Safe Cycling: How Do Risk Perceptions Compare With Observed Risk?

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ABSTRACT

Objective: Safety concerns deter cycling. The Bicyclists' Injuries and the Cycling Environment (BICE) study quantified the injury risk associated with 14 route types, from off-road paths to major streets. However, when it comes to injury risk, there may be discordance between empirical evidence and perceptions. If so, even if protective infrastructure is built people may not feel safe enough to cycle. This paper reports on the relationship between perceived and observed injury risk.

Methods: The BICE study is a case-crossover study that recruited 690 injured adult cyclists who visited emergency departments in Toronto and Vancouver. Observed risk was calculated by comparing route types at the injury sites with those at randomly selected control sites along the same route. The perceived risk was the mean response of study participants to the question "How safe do you think this site was for cyclists on that trip?", with responses scored from +1 (very safe) to -1 (very dangerous). Perceived risk scores were only calculated for non-injury control sites, to reduce bias by the injury event.

Results: The route type with the greatest perceived risk was major streets with shared lanes and no parked cars (mean score = -0.21, 95% confidence interval [CI]: -0.54-0.11), followed by major streets without bicycle infrastructure (-0.07, CI -0.14-0.00). The safest perceived routes were paved multi-use paths (0.66, CI 0.43-0.89), residential streets (0.44, CI 0.37-0.51), bike paths (0.42, CI 0.25-0.60) and residential streets marked as bike routes with traffic calming (0.41, CI 0.32-0.51). Most route types that were perceived as higher risk were found to be so in our injury study; similarly, most route types perceived as safer were also found to be so. Discrepancies were observed for cycle tracks (perceived as less safe than observed) and for multiuse paths (perceived as safer than observed).

Conclusions: Route choices and decisions to cycle are affected by perceptions of safety, and we found that perceptions usually corresponded with observed safety. However, perceptions about certain separated route types did not align well. Education programs and social media may be ways to ensure that public perceptions of route safety reflect the evidence.

Key terms: Safety; transportation; injury; environmental design

La traduction du résumé se trouve à la fin de l'article.

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Lack of safety is a major deterrent to cycling. Cyclists and potential cyclists report safety concerns related to motor vehicle traffic and poor weather.[1,2] These concerns are valid: on a per-trip basis, cycling is more dangerous than car travel, with US data showing that the fatality rate per bike trip was about 2.3 times higher than that for automobile trips and that the police-reported injury rate per bike trip was about 1.8 times higher than that for automobile trips.[3] Similarly, the 73 cyclists killed in Canada in 2006 represented 2.5% of all traffic-related deaths,[4] although cycling represents only 1.3% of commuter travel.[5] Of course, motor vehicles are not the only cause of bicycle crashes. Observational studies indicate that a large proportion of injuries and conflicts result from falls and from collisions with route infrastructure (streetcar tracks, curbs, potholes, etc.) and sometimes with pedestrians, other cyclists and animals.[6-8] These incidents are less likely to be reported to police or captured in insurance records.[7,9,10]

While the bulk of cycling safety research focuses on individual-based protection (e.g., helmet usage), population-level strategies related to the built environment and the provision of cycling infrastructure hold promise to both prevent crashes and encourage cycling.[11] Worldwide, purpose-built bicycle-only facilities (e.g., bike

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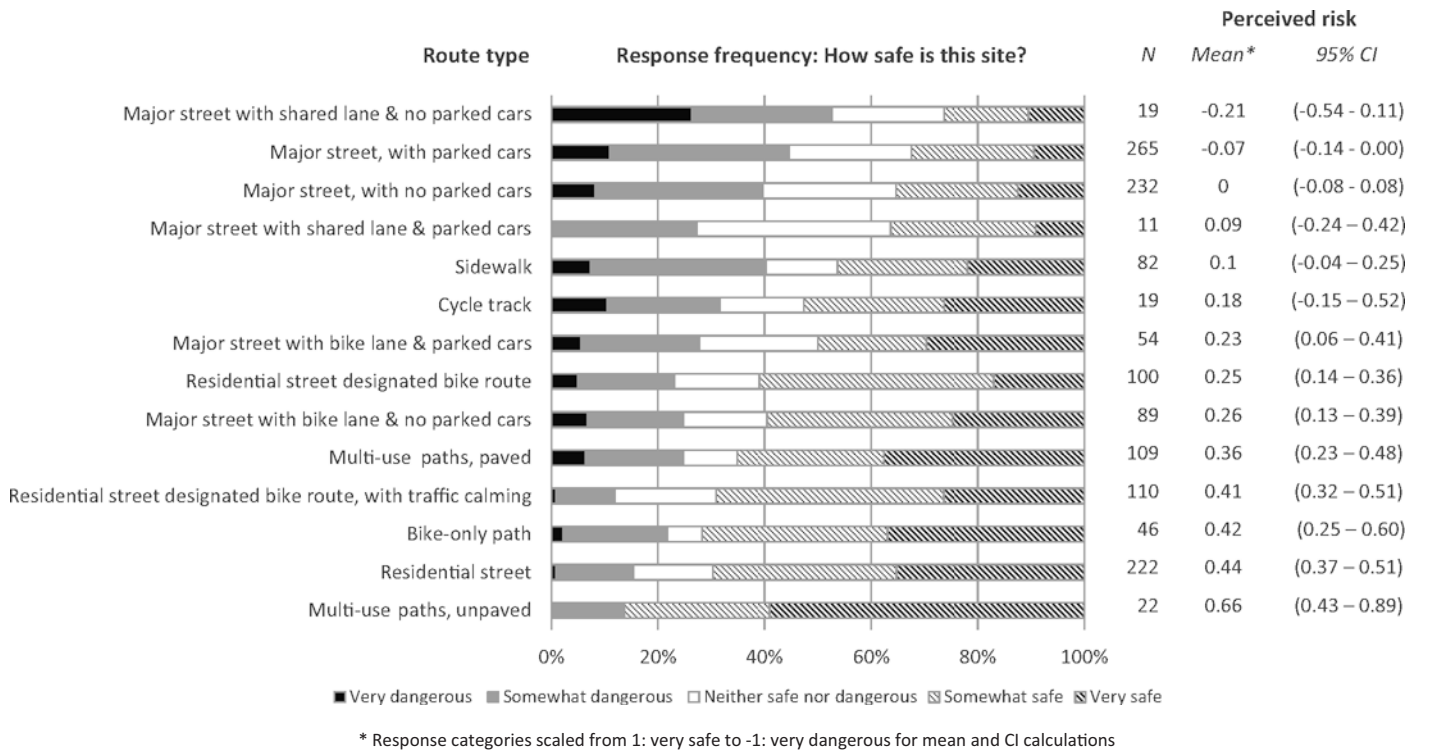
Figure 1. Perceived risk by route type for 1,380 control sites in the Bicyclists' Injuries and the Cycling Environment study



* Response categories scaled from 1: very safe to -1: very dangerous for mean and CI calculations

routes, bike lanes, bike paths, cycle tracks at roundabouts) have been shown to reduce the risk of crashes and injuries compared with cycling on road with traffic or off road with pedestrians.[12] Most studies have used broad, route-type categories (e.g., on road, off road, bike lane), although urban centres have many variations on these themes. The Bicyclists' Injuries and the Cycling Environment (BICE) study was the first to examine a detailed list of route types that exist in North America.[12] This evidence can suggest the types of route that should be built to reduce risk.

However, decisions to cycle may be guided more by perceptions than empirical data.[13] Perceptions of risk or the likelihood that an individual will experience a danger are influenced by both the probability of an adverse event (e.g., the risk of a crash) and the magnitude of the consequences (e.g., the severity of the injury).[14,15] Risk perceptions vary by individual characteristics (sex, age, attitude) but are also heavily influenced by social and cultural conditions and interactions, and by the specific hazard.[16] Perceived reductions in risk may have greater than proportional effects on encouraging or discouraging cycling, so it is especially important that perceptions be taken into account.[17] If there is discordance between what is safe according to the empirical evidence and what is perceived as safe, then even if protective infrastructure were to be built, people might choose not to cycle. The objective of this paper is to compare the perceived and observed injury risk of specific route types, using data from the BICE study.

METHODS

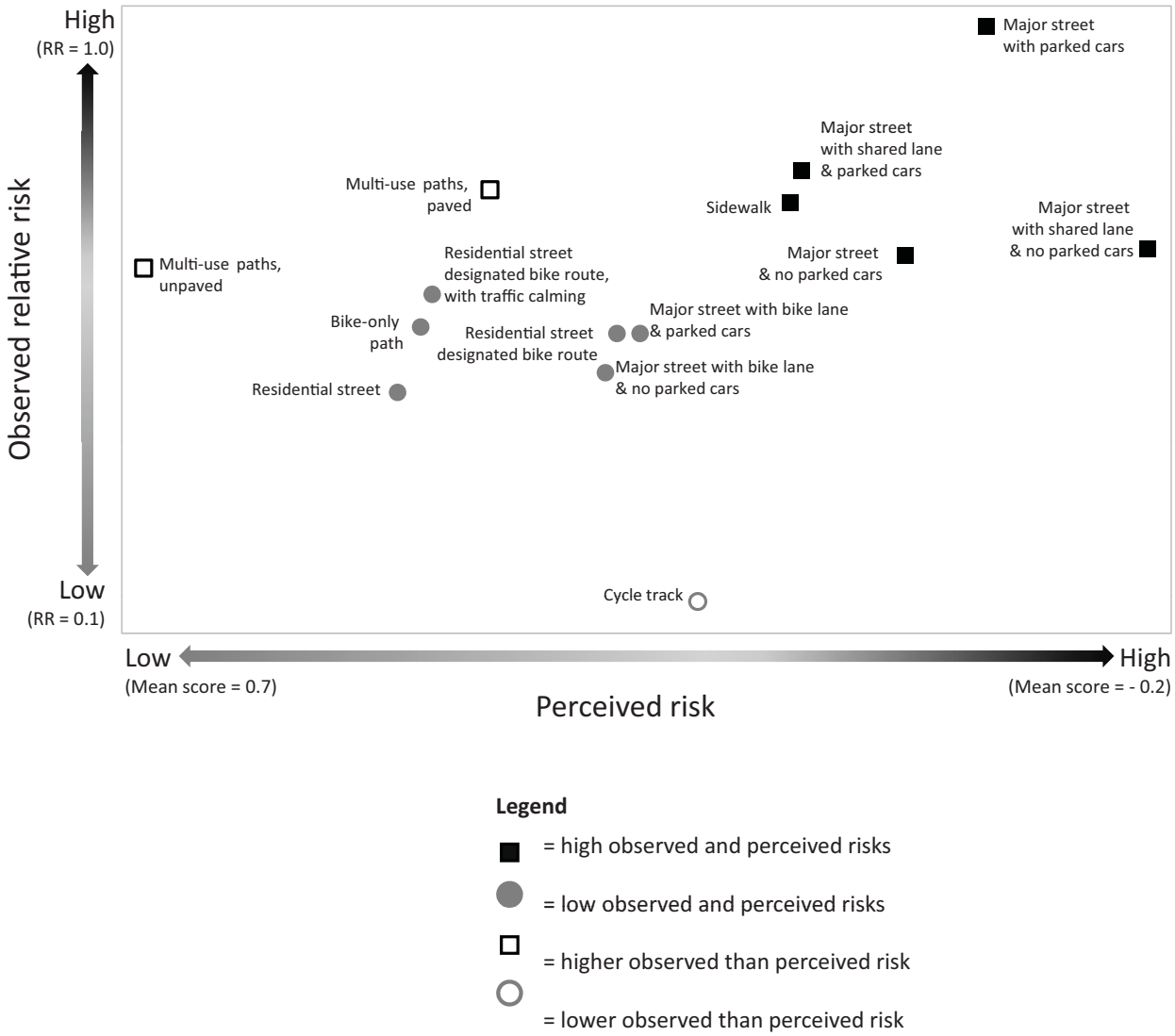
Recruitment

The BICE study is a case-crossover study that recruited 690 adults who visited emergency departments within 24 hours of incurring an injury while cycling in Toronto or Vancouver. The study protocol and details have been published elsewhere.[12,18] In brief, the study population included injured cyclists aged 19 and over who attended the emergency department of one of the study hospitals in Vancouver (St. Paul's, Vancouver General) or Toronto (St. Michael's, Toronto General, Toronto Western) between May 18, 2008, and November 30, 2009. Research staff at each hospital identified injured cyclists and provided contact information to the study coordinators in their respective city (Vancouver or Toronto). Introductory letters were sent to all potential participants, followed by a telephone call from the study coordinator to invite participation and screen for eligibility. Up to 10 contact attempts were made over a period of three months after their injuries. Cyclists were excluded if they were injured outside of Toronto or Vancouver; did not reside within the study cities; were unable to participate in an interview (fatally injured, injured too seriously to communicate, could not speak English or unable to remember the injury trip); were injured while trick riding, racing, mountain biking, participating in a Critical Mass ride or on private property at the time of the crash; were injured while riding a motorized bike (e.g., electric or pedal-assisted bicycle), unicycle or tandem bike; or were already enrolled in the study as a result of a previous injury. The study was approved by research ethics boards at the universities of British Columbia and Toronto, and at each of the five participating hospitals.

Interviews and site observations

Eligible participants were interviewed in person to identify personal and trip characteristics. During the interview the injury location and the injury trip route were recorded on a paper map. The injury trip route distance was calculated using a digital map wheel. For each injury site, two control sites (where no injury occurred) were selected by multiplying a randomly generated proportion by the

Figure 2. Observed relative risk (unadjusted odds ratio) versus perceived risk (mean score) by route type for 1,380 control sites in the Bicyclists' Injuries and the Cycling Environment study



trip distance, then tracing the resulting distance along the route using the map wheel. One site was selected to match the injury site on the basis of location type, adjusted forward or backward, respectively, to match intersection or non-intersection location for control site, and the other was selected purely at random (i.e., not deliberately matched to intersection status). Trained observers blinded to the site status (injury or control) visited each site in the field to collect data on site characteristics related to infrastructure (the route type, intersecting streets, the presence of cycling infrastructure, intersection geometry), the physical environment (topography, visibility, street lighting, construction or other obstacles) and usage (user volumes).

Measures and analysis

According to the street characteristics from site observations, we classified route types into 14 categories, defined with input from city bicycle transportation engineers and bicycling advocates. Observed relative risk for this study was calculated using conditional logistic regression to estimate odds ratios (ORs) as a measure of the relative risk of injury associated with different route types, and these results have been reported elsewhere.[12] In the present paper, we used the unadjusted ORs based on a bivariate model of the route type classification and site (1= injury site, 0=control site), thereby not introducing other physical environment and usage characteristics to the model. Perceived risk scores were based only on the non-injury control sites, reducing bias by the injury event. Perceived risk was calculated as the mean response of study participants to the question "How safe do you think this site was for cyclists on that trip?" with a 5-point response scale: very safe, somewhat safe, neither safe nor dangerous, somewhat dangerous, very dangerous. Responses were scaled from +1 (very safe) to 0 (neutral) to -1 (very dangerous) for calculating and comparing mean scores and 95% confidence intervals (CIs). We compared perceived risk with observed ORs estimates using Pearson's weighted correlation.

RESULTS

Study population

This study recruited 690 injured cyclists (414 in Vancouver, 276 in Toronto), with a response rate of 93.1% of those confirmed to be

eligible or 66.5 % of those estimated as eligible. Details of the recruitment process are reported in other manuscripts from the study.[12,18] Participants were predominately male (59.4%), young (mean age=28), educated (75% with a post-secondary diploma or degree) and employed full time (69.4%). Three quarters of the participants considered themselves experienced cyclists (530/690, 76.8%), 36.5% reporting that they cycled at least once a week in the winter and 89.4% that they did so in the summer.

Study sites

Data from 1,380 control sites (two for each of the 690 injured cyclists) were used in this analysis. Figure 1 lists the 14 route categories and their frequencies. Ubiquitous route types were common in the dataset (major streets with no bike infrastructure and residential streets), whereas certain specialized bicycle infrastructure was relatively rare (major streets with shared lanes and cycle tracks, i.e., bike lanes alongside major streets but separated by a physical barrier).

Perceived risk

Figure 1 also summarizes perceived risk responses by mean scores. The four route types with the highest *perceived* risks were major streets (with and without parking) and either shared lanes (with cars, buses or high occupancy vehicles) or no bicycle infrastructure. The mean score for sidewalks was 0.10 (neither safe nor dangerous), although the response frequency indicates that sites were split between being perceived as safe and being perceived as dangerous. The following route types were considered safe at more than 50% of sites of that type: off-street multi-use paths; residential streets; off-street bike paths; major streets with bike lanes; and cycle tracks.

Observed risk

The results of observed relative risk are reported in detail in another manuscript from this study.[13] To briefly summarize those results, the reference category was major street with parked cars and no cycling infrastructure (OR=1). All other route types had lower risk of injury. Cycle tracks had the lowest relative risk, at almost one tenth of the risk (OR=0.12). Route types with about half the relative risk (ORs from 0.44 to 0.59) were residential streets (designated as bike routes or not, with or without traffic calming), major streets with bike lanes (with or without parking) and off-street paths for bikes only. Multi-use paths, sidewalks and other major street configurations (with shared lanes or with no bike infrastructure) all had higher relative risk (ORs from 0.63 to 0.78).

Comparing perceived and observed relative risk

A comparison of perceived risk and observed relative risk is presented in Figure 2. Four of the more dangerous route types were also perceived as unsafe: major streets with shared lanes or without any bicycle infrastructure. Many safer route types were also perceived as safer: residential streets (designated as bike routes or not, with or without traffic calming), major streets with bike lanes (with or without parking) and off-street paths for bikes only. The rank ordering of risk was not the same for perceived and observed relative risk (Pearson's weighted correlation=-0.68, p=0.007, negative because high perceived risk had negative safety scores, and high observed relative risk had the highest ORs). This moderate correlation was influenced by some major discrepancies between perceived and observed relative risk, as highlighted by the outliers in Figure 2. The safest route type, cycle tracks, was perceived as higher risk than other bicycle-specific route types. Conversely, unpaved multi-use paths were perceived as the safest route type, when in fact they were observed to have a relative risk nearly as high as major streets with no bike infrastructure or with shared lanes. Paved multi-use paths were also more dangerous than perceived.

DISCUSSION

We compared empirical data on observed relative risk with the perceptions of safety of different types of road infrastructure based on the opinions, injury locations and travel patterns of injured cyclists recruited from hospital emergency departments in Toronto and Vancouver. It is known that route choices and decisions to cycle are affected by perceptions of safety,[1,13,19] and we found that perceptions largely aligned with observed evidence, with some exceptions. The injured cyclists in this study were weighted towards experienced cyclists, and this may have allowed them to gauge the risk of cycling infrastructure relatively well.

Perceptions of safety were aligned with published work on cyclists' route preferences. Previous work has indicated that people have a preference for separated routes.[20] The risk perceptions of this population reflected these preferences. Separated route types were perceived as safe, with unpaved multi-use paths, bike paths and paved multi-use paths all rated very safe, and cycle tracks and sidewalks rated more neutrally. Again, corroborating published preferences, residential streets were perceived as safer than major streets. Among major street types, those with bike lanes were perceived as safer, as were streets with no car parking. The absence of parked cars removes the risk of a cyclist colliding with an opening car door and the need to deal with cars moving in and out of parking spaces.

The evidence on observed relative risk of certain separated route types was not as closely aligned with risk perceptions as preferences were. We found that cycle tracks, which separate cyclists and motor vehicles on major city streets, carry about one-tenth the risk of typical major streets, yet these were perceived to have moderate risk. It should be noted that there were only 19 sites of this type in the control site sample, so the small sample leads to more uncertainty in the OR estimate. At the time of this study, there were very few cycle tracks in Vancouver and none in Toronto. Cycle tracks are commonplace in European countries such as Denmark and the Netherlands, where cycling is common and safety risks are low.[21] In Canada, cyclists are less familiar with this infrastructure so may have had more trouble gauging its risk. Multi-use paths, while preferred[20] and perceived as some of the safest types of route (as found in this paper), offered only about a 25%-40% risk reduction compared with major streets. Given that reported safety concerns are primarily around motor vehicles,[1] a possibility may be that people do not recognize the risk of injury from crashes with infrastructure, cyclists, pedestrians or animals, or from falls due to slippery or uneven surfaces along unpaved routes.[6,7]

As suggested in the risk literature, perceptions may be tied to the severity of the consequences,[14,16] that is, there may be a perceived difference between a "risk of any injury" and a "risk of severe injury". Our injury study did not differentiate severity of injuries, although all required attendance at an emergency department. However, others have shown that most severe injuries and fatalities do arise from collisions with motor vehicles.[22,23] This potential for

more severe injuries may have been considered in cyclists' higher risk perception for cycle tracks alongside major streets and lower risk perceptions for multi-use paths away from traffic. The importance of being away from traffic to reduce perceptions of risk has been shown by others,[24] and this tendency to favour quiet routes may explain the discrepancies between observed and perceived risk ratings for both cycle tracks and multi-use paths. However, risk perceptions in this study were not unrefined, as sidewalks were appropriately perceived as intermediate risk. This parallels the empirical risks from our injury study and other literature demonstrating that riding on sidewalks is more dangerous than on bicycle-specific infrastructure and many road types.[25]

Strengths and limitations

The BICE study was a case-crossover study, a robust methodology that compares an injury site with control site(s) for the same individual and trip. Use of this methodology enabled an inquiry into the independent effects of route infrastructure while accounting for challenges facing injury research around exposure to risk and the confounding effects of unmeasured individual and trip characteristics.[18] This provided rigorous estimates for observed relative risk for 14 different route types. While this study included the most diversity of infrastructure in any cycling study we are aware of, it was limited to the existing types of infrastructure in Vancouver and Toronto.

We used only data on the BICE control sites for the analysis of perceived risk to reduce bias introduced by the injury event. When we analyzed the reports of perceived safety at injury sites, we found that the mean reported risk at injury sites was typically 0.3-0.4 units greater than reported for control sites of the same type. This could be bias resulting from the fact that the participants had experienced an injury there, or indeed it could be that conditions at these sites in particular were more dangerous than was the average site of that type. Given this unknown, these were not included in analyses. It may also be that injured individuals have heightened perceptions of risk at any site (injury or control) following an injury event, as compared with the response they may have made in the absence of an injury. Our analysis focused on the order of perceived risk, more so than on absolute scores.

Additionally, this study considered risk of injury from crashes, not safety risks associated with personal crime or bicycle theft, or health risks from exposure to air pollution. Whether study participants restricted the interpretation of our safety question to injury risk is not known, although it seems likely that a cyclist who was recently injured, as in this study, would have that aspect of safety at the forefront of their thoughts. As the interview question referred to "this site", participants may have reflected on other factors (traffic speed and volume, vehicle type, weather) beyond simply the road infrastructure, though some of these features are also strongly related to route type (e.g., traffic volume on major streets was about 20 times higher than on residential streets).

This study included injuries severe enough to require an emergency department visit. Minor injuries were not captured, nor were fatal injuries or people with severe head injuries who could not recall the study trip (although these represented only 1.6% of those known to be eligible, including two fatalities during the study). A future analysis of the BICE study data will examine risk factors for more severe injury, in which we will query the role of route infrastructure and the involvement of motor vehicles.

Contributions

Our results have a number of implications for practice. The data on perceived and observed relative risk can guide municipalities on the types of infrastructure that are safe according to both criteria and are therefore likely to both attract cyclists and keep them safe. The findings on discrepancies between perceived safety and observed relative risk carry different implications for practice and advocacy. This highlights the need to inform public opinion on route safety, perhaps through education programs and social media, in order to encourage cycling and use of the safest possible infrastructure. Improving cyclists' knowledge about the comparative risk of infrastructure types may reduce injury incidence by influencing their route choices or their risk-taking behaviour while using more dangerous types of cycling infrastructure.

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RÉSUMÉ

Objectif : Les préoccupations quant à la sécurité ont un effet dissuasif sur le cyclisme. L'étude BICE (*Bicyclists' Injuries and the Cycling Environment*) a quantifié le risque de blessure associé à 14 types de routes – des sentiers hors route aux grandes artères. Lorsqu'il s'agit du risque de blessure, il peut y avoir discordance entre les preuves empiriques et les perceptions. Quand c'est le cas, même si l'on construit des infrastructures de protection, les gens peuvent ne pas se sentir suffisamment en sécurité pour faire du vélo. Notre article porte sur la relation entre le risque de blessure subjectif et observé.

Méthode : L'étude BICE est une étude de type « case-crossover » pour laquelle nous avons recruté 690 cyclistes adultes s'étant rendus aux services d'urgence de Toronto et de Vancouver après un accident de vélo. Nous avons calculé le risque observé en comparant le type de route sur le lieu de l'accident avec les types de routes sur des lieux sélectionnés au hasard le long du même parcours. Le risque subjectif était la réponse moyenne des participants de l'étude à la question : « Quel était le niveau de sécurité de cet endroit pour les cyclistes durant ce trajet? »; les réponses ont été classées de +1 (très sûr) à -1 (très dangereux). Les scores de risque subjectif n'ont été calculés que pour les lieux témoins (sans accident) afin de réduire le biais induit par l'accident.

Résultats : Les types de routes présentant le plus grand risque subjectif étaient les grandes artères avec voie partagée, sans voitures garées (score moyen = -0,21, intervalle de confiance [IC] de 95 % : -0,54-0,11), suivies des grandes artères sans infrastructures cyclables (-0,07, IC -0,14-0,00). Les routes perçues comme étant les plus sûres étaient les sentiers multi-usages asphaltés (0,66, IC 0,43-0,89), les rues résidentielles (0,44, IC 0,37-0,51), les pistes cyclables (0,42, IC 0,25-0,60) et les rues résidentielles marquées pour les bicyclettes et comportant des mesures de modération de la circulation (0,41, IC 0,32-0,51). La plupart des types de routes perçues comme étant plus dangereuses étaient de fait plus dangereuses dans notre étude; de même, la plupart des types de routes perçues comme étant moins dangereuses l'étaient effectivement. Des divergences ont été notées pour les pistes cyclables (le risque subjectif étant plus élevé que le risque observé) et pour les sentiers multi-usages (le risque observé étant plus élevé que le risque subjectif).

Conclusions : Le choix d'une route et la décision de faire du vélo sont influencés par les perceptions de la sécurité, et nous avons constaté que ces perceptions correspondent généralement à la sécurité objective. Toutefois, les perceptions de certains types de voies séparées concordent moins avec la réalité. Des programmes de sensibilisation du public et dans les médias sociaux pourraient faire en sorte que les perceptions de la sécurité des routes par le public reflètent les données probantes.

Mots clés : sécurité; transports; traumatismes; conception de l'environnement