Novel Methods for Environmental Assessment of Pedestrian Injury: Creation and Validation of the Inventory for Pedestrian Safety Infrastructure

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Abstract Nationally, 80% of pedestrian fatalities occur in urban environments, yet the distribution of injuries across urban areas is not uniform. Identifying street-level risk factors for pedestrian injury is essential for urban planning and improvement projects, as well as targeted injury prevention efforts. However, creating and maintaining a comprehensive database of a city's traffic safety infrastructure can be cumbersome and costly. The purpose of this study was to create and validate a neighborhood environmental observational assessment tool to capture evidence-based pedestrian safety infrastructure using Google Street View (GSV)—The Inventory for Pedestrian Safety Infrastructure (IPSI). We collected measures in-person at 172 liquor stores in Baltimore City from June to August

2015 to assess the tool's reliability; we then collected IPSI measures at the same 172 locations using GSV from February to March 2016 to assess IPSI reliability using GSV. The majority of items had good or excellent levels of inter-rater reliability ($ICC \geq 0.8$), with intersection features showing the highest agreement across raters. Two scales were also developed using exploratory factor analysis, and both showed strong internal consistency (Cronbach's $\alpha \geq 0.6$). The IPSI provides a valid, economically efficient tool for assessing pedestrian safety infrastructure that can be employed for a variety of research and urban planning needs. It can also be used for in-person or GSV observation. Reliable and valid measurement of pedestrian safety infrastructure is essential to effectively prevent future pedestrian injuries.

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Introduction

Nationally, almost 80% of pedestrian fatalities occur in urban environments [1], yet the distribution of pedestrian injuries and injury risk factors across urban areas is not uniform. In a Montreal study, there was a statistically significant inverse relationship between median household income and average number of injured pedestrians in a census tract [2]. Traffic volume was also higher in poorer census tracts versus wealthier census tracts [2]. One study of traumatic injury across Canada and the USA found that locations of injuries were not geographically random; rather, injury events disproportionately clustered in census tracts with higher rates of unemployment, lower educational levels, lower incomes, and more non-White residents [3]. These findings are supported by similar studies of traumatic injury [4–6].

A better understanding of the micro-level street environment could help explain the antecedents of the inequitable distribution of pedestrian injuries across urban neighborhoods. “Micro” refers to “built environment factors that represent details that are smaller in scale and generally changeable more rapidly and with less cost,” including infrastructure such as lighting or crosswalks [7] (p1275). Several studies have shown that, while the large-scale structural attributes of streets may not differ across cities, the micro-level infrastructure located on streets varies dramatically. For example, an Austin, TX, study found that low-income and Hispanic neighborhoods were more walkable than high-income, mostly non-Hispanic White neighborhoods when considering larger scale attributes such as street connectivity and residential density. However, micro-level infrastructure was inequitably distributed, with low-income and Hispanic neighborhoods having worse sidewalk maintenance [8]. Similarly, a study of 32 Seattle and Baltimore neighborhoods found little discrepancy across income strata for larger scale built environment features such as street connectivity and mixed land use, yet micro-level infrastructure including street lighting, crosswalks, and sidewalks were significantly less common in poorer areas [7].

Previous research suggests that the ability of a community to change micro-level pedestrian safety attributes

is closely correlated with socio-economic privilege and social capital [9]. Social capital consists of “resources stemming from the structure of social relationships, which in turn facilitate the achievement of specific goals [10] (p135).” A qualitative study of two California communities found that the higher-income neighborhood was more successful and quicker at bringing about changes to the street environment compared to the lower-income neighborhood in part because of their connections with people in positions of authority in the municipal government [11]. Despite the organization and motivation of residents in the lower income neighborhood, it took them significantly longer to achieve their goal of preventing speeding by installing speed bumps because they lacked these influential social connections [11].

Although some cities are making administrative data on micro-level infrastructure publicly accessible, data are often incomplete or do not address the needs of researchers or urban planners [12]. Furthermore, creating and maintaining a comprehensive database of a city’s traffic safety infrastructure can be cumbersome and costly, and many cities do not have the requisite funds or logistical capacity [12–14]. Consequently, our goal was to create an inexpensive, easy to use, evidence-based tool to assess the presence (or absence) of pedestrian safety infrastructure that could be used for a variety of research, urban planning, and community needs with an environmental justice frame. This study describes the creation and validation of a neighborhood environmental observational assessment tool to capture evidence-based pedestrian safety infrastructure using Google Street View—The Inventory for Pedestrian Safety Infrastructure (IPSI).

Neighborhood environmental audits are a form of systematic social observation, a standardized method for directed observation of the physical, social, and economic characteristics of neighborhoods [15]. Trained researchers record indicators of neighborhood characteristics using a standardized assessment tool and following a prescribed data collection protocol. However, these neighborhood assessments are time-consuming and expensive and, consequently, tend to be limited in their geographic scope [12, 16, 17]. Google Street View (GSV) provides an alternative to in-person observation. GSV is a free tool offering panoramic, street-level images of city streets across the world; the user types in an address and can virtually “walk” forward or backward along a street, revolve 360 degrees, rotate vertically 290

degrees, and zoom in and out [12, 16]. GSV images are also time-stamped with the month and year an image was processed, and many locations allow the user to travel back in time to every previous image taken at a location; this allows for the comparisons of neighborhood features over time. Performing street audits with GSV allows for a large amount of data collection in a shorter period of time. One study of 850 intersections estimated that using GSV in place of in-person audits cut down data collection time from three person-years to one person-month [13, 18]. GSV has already been used successfully to audit a variety of urban environments and characteristics, including physical disorder [17, 19–21], parks and greenspace [22], the local food environment [16], and support for physical activity [23–26]. GSV has also been used previously to assess environmental contributions to traffic-related injuries [12, 13].

Previous environmental observation tools which have been used to examine traffic safety infrastructure were not designed specifically for pedestrian safety. Many of these tools focus on environmental features which promote physical activity such as street slope or perceived attractiveness of the street environment [23, 24, 27–29] or include traffic calming measures that are not necessarily protective of pedestrians [13, 16, 30]. While many of these roadway features may be beneficial to pedestrians, the inclusion of these measures is not reliant on evidence from studies which examine best practices for pedestrian safety; furthermore, physical environment features which are instrumental in predicting pedestrian safety may be overlooked [27]. Previous studies which have attempted to assess pedestrian safety have also limited their scope to crash risk at intersections and have largely overlooked other roadway safety infrastructure [31]. Measures for IPSI were selected based on several studies of accident-reduction infrastructure improvements.

Furthermore, most observational assessments rely on systematic sampling of block faces to obtain an overall representation of neighborhood characteristics [17, 19, 30, 32]. To our knowledge, no observational assessment tool has examined the neighborhood environment at the location of a specific event such as a traffic accident or neighborhood feature such as a playground or corner store. As part of a larger parent study, we pilot tested the IPSI at locations of alcohol outlets in Baltimore City. However, our intent is to expand more broadly to assess

pedestrian safety features, their quality, and their relationship with injury outcomes at a variety of locations and situations.

Methods

Tool Development

We examined the existing literature on road safety design to promote pedestrian safety [31, 33–35] and pedestrian-involved accident analysis [36, 37], as well as recommendations from the Federal Highway Administration [38, 39], technical guides for pedestrian safety [40], and subject-matter experts, to develop a comprehensive list of evidence-based protective and exposing pedestrian safety infrastructure for an urban environment. We subdivided this list into roadway features, midblock features and intersection features to facilitate coding (Table 1). As the purpose of this study was to capture pedestrian safety infrastructure, we did not include measures on traffic or pedestrian volume or average vehicle speed. We conceptualized the IPSI as incorporating the principles set forth in Haddon's Countermeasures [41]. This theory classifies 10 strategies which can be used to prevent injuries and reduce injury severity. For example, countermeasure five is, "Separate the hazard from that which is to be protected by time and space [42] (p62)." For our purposes, this could include crossing signals which prevent pedestrians from entering the roadway at the same time as cars. We also posit that infrastructure impacts pedestrian safety based on the principles described in the social-ecological model [43].

We then created a protocol to best capture the risk environment surrounding a specific location. Most observational assessment studies divide neighborhoods into discrete block faces; this technique was not appropriate for this study as a location of interest could be at an intersection or mid-block. A mid-block incident could be examined using the traditional block-face method, but an intersection would require the examination of two connecting block faces. Consequently, we developed a new technique to assess the pedestrian safety risk environment without stratifying by midblock or intersection. At each location, we measured intersection features, roadway features, and midblock features; however, for stores located on a corner, we collected a second measure for roadway features and midblock features for the intersecting street (Fig. 1). We pilot

Table 1 Inventory for Pedestrian Safety Infrastructure (IPSI) features and definitions

Domain	Definition
Roadway features	
One-way or two-way street	
Number of street lanes	Total number of lanes, regardless of direction
Posted speed limit	Yes or No
If speed limit can be read, please enter it.	Write down the posted speed limit if you see it.
Street lights or lampposts	Yes or No
On-street parking	No on-street parking; Parallel parking only; Diagonal parking only; Both parallel and diagonal parking
Presence of alley streets	Yes or No; the alley could have a name or no name
Presence of driveways	Yes or No
Sidewalks	No sidewalks; Sidewalk on one side of the street only; Sidewalk on both sides of the street
Sidewalk maintenance and walkability	Good = sidewalk is in pristine or near pristine condition, very easy to go across; Fair = sidewalk has some unevenness or obstacles, but it can still be navigated; Poor = sidewalk is extremely difficult or nearly impossible to go across
Traffic island or median	Yes or No
Speed bumps or humps	Yes or No
Pedestrian overpass, underpass, or bridge	Yes or No
Fence or other barrier to prevent street crossing	Yes or No
Bus stop(s)	Yes or No
Highway on-ramp or exit-ramp	Yes or No
Midblock features	
Number of marked mid-block crosswalks	Crosswalks are marked with white painted lines, colored painted lines or zebra striping
Number of crosswalks with reflectors or flashing lights embedded in pavement to mark crosswalk	
Number of pedestrian crossing signs	

Table 1 (continued)

Domain	Definition
Number of pedestrian crossing signals	
Intersection features	
Traffic circle or roundabout	Yes or No
Number of intersecting streets	Example: If there are 4 corners at an intersection, then two streets are intersecting
Number of marked crosswalks at an intersection at the site of a pedestrian walk signal, stop light or stop sign	Crosswalks are marked with white painted lines, colored painted lines or zebra striping.
Intersection features	
Number of marked crosswalks at intersection <u>NOT</u> associated with pedestrian walk signal, stop light or stop sign	Crosswalks are marked with white painted lines, colored painted lines or zebra striping
Number of crosswalks with reflectors or flashing lights embedded in pavement to mark crosswalk	
Number of streets with traffic lights	Traffic light=traffic signal or stop light
Number of stop signs	
Number of yield signs	
Number of pedestrian crossing signals	
Number of pedestrian crossing signs	
Number of streets with stop line set back from crosswalk	

An appendix with illustrated definitions is available online as [Supplementary Material](#)

tested the instrument on 30 alcohol outlets in two neighborhoods in East and West Baltimore and corrected it for clarity and reproducibility.

In-Person Data Collection

In-person street observation occurred from June to August 2015 as part of a larger study of alcohol outlets in Baltimore City; the goal of this parent study was to identify characteristics of liquor stores related to compliance and targets of future policies to reduce the public health impact of liquor stores on communities. Data on the location and license types of all establishments licensed to sell alcohol in Baltimore City were obtained from the Board of Liquor License Commissioners for Baltimore City. There are 12 liquor license types

Example Location: Cardinal Tavern, 901 S Clinton Street.

Roadway 1: 900 block of S Clinton Street

Roadway 2: 3300 block of Hudson Street

A street block is the distance from one intersection to the next intersection, a distance of approximately 0.1 miles. Image taken from Google Maps.

Fig. 1 Diagram of data collection protocol at alcohol outlets located at a corner. Example location: Cardinal Tavern, 901 S Clinton Street. Roadway 1: 900 block of S Clinton Street.

Roadway 2: 3300 block of Hudson Street. A street block is the distance from one intersection to the next intersection, a distance of approximately 0.1 miles. Image taken from Google Maps

administered by the Board. This study focused on the four licensure classes concerned with sale of package goods for off-premise consumption—liquor packaged goods stores, bars/taverns, and wine and beer only stores ($n = 685$). On- and off-premise outlets differentially impact injury risk. Off-premise outlets are more strongly associated with drinking problems, crime, and violence compared to outlets licensed for on-premise consumption only [44–46]. Restaurants, hotels/motels,

entertainment venues, and non-profit private clubs were not included in this study as these establishments only allow on-premise alcohol consumption.

To assess pedestrian safety infrastructure around alcohol outlets, raters took part in a 30-min training which reviewed the study's purpose, protocol, and definitions of all terms, complete with pictures of common roadway features. Raters were given a field guide with the same information. Raters evaluated the roadway features

around every off-premise alcohol outlet location ($n = 685$); a quarter of these locations ($n = 172$) were double coded to assess reliability of the tool. Double-coded locations were selected from various neighborhoods across Baltimore City, representing a socioeconomically and racially diverse sample of the city.

Raters went out in groups of three—one driver and two coders—in order to complete one full assessment of the liquor store and the surrounding pedestrian safety environment. For double-coded assessments, each coder rated the street block separately to create two independent IPSI assessments. Raters were instructed to walk the block as many times as necessary to thoroughly collect all measures. A street block was defined as the distance from one intersection to the next intersection, a distance of approximately 0.1 miles. For double-coded locations, raters were instructed not to discuss or share their assessments. Data were coded on paper forms that were the size of a half sheet of paper. Each IPSI assessment took approximately 20 min to complete. Data sheets included the venue identification number on each page to ensure each section of the assessment could be linked to the venue. After each coding session, raters debriefed with project staff to pose questions and return data sheets for data entry. Data sheets were also reviewed by project staff to assess comprehensiveness and accuracy of data collection.

Google Street View Data Collection

The 172 double-coded alcohol outlet locations were reassessed using GSV by a new set of raters who had not participated in the in-person assessment. Two GSV raters coded the same street blocks assessed by the in-person raters to create two new, independent IPSI assessments for each of the 172 locations. GSV raters took part in the same 30-min training as the in-person raters and were instructed not to discuss or share their assessments. The IPSI instrument was also unchanged, except raters were asked to note the month and year the image was captured for each block and intersection to assess coding discrepancies related to temporal changes in roadway features and GSV image dates [47]. Raters were instructed to type the alcohol outlet's address into the GSV address bar and scan the area as many times as necessary and from as many angles as necessary to thoroughly assess the block (Fig. 2). Raters were instructed to judge the infrastructure by the most recent image, even if it did not give the most complete view of

the street. Each assessment took approximately 7 min to complete. As with the in-person observation, data collection was paper based, and data sheets were reviewed by project staff to assess comprehensiveness and accuracy of data collection. Data collection took place from February to March 2016.

This study was reviewed by the Johns Hopkins University IRB and deemed non-human subjects research.

Analysis

Data sheets collected from the four independent observations (two in-person and two GSV) were entered into SPSS 20 for reliability analysis. Inter-rater reliability was assessed for each observation pair and across all four observations to first assess the reliability of the IPSI itself and the reliability of GSV results. For categorical measures, Cohen's Kappa was calculated for each paired response and two-way mixed single measure consistency intra-class correlation coefficient (ICC) was calculated for four-way reliability [48–50]. For continuous responses, two-way random average measure consistency ICC coefficients were calculated for each paired response and for four-way reliability [48]. Certain features did not show any variability across locations and are labeled “Constant,” indicating their consistent presence or absence from the streetscape. Features with variability across streetscapes but perfect agreement across paired or four-way observers are labeled as “1.00,” indicating perfect agreement among observers across every observed location.

Exploratory factor analysis (EFA) with principal component extraction and varimax rotation was employed to develop intersection and roadway features scales to assess internal consistency. The purpose of EFA was to identify clusters of homogenous variables that could be used to assess the presence of safety infrastructure without having to collect the entire data form. Eigenvalues of greater than 1 were used as criterion for factor extraction; items with loadings of less than 0.15 and double-loaded items were dropped. Items that were significantly correlated (polychoric correlation $p < 0.05$) with two or more variables were excluded as these items tended to assess similar characteristics. A Cronbach's alpha of 0.6 or greater was accepted as a measure of internal consistency for each scale [51].

Example IPSI measures for roadway features:

A: Address of alcohol outlet; Month and Year image was captured

B: Presence of streetlights/lampposts

C: One-way street

D: Sidewalks on both sides of street in good condition

Example IPSI measures for intersection features:

E: Number of streets with stop line set back from crosswalk

F: Number of streets with traffic lights

G: Number of pedestrian crossing signals

H: Number of marked crosswalks at an intersection at the site of a walk signal, stop light or stop sign

Fig. 2 Examples of data collection using Google Street View. Image 1—Example IPSI measures for roadway features: A: address of alcohol outlet; Month and Year image was captured; B: presence of streetlights/lampposts; C: one-way street; D: sidewalks on both sides of street in good condition. Image 2—Example IPSI measures

for intersection features: E: number of streets with stop line set back from crosswalk; F: number of streets with traffic lights; G: number of pedestrian crossing signals; H: number of marked crosswalks at an intersection at the site of a walk signal, stop light or stop sign. Images taken from Google Maps.

Results

Inter-rater reliability estimates for categorical variables are presented in Table 2; reliability estimates for continuous variables are presented in Table 3. Overall, roadway features on the primary roadway (labeled Roadway 1 in Tables 2 and 3) showed strong reliability for paired observations and four-way observation. Bus stops ($ICC = 0.813$, $95\%CI = (0.763, 0.855)$) and one-way streets ($ICC = 0.936$, $95\%CI = (0.918, 0.950)$) showed the highest reliability across all four raters, while presence of street lights, alley streets, driveways, and speedhumps showed moderate agreement with four-way ICCs between 0.60 and 0.65. Sidewalk maintenance reliability was consistently the lowest measure across all paired and four-way measures with an overall ICC of 0.43 ($95\%CI = (0.27, 0.55)$). Presence of posted speed limits showed moderate agreement across all groups ($ICC = 0.61$, $95\%CI = (0.50, 0.70)$), while agreement on the speed limit itself was strong ($ICC = 0.93$, $95\%CI = (0.83, 0.98)$). Pedestrian overpasses and highway exit-ramps were not present; consequently, reliability of these measures could not be assessed. Reliability of second roadway measures (for corner stores only, $n = 64$) were similar to those of the first roadway, with a few exceptions. Four-way reliability for alley streets ($ICC = 0.35$, $95\%CI = (0.02, 0.59)$) and driveways ($ICC = 0.29$, $95\%CI = (0.15, 0.44)$) showed the lowest agreement, while reliability for observed sidewalk maintenance ($ICC = 0.61$, $95\%CI = (0.41, 0.75)$) was higher.

Intersection features were particularly strong with most features showing ICCs above 0.80 for all paired comparisons and four-way comparisons; these included crosswalks, traffic lights, stop signs, yield signs, pedestrian crossing signals, and set-back stop lines. There was moderate reliability of pedestrian crossing signs ($ICC = 0.594$, $95\%CI = (0.485, 0.685)$), and no crosswalks with embedded reflectors were observed.

The majority of midblock safety features were not observed, with the exception of traffic circles and pedestrian crossing signs. Traffic circles showed perfect agreement across groups. The number of midblock pedestrian crossing signs showed high agreement across all paired and four-way comparisons with an ICC for each grouping of approximately 0.80.

During EFA, intersection variables were highly correlated. Set-back stop line was highly positively significantly correlated with crosswalks at signalized intersections ($r = 0.899$, $p < 0.001$), traffic lights ($r = 0.75$,

$p < 0.001$), and pedestrian crossing signals ($r = 0.66$, $p < 0.001$). The intersection measures yielded one distinct scale with high internal consistency: crosswalks, traffic lights, signalized pedestrian crossing, set-back stop lines ($\alpha = 0.86$) (Table 4). There was less correlation among roadway features, which also produced one distinct scale: number of street lanes, presence of driveways, type of parking, presence of bus stops ($\alpha = 0.60$). Because so few of the midblock items were present in the sample, we could not perform EFA on these items.

We also recorded the date of GSV images to account for disagreement related to temporal variability of images across locations and temporal discontinuity of images taken at main roadways versus intersections at the same location [47]. There were large temporal inconsistencies across locations and between intersections and main roadways. Thirty-four percent ($n = 59$) of intersection images were recorded August to October 2015 or roughly within 1 month of in-person observation, while 29% ($n = 50$) of images were taken during the same months for main roadways. In addition, 48.8% ($n = 84$) of intersection images were recorded from September to October 2014, and almost 20% ($n = 29$) of intersection images were recorded prior to 2014—greater than 1 year prior to in-person data collection. Half ($n = 86$) of main roadway images were recorded from September to October 2014, while 21% ($n = 36$) of images were taken before 2014.

Discussion

This study evaluates an evidence-based tool for assessing pedestrian safety infrastructure, either through in-person observation or GSV. The majority of items had good or excellent levels of inter-rater reliability, with intersection features showing the highest agreement across raters. The strong inter-item reliability of the intersection scale is also a strength of the IPSI, especially considering the high number of pedestrian injuries which occur at intersections [52]. We developed and evaluated the reliability of our instrument before engaging in GSV testing; previous studies of environmental observation tools for traffic safety have evaluated their tool's reliability for GSV use without first testing the reliability of the tool itself [12, 17].

As with previous evaluations of observational tools to assess the built environment [12, 13, 17], we found

Table 2 Cohen's Kappa and intra-class correlation (ICC) for categorical IPSI variables

Item	In-person observation			Google Street View observation			Across all observations		
	Kappa coefficient	SE	P value	Kappa coefficient	SE	P value	ICC	95% CI	P value
Roadway 1 (<i>n</i> = 172)									
One-way or two-way street	0.856	0.044	<0.001	0.921	0.032	<0.001	0.936	0.918, 0.950	<0.001
Posted speed limit	0.214	0.079	0.005	0.572	0.073	<0.001	0.610	0.504, 0.697	<0.001
Street lights or lampposts	1.000	0.000	<0.001	0.797	0.198	<0.001	0.627	0.514, 0.703	<0.001
On-street parking (parallel or diagonal/back-in parking)	0.653	0.121	<0.001	0.695	0.086	<0.001	0.635	0.568, 0.699	<0.001
Presence of alley streets	0.501	0.075	<0.001	0.560	0.067	<0.001	0.614	0.510, 0.701	<0.001
Presence of driveways	0.443	0.155	<0.001	0.624	0.060	<0.001	0.582	0.470, 0.676	<0.001
Sidewalk on one or both sides of street?	Constant			1.000	0.000		0.667	0.577, 0.741	<0.001
Traffic island or median	0.900	0.044	<0.001	0.853	0.054	<0.001	0.937	0.920, 0.951	<0.001
Speed bumps or humps	Constant			0.496	0.306	<0.001	0.590	0.480, 0.682	<0.001
Pedestrian overpass, underpass, or bridge	Constant			Constant			Constant		
Fence or other barrier to prevent street crossing	Constant			Constant			Constant		
Bus stops	0.740	0.052	<0.001	0.595	0.067	<0.001	0.813	0.763, 0.855	<0.001
Highway on- or exit-ramp	Constant			Constant			Constant		
Roadway 2 (<i>n</i> = 64)									
Corner store?	0.951	0.024	<0.001	1.000					
One-way or two-way street	0.787	0.082	<0.001	0.805	0.076	<0.001	0.853	0.777, 0.907	<0.001
Posted speed limit	0.255	0.128	0.039	0.739	0.092	<0.001	0.666	0.494, 0.790	<0.001
Street lights or lampposts	Constant			0.703	0.162	<0.001	0.543	0.307, 0.712	<0.001
On-street parking (parallel or diagonal/back-in parking)	0.129	0.161	0.166	0.805	0.109	<0.001	0.837	0.753, 0.897	<0.001
Presence of alley streets	0.050	0.127	0.690	0.449	0.111	<0.001	0.351	0.017, 0.591	0.021
Presence of driveways	0.213	0.202	0.045	0.557	0.099	<0.001	0.288	0.154, 0.441	<0.001
Sidewalk on one or both sides of street?	Constant			Constant			Constant		
Traffic island or median	0.734	0.178	<0.001	1.000	0.000	<0.001	0.590	0.379, 0.742	<0.001
Speed bumps or humps	Constant			1.000	0.000	<0.001	0.667	0.495, 0.790	<0.001
Pedestrian overpass, underpass, or bridge	Constant			Constant			Constant		
Fence or other barrier to prevent street crossing	Constant			Constant			Constant		
Bus stops	0.518	0.133	<0.001	0.817	0.125	<0.001	0.676	0.509, 0.796	<0.001
Highway on- or exit-ramp	Constant			Constant			Constant		
Intersection (<i>n</i> = 172)									
Traffic circle or roundabout	1.000	0.000	<0.001	1.000	0.000	<0.001	1.000		

“Constant” indicates no variability across locations

“1.00” indicates perfect agreement among observers across every observed location

Table 3 Intra-class correlation (ICC) for continuous IPSI variables

Item	In-person observation			Google Street View observation			Across all observations		
	ICC	95% CI	P value	ICC	95% CI	P value	ICC	95% CI	P value
Roadway 1 (<i>n</i> = 172)									
Number of street lanes	0.805	0.736, 0.855	<0.001	0.916	0.886, 0.938	<0.001	0.899	0.872, 0.922	<0.001
Speed limit	0.514	-0.146, 0.794	0.049	1.000			0.933	0.825, 0.981	<0.001
Sidewalk maintenance and walkability	0.347	0.118, 0.517	0.003	0.459	0.268, 0.600	<0.001	0.425	0.270, 0.554	<0.001
Midblock 1									
Number of marked mid-block crosswalks	Constant			Constant			Constant		
Number of crosswalks with reflectors or flashing lights	Constant			Constant			Constant		
Number of pedestrian crossing signs	0.718	0.620, 0.792	<0.001	0.710	0.608, 0.786	<0.001	0.570	0.455, 0.667	<0.001
Number of pedestrian crossing signals	Constant			Constant			Constant		
Roadway 2 (<i>n</i> = 64)									
Number of street lanes	0.192	-0.331, 0.509	0.201	0.823	0.712, 0.891	<0.001	0.605	0.401, 0.751	<0.001
Speed limit	1.000			1.000			1.000		
Sidewalk maintenance and walkability	0.388	-0.008, 0.628	0.027	0.584	0.323, 0.744	<0.001	0.608	0.407, 0.754	<0.001
Midblock 2									
Number of marked mid-block crosswalks	Constant			Constant			Constant		
Number of crosswalks with reflectors or flashing lights	Constant			Constant			Constant		
Number of pedestrian crossing signs	0.802	0.675, 0.880	<0.001	0.741	0.578, 0.841	<0.001	0.786	0.676, 0.865	<0.001
Number of pedestrian crossing signals	Constant			Constant			Constant		
Intersection (<i>n</i> = 172)									
Number of intersecting streets	0.658	0.538, 0.747	<0.001	0.850	0.797, 0.889	<0.001	0.827	0.780, 0.866	<0.001
Number of marked crosswalks at an intersection	0.892	0.854, 0.920	<0.001	0.948	0.930, 0.961	<0.001	0.929	0.910, 0.945	<0.001
at the site of a walk signal, stop light or stop sign									
Number of marked crosswalks at intersection NOT associated with walk signal, stop light or stop sign	0.923	0.896, 0.943	<0.001	0.874	0.830, 0.907	<0.001	0.918	0.896, 0.937	<0.001
Number of crosswalks with reflectors or flashing lights	Constant			Constant			Constant		
Number of streets with traffic lights	0.946	0.927, 0.960	<0.001	0.950	0.933, 0.963	<0.001	0.943	0.927, 0.956	<0.001
Number of stop signs	0.791	0.717, 0.845	<0.001	0.945	0.925, 0.959	<0.001	0.874	0.840, 0.902	<0.001
Number of yield signs	Constant			0.938	0.915, 0.954	<0.001	0.860	0.822, 0.891	<0.001
Number of pedestrian crossing signals	0.895	0.857, 0.922	<0.001	0.940	0.919, 0.956	<0.001	0.908	0.883, 0.928	<0.001
Number of pedestrian crossing signs	0.732	0.638, 0.801	<0.001	0.808	0.740, 0.858	<0.001	0.594	0.485, 0.685	<0.001
Number of streets with stop line set back from crosswalk	0.771	0.691, 0.831	<0.001	0.934	0.911, 0.951	<0.001	0.845	0.804, 0.880	<0.001

“Constant” indicates no variability across locations

“1.00” indicates perfect agreement among observers across every observed location

Table 4 IPSI Intersection and roadway features scales

Domain	Items	Cronbach's Alpha ^a
Roadway	Number of street lanes	0.60
	Presence of driveways	
	On-street parking (parallel or diagonal/back-in parking)	
	Bus stops	
Intersection	Number of marked crosswalks at an intersection at the site of a walk signal, stop light or stop sign	0.86
	Number of streets with traffic lights	
	Number of pedestrian crossing signals	
	Number of streets with stop line set back from crosswalk	

^a A Cronbach's alpha of 0.6 or greater was accepted as a measure of internal consistency for each scale [51]

that the use of GSV provides a reliable alternative to in-person street audits for safety infrastructure. GSV is a low-cost, easy-to-implement alternative to in-person audits that produces relatively quick turn around on data collection [12, 13]. Consequently, GSV allows for a wider area to be surveyed compared to in-person audits, without the need for additional resources or time [16].

The IPSI provides a reliable environmental audit tool designed to assess a variety of pedestrian safety research questions quickly and efficiently. For example, the IPSI can be used to assess pedestrian safety infrastructure around specific neighborhood features such as playgrounds, schools, corner stores, or older adult community centers. It can also be used to assess the prevalence of infrastructure at specific locations, such as the prevalence of stop signs in areas of high versus low alcohol outlet density. In addition, the two scales can be used to assess overall roadway and intersection infrastructure. Future research will evaluate the predictive validity of the IPSI, in particular the validity of the two scales for evaluating pedestrian injury risk at intersections and main roadways.

Limitations

This study only assessed street infrastructure in one metropolitan area. Certain features of Baltimore's street-scapes may limit the generalizability of findings to other urban settings. For example, lanes change from driving to parking for certain times of day, and signage may not

be readily apparent denoting the change. The temporal variation in on-street parking may limit the reliability of findings depending on when in-person observers visited the locations and when GSV images were taken. Alley streets are also unique to Baltimore, and there may be confusion across raters as to what is an alley versus a residential street [53]. As noted by Mooney and colleagues [21], rater familiarity with a neighborhood is an inherent limitation to the environmental observation method as raters familiar with a neighborhood may interpret characteristics differently than raters to whom the neighborhood is unfamiliar. Investigation of the IPSI's reliability in a variety of urban and suburban settings will enhance generalizability.

Furthermore, every IPSI item is weighted as equally important in influencing pedestrian safety. It is possible that certain infrastructure features are more impactful in protecting pedestrians than others. Future research should examine the relative importance of pedestrian safety infrastructure and weight IPSI items accordingly. The absence of traffic and pedestrian volume measures could also be a limitation when using the IPSI to evaluate pedestrian safety. As the aim of the IPSI is to capture the relatively static nature of roadway infrastructure, the absence of these more temporal measures is not an inherent drawback of the tool.

The limitations of GSV as an observational tool are also worth discussing. Because of the lack of fine detail available in images, subjective measures such as sidewalk maintenance may not be reliable [23, 25]. Obstruction also could be problematic as signage, particularly smaller signs such as speed limits or pedestrian crossing signs, as well as driveways and alley streets, may be blocked by trees, trucks, or other vehicles when the image was captured [17]. GSV images are also not updated consistently [47]. In our study, a third of intersection images were taken within 1 month of in-person observation and less than 30% were taken within 1 month for main roadways. This temporal delay in images could reduce the reliability of GSV measures compared to in-person observation.

Conclusion

Disparities in the distribution of pedestrian injuries and injury risk factors across communities can be remedied with targeted infrastructure improvements that are relatively cost effective and quick to implement [7].

Reliable and valid measurement of existing pedestrian safety infrastructure is necessary to effectively prevent future pedestrian injuries. The IPSI provides a valid, economical, and efficient tool for assessing urban safety infrastructure that can be employed for a variety of research, urban planning and community needs.

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