Transportation Research Part F: Psychology and Behaviour 85 (2022) 179–194

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

Investigating relationships among perceptions of yielding, safety, and comfort for pedestrians in unsignalized crosswalks

Gurdiljot Gill [a], Alexander Bigazzi [b,*], Meghan Winters [c]

[a] Department of Civil Engineering, University of British Columbia, Vancouver V6T 1Z4, Canada
[b] Department of Civil Engineering and School of Community and Regional Planning, University of British Columbia, Canada
[c] Faculty of Health Sciences, Simon Fraser University, Burnaby, BC V5A 1S6, Canada

ARTICLE INFO

Keywords:
Pedestrian
Safety
Comfort
Yielding
Crosswalk

ABSTRACT

Interactions with other road users influence the perceived safety and comfort of pedestrians. Yet the relationships among perceptions of yielding, safety, and comfort are poorly understood. To enhance understanding of these key concepts, the objectives of this study are to determine how perception of pedestrian safety at unsignalized crosswalks differs from perception of comfort, and the relationship of each with perception of yielding. A generalized structural equations model is developed using data from an online survey in which 366 participants (i.e., "perceivers") rated yielding, safety, and comfort for sample videos of pedestrian interactions with motor vehicles and bicycles. Results show that an individual's perception of yielding plays a crucial role in mediating the effects of interaction attributes (e.g., vehicle speed, proximity) and perceiver attributes (e.g., travel habits) on their perceptions of pedestrian safety and comfort. For example, people who bicycle more frequently perceive pedestrians as more comfortable than people who walk more frequently, rooted in misalignment on what constitutes adequate yielding. Strategies to address pedestrian comfort can focus on a set of key yielding behaviors by drivers and cyclists – particularly allowing the pedestrian to cross first. Motor vehicle drivers must exhibit stronger yielding behavior (e.g., allow a larger time gap) than bicycles to achieve the same level of perceived pedestrian safety and comfort. Although perceptions of safety and comfort are strongly related and similarly impacted by yielding, researchers should be cautious about using the concepts interchangeably because they are differently impacted by attributes of the interaction and perceiver.

1. Introduction

Walking and bicycling (active modes of transport) are often promoted because of associations with sustainability, health, and well-being (Mueller et al., 2015). For effective policies promoting walking, the safety and comfort of pedestrians are fundamental needs (Pooley et al., 2013). Walking facilities or environments perceived as unsafe provide a poor quality of service and can lead to less walking (Alfonzo, 2005; Bozovic et al., 2020; Landis et al., 2001; Salvo et al., 2018).

One component of street networks that poses substantial risk for pedestrians is unsignalized crosswalks (Olszewski et al., 2015). Crossing a street, though a "banal and mundane activity", can create challenging interactions because pedestrians must process

* Corresponding author.
E-mail addresses: gurdil.gill@ubc.ca (G. Gill), abigazzi@civil.ubc.ca (A. Bigazzi), mwinters@sfu.ca (M. Winters).

https://doi.org/10.1016/j.trf.2022.01.007
Received 24 June 2021; Received in revised form 7 December 2021; Accepted 10 January 2022
Available online 29 January 2022

complex spatial information and convey their intentions while coordinating with other road users through largely nonverbal communications (Kong et al., 2021; Merlino & Mondada, 2019; Zhuang & Wu, 2014). The goal of this paper is to improve understanding of perceptions of safety and comfort for crossing pedestrians, including how those notions differ and how they are influenced by the behavior of interacting road users. We next examine the state of knowledge about pedestrian safety and comfort, including how they have been defined and used, before identifying the specific objectives of this study.

1.1. Comfort, safety, and walking behavior

In social-ecological models of walking grounded in environmental psychology, walking behavior is influenced by environmental factors at multiple levels from the immediate to the societal that are perceived and experienced by the individual according to their unique circumstances and characteristics (i.e., the extent to which the environment is seen to provide affordances of their individual needs) (Alfonzo, 2005; Bozovic et al., 2020). The common needs identified in the widely used hierarchy of walking needs from Alfonzo (2005) include, from most to least primary: feasibility, accessibility, safety, comfort, and pleasurability. In this framework, "safety" is defined as "feel[ing] safe from the threat of crime" (excluding traffic safety) and "comfort" is defined as "level of ease, convenience, and contentment" (including traffic safety). According to these social-ecological models, understanding individual perceptions of the environment is crucial to understanding (and modelling) the effects of the environment and environmental interventions such as street design on travel behavior.[1] Therefore, knowledge about perceptions of safety and comfort is vital to effective planning and design for transportation systems.

In the traffic safety literature, objective safety typically refers to a low risk of a crash or injury for travelers and is a conventional outcome in safety analysis, while subjective or perceived safety refers to an individual's level of concern for being in a crash or injured (Gkekas et al., 2020; Osama et al., 2020; Schneider et al., 2004; Winters et al., 2012). Like Alfonzo (2005), much of the research on active transportation conflates the concepts of perceived (traffic) safety and comfort, and uses the terms interchangeably; for example, evaluating comfort as safety concern or fear of traffic (Chataway et al., 2014; Dill & McNeil, 2013; Hunt & Abraham, 2007), representing perceived safety by stated comfort level (Kaparias et al., 2012), or treating them as indistinguishable (Fitch & Handy, 2018; Griswold et al., 2018). Pedestrian traffic safety has also been studied in relationship to personal security (perceived threat of crime or violence – which is sometimes called 'safety') (Oviedo-Trespalacios & Scott-Parker, 2017). From other literatures there are studies of pedestrian physical comfort focused on weather conditions, particularly wind and temperature, and unrelated to traffic (Metje et al., 2008; Nikolopoulou & Lykoudis, 2006). Since the focus of this study is road-user interactions for crossing pedestrians, for the rest of this paper we use 'safety' to refer to traffic safety only (risk of a crash or injury – not safety from crime), and 'comfort' to refer to level of ease in movement and interactions with other road users (not physical comfort from weather).

1.2. Studies of perceived pedestrian safety and comfort

Since safety and comfort perceptions are subjective phenomena, they are usually assessed by first- or third-person evaluations of road user interactions. In first-person evaluations, pedestrians are intercepted to obtain their perceived safety and comfort after a real-world (Lord et al., 2018) or simulated (Deb et al., 2018) experience. In third-person evaluations, perceptions are obtained from a participant viewing an environment or event in which they do not take part, usually photos or video recordings (Kang & Fricker, 2016; Lehtonen et al., 2016; Monsere et al., 2020; Park & Garcia, 2020). Repeated use of recorded images for multiple observers allows researchers to confidently measure variations in perceptions across individuals, controlling for the multitude of factors that can vary in complex traffic environments and interactions. Perceptions can be self-reported or measured using physiological markers of stress, although no study has yet validated stress markers as a measure of perceived safety or comfort, specifically (Bigazzi, Ausri, Peddie, Fitch, & Puterman, 2022).

In some third-person studies, the observer evaluates an environment or event based on their personal perceptions as an observer. For example, experts subjectively rating the severity of observed interactions or conflicts for traffic safety evaluations (Arun et al., 2021; Tageldin & Sayed, 2019), qualitative behaviour evaluation of observed travellers (Kaparias et al., 2015; Lee et al., 2009), or evaluations of whether cyclists or drivers yielded to pedestrians at unsignalized crosswalks (Foster et al., 2014; Hosford et al., 2020). In other third-person studies, the observer is asked to evaluate the experience they imagine they would have if they were travelling in the observed environment or a party to the observed event. These studies have asked participants to evaluate their imagined comfort, caution, safety, level of service (A through F), and willingness to cross (Clark et al., 2021; Dey et al., 2019; Foster et al., 2015; Monsere et al., 2020; Petritsch et al., 2010). Some studies ask respondents to rate the safety of an environment or facility but are ambiguous as to the specific subject of risk (Clark et al., 2021; Park & Garcia, 2020; Wang & Akar, 2018). There has been limited research validating or comparing perceptions of imagined experience versus real-world (first-person) perceptions, and it has yielded inconsistent results (Fitch & Handy, 2018; Foster et al., 2015; McNeil et al., 2015).

For either real-world or recorded pedestrian interactions, potential determinants of perceptions can be obtained by trained observers coding characteristics of the interactions. A multitude of observable factors have been reported as determinants of perceived safety or comfort for pedestrians (without distinguishing the two). The proximity of other road users in time and space is a key operational determinant of objective safety (Guido et al., 2011) and has also been associated with comfort (Engelniederhammer et al.,

[1] This is the central tenet of the stimulus-organism-response model from environmental psychology (Mehrabian & Russell, 1974).

2019; Kitabayashi et al., 2015). The idea of a 'comfort zone' has been used for decades to model driving behavior – essentially, the minimum distance from other road users for a driver to feel comfortable (conflated with feeling safe) in various situations (Bärgman et al., 2015; Näätänen & Summala, 1974; Summala, 2007; Vaa, 2014). The comfort zone of pedestrians and cyclists has been less studied (Cepolina et al., 2018; Lee, Rasch et al., 2020), even for interactions with motor vehicles, presumably because drivers are viewed as the risk-controlling agents in those situations (Lubbe & Rosén, 2014; Rasch et al., 2020). The effects of design elements have been studied as well, with refuge islands at signalized intersections increasing perceived pedestrian safety (Ni et al., 2017) while longer crossing distances decrease perceived safety for crossing pedestrians (Sucha et al., 2017). Studies have also reported that perceptions of safety and comfort are systematically associated with perceiver age and gender (Kaparias et al., 2012; Sucha et al., 2017) and experience or habits traveling by a specific mode (Gkekas et al., 2020; Kaparias et al., 2012; Washington et al., 2012).

1.3. Yielding at crosswalks

Yielding of interacting road users is a behavioral factor often identified as a key component of pedestrian safety and comfort, particularly at unsignalized crosswalks (Kong et al., 2021; Moody & Melia, 2014; Sucha et al., 2017; Turner et al., 2006). However, yielding is inconsistently defined both conceptually and operationally (Fu et al., 2018). Some studies use yielding strictly to mean that road users follow traffic laws (Turner et al., 2006). Alternatively, yielding has been based on which road user passed first (Goddard et al., 2015), sometimes accounting for the feasibility of vehicle stopping based on speed and distance (Fu et al., 2018; Huybers et al., 2004). Vehicle slowing or stopping has also been used to define yielding (Zhuang & Wu, 2014). And some studies fail to define yielding or explain exactly how it is measured (Gitelman et al., 2017; Kong et al., 2021).

A great deal of safety research has focused on treatments to improve vehicle yielding rates (using varying definitions of yielding). Yielding to crossing pedestrians is associated with design elements such as raised crosswalks and speed humps (Gitelman et al., 2017) and warning signs, pavement markings, and beacons (Costa et al., 2020; Huybers et al., 2004). Contextual factors include the approach speed of vehicles (Bertulis & Dulaski, 2014) and number of pedestrians (Sucha et al., 2017); behavioural factors include pedestrian gestures, staring, and distraction (Guéguen et al., 2015; Sucha et al., 2017; Zhuang & Wu, 2014); and personal factors include age (Al-Kaisy et al., 2018), race (Goddard et al., 2015), and assertiveness (Schroeder & Rouphail, 2011).

1.4. Summary and objectives

To summarize, yielding, comfort, and safety perceptions are important interrelated aspects of transport systems, but they are vaguely and inconsistently defined in the literature and we have a poor understanding of the relationships among them. We do not know how similar or distinct perceptions of traffic safety and comfort are for people in various contexts. Researchers have reported associations of pedestrian safety and comfort with a range of contextual, behavioral, and personal factors, but we know little about the mechanisms through which these observable factors affect (possibly distinct) perceptions of pedestrian safety and comfort.

In particular, one behavioral factor – vehicle yielding – is often considered a key component of pedestrian safety and comfort, but without clear evidence as to how or why. We do not even know what constitutes yielding from the perspectives of diverse individuals.

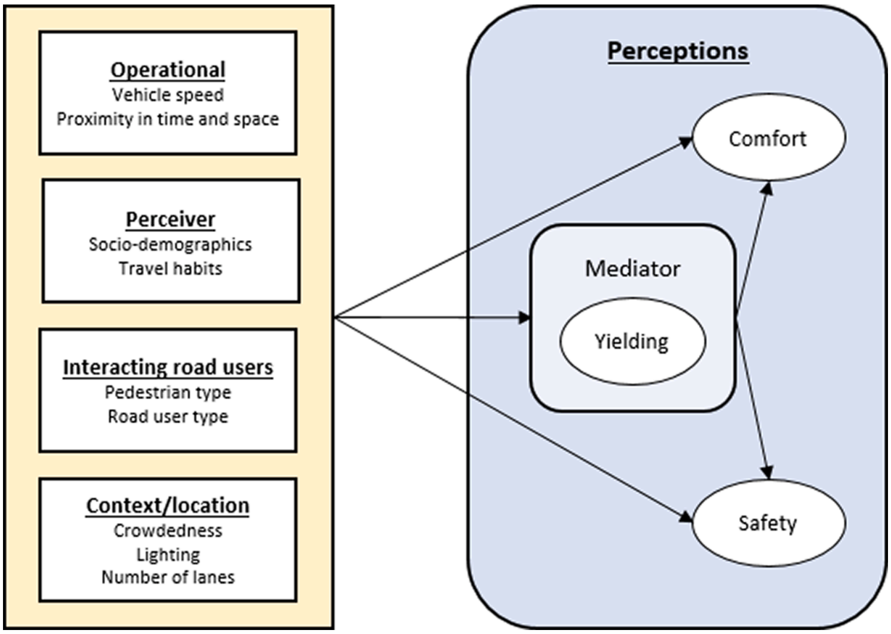

Fig. 1. Analysis framework to examine the relationships among perceptions of yielding, safety, and comfort.

Yielding has been associated with operational factors that may directly affect pedestrian safety and comfort (e.g., lower speed), and the perception that a vehicle is yielding may also have a separate effect on pedestrian safety and comfort (perhaps indicating a driver's awareness and intention to enable a safe crossing). To what extent is a sense of safety or comfort created by the behaviors associated with yielding, versus yielding itself?

Motivated by these knowledge gaps, this study aims to enhance understanding of how perceptions of yielding, safety, and comfort are related. We have three main questions: (a) what perceiver and interaction characteristics influence perceptions of pedestrian safety and comfort in unsignalized crosswalks, (b) how do perceptions of comfort differ from perceptions of safety, and (c) how do perceptions of yielding mediate those relationships? The next section provides an overview of the methods we use to answer these questions.

2. Methods

2.1. Overview of methods

Fig. 1 illustrates the analysis framework for the study, in which yielding, safety, and comfort are all perceived factors. We allow for subjectivity in the definition of yielding to account for the importance of individual perception of environmental conditions, consistent with the socio-ecological models described above for perceived safety and comfort. This approach also negates the need for us to define yielding *a priori*, which would be challenging given the lack of clarity in the literature. As stated above, we confine safety and comfort perceptions for this study as related to traffic, interactions, or movement (not crime or weather).

The observable or objective factors potentially influencing perceptions of yielding, safety, and comfort are organized under four broad categories in Fig. 1: operational, perceiver, interacting road users, and context/location. The arrows in Fig. 1 represent the direct effects of the factors on perceptions of yielding, safety, and comfort, as well as the effects of perceived yielding on perceptions of safety and comfort. We hypothesize that perceived yielding mediates the effects of some objective factors on perceived comfort and safety; i.e., perceived yielding is the mechanism underlying the influence of those variables on perceptions of safety and comfort. The analysis framework uses mediation analysis to test the extent to which the factors that increase yielding improve perceived safety and comfort solely because they increase yielding (a full mediation effect), or because there is also some direct perceived risk mitigation or comfort effect of slower vehicles, etc. (MacKinnon et al., 2007). By examining the direct and indirect (yielding-mediated) effects of the objective factors, we can distinguish the role of yielding in determining perceived pedestrian safety and comfort.

We implement this analysis framework using data from an online survey in which participants rated the yielding, safety, and comfort of video-recorded pedestrian interactions with motor vehicles and bicycles. A third-person web survey method was selected because it allows for a larger and more diverse sample than first-person methods, and for repeated measurements across perceivers and interactions (which is essential to account for omitted variables). Furthermore, it allows for some experimental control of the interaction characteristics – in particular allowing measurement of far more higher-risk interactions than would be possible in a real-world setting (such as with an intercept survey). High-risk interactions are (thankfully) very rare (Hosford et al., 2020), which means a first-person/intercept study design would yield insufficient variation across the main variables of interest (risk and comfort).

A generalized structural equations model is developed with participant ratings of perceptions of safety and comfort as dependent variables, mediated by perceptions of yielding, and perceiver and interaction characteristics as independent variables. The independent variables (described below) are based on the literature on pedestrian perceptions cited above, as well as traffic safety studies showing determinants of objective safety (Stoker et al., 2015; Zegeer & Bushell, 2012).

2.2. Data

2.2.1. Video data

Fig. 2 illustrates the data collection process. Video data were collected at 11 unsignalized marked crosswalk locations in the City of Vancouver, British Columbia, Canada. In British Columbia, all intersections with sidewalk facilities are crosswalks unless otherwise marked, but compliance is low at unsignalized intersections unless the crosswalks are marked with "zebra" stripes. Zebra markings are typically added where crossing volumes are high or crash history warrants such a treatment (or to create a mid-block crosswalk outside of an intersection). High-traffic and multi-lane streets will typically warrant the installation of a traffic signal controlling both pedestrian crossings and vehicle through movements, so unsignalized marked crosswalks are generally only found on moderate-traffic two-lane "collector" streets (British Columbia Ministry of Transportation and Infrastructure, 2019). Although we have not used a legal definition in this study, for context, the British Columbia Motor Vehicle Act dictates that drivers "must yield the right of way to a pedestrian…when the pedestrian is crossing the [street] in a crosswalk" but that also the "pedestrian must not leave a curb…so close it is impracticable for the driver to yield the right of way" (British Columbia Motor Vehicle Act, 1996).

The selection of crosswalk locations was based on a City project to evaluate the pedestrian experience in a re-designed hospital corridor.[2] Seven crosswalks were located along the hospital corridor and four others were from nearby corridors (within 5 km) with similar traffic volumes and street design context. All locations were two-lane collector street corridors with no directional dividing line and substantial pedestrian and bicycle volumes – see Supplementary Material. Due to the recent re-design, the hospital corridor

[2] The 10th Avenue Corridor Project, near Vancouver General Hospital; see https://vancouver.ca/streets-transportation/10th-avenue-corridor-project.aspx

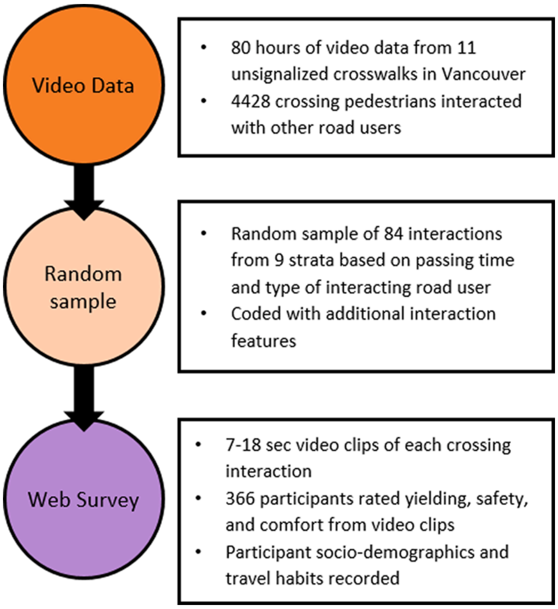

Fig. 2. Data collection process.

locations had one-way protected bicycle facilities (versus bicycles in shared lanes with motor vehicles in the other locations) and street markings in better condition. One crossing in the hospital corridor only involved interactions with bicycles because the crosswalk traversed the bicycle lane but not the motor vehicle lanes.

The cameras were oriented to capture the motor vehicle or bicycle approach to the crosswalk. Video quality was limited to maintain privacy of road users due to City policy. Data were collected for six hours (8–10 h, 11–13 h, and 16–18 h) on three weekdays in September through December 2018 at each location. The video recording times were selected based on peak expected combined volumes of pedestrians, bicycles, and motor vehicles, with a target of observing 200 pedestrian crossings with interactions from each location.

Video data were manually reviewed to identify potential interactions of crossing pedestrians with motor vehicles or bicycles, defined using a conservative threshold of approximately 5 s passing time. Passing time (sometimes referred to as post encroachment time) is the time gap between when the first road user exits the point at which their paths intersect and when the second road user enters it. Although no conflict indicator completely captures risk, passing time is the most popular measure for studies of crossing pedestrians and other road users on transverse trajectories (Mahmud et al., 2017).

A total of 4428 potential pedestrian interactions were identified: 3176 (72%) with motor vehicles and 1252 (28%) with bicycles. Due to the time cost of coding interactions, a random sample of 50 pedestrian crossings with interactions was selected from each location (except for the one low-volume location that had only 36), giving 536 crossings for further analysis. These 536 crossings were then stratified on combinations of passing time (<2, 2–3, 3–4 s) and interacting road user type (bicycles, motor vehicles, or both), which were both manually coded (see Table 1). The passing time was recorded between the closest points of the vehicle and pedestrian: i.e., the part of the car that first intersected the pedestrian path after the pedestrian had passed (if the pedestrian passed first), or the part that last intersected the pedestrian path before the pedestrian arrives (if the car passed first). Electric bicycles were coded the same as bicycles (not reliably distinguishable in the video data), and three observed motorcycles were coded as motor vehicles (including mopeds or sit-down scooters, which are classified as limited-speed motorcycles in the British Columbia Motor Vehicle Act); no kick/stand-up scooter or skateboard interactions were recorded.

From the 536 crossings, 84 were then selected for the web survey, based on consideration of the time burden for participants (see below). To balance the number of bicycle and motor vehicle interactions and generate more observations of (i.e., over-sample) higher severity (shorter passing time) interactions, the 84 crossings were randomly drawn from the 9 strata shown in Table 1. These strata were designed to generate perception data over a range of interaction types from each respondent, not to represent the distribution of interaction types observed at the crosswalk locations. One motorcycle interaction was included in the 84 sample crossings (as a motor vehicle).

2.2.2. Web survey

The web survey was implemented in Qualtrics software. After providing consent, participants answered questions about their socio-demographics (gender, educational attainment, age, household income), travel habits (frequency of travel by automobile, bicycle, walking, and public transit), and overall self-assessed risk-aversion (on a 7-point scale ranging from “Extremely comfortable taking risks” to ”Extremely uncomfortable taking risks”, based on Glanz et al. (2016)). The participant variables were selected based on consideration of the existing literature on perceptions of safety and comfort and the availability of census data for weighting, balanced

Table 1
Strata for pedestrian crossings in video clips.

Interacting road user	Passing time	Number (%) in pool of 536 coded crossings*	Number (%) in 84 sample crossings used in web survey**	Number (%) shown to non-expert participants in web survey
1 bicycle	<2 s	46 (9%)	12 (14%)	3 (20%)
1 bicycle	2–3 s	30 (6%)	10 (12%)	2 (13%)
1 bicycle	3–4 s	14 (3%)	8 (10%)	1 (7%)
1 motor vehicle	<2 s	29 (5%)	12 (14%)	3 (20%)
1 motor vehicle	2–3 s	79 (15%)	10 (12%)	2 (13%)
1 motor vehicle	3–4 s	42 (8%)	8 (10%)	1 (7%)
≥2 motor vehicles	<4 s	50 (9%)	8 (10%)	1 (7%)
≥1 motor vehicle and ≥ 1 bicycle	<4 s	46 (9%)	8 (10%)	1 (7%)
≥2 bicycles	<4 s	25 (5%)	8 (10%)	1 (7%)

* An additional 175 (33%) had passing time over 4 s.
** And shown to expert participants.

against considerations of overall survey burden.

Participants were then shown a series of randomly ordered 7–18 s video clips drawn from the stratified sub-sample of 84 crossings. On each page they were prompted with: “Regarding the interaction between the crossing pedestrian and the [road user] shown in the video, please indicate your level of agreement with the statements below:” followed by

- The [road user] yielded to the pedestrian.
- The [road user] *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.

and Likert scale options of “Strongly disagree”, “Somewhat disagree”, “Somewhat agree”, “Strongly agree”, and “I don’t know” for each statement. A reduced form summary of the survey instrument is given in the Supplementary Material. Participants were not given definitions for yielding, comfort, risk, or safety in the survey instrument, so that responses reflect their individual perceptions of these terms.

As noted above, the literature is inconsistent in measurement and use of terms relating to yielding, safety, and comfort. The instrument was designed after extensive consideration of the literature, and pilot testing of twelve draft statements to measure yielding, safety, and comfort. For example, other draft statements for safety were: “This crossing was safe for the pedestrian”; “There was a low risk of injury for the pedestrian in this crossing”; “There was a low risk of the pedestrian being hurt in this crossing”; and “There was a low risk of collision for the pedestrian in this crossing”. Other draft statements for comfort included: “I would have felt comfortable as the pedestrian in this crossing” and “The pedestrian felt safe in this crossing”. To test the draft measures, two researchers prompted and then discussed the draft statements with nine non-experts while viewing pedestrian crossings (not included in the survey). Feedback from the pilot testing and academic and professional colleagues led to the selection of the final wording in the survey. Comfort was framed for the crossing pedestrian, as perceived by the observer, to be consistent with the framing of the statement for safety/risk, and because some pilot participants indicated they would have behaved differently than the observed pedestrians in the situation (leading to an unobserved counterfactual when asked what they “would have felt”). Two questions on yielding were included to distinguish perceptions of a road user failing to yield from a road user not needing to yield due to the timing of the interaction.

2.2.3. Participants

The survey recruitment involved three groups of participants: **Public**, comprised of people with experience travelling alone in Vancouver; **Committee**, comprised of a citizen’s advisory group working with the City on the corridor project; and **Experts**, comprised of a small set of non-local transportation professionals from North America with traffic safety expertise. Members of the public were recruited through social media posts and advertisements; Committee and Experts were recruited by direct email contact. There were no demographic criteria for participation. All research methods were reviewed and approved by the Behavioral Research Ethics Boards of the University of British Columbia (H18-03637) before recruitment began. The Experts rated all 84 videos while the Public and Committee groups rated 15 (1–3 from each strata, as shown in Table 1). This number of videos was selected based on consideration of the required time to complete the survey (targeting 15 min for non-experts and 90 min for experts).

The participants were incentivized; each Expert was offered an honorarium of CA$300 and four random Public or Committee members received a CA$25 gift card of their choice. The incentive amounts were based on the time required and professional service rates for expert review. Over 41 days of data collection (March 15–April 24, 2019), 451 responses were received. Responses were excluded based on declined consent (2), spending less than 12 s on more than one of the video rating pages (11), or rating fewer than four videos (72), leaving 366 complete responses for analysis (343 Public, 17 Committee, and 6 Expert), with 5,529 total video ratings.

2.2.4. Interaction features

Interaction features were obtained by coding the 84 videos from the web survey. Four members of the research team independently coded 10 random videos for 29 draft features related to the road users, operations, street design, etc. Features were considered reliably coded based on a Kappa statistic threshold of > 0.6 (McHugh, 2012); unreliably coded factors were discarded, including some related to pedestrian distraction, communication between road users, and bicyclist pedaling. The final set of objective features coded for the 84 videos and used in the analysis were:

- *Operational:* passing time, speed of interacting road user through crosswalk (manually calculated), whether the pedestrian or interacting road user passed the conflict point first, pedestrian location when the interacting road user entered crosswalk (parallel sidewalk, crosswalk/street, curb-cut/island, or off-street/off-screen), yielding-related maneuvers by interacting road user (full stop, speed deviation, or path deviation), turning movement by the interacting road user,
- *Interacting road users:* uncommon pedestrian type (child, mobility-assisted, or with cart/trolley), whether the motor vehicle was a passenger car or not (e.g., versus truck), whether the pedestrian or interacting road user were in a group,
- *Context/location:* total road users (pedestrians, bicycles, and motor vehicles) in scene, low light, condition of crosswalk marking (good, poor, or missing), and number of general purpose and bike lanes to cross.

2.3. Analysis

Sampling weights were applied to compensate for demographic differences between the Public group participants and population data for the City of Vancouver from the Census (Statistics Canada, 2017). Survey weights for each participant were created using iterative proportional fitting (Mercer et al., 2018) using the "survey" package in R (Lumley, 2019; R Core Team, 2019). Target marginal distributions were taken from the census data along four dimensions: age (nine-level factor), gender (binary), income (six-level factor), and education (five-level factor). No weights were applied to the Committee or Expert groups, which were not designed to be representative of a population.

A weighted generalized structural equations model (GSEM) (Rabe-Hesketh et al., 2004) was specified and estimated using the GSEM builder in Stata 16 (StataCorp, 2019) to examine the relationships illustrated in the analysis framework in Fig. 1. Structural equations models are commonly used in travel research examining perceptions or attitudes, as these models allow specification of interrelationships among multiple dependent, mediating, moderating, latent, and independent variables (He et al., 2021; Vallejo-Borda et al., 2020; Zhao et al., 2019). GSEM was selected because it allows for estimation of key elements of our analysis framework and dataset: multiple dependent variables (yielding, safety, and comfort); covariance between comfort and safety; yielding as a variable mediating the effects of independent variables on safety and comfort; and effects (correlated errors) from repeated measures of the same videos.

The GSEM model specification is based on independent variable selection from univariate (single dependent variable) models. Before model development, independent variables were checked for multicollinearity. Univariate weighted mixed regression models for all dependent variables were developed by step-wise addition of independent variables, retained at $p < 0.05$ for any of the dependent variables. The independent variables specified for each of the final univariate models were brought into the multivariate GSEM specification. The final GSEM specification was determined by conducting additional variable selection where only significant (at $p < 0.05$) independent variables were retained for each dependent variable.

The ideal specification for our conceptual framework was a GSEM model with correlated errors across perceived safety and comfort as well as crossed random effects for video and participant. However, only one set of effects could be included in the specification because inclusion of both video and participant effects (as either fixed or random effects) along with the correlated dependent variable errors created identification issues. Video random effects were included in the final model based on a comparison of estimation results and the desire to account for potential omitted interaction features (Bell et al., 2019). Stata 16 does not generate model fit indices for GSEM with random effects and sampling weights, so fit indicators for the final specification were approximated by estimating a simpler model with the same variable specification but excluding random effects and weights.

Responses to all four severity statements were coded as: 1 = strongly disagree, 2 = somewhat disagree, 3 = somewhat agree, and 4 = strongly agree. Responses to "The pedestrian felt comfortable in this crossing" were used as the dependent variable representing Comfort; responses to "The risk of injury for the pedestrian in this crossing was low" were used as the dependent variable representing (perceived) Safety. For the Yielding mediating variable, a construct named "adequate yielding" was calculated from the two statements on yielding by subtracting the rating of "The [road user] *should* have yielded to the pedestrian" from the rating of "The [road user] yielded to the pedestrian". For example, an interaction rated as "somewhat disagree" that the road user yielded and "somewhat agree" that the road user should have yielded generates an adequate yielding score of -1. The adequate yielding scale ranges from -3 (severely inadequate yielding) to 3 (excessive yielding). In this way, perception that a road user did not need to yield is distinguished from perception that a road user failed to yield (both of which would generate a "disagree" response to a statement that the road user yielded). The independent variables considered for model specification were: the 13 coded interaction features described above, and 9 attributes of the perceiver (respondent) collected from the web survey (gender, education, age, household income, frequency of travel by automobile, bicycle, walking, and public transit, and overall self-assessed risk-aversion).

Note that the same survey data were used in a previous analysis with the objective of contrasting the perspectives of the three groups of participants (Bigazzi et al., 2021). Key findings were that the Committee and Public group perceptions were aligned but the Experts assessed pedestrian risk as significantly lower (despite similar views of yielding and comfort), and that sample representation should be assessed in relation to travel habits rather than socio-demographics. That paper did not investigate the relationships among comfort, safety, and yielding perceptions, which is the objective of this paper.

Table 2
Summary statistics (unweighted) of data used in analysis.

Variable	Summary value
Perceiver (N = 366)	
Female	54%
Age (years)	37 mean (standard deviation 13)
Educational attainment	71% Bachelor's or higher degree
Household income	53% under CA$100,000
Risk aversion	42% comfortable, 29% neutral, 30% uncomfortable
Travel mode (use several times a month or more)	95% walk, 42% bicycle, 78% transit, 76% auto
Interactions (N = 84)	
Passing time (seconds)	2.7 mean (standard deviation 1.0)
Pedestrian passed conflict point before interacting road user	57%
Interacting road user in a group (e.g. more than one vehicle involved)	11%
Speed of interacting road user (km/hr)	19 mean (standard deviation 7)
Interacting road user deviation of speed or path	67%
Pedestrian location when interacting road user entered crosswalk	50% on-street, 27% pedestrian ramp/island, 19% parallel sidewalk, 4% off-street/off-screen
Uncommon pedestrian (child, mobility-assisted, etc.)	11%
Number of pedestrians in the scene	4.8 mean (standard deviation 2.8)
Site is along the hospital corridor	75%

3. Results

3.1. Data overview

Table 2 and Fig. 3 give summary statistics for the survey data used in the analysis. Socio-demographic data for the Public group were not representative of the census data for the City of Vancouver (see comparison in Supplementary Material). As described above, the sample was weighted over gender, age, education, and income dimensions; a final median weight of 0.997 was obtained after trimming 30% of the weights at lower and upper bounds of 0.3 and 3.0 times the median weight. Because of the stratification method used in the survey, interactions with closer passing times received more ratings; hence, the summary ratings shown are not representative of all interactions in the video data. As illustrated in Fig. 3, in the majority of ratings, respondents indicated the road user did not yield to the pedestrian, but should have, and that the interactions were still comfortable and low-risk for the pedestrian. Participants more frequently disagreed that bicycles yielded and should have yielded, compared to interactions with motor vehicles.

Fig. 4 illustrates the average yielding ratings for each video. The adequate yielding scale ranges from −3 (severely inadequate yielding) to 3 (excessive yielding); darker colors and points more toward the top left corner in the figure indicate less adequate yielding. The top right corner in the figure indicates perceptions that the road user yielded and needed to yield; the bottom left corner indicates the road user did not yield and did not need to yield. No video had an average adequate yielding rating over 0.5; in other words, none of the interactions was widely seen as excessive yielding (hence the empty bottom right area in the figure). Even at a disaggregate level, only 7% of all individual ratings describe excessive yielding (adequate yielding score of 1 or more). Along the light-colored adequate yielding diagonal where roughly equal proportions of respondents agreed the road user Should have yielded and Yielded, motor vehicle interactions tend to be in the top right (needed to yield and did) while bicycle interactions tend to be in the lower left (did not need to yield and did not).

3.2. Estimated model

As stated in the Analysis section, only significant (at $p < 0.05$) independent variables from univariate weighted mixed models were used in the multivariate GSEM specification (univariate and multivariate model results are in the Supplementary Material). The following variables were not significant in any univariate model: socio-demographic factors (age, gender, income, and education), risk aversion, travel habits for transit and automobiles, turning movement by the interacting road user, whether the motor vehicle was a passenger car or not (e.g., versus truck), low light, and condition of crosswalk marking. Two of the variables significant in the univariate models were not significant in the GSEM estimation results and hence removed from the final model specification: yielding maneuvers by pedestrians and total lanes to cross.

Fig. 5 illustrates the standardized coefficients from the final model estimation (all significant at $p < 0.05$), which achieved a good fit to the data[3]. Green and red boxes indicate positive and negative effects, respectively; box sizes are proportional to the standardized coefficients. The comfort-safety covariance is indicated with a double-headed arrow. Fig. 5 shows that perceived safety and comfort share substantial error covariance, and are both positively influenced by adequate yielding, and with similar magnitudes. Perception of adequate yielding, in turn, is most strongly determined by the pedestrian passing the conflict point first, followed closely by time/space

[3] As described above, model fit indices were approximated with a reduced model excluding random effects and weights. These model fit values indicate good fit to the data: Standardized Root Mean Squared Residual (SRMR) of 0.01, Root Mean Square Error of Approximation (RMSEA) of 0.04, Comparative Fit Index (CFI) of 0.99, and Tucker–Lewis Index (TLI) of 0.95.

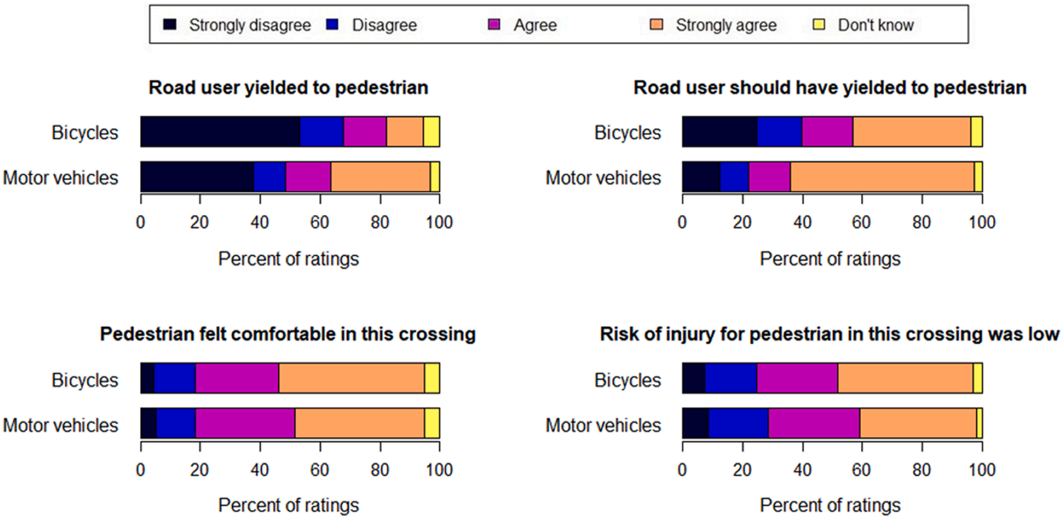

Fig. 3. Distribution of all 5529 ratings from the web survey.

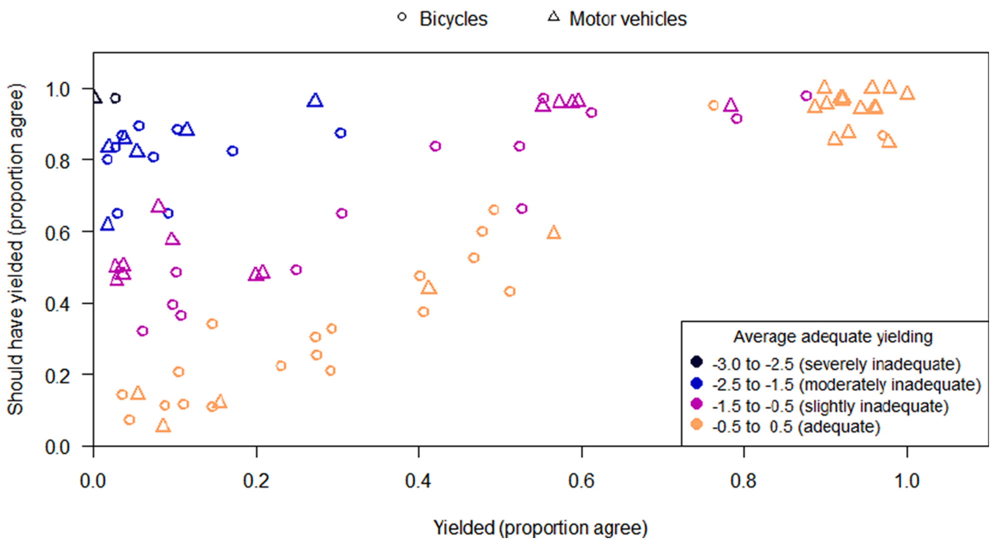

Fig. 4. Aggregate yielding variables for each video, by interacting road user type.

proximity factors: passing time and location of pedestrian when road user entered crosswalk (adequate yielding decreasing with closer proximity). In contrast, no significant relationship was found between the perception of adequate yielding and speed or path *deviations* by interacting road users. Overall, the larger-sized boxes associated with operational characteristics show that they are more important to perceived yielding than the perceiver or road user characteristics considered in this study.

Perceptions of safety and comfort are most strongly determined by adequate yielding, longer passing time, and pedestrian *not* in the crosswalk or on-street when the motor vehicle/bicycle enters the crosswalk. Controlling for operational factors, interactions with bicycles are perceived as more comfortable and safe than otherwise similar interactions with motor vehicles. As noted above, socio-demographic variables were not significant, but perceptions do vary with the participant/perceiver's walking and bicycling frequency. Participants who walk or bicycle more frequently perceive pedestrians to be less comfortable, while bicycling frequency increases perceptions of pedestrian safety.

Safety and comfort ratings were the same (e.g., both "strong agree") for most (66%) of the individual video responses. For 17% of responses the safety and comfort ratings diverged only on the strength of agreement or disagreement (e.g., "agree" for one and "strongly agree" for the other). The other 17% of responses agreed with one statement and disagreed with the other (more often agreeing with comfort but disagreeing with safety). To investigate the contributing factors to divergent safety and comfort perceptions, Fig. 6 illustrates the direct, indirect (yielding-mediated), and total (direct + indirect) effects of the independent variables on each dependent variable (all significant at $p < 0.05$). A negative direct effect of participant bicycling frequency on perceived comfort is

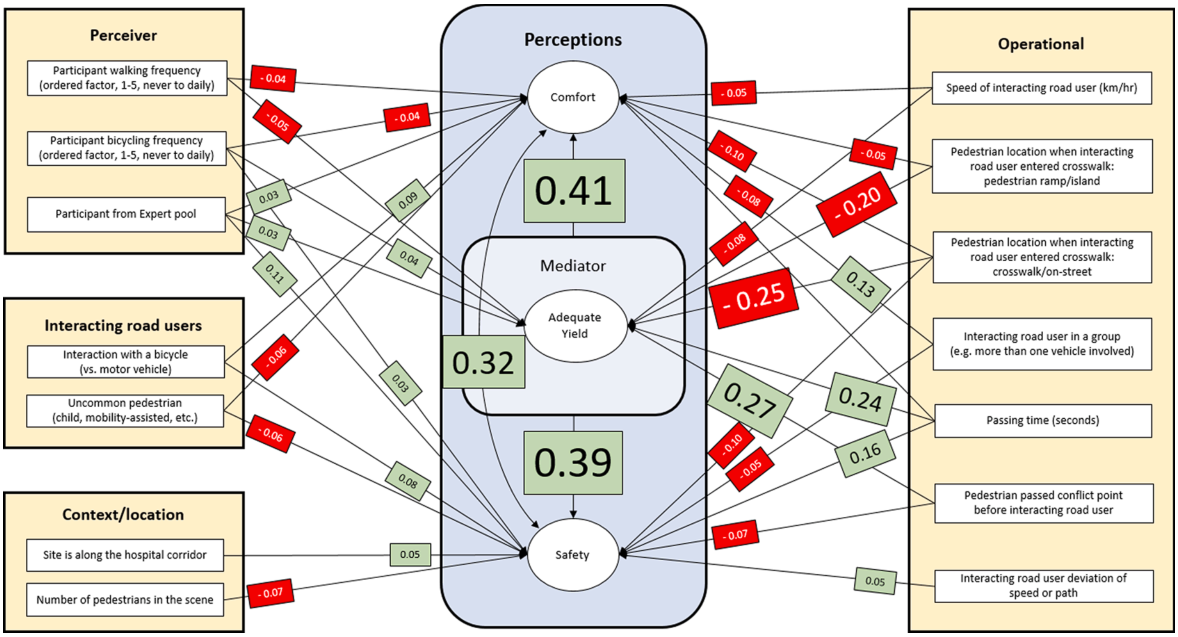

Fig. 5. Standardized effect estimates from generalized structural equation model. (box size is proportional to the standardized effect magnitude; green indicates positive effect and red indicates negative effect). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

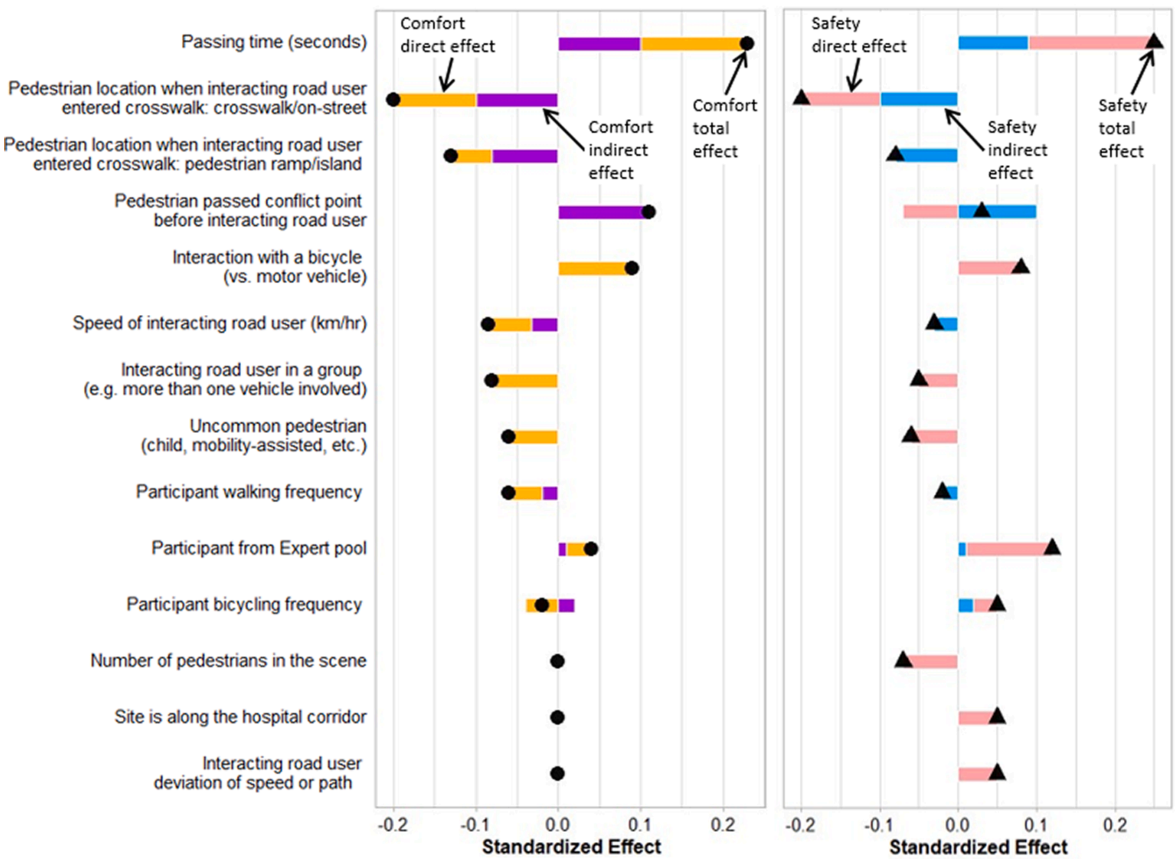

Fig. 6. Direct and indirect standardized effects on perceptions of safety and comfort.

partially offset by a positive indirect effect through increased yielding perception; a negative direct effect of the pedestrian passing first on perceived safety is outweighed by a greater positive indirect effect through increased yielding, leading to a positive total effect. For all other variables, either both the direct and indirect effects are in the same direction (and hence compounded), or only one is significant and included in the model.

Pedestrian passing the conflict point first has only an indirect effect on perceived comfort, indicating full mediation through perceived yielding. For perceived safety, the effects of the speed of the interacting road user, the pedestrian being in a curb ramp or island when the road user entered the crosswalk, and perceiver walking frequency are similarly fully mediated by perceived yielding. In contrast, several of the variables have only direct effects on safety and comfort perceptions, and are not mediated by yielding for either outcome: uncommon pedestrian types, interactions with bicycles (versus motor vehicles), and road users in a group (versus isolated).

Fig. 7 gives a comparison of the total effects of each independent variable on perceived safety and comfort (three variables have no total effect on comfort – see Fig. 6). The figure does not include adequate yield (mediating variable), the effects of which on perceived comfort (0.41) and safety (0.39) were not significantly different. The factors are ordered in decreasing difference of total effects, so the most contrasting factors are shown at the top. Ten of the 14 variables have significantly different total effects on perceived safety and comfort, although for only one of the variables are the effects in different directions (participant bicycling frequency increases perception of pedestrian safety but decreases perception of pedestrian comfort). Participant walking frequency negatively influences perceptions of both safety and comfort, with a much larger effect on comfort.

The speed of interacting road users has a stronger effect on comfort than safety perceptions in this context (note that the average speed of interacting road users was around 20 km/h). In contrast, *deviations* in speed or path have a stronger effect on perceived safety than comfort. The pedestrian passing first is perceived to have a larger effect on comfort than safety. If the road user enters the

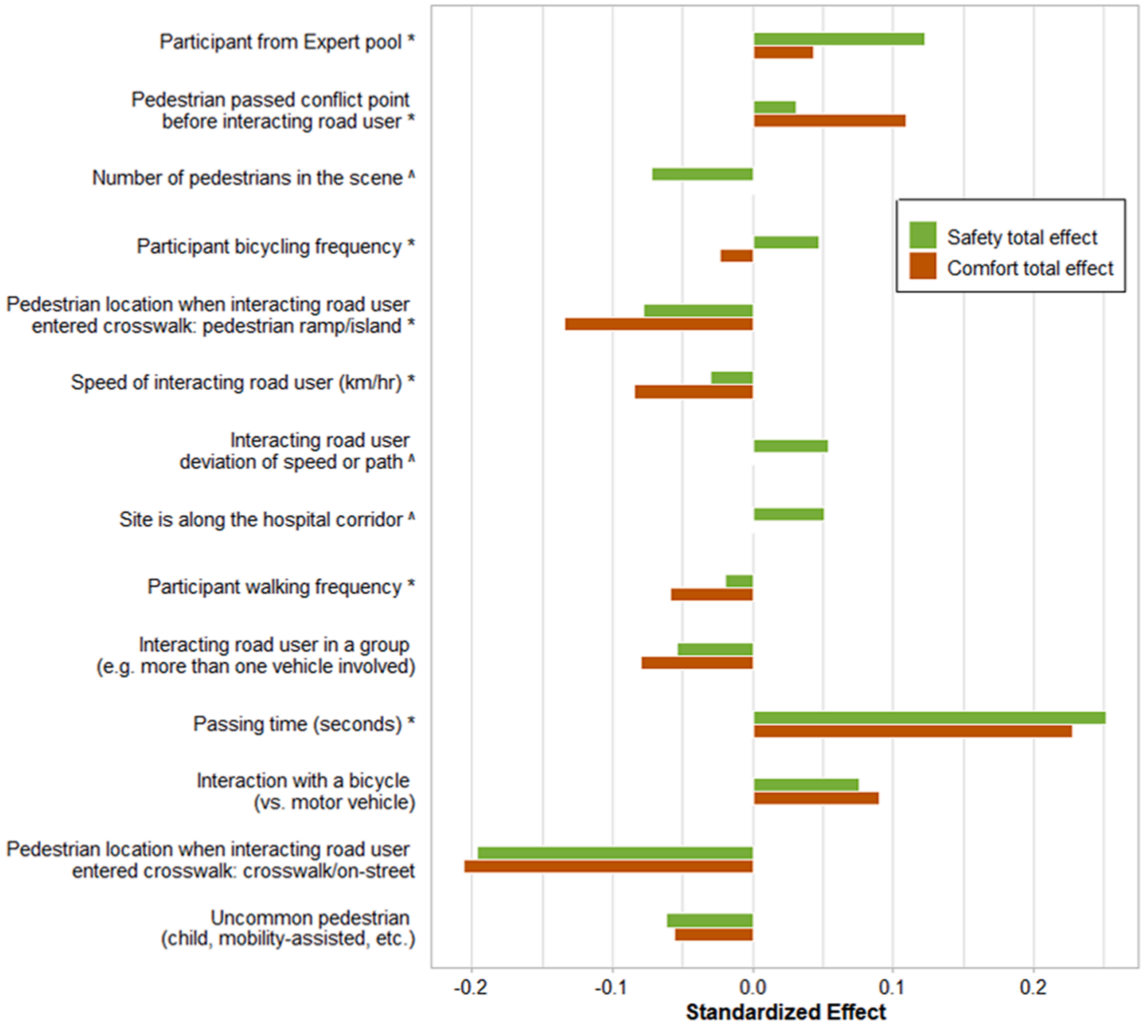

Fig. 7. Comparison of total standardized effects on perceptions of safety and comfort (^ indicates significantly different from zero; * indicates significantly different between safety and comfort – both at 95% confidence).

crosswalk while the pedestrian is still on the street, it has a substantial negative effect on both perceived safety and comfort, while entering while the pedestrian is in a curb ramp or island has a larger impact on perceived comfort than safety. Consistent with previous findings (Bigazzi et al., 2021), traffic safety experts have significantly higher safety perception than the general public (in this context), but similar perception of comfort.

4. Findings and conclusion

*Perception of yielding is a strong determinant of perceptions of pedestrian safety and comfort, partially or fully mediating the effects of interaction attributes (*e.g.*, vehicle speed and proximity) and perceiver attributes (*e.g.*, travel habits).* Different perceptions of safety and comfort across respondents arise from different conceptions of adequate yielding, which in turn relate to the perceiver's travel habits (walking and bicycling frequency). More frequent walking and bicycling have the same direct effects of decreased perceived pedestrian comfort, but opposite effects on perceptions of whether or not a road user adequately yielded to the pedestrian in a given interaction. The net result is that people who bicycle more frequently perceive pedestrians as more comfortable than people who walk more frequently, rooted in misalignment on yielding. Varying standards for yielding behavior may be related to perceptions of "ownership" of road space among people walking, bicycling, and driving (Hatfield & Prabhakharan, 2016; Paschalidis et al., 2016). As another example, a vehicle entering the crosswalk while the pedestrian is in the curb ramp or island is perceived as unsafe only as an indication of failure to yield (i.e., fully mediated), whereas entering the crosswalk while the pedestrian is still on the street is perceived as inherently unsafe, in addition to indicating a failure to yield (with roughly equal direct and indirect effects).

These findings highlight the importance of understanding perceptions of yielding for evaluating and developing strategies to improve the pedestrian experience. In the study context, *perception of adequate yielding is most strongly determined simply by whether the pedestrian crossed before or after the interacting road user* – more so than by maneuvering or speed of the road user. Proximity of the interacting vehicle to the pedestrian in space and time are the next most important factors for yielding perceptions. This finding suggests that studies using crossing order as a yielding measure (Fu et al., 2018; Goddard et al., 2015) are most aligned with public perceptions, versus studies using a behavior such as slowing (Zhuang & Wu, 2014).

Bicycle interactions are seen as significantly more comfortable and safe than otherwise similar interactions with motor vehicles, without mediation by yielding perceptions. Interactions with motor vehicles carry a safety and comfort cost unrelated to the yielding behavior of the road user. The magnitude of this effect is not significantly different between safety and comfort. The safety finding may be due to the size and weight difference between bicycles and motor vehicles, and the consequent risk differential, particularly in crash severity (Henary et al., 2003). It could also relate to ease of visual communications with bicyclists, relative to drivers, or clarity of intentions from visual cues (Guéguen et al., 2015), although there is no significant difference in perceptions of adequate yielding. This finding helps to put the growing concerns about pedestrian-bicycle conflicts (Gkekas et al., 2020; Paschalidis et al., 2016) into perspective, as motor vehicle interactions are still more of a concern for perceived pedestrian safety and comfort.

Perceptions of pedestrian safety and comfort are strongly related but distinct, differently impacted by attributes of the interaction and perceiver. The differences between safety and comfort perceptions are not related to perception of yielding, which has the same positive effect on both. Observers perceive more *comfort* when vehicles go slowly, and more *safety* when vehicles visibly slow down – possibly because it indicates a driver's awareness and intention. The differential effects of vehicle speed may be contextual, with stronger comfort effects here due to relatively low speeds (Kang & Fricker, 2016). The pedestrian passing the conflict point before the interacting road user has a larger positive impact on comfort than safety perception: both are improved due to increased perceived yielding, but there is an off-setting direct negative impact on safety perception (possibly due to the pedestrian being exposed to risk from an approaching vehicle). More frequent walking and bicycling by the perceiver both have a more negative impact on comfort than safety perceptions, possibly due to past personal experiences feeling uncomfortable (Aldred, 2016), or differences in empathy related to identity as a user of non-auto modes (Paschalidis et al., 2016). Although it decreases perception of pedestrian comfort, more frequent bicycling increases perception of pedestrian safety, perhaps by contrast to a perceived higher risk when bicycling on city streets. There could also be reverse causality, if more risk-insensitive persons are more likely to bicycle, but the risk aversion question tested to control for that effect was not significant.

4.1. Limitations

The generalizability of these findings is uncertain because the data were collected from a limited set of similar locations in a single city. Future studies should examine the mechanisms underlying perceptions of intermodal interactions in other contexts such as stop-controlled or signalized intersections, off-street paths, and shared spaces. None of the sites were high speed arterials: vehicle speed may be a more important factor for safety and comfort perceptions on higher-speed or higher-volume facilities. Similar studies in other cities could reveal the extent to which traffic culture influences perceptions of pedestrian safety and comfort – particularly in cities with much lower or higher pedestrian volumes and countries with substantially different yielding norms. The number of sites and interactions also restricted the number of contextual variables that could be included in the model, and so the effects of specific design features could not be tested in this study, nor could detailed pedestrian or road user features such as ambulatory disability or more detailed motor vehicle/bicycle types (e.g., limited-speed motorcycles may be perceived more similarly to a bicycle than motor vehicle).

Another limitation is that the perceptions reported here are of the observers; they do not (and are not intended to) represent the perceptions of the individuals in the video recordings. Our study and others have shown that perceptions can vary substantially across individuals, and so observer perceptions likely vary from those of the people in the interactions. Beyond interpersonal differences, past research has shown that third-person, imagined experience evaluations of cycling facilities can differ systematically from first-person, real world evaluations of the same type of facility (Fitch & Handy, 2018; Foster et al., 2015; McNeil et al., 2015). It is not yet known whether there are systematic differences between perceptions of observed vs. experienced road user interactions. Hence, the transferability of our findings to first-person traveller perceptions is uncertain, and should be investigated in future research using a first-person data collection method.

We could not reliably extract and include some nuanced interaction elements such as distraction, head movements, or visible communication between road users because the video quality was limited. Future work should examine the role of communication in this perception framework. The roles of other perceiver factors should be investigated as well, including disability status, ethno-racial status, and familiarity with the specific locations shown in the video (including experienced incidents or near-miss events).

4.2. Implications

Despite the limitations, the findings from this study have implications for researchers and practitioners.

a) Strategies to address pedestrian comfort can focus on increasing a set of key yielding behaviors by interacting road users: allowing the pedestrian to cross first, not entering the crosswalk until the pedestrian is fully off the street, and giving several seconds of a passing time gap. Specific messaging to drivers and cyclists may be more effective than the typical exhortation to “give way” or simply “yield”. This approach may be particularly effective for improving pedestrian-bicycle interactions (Gkekas et al., 2020), because misalignment on yielding is at the root of some discrepancies between pedestrian and bicyclist perspectives. The key yielding behaviors can also be used to design autonomous vehicle operation that is perceived as comfortable and safe by the public (Burns et al., 2020; Lee, Rhee et al., 2020; Rahman et al., 2021).
b) Besides communication strategies (Shaon et al., 2018; Zhuang & Wu, 2014), engineering treatments are a common approach to improve yielding, and the subject of numerous studies (Anciaes et al., 2020; Gitelman et al., 2017; Pulugurtha et al., 2012). We recommend that future studies of design interventions consider using these key yielding behaviors, which can be reliably recorded in field studies, to assess yielding in a way that reflects public perception. The easiest approach is simply noting who passed the conflict point first; additional details would be the pedestrian location when the road user entered the crosswalk and the passing time gap.
c) Practitioners should anticipate that interactions with motor vehicles at crosswalks are perceived by the public as less comfortable and less safe than otherwise similar interactions with bicycles. Motor vehicle drivers must yield more (allow the pedestrian to pass first, give more space and time, go slower, etc.) than bicycles to achieve the same level of perceived pedestrian safety and comfort. Policy makers should consider these differences when developing transportation system regulations; for example, this finding may give support to approaches that distinguish driving and cycling regulations such as the “Idaho stop” law for cyclists (Jackson et al., 2021). Also, when considering public perceptions, conflict analysis based only on operational features (speed, time and distance gaps, etc.) should not use the same measures or thresholds for comparing motor vehicle and bicycle interactions.
d) Although they are strongly related and similarly impacted by yielding, researchers should be cautious about using the concepts of safety and comfort perceptions interchangeably, as they differ in several key ways – particularly the attributes of the perceiver. Studies comparing comfort or safety perceptions across population groups should clearly define their measure of interest and consider the moderating effects of respondent travel habits on each.

CRediT authorship contribution statement

Gurdiljot Gill: Methodology, Writing – original draft. **Alexander Bigazzi:** Conceptualization, Methodology, Writing – review & editing. **Meghan Winters:** Conceptualization, Writing – review & editing.

Acknowledgements

The authors would like to thank the following people for offering valuable direction and advice: Dylan Passmore, Dr. Marie-Soleil Cloutier, Dr. Rebecca Sanders, Elmira Berjisian, Amir Hassanpour, Kate Hosford and Sarah Power. We would also like to acknowledge the time and input from the study participants and the 10th Avenue Evaluation Committee. This research was funded by the City of Vancouver, under Contract Number PS20181727. The views expressed in this paper are those of the authors and do not represent the views of the project funders.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2022.01.007.

References

Aldred, R. (2016). Cycling near misses: Their frequency, impact, and prevention. *Transportation Research Part A: Policy and Practice, 90*, 69–83. https://doi.org/10.1016/j.tra.2016.04.016

Alfonzo, M. A. (2005). To walk or not to walk? The hierarchy of walking needs. *Environment and Behavior, 37*(6), 808–836. https://doi.org/10.1177/0013916504274016

Al-Kaisy, A., Miyake, G. T., Staszcuk, J., & Scharf, D. (2018). Motorists' voluntary yielding of right of way at uncontrolled midblock crosswalks with rectangular rapid flashing beacons. *Journal of Transportation Safety & Security, 10*(4), 303–317. https://doi.org/10.1080/19439962.2016.1267827

Anciaes, P., Di Guardo, G., & Jones, P. (2020). Factors explaining driver yielding behaviour towards pedestrians at courtesy crossings. *Transportation Research Part F: Traffic Psychology and Behaviour, 73*, 453–469. https://doi.org/10.1016/j.trf.2020.07.006

Arun, A., Haque, M. M., Washington, S., Sayed, T., & Mannering, F. (2021). A systematic review of traffic conflict-based safety measures with a focus on application context. *Analytic Methods in Accident Research, 32*, Article 100185. https://doi.org/10.1016/j.amar.2021.100185

Bärgman, J., Smith, K., & Werneke, J. (2015). Quantifying drivers' comfort-zone and dread-zone boundaries in left turn across path/opposite direction (LTAP/OD) scenarios. *Transportation Research Part F: Traffic Psychology and Behaviour, 35*, 170–184. https://doi.org/10.1016/j.trf.2015.10.003

Bell, A., Fairbrother, M., & Jones, K. (2019). Fixed and random effects models: Making an informed choice. *Quality & Quantity, 53*(2), 1051–1074. https://doi.org/10.1007/s11135-018-0802-x

Bertulis, T., & Dulaski, D. M. (2014). Driver Approach Speed and Its Impact on Driver Yielding to Pedestrian Behavior at Unsignalized Crosswalks. *Transportation Research Record, 2464*(1), 46–51. https://doi.org/10.3141/2464-06

Bigazzi, A., Ausri, F., Peddie, L., Fitch, D. T., & Puterman, E. (2022). Physiological Markers of Traffic-Related Stress during Active Travel. *Transportation Research Part F: Traffic Psychology and Behaviour, 84*, 223–238. https://doi.org/10.1016/j.trf.2021.12.003

Bigazzi, A., Gill, G., & Winters, M. (2021). Contrasting Perspectives on the Comfort and Safety of Pedestrians Interacting with Other Road Users. *Transportation Research Record, 2675*(3), 33–43. https://doi.org/10.1177/0361198121992272

Bozovic, T., Hinckson, E., & Smith, M. (2020). Why do people walk? Role of the built environment and state of development of a social model of walkability. *Travel Behaviour and Society, 20*, 181–191. https://doi.org/10.1016/j.tbs.2020.03.010

British Columbia Ministry of Transportation and Infrastructure. (2019). British Columbia Active Transportation Design Guide. *Province of British Columbia.* https://www2.gov.bc.ca/gov/content/transportation/funding-engagement-permits/funding-grants/cycling-infrastructure-funding/active-transportation-design-guide.

Burns, C. G., Oliveira, L., Hung, V., Thomas, P., & Birrell, S. (2020). Pedestrian Attitudes to Shared-Space Interactions with Autonomous Vehicles – A Virtual Reality Study. In N. Stanton (Ed.), *Advances in Human Factors of Transportation* (pp. 307–316). Springer International Publishing. https://doi.org/10.1007/978-3-030-20503-4_29.

Cepolina, E. M., Menichini, F., & Gonzalez Rojas, P. (2018). Level of service of pedestrian facilities: Modelling human comfort perception in the evaluation of pedestrian behaviour patterns. *Transportation Research Part F: Traffic Psychology and Behaviour, 58*, 365–381. https://doi.org/10.1016/j.trf.2018.06.028

Chataway, E. S., Kaplan, S., Nielsen, T. A. S., & Prato, C. G. (2014). Safety perceptions and reported behavior related to cycling in mixed traffic: A comparison between Brisbane and Copenhagen. *Transportation Research Part F: Traffic Psychology and Behaviour, 23*, 32–43. https://doi.org/10.1016/j.trf.2013.12.021

Clark, C., Mokhtarian, P. L., Circella, G., & Watkins, K. (2021). The role of attitudes in perceptions of bicycle facilities: A latent-class regression approach. *Transportation Research Part F: Traffic Psychology and Behaviour, 77*, 129–148. https://doi.org/10.1016/j.trf.2020.12.006

Costa, M., Lantieri, C., Vignali, V., Ghasemi, N., & Simone, A. (2020). Evaluation of an integrated lighting-warning system on motorists' yielding at unsignalized crosswalks during nighttime. *Transportation Research Part F: Traffic Psychology and Behaviour, 68*, 132–143. https://doi.org/10.1016/j.trf.2019.12.004

Deb, S., Strawderman, L. J., & Carruth, D. W. (2018). Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment. *Transportation Research Part F: Traffic Psychology and Behaviour, 59*, 135–149. https://doi.org/10.1016/j.trf.2018.08.016

Dey, D., Martens, M., Eggen, B., & Terken, J. (2019). Pedestrian road-crossing willingness as a function of vehicle automation, external appearance, and driving behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour, 65*, 191–205. https://doi.org/10.1016/j.trf.2019.07.027

Dill, J., & McNeil, N. (2013). Four Types of Cyclists? *Transportation Research Record: Journal of the Transportation Research Board, 2387*, 129–138. https://doi.org/10.3141/2387-15

Engelniederhammer, A., Papastefanou, G., & Xiang, L. (2019). Crowding density in urban environment and its effects on emotional responding of pedestrians: Using wearable device technology with sensors capturing proximity and psychophysiological emotion responses while walking in the street. *Journal of Human Behavior in the Social Environment, 29*(5), 630–646. https://doi.org/10.1080/10911359.2019.1579149

Fitch, D. T., & Handy, S. L. (2018). The Relationship between Experienced and Imagined Bicycling Comfort and Safety. *Transportation Research Record, 2672*(36), 116–124. https://doi.org/10.1177/0361198118787635

Foster, N., Monsere, C. M., & Carlos, K. (2014). Evaluating Driver and Pedestrian Behaviors at Enhanced, Multilane, Midblock Pedestrian Crossings: Case Study in Portland. *Oregon. Transportation Research Record, 2464*(1), 59–66. https://doi.org/10.3141/2464-08

Foster, N., Monsere, C. M., Dill, J., & Clifton, K. (2015). Level-of-Service Model for Protected Bike Lanes. *Transportation Research Record, 2520*(1), 90–99. https://doi.org/10.3141/2520-11

Fu, T., Miranda-Moreno, L., & Saunier, N. (2018). A novel framework to evaluate pedestrian safety at non-signalized locations. *Accident Analysis & Prevention, 111*, 23–33. https://doi.org/10.1016/j.aap.2017.11.015

Gitelman, V., Carmel, R., Pesahov, F., & Chen, S. (2017). Changes in road-user behaviors following the installation of raised pedestrian crosswalks combined with preceding speed humps, on urban arterials. *Transportation Research Part F: Traffic Psychology and Behaviour, 46*, 356–372. https://doi.org/10.1016/j.trf.2016.07.007

Gkekas, F., Bigazzi, A., & Gill, G. (2020). Perceived safety and experienced incidents between pedestrians and cyclists in a high-volume non-motorized shared space. *Transportation Research Interdisciplinary Perspectives, 4*, Article 100094. https://doi.org/10.1016/j.trip.2020.100094

Glanz, B. I., Greeke, E., LaRussa, A., Stuart, F., Rintell, D. J., Chitnis, T., & Healy, B. C. (2016). Risk attitudes and risk perceptions in individuals with multiple sclerosis. *Multiple Sclerosis Journal – Experimental, Translational and Clinical, 2*. https://doi.org/10.1177/2055217316665406, 205521731666540.

Goddard, T., Kahn, K. B., & Adkins, A. (2015). Racial bias in driver yielding behavior at crosswalks. *Transportation Research Part F: Traffic Psychology and Behaviour, 33*, 1–6. https://doi.org/10.1016/j.trf.2015.06.002

Griswold, J. B., Yu, M., Filingeri, V., Grembek, O., & Walker, J. L. (2018). A behavioral modeling approach to bicycle level of service. *Transportation Research Part A: Policy and Practice, 116*, 166–177. https://doi.org/10.1016/j.tra.2018.06.006

Guéguen, N., Meineri, S., & Eyssartier, C. (2015). A pedestrian's stare and drivers' stopping behavior: A field experiment at the pedestrian crossing. *Safety Science, 75*, 87–89. https://doi.org/10.1016/j.ssci.2015.01.018

Guido, G., Saccomanno, F., Vitale, A., Astarita, V., & Festa, D. (2011). Comparing Safety Performance Measures Obtained from Video Capture Data. *Journal of Transportation Engineering, 137*(7), 481–491. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000230

Hatfield, J., & Prabhakharan, P. (2016). An investigation of behaviour and attitudes relevant to the user safety of pedestrian/cyclist shared paths. *Transportation Research Part F: Traffic Psychology and Behaviour, 40*, 35–47. https://doi.org/10.1016/j.trf.2016.04.005

He, Y., Sun, C., Huang, H., Jiang, L., Ma, M., Wang, P., & Wu, C. (2021). Safety of micro-mobility: Riders' psychological factors and risky behaviors of cargo TTWs in China. *Transportation Research Part F: Traffic Psychology and Behaviour, 80*, 189–202. https://doi.org/10.1016/j.trf.2021.04.001

Henary, B. Y., Crandall, J., Bhalla, K., Mock, C. N., & Roudsari, B. S. (2003). Child and Adult Pedestrian Impact: The Influence of Vehicle Type on Injury Severity. *Annual Proceedings / Association for the Advancement of Automotive Medicine, 47*, 105–126.

Hosford, K., Cloutier, M.-S., & Winters, M. (2020). Observational Study of Pedestrian and Cyclist Interactions at Intersections in Vancouver, BC and Montréal, QC. *Transportation Research Record, 2674*(6), 410–419. https://doi.org/10.1177/0361198120919407

Hunt, J. D., & Abraham, J. E. (2007). Influences on bicycle use. *Transportation, 34*(4), 453–470. https://doi.org/10.1007/s11116-006-9109-1

Huybers, S., Houten, R. V., & Malenfant, J. E. L. (2004). Reducing Conflicts Between Motor Vehicles and Pedestrians: The Separate and Combined Effects of Pavement Markings and a Sign Prompt. *Journal of Applied Behavior Analysis, 37*(4), 445–456. https://doi.org/10.1901/jaba.2004.37-445

Jackson, S., Retting, R., & Miller, S. (2021). *Impact analysis of bicycle safety laws* (DOT 813 123). *National Highway Traffic Safety*. Administration.

Kang, L., & Fricker, J. D. (2016). Sharing urban sidewalks with bicyclists? An exploratory analysis of pedestrian perceptions and attitudes. *Transport Policy, 49*, 216–225. https://doi.org/10.1016/j.tranpol.2016.04.013

Kaparias, I., Bell, M. G. H., Biagioli, T., Bellezza, L., & Mount, B. (2015). Behavioural analysis of interactions between pedestrians and vehicles in street designs with elements of shared space. *Transportation Research Part F: Traffic Psychology and Behaviour, 30*, 115–127. https://doi.org/10.1016/j.trf.2015.02.009

Kaparias, I., Bell, M. G. H., Miri, A., Chan, C., & Mount, B. (2012). Analysing the perceptions of pedestrians and drivers to shared space. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(3), 297–310. https://doi.org/10.1016/j.trf.2012.02.001

Kitabayashi, H., Zhang, X., Asano, Y., & Yoshikawa, M. (2015). An Analysis of the Walking Environmental Factors Affecting the Stress of Pedestrians for Route Recommendation. *2015 16th IEEE International Conference on Mobile Data Management*, *2*, 44–49. https://doi.org/10.1109/MDM.2015.27.

Kong, X., Das, S., Zhang, Y., & Xiao, X. (2021). Lessons learned from pedestrian-driver communication and yielding patterns. *Transportation Research Part F: Traffic Psychology and Behaviour, 79*, 35–48. https://doi.org/10.1016/j.trf.2021.03.011

Landis, B. W., Vattikuti, V. R., Ottenberg, R. M., McLeod, D. S., & Guttenplan, M. (2001). Modeling the Roadside Walking Environment: Pedestrian Level of Service. *Transportation Research Record, 1773*(1), 82–88. https://doi.org/10.3141/1773-10

Lee, H., Strawderman, L., & Usher, J. M. (2009). Analyzing Pedestrian Traffic Behavior Using Video Footage, Zone of Comfort and Situation Awareness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 53*(10), 600–604. https://doi.org/10.1177/154193120905301004

Lee, O., Rasch, A., Schwab, A. L., & Dozza, M. (2020). Modelling cyclists' comfort zones from obstacle avoidance manoeuvres. *Accident Analysis & Prevention, 144*, Article 105609. https://doi.org/10.1016/j.aap.2020.105609

Lee, Y. K., Rhee, Y. -E., Ryu, J. -K., & Hahn, S. (2020). Gentlemen on the Road: Understanding How Pedestrians Interpret Yielding Behavior of Autonomous Vehicles using Machine Learning. *ArXiv Preprint ArXiv:2005.07872.*, 14.

Lehtonen, E., Havia, V., Kovanen, A., Leminen, M., & Saure, E. (2016). Evaluating bicyclists' risk perception using video clips: Comparison of frequent and infrequent city cyclists. *Transportation Research Part F: Traffic Psychology and Behaviour, 41*, 195–203. https://doi.org/10.1016/j.trf.2015.04.006

Lord, S., Cloutier, M.-S., Garnier, B., & Christoforou, Z. (2018). Crossing road intersections in old age—With or without risks? Perceptions of risk and crossing behaviours among the elderly. *Transportation Research Part F: Traffic Psychology and Behaviour, 55*, 282–296. https://doi.org/10.1016/j.trf.2018.03.005

Lubbe, N., & Rosén, E. (2014). Pedestrian crossing situations: Quantification of comfort boundaries to guide intervention timing. *Accident Analysis & Prevention, 71*, 261–266. https://doi.org/10.1016/j.aap.2014.05.029

Lumley, T. (2019). *survey: Analysis of complex survey samples* (version 3.35-1) [R package]. https://cran.r-project.org/web/packages/survey/citation.html.

MacKinnon, D. P., Fairchild, A. J., & Fritz, M. S. (2007). Mediation Analysis. *Annual Review of Psychology, 58*, 593. https://doi.org/10.1146/annurev.psych.58.110405.085542

Mahmud, S. M. S., Ferreira, L., Hoque, M. S., & Tavassoli, A. (2017). Application of proximal surrogate indicators for safety evaluation: A review of recent developments and research needs. *IATSS Research, 41*(4), 153–163. https://doi.org/10.1016/j.iatssr.2017.02.001

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. *Biochemia Medica, 22*(3), 276–282.

McNeil, N., Monsere, C. M., & Dill, J. (2015). Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists. *Transportation Research Record: Journal of the Transportation Research Board, 2520*, 132–142. https://doi.org/10.3141/2520-15

Mehrabian, A., & Russell, J. A. (1974). The Basic Emotional Impact of Environments. *Perceptual and Motor Skills, 38*(1), 283–301. https://doi.org/10.2466/pms.1974.38.1.283

Mercer, A., Lau, A., & Kennedy, C. (2018). For Weighting Online Opt-In Samples, What Matters Most? *Pew Research Center*. https://www.pewresearch.org/methods/2018/01/26/for-weighting-online-opt-in-samples-what-matters-most/.

Merlino, S., & Mondada, L. (2019). Crossing the street: How pedestrians interact with cars. *Language & Communication, 65*, 131–147. https://doi.org/10.1016/j.langcom.2018.04.004

Metje, N., Sterling, M., & Baker, C. J. (2008). Pedestrian comfort using clothing values and body temperatures. *Journal of Wind Engineering and Industrial Aerodynamics, 96*(4), 412–435. https://doi.org/10.1016/j.jweia.2008.01.003

Monsere, C. M., McNeil, N. W., & Sanders, R. L. (2020). User-Rated Comfort and Preference of Separated Bike Lane Intersection Designs. *Transportation Research Record, 2674*(9), 216–229. https://doi.org/10.1177/0361198120927694

Moody, S., & Melia, S. (2014). Shared space – research, policy and problems. *Proceedings of the Institution of Civil Engineers - Transport, 167*(6), 384–392. https://doi.org/10.1680/tran.12.00047

Mueller, N., Rojas-Rueda, D., Cole-Hunter, T., de Nazelle, A., Dons, E., Gerike, R., Götschi, T., Int Panis, L., Kahlmeier, S., & Nieuwenhuijsen, M. (2015). Health impact assessment of active transportation: A systematic review. *Preventive Medicine, 76*, 103–114. https://doi.org/10.1016/j.ypmed.2015.04.010

Näätänen, R., & Summala, H. (1974). A model for the role of motivational factors in drivers' decision-making*. *Accident Analysis & Prevention, 6*(3), 243–261. https://doi.org/10.1016/0001-4575(74)90003-7

Ni, Y., Cao, Y., & Li, K. (2017). Pedestrians' Safety Perception at Signalized Intersections in Shanghai. *Transportation Research Procedia, 25*, 1955–1963. https://doi.org/10.1016/j.trpro.2017.05.222

Nikolopoulou, M., & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: Analysis across different European countries. *Building and Environment, 41*(11), 1455–1470. https://doi.org/10.1016/j.buildenv.2005.05.031

Olszewski, P., Szagała, P., Wolański, M., & Zielińska, A. (2015). Pedestrian fatality risk in accidents at unsignalized zebra crosswalks in Poland. *Accident Analysis & Prevention, 84*, 83–91. https://doi.org/10.1016/j.aap.2015.08.008

Osama, A., Albitar, M., Sayed, T., & Bigazzi, A. (2020). Determining If Walkability and Bikeability Indices Reflect Pedestrian and Cyclist Safety. *Transportation Research Record*. https://doi.org/10.1177/0361198120931844

Oviedo-Trespalacios, O., & Scott-Parker, B. (2017). Footbridge usage in high-traffic flow highways: The intersection of safety and security in pedestrian decision-making. *Transportation Research Part F: Traffic Psychology and Behaviour, 49*, 177–187. https://doi.org/10.1016/j.trf.2017.06.010

Park, Y., & Garcia, M. (2020). Pedestrian safety perception and urban street settings. *International Journal of Sustainable Transportation, 14*(11), 860–871. https://doi.org/10.1080/15568318.2019.1641577

Paschalidis, E., Basbas, S., Politis, I., & Prodromou, M. (2016). "Put the blame on…others!": The battle of cyclists against pedestrians and car drivers at the urban environment. A cyclists' perception study. *Transportation Research Part F: Traffic Psychology and Behaviour, 41*, 243–260. https://doi.org/10.1016/j.trf.2015.07.021

Petritsch, T. A., Ozkul, S., McLeod, P., Landis, B., & McLeod, D. (2010). Quantifying Bicyclists' Perceptions of Shared-Use Paths Adjacent to the Roadway. *Transportation Research Record, 2198*(1), 124–132. https://doi.org/10.3141/2198-14

Pooley, C. G., Horton, D., Scheldeman, G., Mullen, C., Jones, T., Tight, M., Jopson, A., & Chisholm, A. (2013). Policies for promoting walking and cycling in England: A view from the street. *Transport Policy, 27*, 66–72. https://doi.org/10.1016/j.tranpol.2013.01.003

British Columbia Motor Vehicle Act. (1996). *Pub. L. No. RSBC, 1996*.

Pulugurtha, S. S., Vasudevan, V., Nambisan, S. S., & Dangeti, M. R. (2012). Evaluating Effectiveness of Infrastructure-Based Countermeasures for Pedestrian Safety. *Transportation Research Record, 2299*(1), 100–109. https://doi.org/10.3141/2299-11

R Core Team. (2019). *R: A language and environment for statistical computing* (3.3.0) [Computer software]. *R Foundation for Statistical Computing*. http://www.R-project.org/.

Rabe-Hesketh, S., Skrondal, A., & Pickles, A. (2004). Generalized multilevel structural equation modeling. *Psychometrika, 69*(2), 167–190. https://doi.org/10.1007/BF02295939

Rahman, M. T., Dey, K., Das, S., & Sherfinski, M. (2021). Sharing the road with autonomous vehicles: A qualitative analysis of the perceptions of pedestrians and bicyclists. *Transportation Research Part F: Traffic Psychology and Behaviour, 78*, 433–445. https://doi.org/10.1016/j.trf.2021.03.008

Rasch, A., Panero, G., Boda, C.-N., & Dozza, M. (2020). How do drivers overtake pedestrians? Evidence from field test and naturalistic driving data. *Accident Analysis & Prevention, 139*, Article 105494. https://doi.org/10.1016/j.aap.2020.105494

Salvo, G., Lashewicz, B. M., Doyle-Baker, P. K., & McCormack, G. R. (2018). Neighbourhood Built Environment Influences on Physical Activity among Adults: A Systematized Review of Qualitative Evidence. *International Journal of Environmental Research and Public Health, 15*(5), 897. https://doi.org/10.3390/ijerph15050897

Schneider, R. J., Ryznar, R. M., & Khattak, A. J. (2004). An accident waiting to happen: A spatial approach to proactive pedestrian planning. *Accident Analysis & Prevention, 36*(2), 193–211. https://doi.org/10.1016/S0001-4575(02)00149-5

Schroeder, B. J., & Rouphail, N. M. (2011). Event-Based Modeling of Driver Yielding Behavior at Unsignalized Crosswalks. *Journal of Transportation Engineering, 137*(7), 455–465. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000225

Shaon, M. R. R., Schneider, R. J., Qin, X., He, Z., Sanatizadeh, A., & Flanagan, M. D. (2018). Exploration of Pedestrian Assertiveness and Its Association with Driver Yielding Behavior at Uncontrolled Crosswalks. *Transportation Research Record, 2672*(35), 69–78. https://doi.org/10.1177/0361198118790645

StataCorp (Stata Statistical Software: Release 16). (2019). [Computer software].

Statistics Canada. (2017). *2016 Census Profile*. http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm.

Stoker, P., Garfinkel-Castro, A., Khayesi, M., Odero, W., Mwangi, M. N., Peden, M., & Ewing, R. (2015). Pedestrian Safety and the Built Environment: A Review of the Risk Factors. *Journal of Planning Literature, 30*(4), 377–392. https://doi.org/10.1177/0885412215595438

Sucha, M., Dostal, D., & Risser, R. (2017). Pedestrian-driver communication and decision strategies at marked crossings. *Accident Analysis & Prevention, 102*, 41–50. https://doi.org/10.1016/j.aap.2017.02.018

Summala, H. (2007). Towards Understanding Motivational and Emotional Factors in Driver Behaviour: Comfort Through Satisficing. In *Modelling Driver Behaviour in Automotive Environments* (pp. 189–207). https://doi.org/10.1007/978-1-84628-618-6_11.

Tageldin, A., & Sayed, T. (2019). Models to evaluate the severity of pedestrian-vehicle conflicts in five cities. *Transportmetrica A: Transport Science, 15*(2), 354–375. https://doi.org/10.1080/23249935.2018.1477853

Turner, S., Fitzpatrick, K., Brewer, M., & Park, E. S. (2006). Motorist Yielding to Pedestrians at Unsignalized Intersections: Findings from a National Study on Improving Pedestrian Safety. *Transportation Research Record, 1982*(1), 1–12. https://doi.org/10.1177/0361198106198200102

Vaa, T. (2014). From Gibson and Crooks to Damasio: The role of psychology in the development of driver behaviour models. *Transportation Research Part F: Traffic Psychology and Behaviour, 25*, 112–119. https://doi.org/10.1016/j.trf.2014.02.004

Vallejo-Borda, J. A., Cantillo, V., & Rodriguez-Valencia, A. (2020). A perception-based cognitive map of the pedestrian perceived quality of service on urban sidewalks. *Transportation Research Part F: Traffic Psychology and Behaviour, 73*, 107–118. https://doi.org/10.1016/j.trf.2020.06.013

Wang, K., & Akar, G. (2018). The perceptions of bicycling intersection safety by four types of bicyclists. *Transportation Research Part F: Traffic Psychology and Behaviour, 59*, 67–80. https://doi.org/10.1016/j.trf.2018.08.014

Washington, S., Haworth, N., & Schramm, A. (2012). Relationships between Self-Reported Bicycling Injuries and Perceived Risk of Cyclists in Queensland. *Australia. Transportation Research Record, 2314*(1), 57–65. https://doi.org/10.3141/2314-08

Winters, M., Babul, S., Becker, H. J. E. H. (Jack), Brubacher, J. R., Chipman, M., Cripton, P., Cusimano, M. D., Friedman, S. M., Harris, M. A., Hunte, G., Monro, M., Reynolds, C. C. O., Shen, H., & Teschke, K. (2012). Safe Cycling: How Do Risk Perceptions Compare With Observed Risk? *Canadian Journal of Public Health / Revue Canadienne de Santé Publique, 103*, S42–S47.

Zegeer, C. V., & Bushell, M. (2012). Pedestrian crash trends and potential countermeasures from around the world. *Accident Analysis & Prevention, 44*(1), 3–11. https://doi.org/10.1016/j.aap.2010.12.007

Zhao, X., Xu, W., Ma, J., Li, H., & Chen, Y. (2019). An analysis of the relationship between driver characteristics and driving safety using structural equation models. *Transportation Research Part F: Traffic Psychology and Behaviour, 62*, 529–545. https://doi.org/10.1016/j.trf.2019.02.004

Zhuang, X., & Wu, C. (2014). Pedestrian gestures increase driver yielding at uncontrolled mid-block road crossings. *Accident Analysis & Prevention, 70*, 235–244. https://doi.org/10.1016/j.aap.2013.12.015