to this issue in a transparent manner by working with local researchers with expertise in this field.

1.2 Objectives

The objectives of this project were to:

1. Determine the concerns of pedestrians, particularly seniors and persons with disabilities, in navigating the recently rebuilt portion of 10th Ave. between Willow Street and Oak Street, hereafter the 10th Avenue Hospital Zone (TAHZ)
2. Determine the frequency of road user (pedestrian, cyclist, and motorist) interactions in the TAHZ, as well as at comparable sites in the city,
3. Determine the frequency of non-compliant, uncomfortable, and unsafe interactions, as perceived by different groups of stakeholders, and
4. Examine systematic differences in the perceptions of interactions among stakeholders.

1.3 Overview of study methods

The project objectives required a unique analysis approach. Traditional traffic safety analysis has limited application in this context due to a reliance on crash data or vehicle-oriented conflict approaches. In addition, expert evaluations of comfort and safety may not reflect public perspectives on road-user interactions. Even within the traffic professional context, there are unclear and inconsistent definitions of when road users have interacted and yielded. The study methods were developed with the intention of understanding a broad range of perspectives, recognizing the subjective nature of comfort and safety perception.

The study framework is summarized in Figure 3 – more detailed information is given in the subsequent sections of this report. Video data were used to gather information on traveller volumes and interactions at seven pedestrian crosswalks in the study area and four nearby comparison sites. Volumes and interactions were recorded for six hours (8-10hr, 11-13hr, 16-18hr) on one mid-week day at each

[1] https://council.vancouver.ca/20170516/documents/rr4.pdf

location. Video data from second and third days (over the same hours) were added if the number of recorded pedestrian crossings at any site was less than 200.

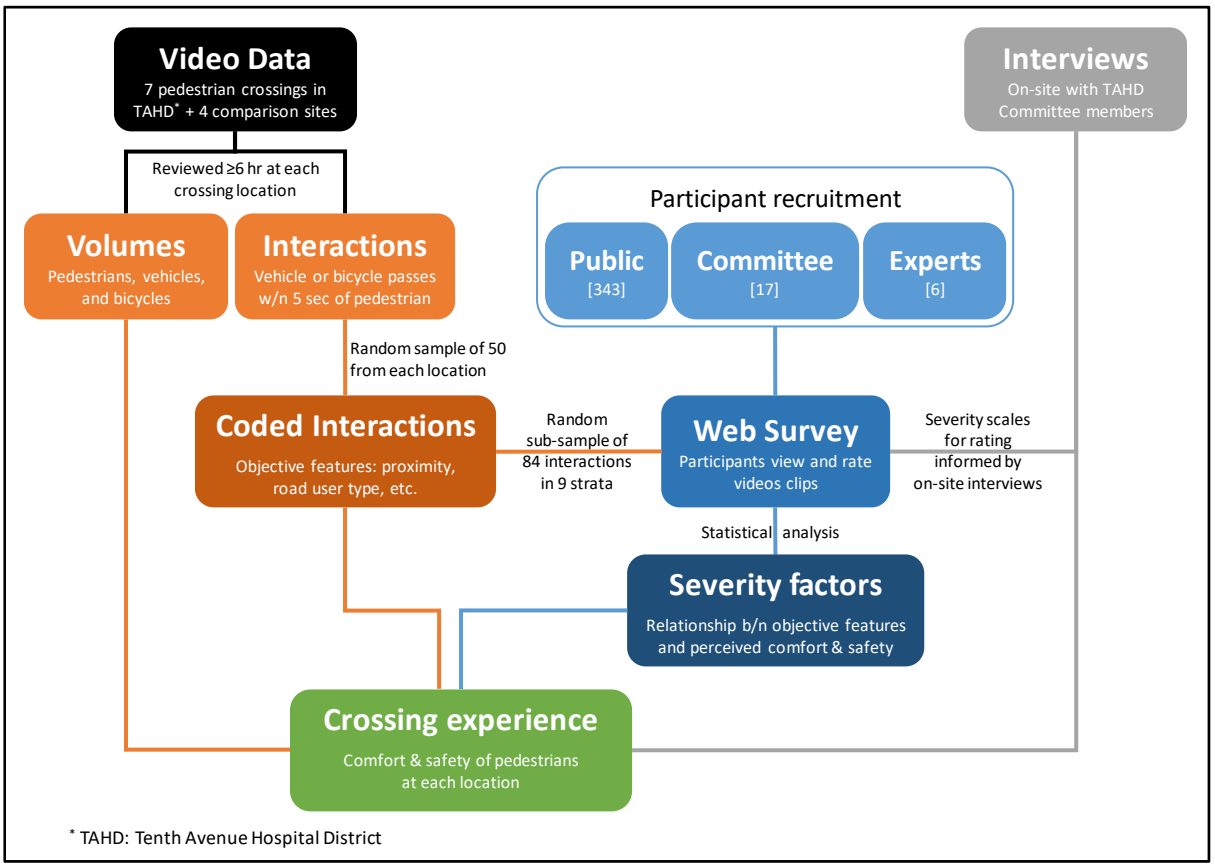

Figure 3. Study framework

Identification of interacting road users was based on passing time[2], as illustrated in Figure 4. For two road users on intersecting paths that cross at a conflict point, the passing time is the time gap between when the first road user exits the conflict point and when the second road user enters it. ***Potential interactions*** were initially defined using a conservative threshold of under 5-seconds passing time. As described in subsequent sections, that initial threshold was later refined to a data-driven 3-seconds interaction threshold based on the survey results.

Objective features (passing time, whether the pedestrian or other road users passed the conflict point first, the pedestrian location when the other road users entered the crosswalk, etc.) were coded for 50 randomly-selected sample crossings from each location (if available – fewer than 50 crossings were recorded at one location). The 536 sample crossings were then separated into nine strata based on passing time and interacting road user type (vehicle/bicycle), and 84 were extracted (randomly by strata) for use in the web survey.

[2] Referred to as "Post Encroachment Time" in the traffic safety literature

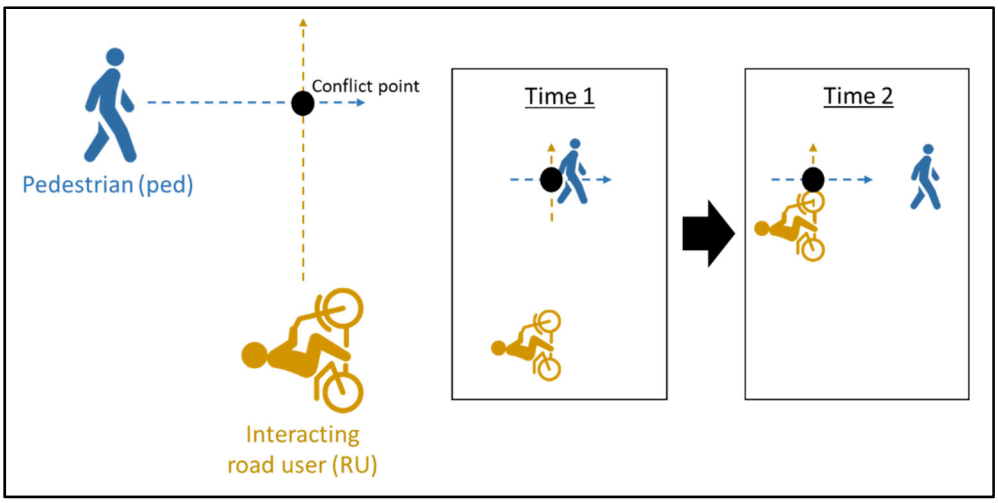

Figure 4. Illustration of passing time for identification of road user interactions

Three pools of participants were recruited for the web survey: 343 from the general public, 17 from the 10th Avenue Evaluation Committee, and six traffic safety experts from outside of British Columbia. The survey participants viewed a stratified sample of 15 of the 84 videos (except for the Experts, who viewed all 84), and rated them on four scales of severity[3] using the questions:

1. The [driver/cyclist] yielded to the pedestrian.
2. The [driver/cyclist] ***should*** have yielded to the pedestrian.
3. The pedestrian felt comfortable in this crossing.
4. The risk of injury for the pedestrian in this crossing was low.

Statistical analysis was then used to investigate: 1) agreement on interaction severity within and between the participant pools, and 2) objective determinants of perceived severity levels. Statistical models were generated from the survey data to predict interaction severity from the coded interaction features. These severity prediction models were then applied to characterize the interaction severity at each location (based on the ~50 sample interactions by location). Finally, the full set of volume and interaction data were combined with the severity information to assess the crossing experience of pedestrians at each location. The assessment gave the expected fraction of pedestrians experiencing no interaction, a positive interaction, or a negative interaction (meaning most people would disagree that it was comfortable or low risk).

On-site interviews with nine members of the 10th Avenue Evaluation Committee were used to 1) characterize perceptions of safety in the TAHZ, 2) inform the wording of the severity scales used in the web survey, and 3) verify the findings of the statistical analysis with qualitative information. The research methods were approved by the Behavioural Research Ethics Boards of the University of British Columbia and Simon Fraser University, under approval H18-03637.

[3] As “Strongly disagree”, “Somewhat disagree”, “Somewhat agree”, “Strongly agree”, or “I don’t know”

2 On-site interviews

The entire 10th Avenue Evaluation Committee was invited to take part in on-site interviews in February and March, 2019. The 30-45 minute semi-structured interviews were led by two study team members (M. Winters and K. Hosford) and took place on-site[4] in the TAHZ. First, the interviewee's general concerns about street activity in the area were examined with the prompt: "What are your general concerns along the corridor?" Second, locations with perceived conflicts among road users were identified with the prompt: "Are there specific areas that you have concerns about?" The interviewers and interviewees then watched and discussed some interactions, and interviewees were prompted to evaluate the interactions in terms of a set of draft severity scales (see Appendix C: Interaction Severity Scales for a description of the draft scales). Comprehension and clarity of the draft scales were explored with the prompt: "Were these easy to understand? Did you have any challenges in answering them?" Nine Committee members took part in the interviews (seven on-site and two by phone/e-mail).

2.1 Summary of observations

The general comments on safety in the redesigned portion of the 10th Ave. Hospital Zone can be summarized as below. Location-specific results are summarized in Appendix H: Location-specific on-site interview results. Overall points:

- There is an **overall improvement** in the area, with more awareness and delineation of where people should be, and a perception of slower speeds.
- **Wayfinding** is good in the redesigned corridor, and especially helpful for out-of-town visitors.
- **Complexity**: there is a lot of activity in the street area, but changes are an improvement and for the most part it is clear where people are supposed to go.
- **Many of the existing challenges are inherited** (Hospital emergency access, street geometry at Laurel St., etc.), and the new design is an improvement.
- During **construction,** traffic control personnel (i.e. "flaggers") were exceptional and a model for future city projects (with the exception of a comment about smoking).
- **Inherent conflicts** in the design features that accommodate users with different needs is a continuing challenge (e.g., people using wheelchairs and people with guide dogs).
- The **phased approach** taken by the City created problems in terms of infrastructure discontinuity at the edges.
- Pedestrian jaywalking may suggest the need for **mid-block crosswalks**. Additional crosswalks for pedestrians with mobility limitations may also be needed.
- Significant numbers of users are not familiar with the corridor (e.g., **visitors to the area**), which creates additional challenges.

[4] Members were also able to respond to the interview prompts with written or verbal answers off-site.

The in-the-field interviews also enabled observation of specific crossing and interactions. The following points are a summary of the discussion of interactions observed during interviews, from the perspectives of the interviewees:

- **Eye contact and non-verbal communication** are important in negotiating the complex road user environment. This may be easier between pedestrians and people bicycling, rather than people in cars.
- Many pedestrians **gave way** to bikes and cars at crosswalks, even if they have the legal right-of-way.
- Virtually all the observed interactions were **considerate.**
- The **travel speeds** at mid-day time periods were very slow.
- **Pick-up/drop-off** zones were perceived to be working well, with minimal conflicts.
- **Driveways** are interaction zones of concern (in addition to the intersections and marked crosswalks), based on field observations and past experience of interviewees.

2.2 Evaluation of draft severity scales

The interviews provided an opportunity to test question wording for the online survey, and concepts of yielding, comfort, and safety. In rich conversations with the Committee members, we learned:

- The strict legal requirements for right-of-way and yielding were not well known and not considered highly important.
- The simple yielding question (i.e., "Did the cyclist yield to the pedestrian?") was clear and easy to answer. It included multiple dimensions of a complex social interaction and was not perceived as law-based but more behavioural (slowed, went around, allowed to pass, etc.).
- "Careful", "Respectful", and "Considerate" were considered too subjective of terms.
- Comfort and Safety were distinct constructs: comfort was perceived as a subjective characteristic and in the mind of the pedestrian, whereas safety was an external/objective characteristic of an interaction; mobility aids did not seem to affect 3rd-person assessed comfort.
- The wording of the Comfort scale was important – particularly whether they were meant to try to empathize with or infer an observed pedestrian's personal experience.
- Risk of collision and risk of injury were both perceived as equivalent to safety.
- Some interviewees felt the researchers were "over-thinking" the wording.

3 Video data collection and coding

Video data were collected at 11 locations (camera scenes) for three days each, and provided by the City to the research team: seven crosswalks in the recently redesigned portion of the TAHZ and four crosswalks at comparison sites. Recorded video dates ranged from September 25 to December 5, 2019. The names of all 11 crosswalks and their still images from the video data are given in Appendix A: City coding of volumes and interactions in video data. Video data were reviewed, and volume and interaction counts were recorded in 15-minute intervals by the City for six hours (8-10hr, 11-13hr, 16-18hr) per location on a single weekday. A target sample of 200 pedestrian[5] crossings at each location was established. Validity tests conducted by the research team for the City-coded video data are described in Appendix A: City coding of volumes and interactions in video data.

Table 1 gives the data extent and mean hourly counts and interactions by location. Because the approach from only one direction was visible in each video scene, only interactions from that traffic were recorded and considered for further analysis. The same traffic directions were used for counts. Pedestrians crossing in both directions were included in the counts and interactions. In total, in 80 hours of coded video data, almost 14,000 road users were counted at 10th Ave. sites and 5,000 at comparison sites. The overall road user mix counted at the 10th Ave. sites was 37% pedestrians, 39% vehicles, and 24% bicycles - although the comparison is imprecise because not all movements were recorded. The volumes varied substantially by time of day, travel mode, and location (see Appendix A: City coding of volumes and interactions in video data for details).

Table 1. Summary of volume and interaction counts

Location	Number of (15-min) intervals	Crossing pedestrians	Vehicle counts	Bicycle counts	Interactions with vehicles	Interactions with bicycles
		(mean, per hour)				
Main 10th Ave sites (x6)	144	116	162	71	70	28
Laurel North & 10th (East)	24	98	168	77	72	26
Laurel North & 10th (West)	24	144	139	79	75	43
Laurel South & 10th (East)	24	40	139	77	27	14
Laurel South & 10th (West)	24	84	180	63	40	13
Willow & 10th (West)	24	161	173	67	138	37
Willow & 10th (East)	24	169	171	67	70	35
Arthritis Centre	72	13	0	77	0	5
Comparison sites (x4)	105	109	58	21	25	6
Heather & 11th	24	49	147	22	31	8
Laurel & 7th	24	69	24	29	6	9
Haro & Bute	24	298	41	5	66	6
Lakewood & Adanac	33	19	21	30	3	3
All 11 locations	**321**	**104**	**109**	**54**	**40**	**16**

[5] Pedestrians included persons in wheelchairs or using mobility devices

In total, 2529 vehicle interactions and 1090 bike interactions were recorded at the seven 10th Ave. locations, and 647 vehicle interactions and 162 bike interactions were recorded at the four comparison crosswalks, for a grand total of 3176 vehicle interactions and 1252 bike interactions recorded at all 11 crosswalks (see Appendix A: City coding of volumes and interactions in video data for mean hourly potential interactions distributed by the time of day). As described previously, these recorded interactions are based on a conservative definition of under 5-seconds passing time.

To examine the interactions in further detail, 50 potential interactions were randomly selected from each location. One location (Lakewood & Adanac) did not have 50 potential interactions, yielding 536 total sample interactions at all 11 locations. The following objective features were coded for each of the sample interactions: 1) passing time (defined above), 2) whether the pedestrian passed the conflict point before the interacting road user or after, 3) pedestrian location when the road user entered the crosswalk, 4) interactions with road users from the opposing direction, and 5) interacting road user types.

Figure 5 summarizes the passing times at the seven TAHZ locations, separated by interacting road user types (N=185, 51, and 110 for Vehicles only, Vehicles + Bikes, and Bikes only, respectively). Interactions with bicycles had shorter passing times than interactions with vehicles, and all three distributions are statistically significant based on Chi-squared tests at $p<0.05$. There were no significant differences in whether the pedestrian passed first in interactions with vehicles versus bicycles, or in the pedestrian location when the interacting road users entered the crosswalk.

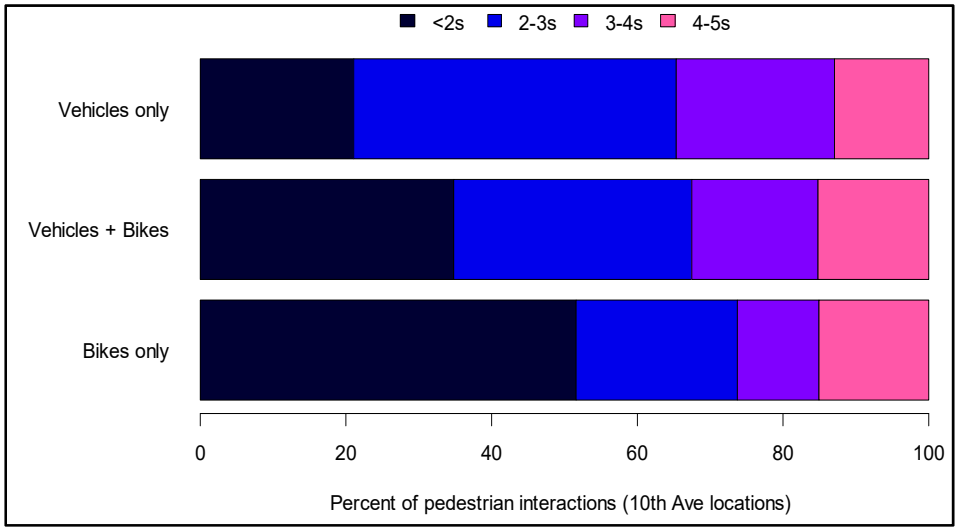

Figure 5. Passing times for sample interactions at TAHZ locations by interacting road user type

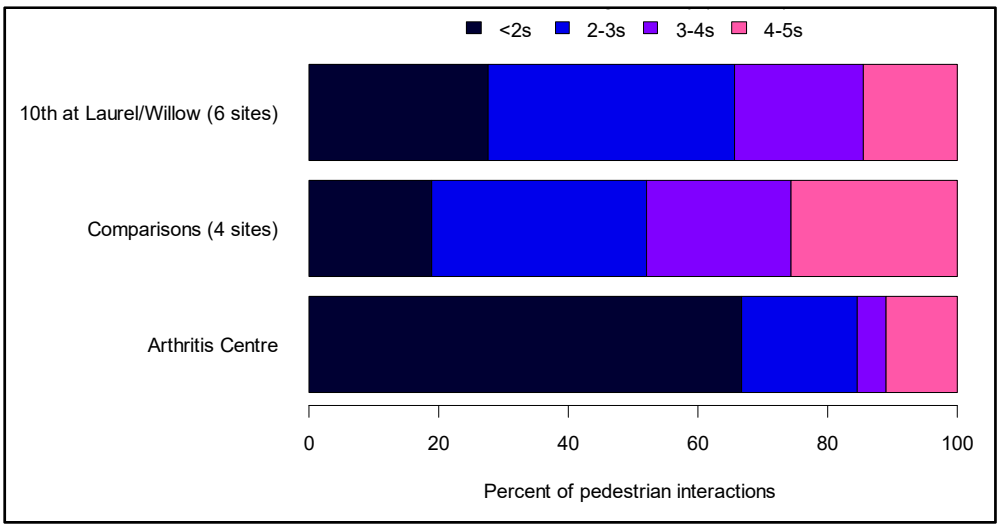

Figure 6. Passing times for sample interactions by location

Figure 6 summarizes the passing times by location. There were no significant differences among the 6 main 10th Ave locations, or among the 4 comparison sites, but the Arthritis Centre had significantly closer interactions than the other sites, and the TAHZ sites together had closer interactions than the comparison sites. The Arthritis Centre location is unique because it is a much shorter crossing than the other locations (hence the closer passing times). There were no significant differences in whether the pedestrian passed first by location (on average 60%), but there were significant differences by location in the pedestrian location when the interacting road user entered the crosswalk (the pedestrian was on-street 51% of the time for the main 10th Ave sites, 37% at Arthritis Centre, and 31% at comparison sites).

4 Web survey to investigate perceptions of interaction severity

4.1 Survey methods

After extracting the sample interactions and coding their objective features, the next step was to conduct an online survey to elicit severity ratings from a variety of participants for a sub-sample of interactions. The survey sub-sample of 84 interactions was taken from the set of 536 sample interactions by randomly sampling within nine strata based on interacting road user type and passing time. The nine strata are given in Table 2, along with the number of videos in the survey from each stratum. Additional objective features were then coded for the survey sub-sample of interactions: whether the pedestrian and road user adjusted speed or course, vehicle type, number of pedestrians and other road users in the scene, whether the pedestrian and other road user were in a group or isolated, and others (see Appendix B: Coding of interaction characteristics for survey sample).

Table 2. Nine strata for interactions shown in web survey video clips

Stratum	Interacting road users	Passing time gap	Videos in survey (& shown to Expert pool)	Videos shown to Community and Public pools	Total ratings
1	1 bicycle	<2 sec	12	3	1080
2	1 bicycle	2-3 sec	10	2	734
3	1 bicycle	3-4 sec	8	1	381
4	1 vehicle	<2 sec	12	3	1081
5	1 vehicle	2-3 sec	10	2	728
6	1 vehicle	3-4 sec	8	1	383
7	2 or more vehicles	<4 sec	8	1	380
8	1+ vehicles and 1+ bicycles	<4 sec	8	1	381
9	2 or more bicycles	<4 sec	8	1	381

An online questionnaire was implemented in Qualtrics survey software. It began with a consent form, followed by a one-page set of travel habit and demographic questions: frequency of travel by different modes, frequency of travel in the TAHZ, age, gender, home postal code, education, household income, and level of comfort taking risks (based on Glanz et al.[1]). Next, participants were shown a series of short video clips in random order, each on a different page, with the prompt to indicate their agreement with the following statements regarding the interaction shown in the video (see Figure 7). The four statements were:

1. The [driver/cyclist] yielded to the pedestrian.
2. The [driver/cyclist] ***should*** have yielded to the pedestrian.
3. The pedestrian felt comfortable in this crossing.
4. The risk of injury for the pedestrian in this crossing was low.

The response options were: “Strongly disagree”, “Somewhat disagree”, “Somewhat agree”, “Strongly agree”, or “I don’t know”. The wording of the severity scales was selected after extensive consideration using input from the scientific literature, on-site interviews with Committee members, pilot testing, and input from professional and academic colleagues (see Appendix C: Interaction Severity Scales). Each video page also included an open comment text box for survey participants to offer clarification of their ratings if needed.

Regarding the interaction between the crossing **pedestrian** and the closest **vehicle** shown in the video, please indicate your level of agreement with the statements below:

	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree	I don't know
The driver yielded to the pedestrian.	○	○	○	○	○
The driver ***should*** have yielded to the pedestrian.	○	○	○	○	○
The pedestrian felt comfortable in this crossing.	○	○	○	○	○
The risk of injury for the pedestrian in this crossing was low.	○	○	○	○	○

Figure 7. Video rating in the questionnaire

Three participant pools were recruited for the survey:

1. Members of the **Public** in Vancouver, recruited through online posts by the City and researchers and Facebook ads,
2. Engaged community stakeholders, defined as the 10th Ave Advisory **Committee**, recruited through email from the City, and
3. Transportation safety **Experts**, defined as transportation professionals from North America but not British Columbia who have previously taken part in professional safety evaluations involving pedestrians or cyclists, recruited through email from the researchers.

As incentives, participants in the first two pools were entered into a draw for four gift cards of $25 each; the third pool was offered an honorarium of $300.

4.2 Survey results

Survey data processing, response rates, and sample characteristics are described in the Appendix D: Survey data processing. After processing and filtering, 343 complete responses were received from the Public pool, 17 from the Committee pool, and 6 from the Expert pool. Socio-demographic and travel characteristics of each pool and the City's census data are summarized in Figure 8. Missing bars represent no available data (not in Census data or not asked of participants). The sample was younger and better educated than the city's average, and so sampling weights were applied to represent the age, gender, income, and education distributions from the 2016 Census (see Appendix D: Survey data processing).

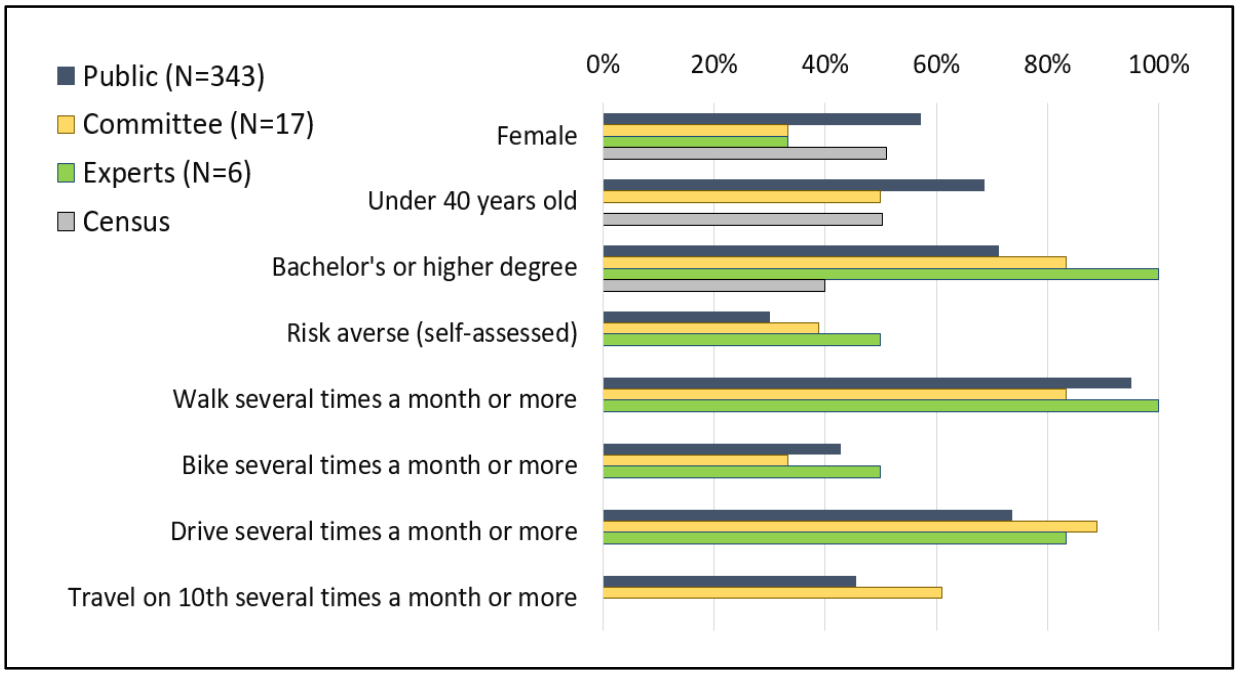

Figure 8. Sample characteristics (with 2016 City of Vancouver Census subdivision comparisons)

A summary of all the ratings is given in Figure 9. Note that these are *not* representative of all interactions because the rated videos were selected by strata, and had disproportionately short passing times. Overall, most responses disagreed that the pedestrians were yielded to, but agreed they should have been yielded to, they felt comfortable, and the interactions were low risk. Participants more frequently rated motor vehicle interactions as both yielded and should have yielded, compared to bicycle interactions. Interactions involving both motor vehicles and bicycles were rated as less comfortable and less low risk than interactions with just one type of interacting road user. Additional figures for all nine strata are given in Appendix E: Video Rating Results.

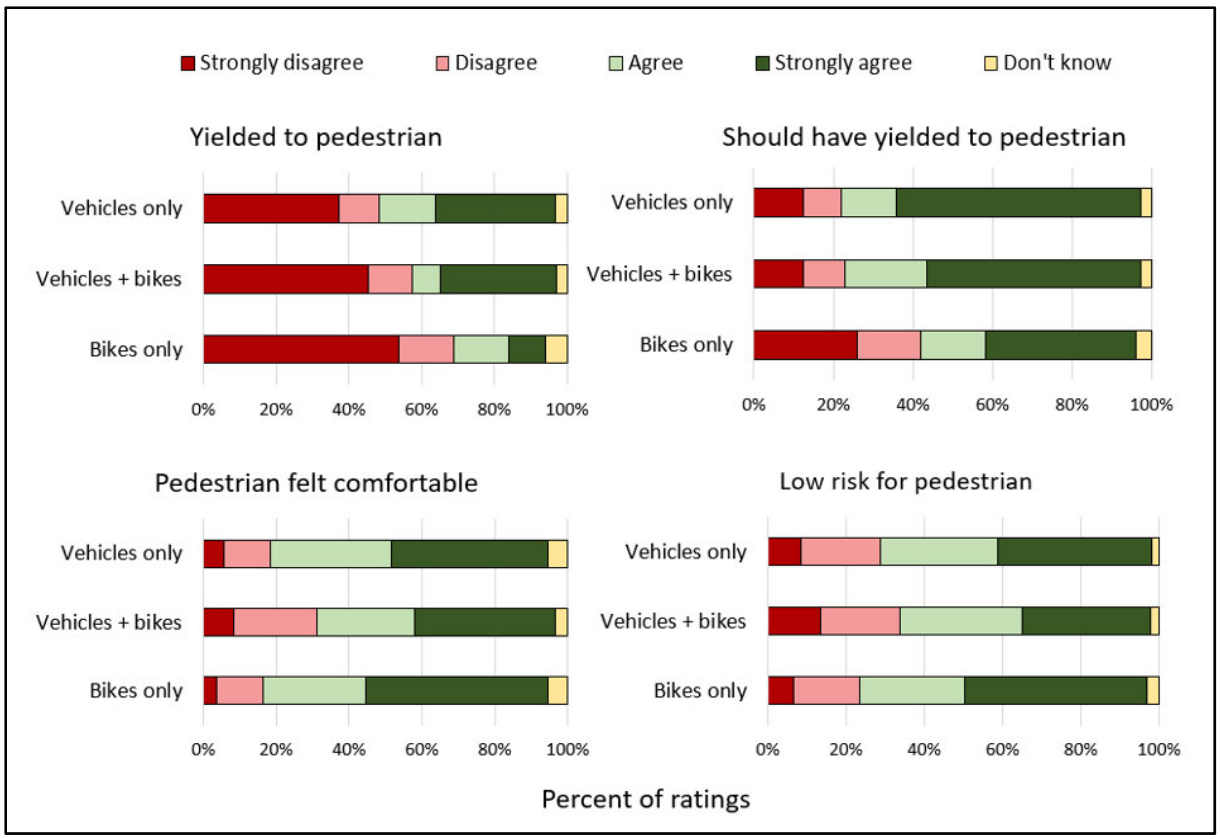

Figure 9. Summary of all 5529 video ratings in the web survey

The responses for "yielded" and "should have yielded" were combined to create a composite variable of "Adequate yielding", illustrated in Figure 10:

- No need to yield: Disagree or Strongly disagree to "should have yielded"
- Adequate yield: Agree or Strongly agree to both "yielded" and "should have yielded"
- Failed to yield: Agree or Strongly agree to "should have yielded", and Disagree or Strongly disagree to "yielded"

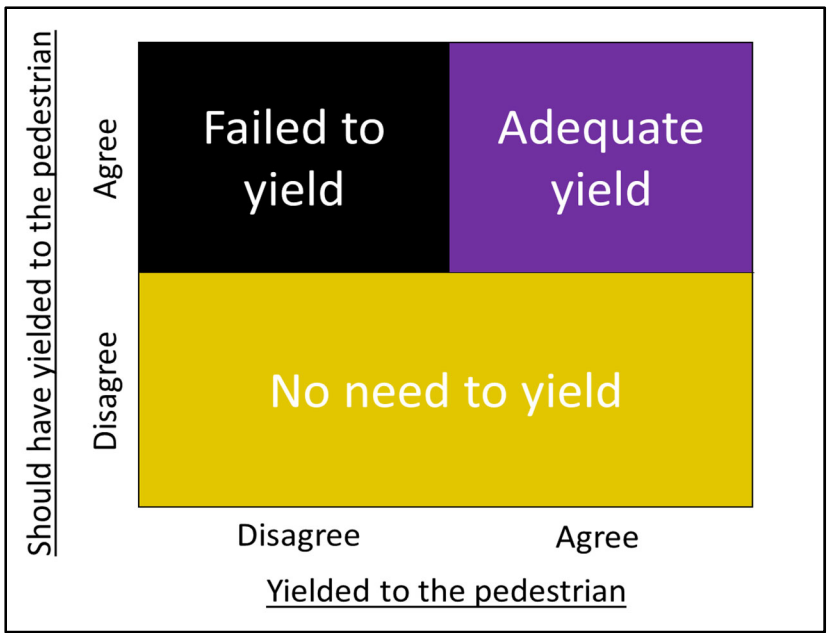

Figure 10. Illustration of "Adequate yielding" from the two questions on yielding

Figure 11 summarizes the "adequate yielding" variable for all survey responses, again as the percent of ratings (and not a representative distribution of all observed interactions). Here the proportion of interactions rated as a failure to yield is similar across road user types, but for interactions with bicycles there is a substantially larger share of "no need to yield", and smaller share of "adequate yield". Very few ratings indicated "yielded" but not "should have yielded" (i.e., the bottom right quadrant in Figure 10).

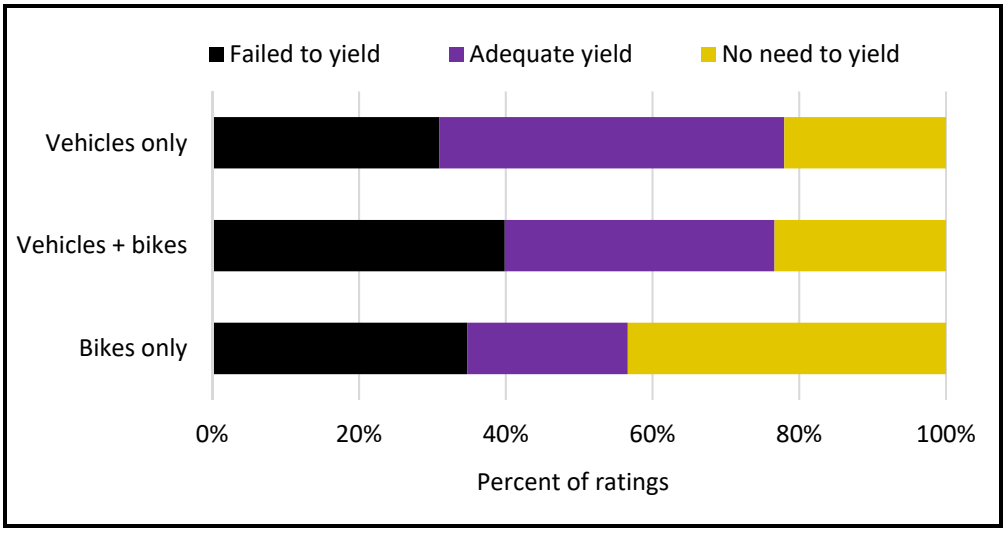

Figure 11. Adequate yielding for all 5529 video ratings in the web survey

The survey responses were used to estimate a weighted mixed ordered logistic regression model for each outcome: "yielded", "should have yielded", "comfortable", and "low risk". The models included random effects for each video (84) and each respondent (366). The best-fit[6] models for each outcome are given in Table 3. The model results show that after controlling for other factors (passing time, road user type, rater characteristics, etc.), yielding and risk were rated significantly better for interactions on 10th Ave than at control sites. Limited street design variables could be tested in the model due to video data coming from only eleven locations (which can lead to multicollinearity – a barrier to regression analysis). Alternative location variables were also tested (crosswalk length, path separation, uphill direction, near/far-side crossing, etc.), but the two in Table 3 (TAHZ location and number of lanes to cross) had the best statistical fits. The TAHZ variable likely includes the effects of the street design as well as other less tangible aspects of the Hospital Zone. To visualize the model results, Figure 12 shows an example of model-predicted percent agreement for all four outcomes, given a pedestrian in the ramp crossing a 2-lane road with 2.5 sec passing time and other average interaction features.

Model results in Table 3 indicate that perceptions of Comfort are hardest to predict (lowest pseudo R^2), followed by risk, obligation to yield, and yielding. Passing time was the only significant predictor of all four severity outcomes, supporting its use in defining interactions. Interactions with cyclists were rated as more comfortable than interactions with motor vehicles; cyclists were rated as yielding less, but there was also less agreement that they "should have yielded."

Table 3. Best-fit explanatory models of rater agreement with each outcome

Odds ratios (>1 increased odds of agreement, <1 decreased odds of agreement)	**Yielded**	**Should have yielded**	**Comfortable**	**Low risk**
Passing time (seconds)	1.71	0.52	2.17	2.35
Interaction with a bicycle (vs. vehicle)	0.25	0.21	1.46	-
Ped passed conflict point before interacting RU	24.12	6.03	1.68	-
Ped location when RU entered crosswalk: *Crosswalk/on-street*	-	2.99	0.36	0.32
Ped location when RU entered crosswalk: *Ped ramp/island*	-	3.76	0.42	0.48
Interacting RU was in a group (not isolated)	-	2.36	0.40	0.42
Uncommon pedestrian type (child, mobility-impaired, etc.)	-	-	-	0.44
Noticeable deviation of speed or path *by interacting RU*	4.67	2.27	-	2.01
Noticeable deviation of speed or path *by pedestrian*	4.01	2.49	-	-
Number of pedestrians in the scene	-	1.12	0.90	0.86
10th Ave Hospital Zone location	3.21	-	-	2.71
Total lanes to cross	0.58	-	-	0.74
Rater walking frequency (ordered factor, 1-5, never to daily)	-	1.16	0.80	-
Rater biking frequency (ordered factor, 1-5, never to daily)	-	-	-	1.13
Rater from Expert pool	-	-	-	3.76
Pseudo R^2	**0.582**	**0.516**	**0.330**	**0.410**

[6] Highest log-likelihood, with all independent variables significant at $p<0.05$

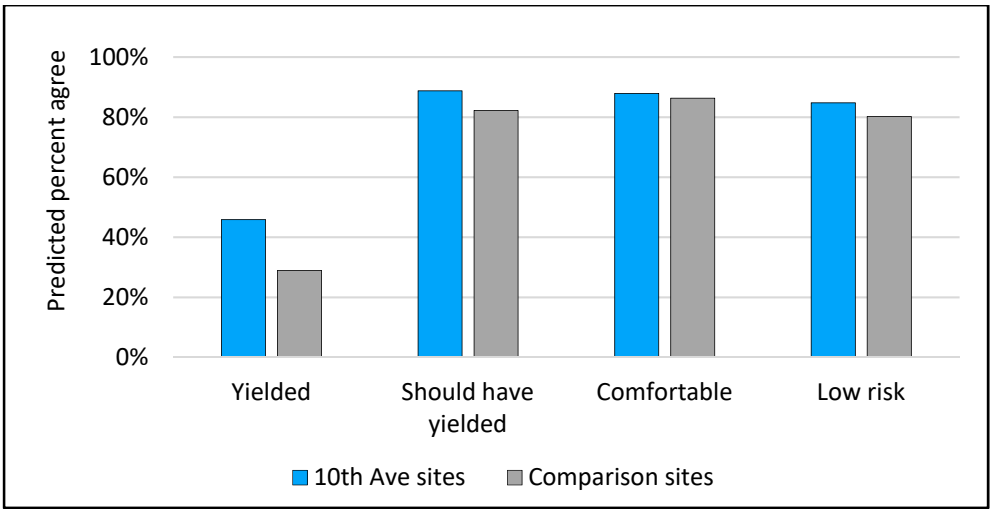

Figure 12. Modelled differences in severity between 10th Ave and Comparison sites, for a pedestrian crossing a 2-lane road with 2.5 sec passing time and other average features

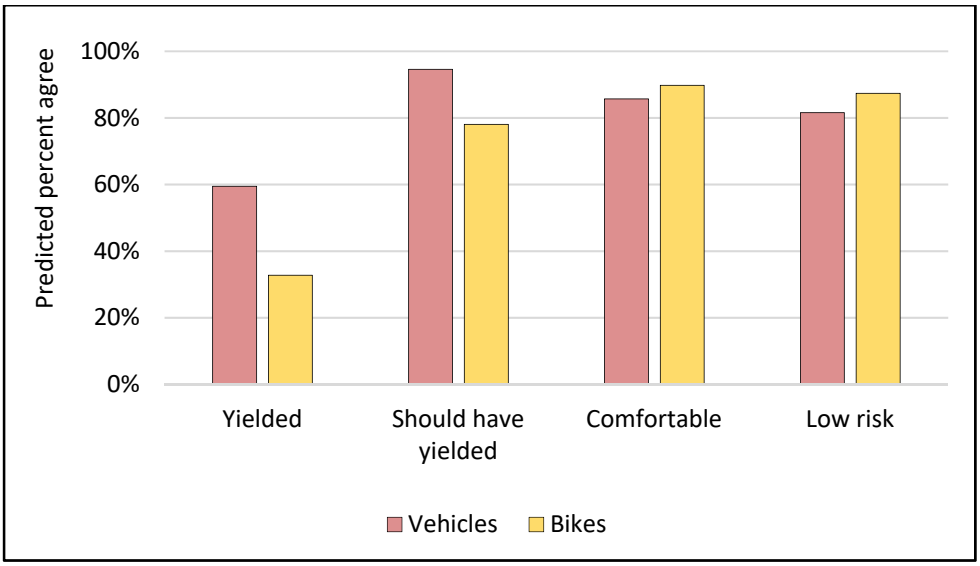

Figure 13. Modelled differences in severity between interactions with vehicles and bicycles, for a pedestrian crossing a 2-lane road in the TAHZ with 2.5 sec passing time and other average features

Figure 13 shows the model-predicted percent agreement for all four outcomes, given a pedestrian crossing a two-lane road in the TAHZ with 2.5 sec passing time and other average interaction features. Whether the pedestrian passed first was crucial for perceptions of yielding – more important than speed or path deviations, for example. Pedestrians passing first was perceived as more comfortable, but not necessarily lower risk. Interactions involving more vulnerable pedestrians (children, mobility impaired) were rated as higher risk, but there were no significant differences for the other severity outcomes. This finding corroborates the observation from Committee member interviews that Comfort and Safety are distinct constructs and mobility aids may not affect assessed comfort.

A statistical comparison of the responses among the participant pools is given in Appendix F: Comparisons among and between pools. The 'excellent' reliability of the combined (average) severity

rating, contrary to the 'poor' reliability of *individual* ones, gives us confidence in applying the survey results to summarize the observed interactions. Rating agreement among individuals was highest for Yielding and lowest for Comfort and Risk.

There were no significant differences in the ratings of the Public and Committee pools. This finding shows that the Committee, whose members have higher average age, represents the younger-aged Public in terms of severity ratings of interactions. There were no significant differences between the Expert pool and the other two pools on the Yielding or Comfort questions, but Experts rated both vehicle and bicycle interactions as significantly lower risk. Hence, Experts align with the Public in assessing yielding and comfort, but not on what that behaviour implies for safety. This finding is reinforced by the fact that Experts expressed higher self-assessed risk aversion than the other two pools, meaning the lower risk ratings are likely not attributable to a higher threshold for risk in this pool. The Expert effect on risk rating in Table 3 was tested for differences between vehicle and bicycle interaction types, and found to be not significant ($p=0.61$); i.e., the systematic difference in risk perception between Experts and the Public was similar for interactions with vehicles and bicycles.

Somewhat surprisingly, there were no significant effects of socio-demographics or 10th Ave familiarity on the severity ratings. Model results in Table 3 show that raters who bicycle more also rate risk as lower (for all interaction types - vehicles and bicycles). Raters who walk more rate Comfort as lower for the pedestrians in interactions, and also more strongly agree that other road users "should have yielded".

4.3 Definition of interactions

Statistical models from the ratings data were used to refine the passing time threshold for defining when an interaction has occurred. Table 4 gives the derived passing time thresholds that yield at least 85% predicted agreement with each severity outcome for a pedestrian in the ramp crossing a two-lane road, interacting with a vehicle or bicycle. The 85th percentile is selected as a common threshold in transportation engineering practice.

For vehicle interactions, at least 85% agreement with "should have yielded" is expected for interactions with passing times under 3.3 seconds, and for bicycle interactions, it is expected for passing times under 1.2 seconds. Lower agreement levels are achieved at higher passing times. Based on the results in Table 4, the remainder of the analysis applies a 3-second passing time threshold to define interactions. The same threshold is used for interactions with motor vehicles and bicycles, for consistency. Previously identified potential interactions with passing times over three seconds are excluded from the interaction pool, which reduces the set of sample interactions from 536 to 277 (58% of potential interactions at 10th Ave locations and 41% at comparison sites were under 3 seconds).

Table 4. Passing time thresholds for ≥ 85% predicted agreement with severity outcomes (pedestrian in ramp, crossing a two-lane road)

Outcome	Interactions with vehicles	Interactions with bicycles
Should have yielded	≤ 3.3 s	≤ 1.2 s
Comfortable	≥ 2.7 s	≥ 2.1 s
Low risk (Public)	≥ 3.2 s	≥ 2.6 s
Low risk (Experts)	≥ 1.6 s	≥ 1.0 s

5 Evaluating comfort and safety

The process of evaluating crossing experiences at the 10th Ave and Comparison sites is illustrated in Figure 14. In the first step, 4400 interactions (at 5 seconds) were identified in 80 hours of video data from 11 locations. Then, 50 crossings with interactions were randomly selected for each location and objective features were coded (including passing time). In the third step, a web survey was used to investigate perceptions of the severity of a sub-sample of 84 interactions with a controlled mixture of passing times and road user types. In the final two steps of the analysis, statistical models from the web survey data were applied to predict the perceived severity of all the sample interactions, and then those sample interactions were combined with interaction rates to summarize the crossing experience by location.

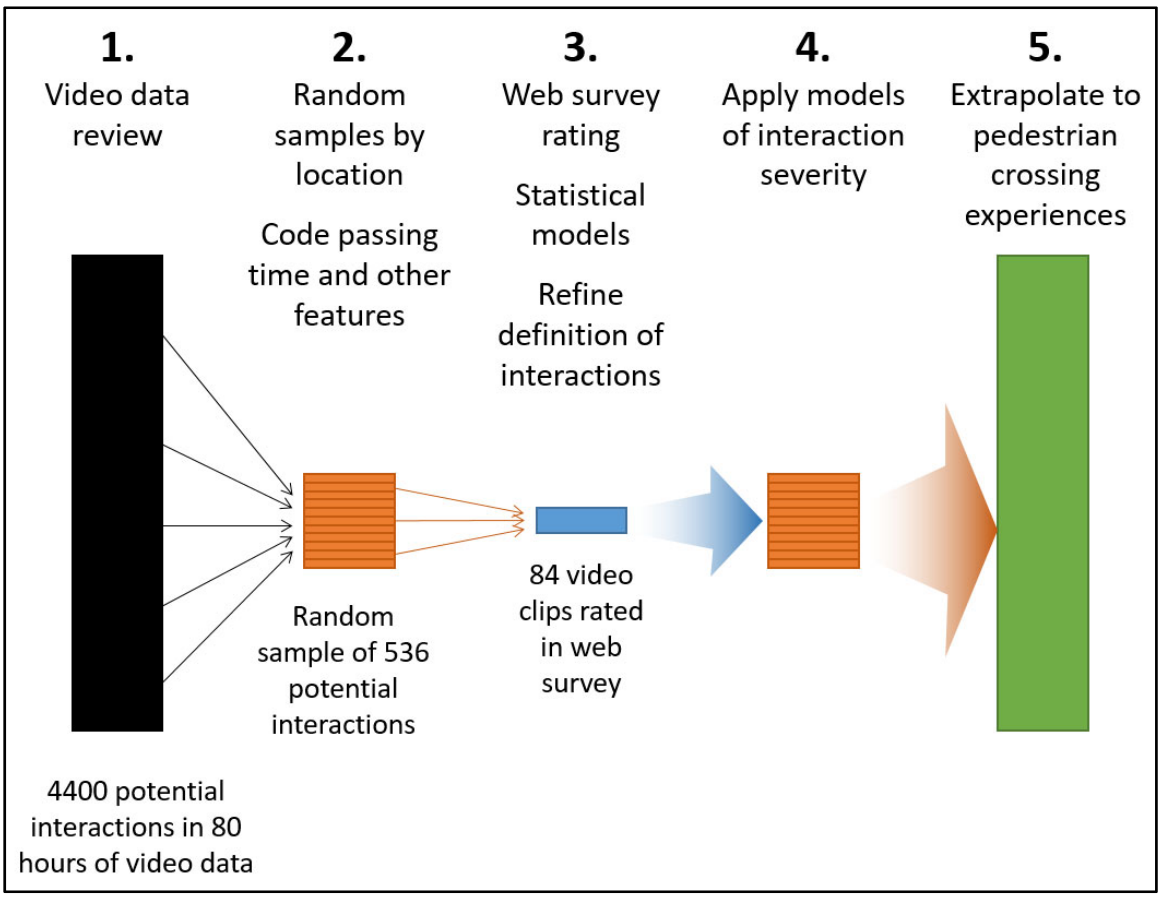

Figure 14. Summary of method for evaluating crossing experiences from sample interactions

5.1 Severity of interactions by location

To predict perceived severity by location, a reduced set of four regression models (one for each outcome) was estimated using only those independent variables that were coded for the sample interactions and significant ($p<0.05$) for at least one of the outcomes in the best-fit models. The same set of variables was used in all four models for consistency, other than the variable Expert, which was only included in the Risk model. The prediction models in Table 5 show that they have only a slightly poorer overall goodness-of-fit and the estimated parameters are similar to the best-fit models (see Table 3).

Table 5. Reduced-from models to predict perceived severity of sample interactions (limited to variables coded for all interactions)

Odds ratios (>1 increased odds of agreement, <1 decreased odds of agreement)	**Yielded**	**Should have yielded**	**Comfortable**	**Low Risk**
Passing time (seconds)	1.26	0.45	2.17	2.30
Interaction with a bicycle (vs. vehicle)	0.33	0.20	1.47	1.56
Ped passed conflict point before interacting RU	33.32	6.10	1.84	1.43
Ped location when RU entered crosswalk: *Crosswalk/on-street*	1.38	5.08	0.31	0.30
Ped location when RU entered crosswalk: *Ped ramp/island*	1.78	6.11	0.41	0.55
10th Ave Hospital Zone location	2.08	1.70	1.15	1.37
Total lanes to cross	0.71	0.95	0.91	0.90
Expert rater	NA	NA	NA	3.98
Pseudo-R^2	**0.579**	**0.513**	**0.327**	**0.406**

Results of applying the statistical models in Table 5 to the sample interactions by location and interacting road user type are summarized in Figure 15 (using Expert assessment of risk). The figure shows the expected percent of interactions which would be perceived as adequate yielding, comfortable, and low risk. Overall, the severity of interactions is roughly similar by type and location: 86-91% are low risk, 78-84% are comfortable, and 50-58% involve adequate yielding. Public perception of Low Risk is in line with the Comfort results. Although the 10th Ave sites had better severity outcomes *controlling for other interaction characteristics* in the modelling results above, those effects are offset by longer crosswalks, higher volumes, and closer interactions on 10th Ave than the Comparison sites. Thus, Figure 15 shows that the severity is slightly worse at the 10th Ave sites than the Comparison sites; the exception is cyclist yielding, which is higher on 10th Ave. Bicycle interactions are more comfortable and lower risk than vehicle interactions at each site.

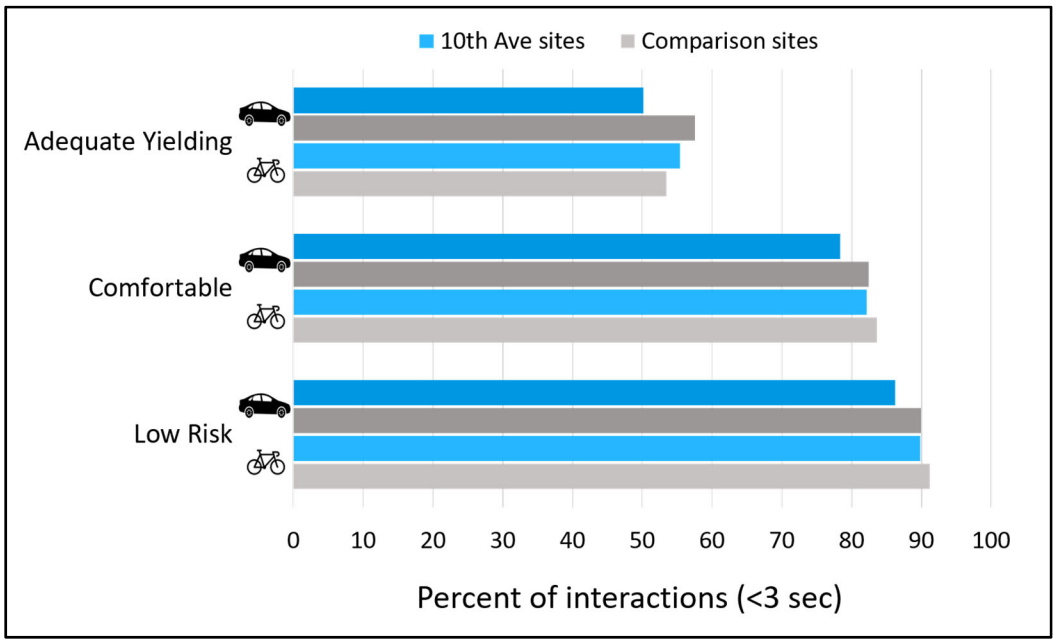

Figure 15. Predicted severity of interactions by location and type

5.2 Interaction rates

Volumes and interactions were only recorded for one direction of interacting traffic (due to the limited camera scenes). Hence, a two-way adjustment was made to the raw interaction rates. The statistical evidence from a subset of video data that was coded in both directions supports an assumption of independent likelihood of pedestrians experiencing interactions from each direction (see Appendix G: Bi-directional traffic adjustment). A further assumption is made of equal severity of interactions with traffic from each direction (by location).

Figure 16 summarizes the frequency of two-way interactions by type and location. Due to the higher volumes on 10th Ave, pedestrians are much more likely to interact with a vehicle or bicycle while crossing than at the Comparison sites. Half of the pedestrians experience an interaction while crossing 10th Ave during weekday peak periods, compared to just 20% pedestrians crossing at the Comparison sites. This finding reinforces the perceptions expressed during the interviews that 10th Ave is a uniquely complex multi-modal street. The interaction rates by road user type are consistent with volume differences: 10th Ave had roughly two times higher vehicle volumes and 3.5 times higher bicycle volumes than the comparison sites. Also, vehicle volumes were two to three times higher than bicycle volumes.

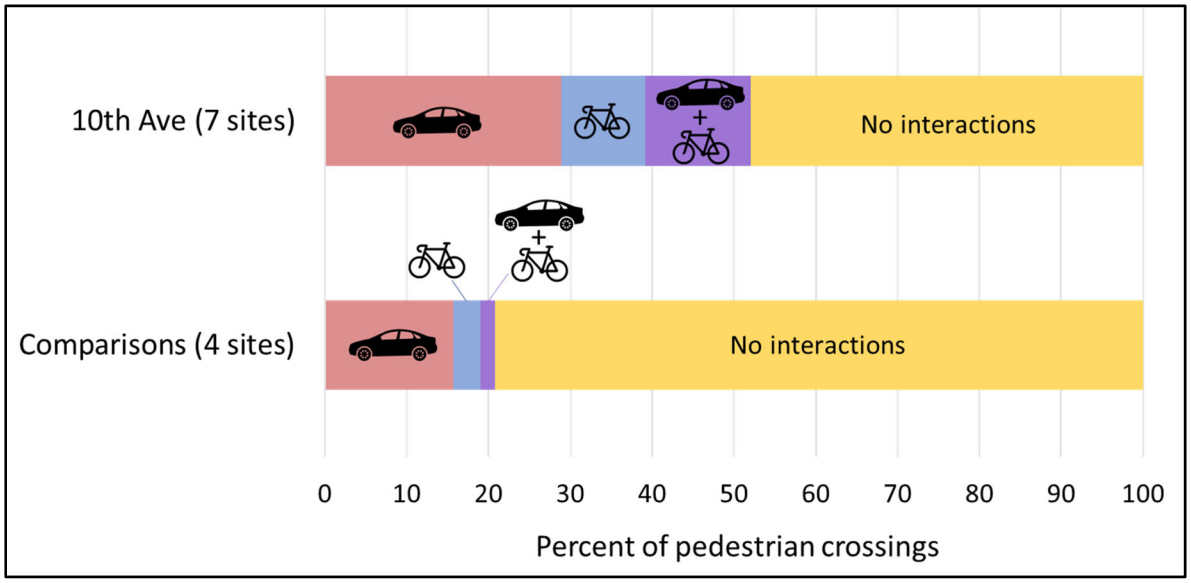

Figure 16. Frequency of interactions by type and location (including 2-way interactions, based on ±3 sec passing time)

5.3 Overall crossing experience

Combining the severity by location and type with interaction rates yields the crossing experiences shown in Figure 17 for 10th Ave during weekday peak periods. "Negative interactions" were those with predicted disagreement (strong or otherwise) that they involved adequate yielding, were comfortable, or were low risk, while "Positive interactions" were the opposite (predicted agreement). **A quarter of crossing pedestrians experience a negative interaction from the perspective of yielding, while 10% experience an interaction that was not comfortable and 6% that was not low risk.** Isolating the most problematic interactions as those responses predicted as "strongly disagree" rather than "somewhat disagree", the numbers are much lower, with under 2% of crossings strongly negative for comfort and under 1% strongly negative for risk.

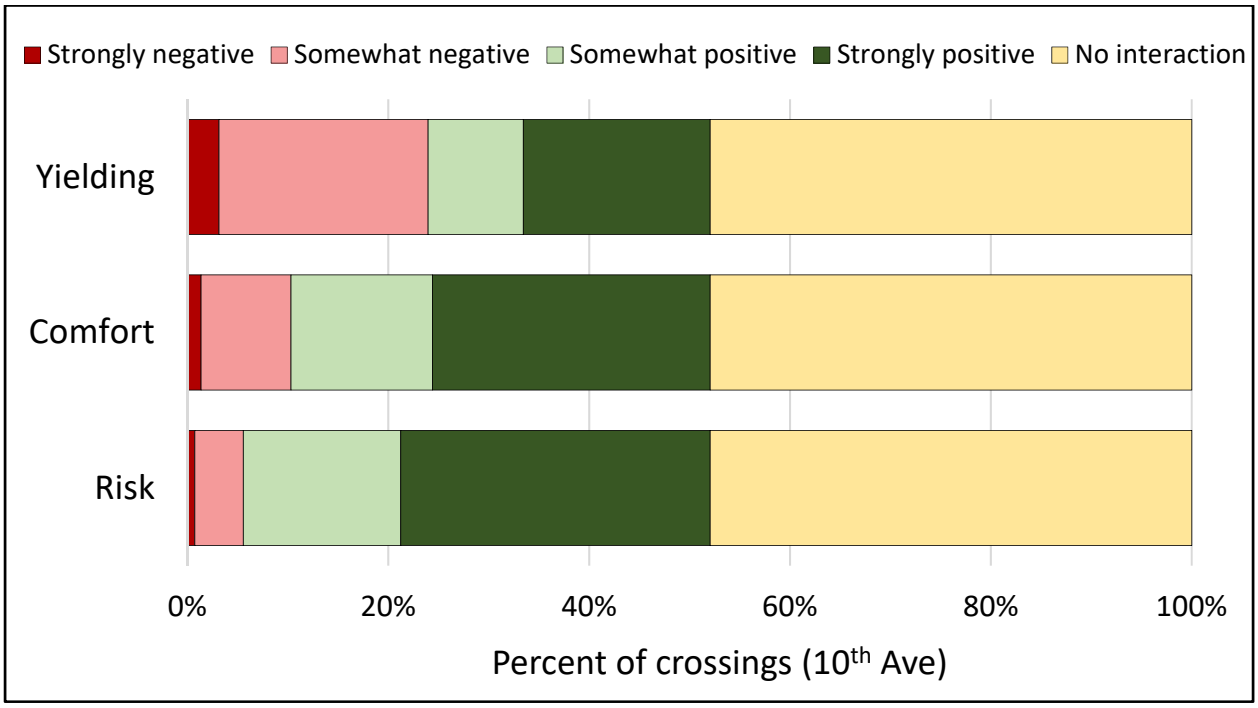

Figure 17. Overall crossing experience based on interaction frequency and perceived severity of sample interactions (negative/positive interactions indicate disagreement/agreement that there was adequate yielding, that the pedestrian was comfortable, and that there was low risk)

5.4 Summary of findings

- Most crossings are perceived as "low risk" (94%) and "comfortable" (90%), although 25% of crossings involve inadequate yielding (rated as "should have yielded", but did not).
- With high volumes of people walking, driving, and cycling, 10th Ave. has high interaction rates during weekdays. Just over half (52%) of pedestrian crossings involved an interaction (defined from the survey results as another road user passing within 3 seconds before or after a crossing pedestrian).
- The observation sites along 10th Ave. have higher yielding rates and lower risk than the comparison sites. However, these effects are partially offset by longer crossings, higher volumes, and closer interactions along 10th Ave. Overall severity of interactions are similar among the study locations, with around 50% adequate yielding, 80% comfortable, and 80-90% low risk (depending on perspective).
- Perceptions of yielding, comfort, and safety do not vary significantly with a rater's socio-demographics (age, gender, income, education), but perceptions do vary with a rater's travel habits. People who walk more frequently rate pedestrian comfort as lower, and are more likely to agree that road users "should have yielded". People who cycle more frequently rate risk as lower (for pedestrian interactions with both bicycles and motor vehicles).
- There are no significant differences in perceptions of yielding, comfort, and safety between members of the public and Committee members who participated in the survey. The traffic safety experts have similar views of yielding and comfort to the Public and Committee pools, but a consistently lower assessment of risk for pedestrians in interactions with motor vehicles and bicycles. This finding is reinforced by the fact that the experts expressed higher self-assessed risk aversion than the other two pools, suggesting that the lower risk ratings are likely not attributable to greater general risk acceptance.
- Pedestrian interactions with bicycles are more comfortable and lower risk than interactions with motor vehicles. This finding may be explained by the size difference between bicycles and motor vehicles and easier visual communication between pedestrians and cyclists. Rates of inadequate yielding are similar in pedestrian interactions with either motor vehicles or bicycles. In otherwise similar interactions, cyclists are much more likely to be perceived as not needing to yield than drivers.
- Interactions involving more vulnerable pedestrians (children, mobility impaired) are perceived as higher risk but there were no significant differences for the other severity outcomes of comfort or yielding. This finding is supported by the interview result that comfort and safety are distinct constructs and mobility aids may not affect assessed comfort.
- Perceptions of yielding are most strongly based on whether the pedestrian passed first, rather than specific manoeuvres by the other road user (i.e., visible slowing). Legal definitions of right-of-way and yielding are neither well-known nor considered of main importance, based on the interview results.

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Appendix A: City coding of volumes and interactions in video data

The City collected video data from 11 locations for three days each. Figure 18 and Figure 19 show the names and still images of the crosswalks from the video data. Seven crosswalks were selected in the recently redesigned portion of the TAHZ, based on the expectation of significant pedestrian, motor vehicle, and cycling activity. Only crosswalks at intersections were included (no mid-block crosswalks). Four comparison sites were selected based on similar operating characteristics (uncontrolled crosswalks) and high pedestrian volumes.

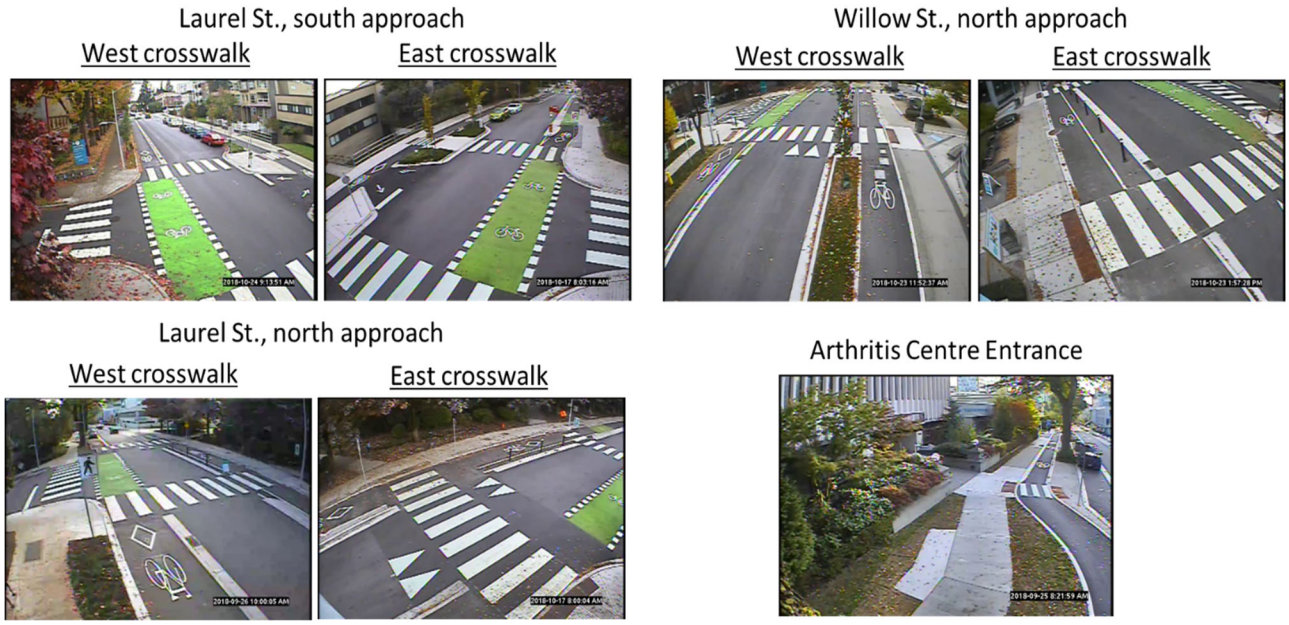

Figure 18. Video data from 10th Ave crosswalks

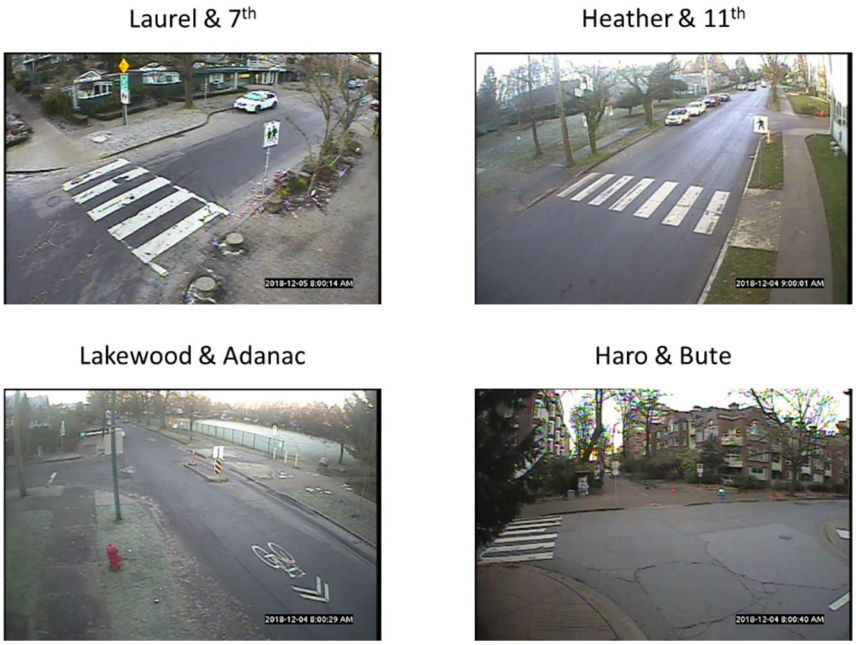

Figure 19. Video data from comparison crosswalks

The video data were reviewed and volume and interaction counts were recorded in 15-minute intervals by the City for six hours (8-10hr, 11-13hr, 16-18hr) per location on a single weekday. A target sample of 200 pedestrian crossings at each location was established, and two locations (Arthritis Centre Entrance and Lakewood & Adanac) failed to reach that target in a single day of data. Two additional days of video data from Arthritis Centre Entrance were reviewed to reach the target pedestrian volume in 18 hr of video data. Due to video data loss at Lakewood & Adanac, only 33 15-minute observation intervals were available for review, providing a final pedestrian sample volume of 157 crossings at that location.

The overall road user mix counted at 10th Ave sites was 37% pedestrians, 39% vehicles, and 24% bicycles – based on counts from one direction (see Table 1 for a summary of hourly volume). Figure 20 gives mean volumes for the six main 10th Ave sites by the time of day. The volumes varied substantially by time of day, travel mode, and location. Based on long-term monitoring data from the City, hourly bike volumes range 40-140 on 10th Ave. at Clark St. (several km east of the study area) for comparable hours over the course of the year. Hence, we are at the low end of the middle/shoulder season for bicycle volumes – and seeing a typical range over the course of the day. Figure 21 gives mean hourly potential interactions recorded for the six main 10th Ave sites by the time of day which resembles the hourly volumes from Figure 20, hence demonstrating their positive relationship with interactions.

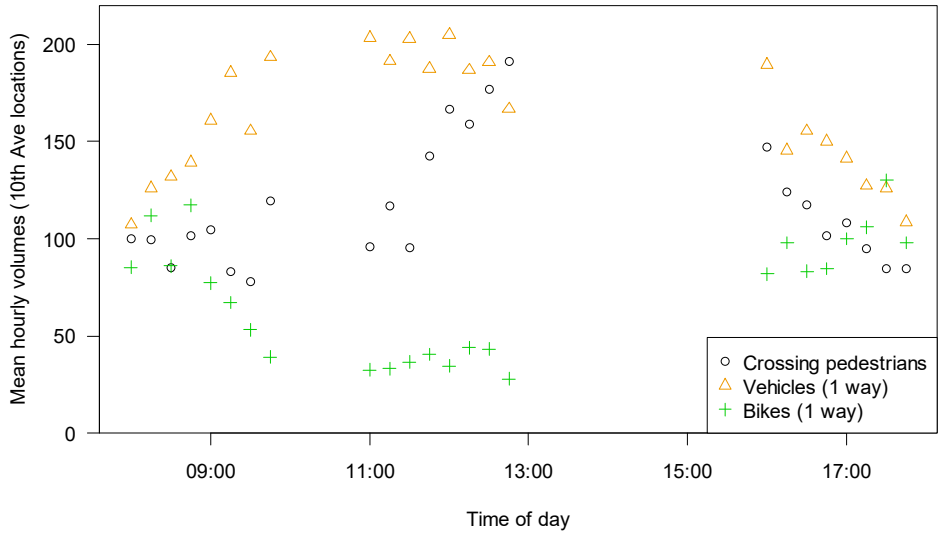

Figure 20. Mean hourly volumes over the course of the day at the 6 main 10th Ave. locations (based on 36 hours of video data)

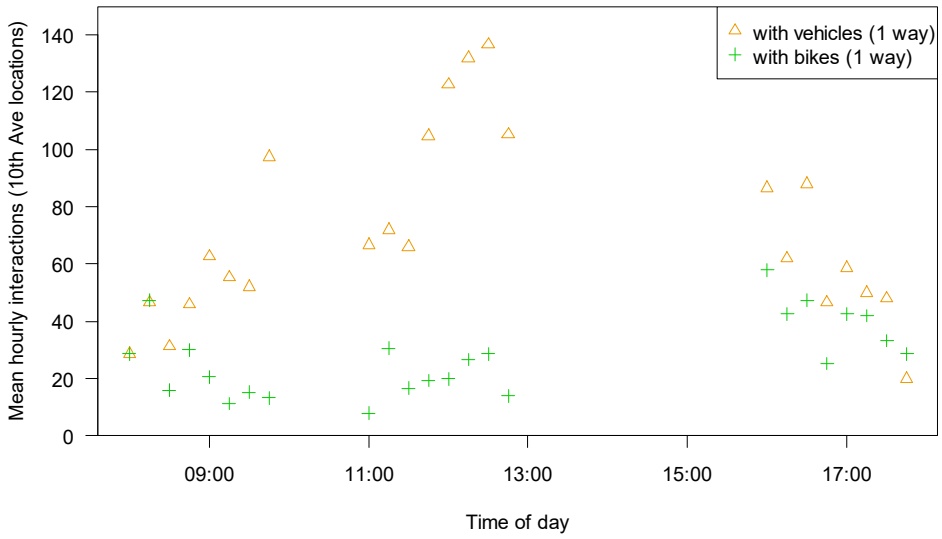

Figure 21. Mean hourly interactions (passing time <5 sec) over the course of the day at the 6 main 10th Ave. locations (based on 36 hours of video data)

The research team independently coded eleven 15-minute periods of video data (one randomly selected from each location) using the same methods as the City and compared with the City coding results. The results given in Table 6 show that the counts are very well validated, with correlations of at least 0.997 and mean errors of less than 1 per 15 minutes. The interaction coding was not as well validated, as expected, but still showed good agreement with correlations of 0.97 and 0.81 for vehicle and bicycle interactions, respectively. The discrepancies in the number of interactions are due to interactions with long passing times (around 5-seconds passing time), which gives more confidence that all of the <4s passing time interactions were recorded.

Table 6. Interaction Coding Validation Results (based on eleven 15-minute periods)

	Volumes			**Number of interactions of crossing pedestrians with…**	
	Pedestrians	**Bicycles**	**Vehicles**	**Vehicles**	**Bicycles**
Mean (standard deviation) in validation periods	23.9 (19.8)	14.2 (9.2)	26.1 (19.5)	10.7 (11.1)	3.3 (3.1)
Correlation	0.998	0.997	1.000	0.974	0.813
Mean difference	0.545	-0.091	0.000	-0.727	0.182
Mean absolute difference	0.909	0.273	0.182	1.455	1.273

Appendix B: Coding of interaction characteristics for survey sample

The survey was composed of 84 crossings, which were a sub-sample taken from the set of 536 sample crossings by randomly sampling within nine strata based on interacting road user type and passing time. After selecting the sub-sample, video clips of the selected interactions were reviewed and replaced with other random interactions from the same stratum if the interaction was not clear and dominant in the video scene. For example, a goose crossing the road or a conflict between road users in some other part of the scene.

Apart from the characteristics coded by the City for the video data, the research team further tested additional characteristics for the interactions in survey videos. To determine what additional interaction characteristics could be reliably extracted from the sample interaction videos, a draft set of 29 characteristics was first created, and then four raters on the research team independently coded 10 video clips of randomly selected interactions. Several features of interest were not coded because of unreliability, including distracted pedestrians, elderly pedestrians, whether the cyclists stopped pedaling. Based on those results, the following variables were coded for each of the 84 sample interactions included in the survey:

1. Total number of pedestrians in the scene
2. Total number of vehicles and bicycles in the scene
3. Motor vehicle type: passenger or not
4. Pedestrian type: mobility-assisted, cart/trolley, child, or none
5. Who passed the conflict point first: pedestrian or other road user
6. Vehicle in a group: influenced or isolated
7. Cycle in a group: influenced, isolated, or grouped
8. Pedestrian in a group: influenced, isolated, or grouped
9. Pedestrian position when road user enters crosswalk: parallel sidewalk, crosswalk/street, curb-cut/island, or off-street/off-screen
10. Yielding-related manoeuvres by vehicle: full stop or speed deviation
11. Yielding-related manoeuvres by bicycle: full stop, speed deviation, or path deviation
12. Yielding-related manoeuvres by pedestrian: full stop, speed deviation, or path deviation
13. Road user turning movement: yes or no
14. Cycle in a general purpose lane: yes or no
15. Low light: yes or no
16. Crosswalk marking: good, poor, or missing
17. General purpose lanes to cross: zero, one, or two
18. Bike lanes to cross: zero, one, or two.

Appendix C: Interaction Severity Scales

Rating scales were needed for three dimensions of severity: adequacy of compliance/yielding, comfort, and safety. Draft severity scales were developed from the literature to test during the interviews, before selecting the final wording for the web survey.

Objective safety: "Comfort", "safety" and "severity" are all widely used in safety and pedestrian/cycling literature. The traffic conflict literature, which aims to systematically evaluate objective risks, tends to frame risk as "conflict severity", where more severe conflicts represent a greater likelihood of a collision occurring [2]–[9]. The severity of the potential collisions (in terms of bodily injury/death given a collision occurs) is not generally included in conflict severity. The severity of a conflict is usually assessed as qualitative levels (e.g., low, medium, high) by human observers or quantitative bins based on objective conflict indicators such as Time to Collision (TTC) or Post Encroachment Time (PET). Both are accepted as valid methods, with expert observers suffering from consistency issues and objective measures from simplicity and lack of comprehensiveness. There is wide recognition that there is no one best objective conflict measure for all types of interactions and risks; PET has been used successfully and frequently in the past for ped and bike interactions [2], [5].

Perceived safety: Comfort and safety are sometimes used interchangeably in the pedestrian/cyclist literature, although the former tends to indicate subjective or perceived safety, while the latter may mean perceived risk in terms of crash or injury likelihood. Less often, comfort can refer to other factors such as weather or hills. A common phrasing to measure perceived safety is to ask travellers if they "would feel comfortable" in a certain situation or something similar. Comfort has also been evaluated as a safety concern, fear of traffic, and concern about traffic and conflicts with vehicles [10]–[14]. Two recent studies reported comfort and safety as essentially indistinguishable or interchangeable [15], [16]. Kaparias et al. [17] addressed perceived safety with a binary-response question of whether respondents "would be comfortable moving around as a pedestrian" in a specific shared-space area. Lord et al. [18] designed a questionnaire with a Likert scale response to evaluate perceived safety based on pedestrian crossing experience in different traffic conditions (jaywalking, crossing at an intersection without traffic lights, crossing without looking at traffic, etc.) Moody and Melia [19] assessed comfort as to whether travellers "feel safer" and "are…ever worried about sharing space in" a given location. Another study asked cyclists to "report all episodes in which they felt uncomfortable while riding (subjective risk perception)" [20].

Yielding and compliance: Definitions of yielding are similarly inconsistent and vague in the multi-modal road user literature; even compliance is not always strictly defined [21], [22]. Moody and Melia [19] asked whether pedestrians "feel [they] have more, less or equal priority" than other road users. They also assessed which road user "gave way" in conflicts, without clearer definition. Yielding is sometimes simply assessed as which road user passed first, and sometimes based on subjective indicators of slowing or avoidance manoeuvres.

Identifying interactions: A standard definition of a conflict in traffic conflict analysis is "an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remained unchanged" [23]. In a recent review, Mahmud et al. [5] state that a "standard value has not been determined yet to distinguish conflict and normal events". Tageldin and Sayed [8] suggest conflict thresholds of 1.5 to 3 sec, while others have used as high as 8.5 sec for "minimal" conflicts [2], [5]. There is no clear threshold for differentiating a conflict from a normal interaction; they are often presented as different areas on the same severity continuum

[3], [8]. Ismaili et al. [2] defined “exposure events” (interactions) as road users within 10m spatial proximity and a convergent path direction. Moody and Melia [19] described ‘conflicting movements’ simply as when the paths of two road users crossed. Beitel et al. [24] define an interaction as non-motorized road users with a PET under 5 sec, and a conflict as PET under 2 sec, without clear justification. Beitel et al. [9] manually identified “potentially dangerous events and potential conflicts” from video data, without clearer definitions. In contrast, Paschalidis et al. [25] take a perception approach and described conflicts as "a subjective procedure related to situations of competitiveness, stress, frustration and inconvenience", and asked cyclists "to report any incident they had experienced with pedestrians and/or car drivers, which caused them feelings similar to the aforementioned, and not including physical contact necessarily".

Draft scales: The draft severity questions in Table 7 were generated from the literature above and other sources. They were presented to interviewees and piloted with colleagues before selecting a final set for the web survey.

Table 7. Interaction Severity Draft Question[1] Bank

Set	Yielding	Comfort	Safety
1	The [cyclist/driver] yielded to the pedestrian.	The pedestrian felt comfortable in this crossing.	This crossing was safe for the pedestrian.
2	The [cyclist/driver] was considerate of the pedestrian.	The pedestrian felt safe in this crossing.	There was a low risk of injury for the pedestrian in this crossing.
3	The [cyclist/driver] was careful with respect to the pedestrian.	I would have felt comfortable as the pedestrian in this crossing.	There was a low risk of the pedestrian being hurt in this crossing.
4	The [cyclist/driver] obeyed the law.	I would have felt safe as the pedestrian in this crossing.	There was a low risk of collision for the pedestrian in this crossing.

[1] “Please indicate your level of agreement with each statement”

Appendix D: Survey data processing

The online survey was opened on 15-03-2019 and closed on 24/4/2019 (41 days). The numbers of raw responses were: 425 Public, 18 Committee, and six Experts. Based on the observed timing of responses (Figure 22), "low timing" ratings were flagged as those with under 12 seconds spent on the video page (which roughly aligns with the video lengths). Entire responses were excluded if more than one of a participant's rated videos were flagged as "low timing": this led to 11 exclusions (not highly sensitive to the low timing thresholds). Individual ratings were excluded for remaining participants with "low timing" ratings (five video ratings in total). Participants who rated fewer than four videos were also excluded, leading to another 72 exclusions. The exclusions were moderately sensitive to this threshold: 54 participants rated zero videos, 18 rated one to three videos, 18 rated four to six videos, 10 rated seven to nine videos, eight rated 12-14 videos, and 324 rated all 15 videos (excluding the six Expert participants who rated all 84 videos). The final sample size was 366 (343 Public, 17 Committee, and 6 Expert). Of the 427 submitted responses, 84 Public (71 incomplete, 11 low timing, and two declined consent) and one Committee (incomplete) response were excluded.

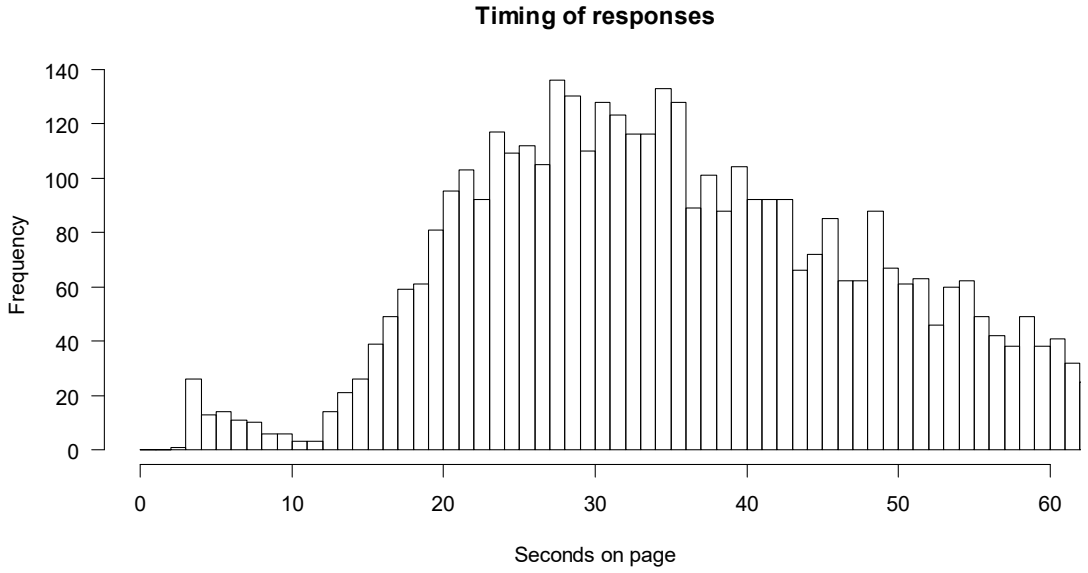

Figure 22. Distribution of response time on a page by survey participants

Response rates do not apply to the Public sample, due to the open recruitment method. For the Committee sample, 17 complete responses were received out of 59 invitations from the city (29% response rate). The sample characteristics cannot be compared because socio-demographics of the Committee population were not available. Of 11 invitations, six complete surveys were received from the Expert pool (55% response rate); one employed in Academics, three in Government, and two in Consulting. The completed responses were from four US cities (Boston, Corvallis, Portland, Seattle) and one Canadian city (Montreal).

Rating completions by video are consistent with expectations across strata, based on the Public and Committee samples rating one of eight videos in five strata, two of 10 videos in two strata, and three of 12 videos in two strata. Time spent on each video page was similar across pools, with median times of

43, 49, and 38 seconds for the Public, Committee, and Expert pools, respectively (no differences by pool are statistically significant at $p<0.05$ based on a two-tailed t-test).

The sample differs from the socio-demographic characteristics of the City and Region, based on a comparison to Census data. Figure 23 gives age, education, and income distributions for the survey, City, and Region. The sample overall is 54% female; 55%, 35%, and 33% for the Public, Committee, and Expert pools, respectively. Some of the sample bias is possibly due to the recruitment methods, and some to self-selection of those interested in non-motorized transportation in the city. The sample travel habits (other than the Expert pool) are given in Figure 24. The sample likely over-represents non-auto travellers and 10th Ave. travellers, compared to the City at large.

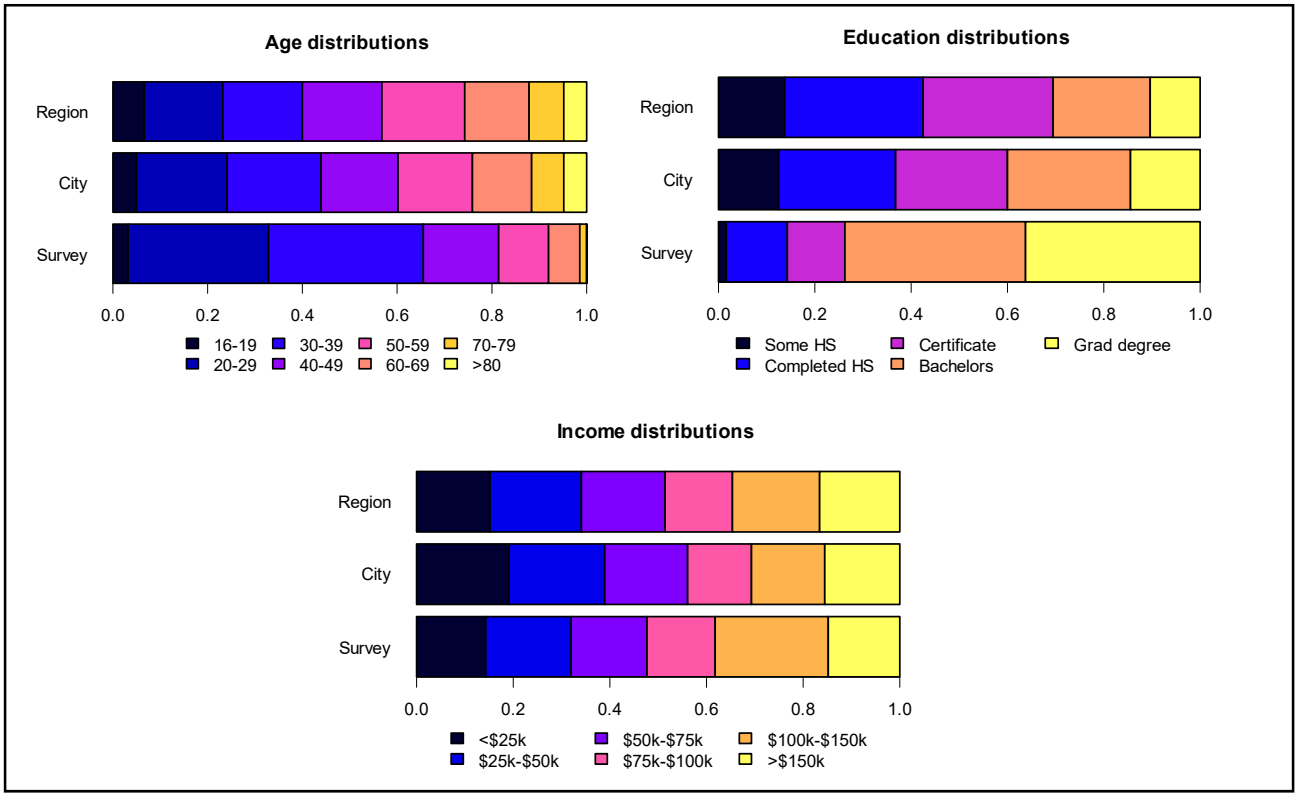

Figure 23. Sample socio-demographic statistics

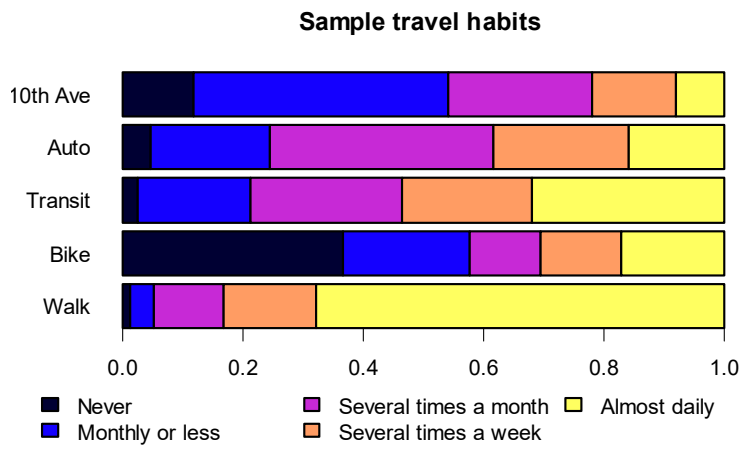

Figure 24. Sample travel statistics

All data analysis was performed in the statistical software package R [26]. Survey weights were created by raking [27], using the "survey" package in R [28]. Weights were created only for the Public sample, to match the age (9-level factor), gender (Female binary), education (5-level factor), and income (6-level factor) marginal distributions in census data for the City of Vancouver.[29] For raking, missing respondent socio-demographic data were maintained as a synthetic marginal category in the comparison population data [30]. Weights were trimmed (strictly) at lower and upper bounds of 0.3 and 3.0 times the median weight, respectively (0.14 and 1.36). This led to trimming of 102 (30%) of the weights and a final median weight of 0.997.

Appendix E: Video Rating Results

Summary rating results by video strata are given in Figure 25. The ratings for all nine strata show that with higher passing times there was more agreement of yielding, comfort, and low risk, and less agreement that the road user "should have yielded", as expected. Figure 26 illustrates how the two yielding questions relate to comfort assessment, again aggregated by strata. Low risk and Comfort were highly correlated.

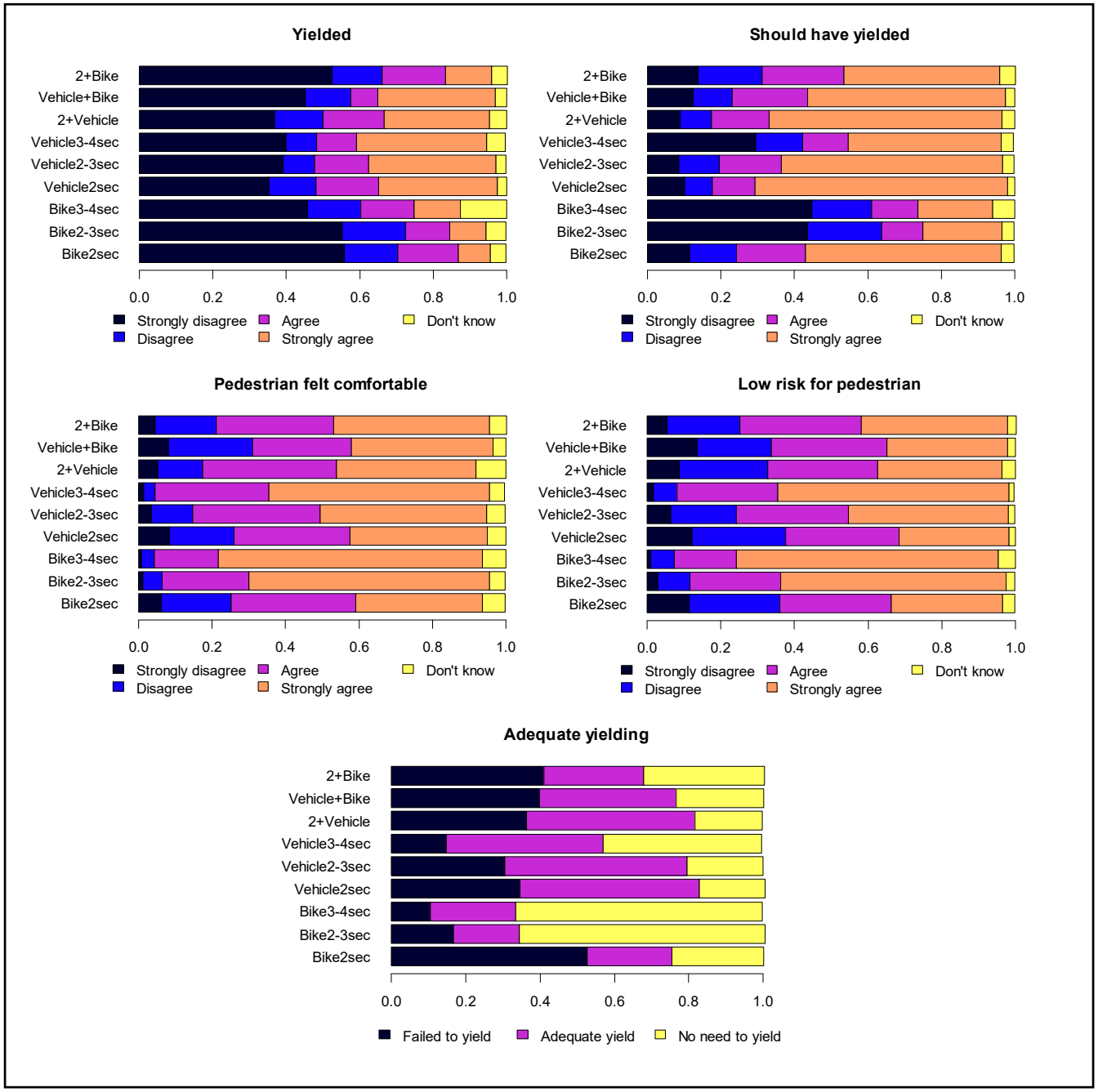

Figure 25. Summary of all video ratings by strata

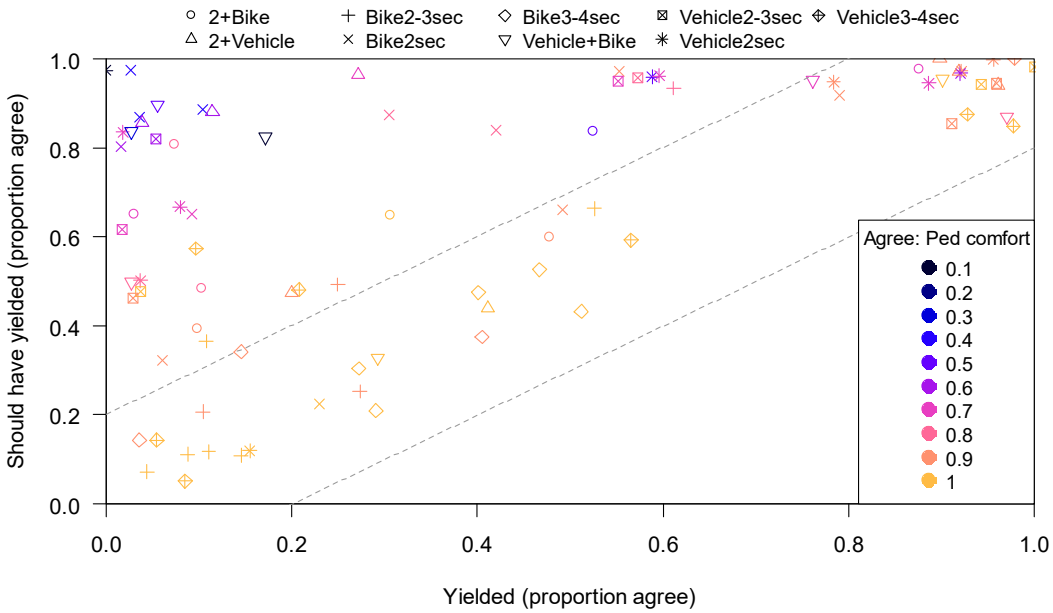

Figure 26. Relationship of yielding and comfort assessment

Appendix F: Comparisons among and between pools

Ratings distributions by respondent pool and strata are given in the following figures (Figure 27, Figure 28, Figure 29, Figure 30, and Figure 31). There is generally good agreement among the pools on the ratings. Interclass correlation coefficients (ICC) for *average ratings* are given in Table 8, all significant at $p<0.01$ (based on two-way effects) [31]. All the ICC are high, with typical good values of at least 0.60 and excellent values of at least 0.75. Yielding was most consistently rated, with comfort and risk less consistent across all pools.

Table 8. Interclass correlation coefficients for average ratings

Survey participants	Yielded	Should have yielded	Adequate yielding	Comfortable	Low risk
Experts	0.789	0.826	0.735	0.661	0.650
Committee	0.841	0.812	0.653	0.565	0.681
Public	0.978	0.978	0.970	0.940	0.955
All	0.981	0.981	0.974	0.949	0.961

Conversely, Interclass Correlation Coefficients (ICC) for *individual ratings* were lower, in the 'poor' range of 0.23 to 0.45, meaning substantial variability among respondents (even Experts). At least 85% of raters agreed or disagreed on 58% of videos for Yielded, 48% for Should have yielded, 52% for Comfortable, and 39% for Low Risk. Hence, the reliability of using individual ratings to represent population perspectives on the severity of interactions is low, but the combined ratings from the survey are reliable. This finding supports the approach taken in this research of gathering a range of perspectives on comfort and safety. In the future, we will continue to need pools of raters to assess severity (or infer from objective features).

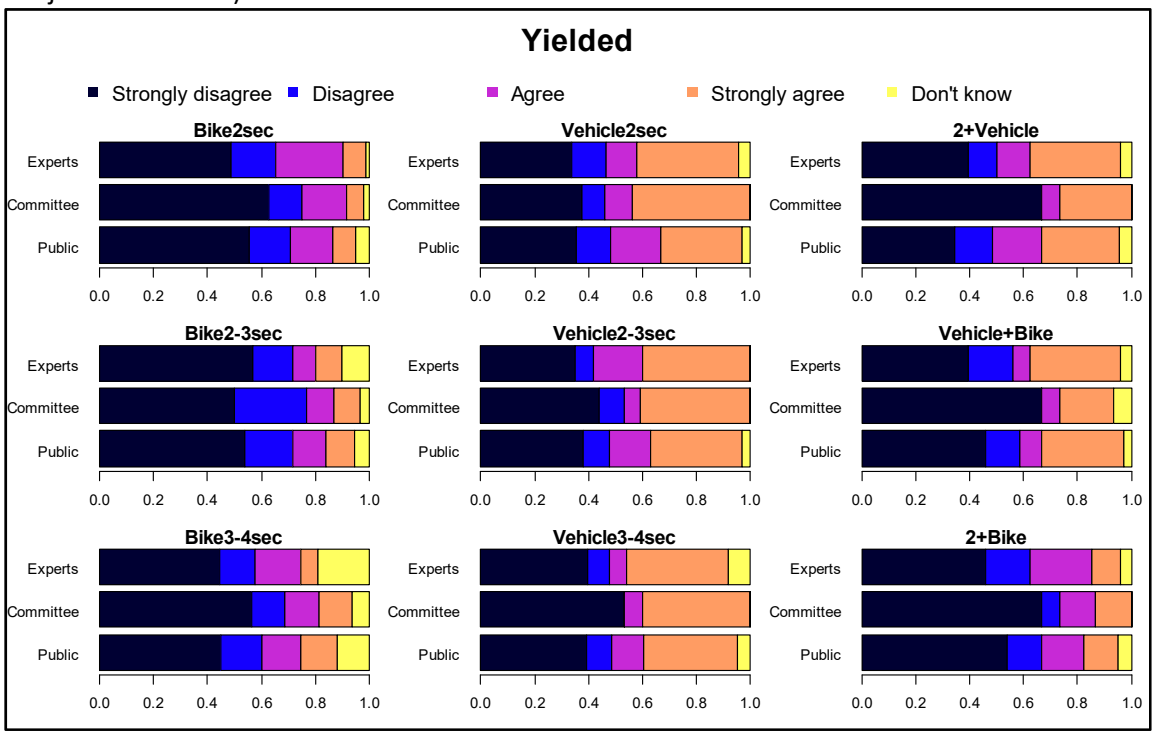

Figure 27. Ratings distributions by respondent pool and strata for yielding

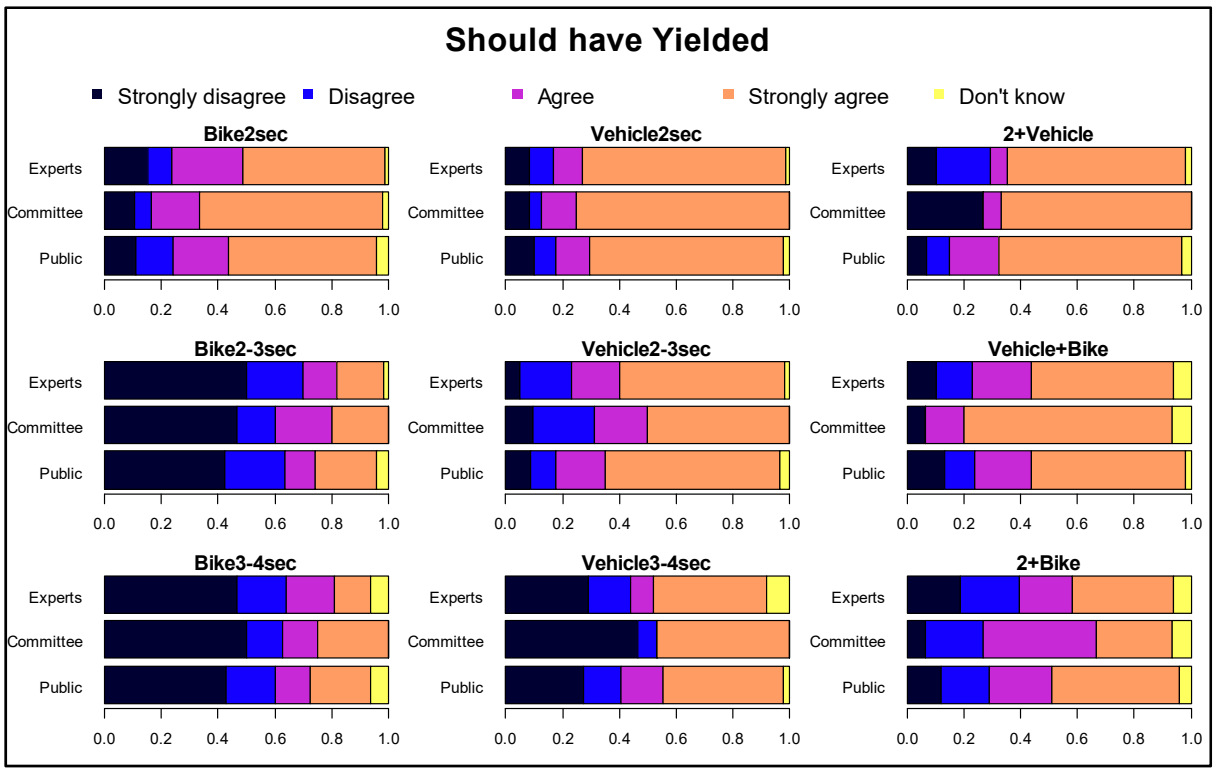

Figure 28. Ratings distributions by respondent pool and strata for should have yielded

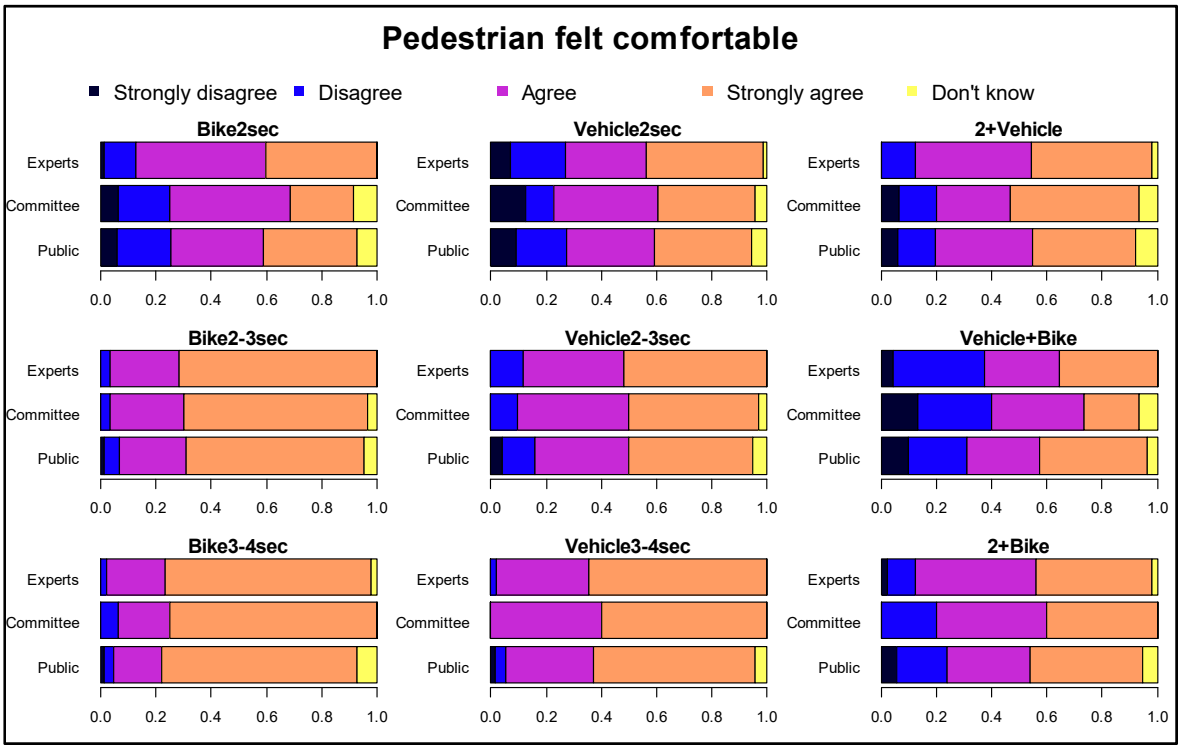

Figure 29. Ratings distributions by respondent pool and strata for comfortable

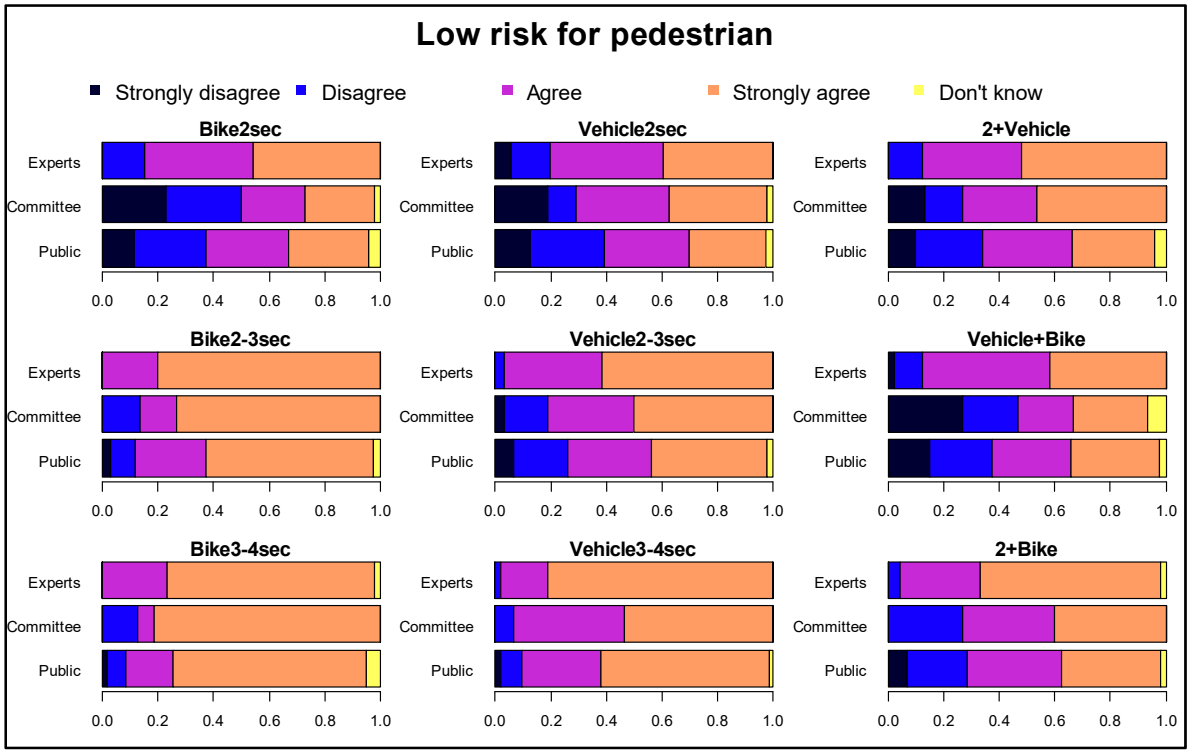

Figure 30. Ratings distributions by respondent pool and strata for low risk

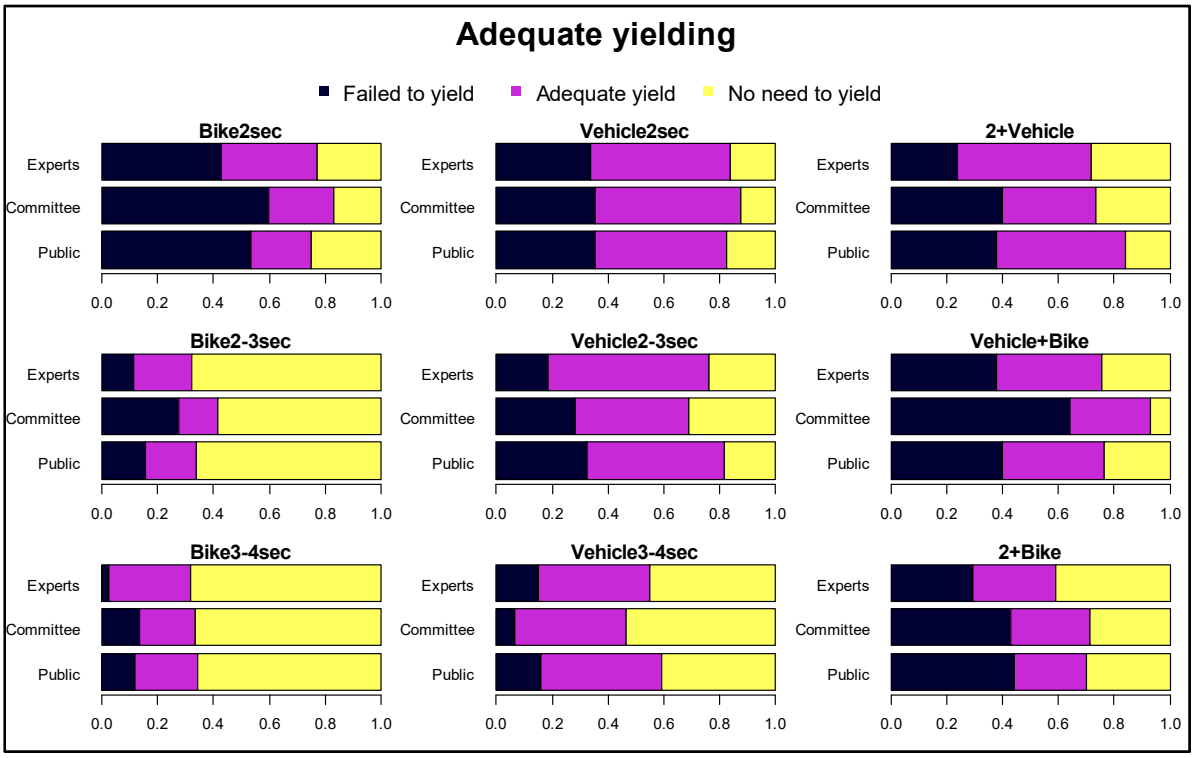

Figure 31. Ratings distributions by respondent pool and strata for adequate yielding

Response distributions among pools were compared for all 45 strata-outcome combinations (i.e., the preceding five figures) using Chi-squared tests with a 95% confidence threshold. Only nine of the 45 tests were significant at $p<0.05$, summarized in Table 9.

Table 9. Significant differences in video ratings among pools

Stratum	Outcome	Differences	
2+ Vehicle	Should have yielded	Public vs Committee	Committee members more strongly disagreed that motorists should have yielded than the Public (marginal difference)
Bike 2 sec	Comfortable	Expert vs both other pools	Experts more frequently agreed that the pedestrians were comfortable in these interactions than either of the other two pools
Bike 2 sec	Low risk	Expert vs both other pools	Experts consistently agreed that the interactions were low-risk more frequently and strongly than the other two pools
Bike 2-3 sec	Low risk	Expert vs Public	
Vehicle 2 sec	Low risk	Expert vs Public	
Vehicle 2-3 sec	Low risk	Expert vs Public	
2+ Vehicle	Low risk	Expert vs Public	
Vehicle+Bike	Low risk	Expert vs both other pools	
2+ Bike	Low risk	Expert vs Public	

Appendix G: Bi-directional traffic adjustment

The same validation sub-sample described above to validate the City coding was used to estimate the interaction frequency with bi-directional traffic. The validation sub-sample included 266 pedestrian crossings. The joint distribution of interactions by type in each direction is given in Table 10. Bi-directional interaction rates are remarkably symmetrical, with nearly equivalent marginal distributions of the interaction frequency with vehicles and bicycles in each direction. The joint distribution of the sample interactions at the TAHZ locations with vehicle traffic (i.e., not Arthritis Centre Entrance) was similarly examined. Based on Chi-squared tests at a threshold of $p<0.05$, 1) we fail to reject independence of the marginal distributions of interaction frequency with vehicles and bicycles in each direction in the validation sub-sample, 2) we fail to reject independence of the marginal distributions of interaction frequency with vehicles and bicycles in each direction between the sample and the validation sub-sample, and 3) we fail to reject independence of the joint distribution of interaction frequency with vehicles and bicycles in each direction in the sample, but 4) we successfully reject independence of the joint distribution in the validation sub-sample.

Table 10. Joint distribution of bi-direction interactions in validation sub-sample

		Other direction				
		No interactions	1+ Vehicle	1+ Bike	Vehicle + Bike	Total
Coded direction	No interactions	42.9%	9.8%	3.8%	1.1%	57.5%
	1+ Vehicle	10.5%	15.4%	3.4%	1.5%	30.8%
	1+ Bike	4.5%	3.0%	1.1%	0.0%	8.6%
	Vehicle + Bike	1.1%	0.8%	0.4%	0.8%	3.0%
	Total	59.0%	28.9%	8.6%	3.4%	100%

Overall, independence by direction is a reasonable and convenient assumption to account for bi-directional traffic. We can further reasonably assume equal marginal distributions for traffic in each direction, given the similarities in interaction types. Thus, for interaction analysis, we assume equal marginal distributions of interaction types with traffic in each direction and independent joint distributions. To relax the independence assumption in future analysis, iterative proportional fitting could be used to match the (assumed equal) marginal distributions from an assumed joint distribution table (derived from validation data).

Appendix H: Location-specific on-site interview results

Location-specific safety concerns described during the on-site interviews are summarized in the following figures.

Figure 32. Lack of notice for eastbound pedestrians and cyclists of leading protected left phase for the east approach

Figure 33. Difficult for paramedics driving ambulances turning right into the Emergency entrance to see cyclists headed eastbound in protected bike lane

Figure 34. Design complexity pedestrians in front of the Mary Pack Arthritis Centre and the Spinal Cord Centre; varying paving materials can be a challenge, especially for people with disabilities and guide dogs

Figure 35. Access to VCH Cycling Centre is awkward for westbound cyclists; Cycling Centre door also opens directly into the pedestrian space (access has since been modified by VCH Cycling Centre)

Figure 36. Design complexity for pedestrians in front of the Eye Care Centre; end of cycling facility through parking lot driveway into the road right-of-way is also a significant conflict point