A global analysis of urban design types and road transport injury: an image processing study

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Summary

Background Death and injury due to motor vehicle crashes is the world's fifth leading cause of mortality and morbidity. City and urban designs might play a role in mitigating the global burden of road transport injury to an extent that has not been captured by traditional safe system approaches. We aimed to determine the relationship between urban design and road trauma across the globe.

Methods Applying a combined convolutional neural network and graph-based approach, 1692 cities capturing one third of the world's population were classified into types based on urban design characteristics represented in sample maps. Associations between identified city types, characteristics contained within sample maps, and the burden of road transport injury as measured by disability adjusted life-years were estimated through univariate and multivariate analyses, controlling for the influence of economic activity.

Findings Between Mar 1, 2017, and Dec 24, 2018, nine global city types based on a final sample of 1632 cities were identified. Burden of road transport injury was an estimated two-times higher (risk ratio 2·05, 95% CI 1·84–2·27) for the poorest performing city type compared with the best performing city type, culminating in an estimated loss of 8·71 (8·08–9·25) million disability-adjusted life-years per year attributable to suboptimal urban design. City types that featured a greater proportion of railed public transport networks combined with dense road networks characterised by smaller blocks showed the lowest rates of road traffic injury.

Interpretation This study highlights the important role that city and urban design plays in mitigating road transport injury burden at a global scale. It is recommended that road and transport safety efforts promote urban design that features characteristics inherent in identified high-performance city types including higher density road infrastructure and high rates of public transit.

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Introduction

The design of cities that evolved during the 20th century has been heavily influenced by the needs of motorised vehicles (eg, cars, lorries, motorcycles).[1] Considerable economic and industrial benefit has accrued as a consequence of the motor vehicle industry,[2,3] yet it has also brought significant population and planetary health challenges.[4,5] For example, death and injury due to motor vehicle crashes is now the world's fifth leading cause of mortality and morbidity,[6,7] claiming an estimated 1·35 million lives per year and 50 million non-fatal injuries.[8] Adding to this burden is escalating exposure to traffic-related air pollution, which accounts for 4·2 million deaths per year.[9] The costs associated with managing a predominantly private motor vehicle transport system are also significant. They include habitat destruction,[10,11] escalating costs in managing injury insurance and legal systems,[12,13] the ongoing costs of building and maintaining road and parking infrastructure,[14,15] and the costs of transport-related policing and law enforcement activities.[16]

Urban design interventions that can reduce dependence on private vehicle transport without creating reductions in population mobility or productivity could be essential for preventing many of the environmental and public health issues facing 21st century cities and populations.[17,18] However, understanding the association between urban design and health or environmental outcomes remains difficult, especially when underlying data, locations, models, methods, and demographics upon which statistical models are developed vary considerably across the planet and between studies.[19,20]

As cities are complex, dynamic systems, it is essential that researchers take a systems-oriented approach to understanding cities and the concomitant health of residents.[17,21–23] It is also crucial that, when possible, researchers access standardised global sources of data and health information so that valid between-city, country, or regional comparisons can be readily made, rather than relying on methods such as land-use regression models, which might not prove generalisable.[20] This Article embraces this approach, using advances in

Research in context

Evidence before this study

The *Lancet* Series on Urban Design and Health highlighted evidence of health benefits that can be accrued through a focus on improved city planning that results in a more compact urban form. Extending this work, this research draws on calls for systems-based, transdisciplinary studies to address pressing global health challenges. We considered a wide range of interdisciplinary sources consistent with our backgrounds that were unrestricted to any given database or reference lists. Searches were done between Jan 1, 2017, and Dec 31, 2018. No specific exclusion criteria were applied. Sources spanned across medicine, psychology, epidemiology, complexity science, computer science, mathematics, urban studies, geography, architecture, and earth sciences.

Added value of this study

We generated methods to objectively identify global city types that can then be linked to potential health outcomes associated with urban design. Our method overcomes multiple challenges and limitations of observational dependence associated with previous work and urban data collection exercises. It produces a degree of fidelity for understanding city types not previously possible, which can be adapted to suit questions applicable at the local (ie, neighbourhood) to global scale.

Implications of all the available evidence

The implications of this work are that the underlying structure of cities can be categorised, and that the structures within the different categories are likely to facilitate or mitigate exposure to road transport injury burden for residents. Our research implies that transport safety efforts that attempt to reduce road transport injury burden without consideration of underlying city structures are likely to be hindered by initial conditions. Conversely, our research suggests that good urban design principles can mitigate conditions that precipitate road transport injury burden. Our study provides researchers with a method and platform upon which to extend our findings to other health domains associated with urban form typologies, improve interpretation and understanding of city types, and refine the method itself. It provides a basis upon which health data collected at a more granular geographical (eg, between and within city) level can be linked to city design.

remote sensing, artificial intelligence, complexity science, and the availability of global geospatial data to identify city design typologies associated with the highest burden of road transport injury. Providing a global perspective on road trauma is crucial, particularly as low-income and middle-income countries are rapidly motorising[24] and where the identification of strategies to reduce the growing burden of road transport-related injury is increasingly urgent.[18] Therefore, we used contemporary methods drawn from the field of artificial intelligence and machine learning to identify global city typologies, and to determine whether these city typologies are associated with variation in rates of road transport injury burden.[25]

Methods

City sampling

A list of 1692 global cities with populations exceeding 300 000 residents was assembled from the 2014 UN world urbanization prospects.[26] This list captured cities housing a combined 2·2 billion people, equivalent to approximately 31% of the world's population. Map images for each city were obtained using a two-stage approach.

In the first stage, a circular baseline image sampling area was calculated for each city with a centroid derived from the UN dataset[26] and an initial minimum radius of 1·5 km. As each city's population size increased, the sampling area from which images of the city were extracted increased by a power of 0·85 to the proportional increase in population.[27] Standardising the sampling area in this way avoided sociopolitical discrepancies related to urban boundaries.[28] Further, it captured differences in urban density between cities while also appropriately adjusting for areas of the world's mega-cities (eg, Tokyo, Japan and Delhi, India). The sampling area for each city was adjusted for the earth's curvature at various latitudes.[29]

The second sampling stage involved selecting precinct level image representations of each city using a customised version of Google Static Maps[30] of approximately 400×400 m at a resolution of 256×256 pixels. Each image provided a high-level abstraction of the urban characteristics of interest—namely, road networks, rail transit networks, water bodies, and designated parks or greenspace. Images containing only water did not provide insight into urban form and were re-sampled. All South Korean cities were removed from the sample (n=25) due to South Korean Government restrictions on the availability of map information at the scale used in this study;[31] hence the sample comprised 1667 cities. Figure 1 shows four typical precinct level images for Paris, France. 1000 images were generated for each city, producing a final dataset containing 1·7 million map images.

City image classification

With the map image database for each city established, a convolutional neural network based on Inception V3 architecture[32] was used to determine whether cities could be correctly classified based on the urban design characteristics present within the sample maps (hereby referred to as the model). The model was calibrated using a supervised learning procedure that passed through two phases: a training phase featuring 75% of images (1 250 250 maps) in which it learned which images were

Figure 1: **Four sample images for Paris, France**
The images show combinations of rail transit networks (A, orange), green space (B, green), water bodies (C, blue), and road infrastructure (D, black).

associated with which city, and a validation phase (25% or 416 750 images), in which it tested model performance. During the validation phase, the model predicted the probability that each validation image was from each of the 1667 cities, including its own actual location. An accuracy of 86% correct classification for the validation set was achieved after iteration over 300 epochs whereupon a 1667×1667 confusion matrix[33] was generated. This confusion matrix was a table that showed the frequency that maps from any individual city were incorrectly predicted (ie, confused) by the model to be from an alternative city. When city map images from the validation set were confused between the actual city location and an alternate city, it indicated that shared features existed between maps from each location. However, while the goal of most convolutional neural network applications used for image recognition is model accuracy, our primary interest was not in those maps that the model correctly predicted, but in the mistakes it made in confusing one city for another. The more the model confused cities for one another, the more likely they were to share similar urban design features.

Although not strictly part of the analysis for this stage, within-city-type similarities were also confirmed by subjective visual analysis by the research team and additional objective methods, which included descriptive statistics associated with pixel colour counts and block-size and regularity measures using flood-fill techniques for individual cities[34] (appendix p 7). Subsequent analyses

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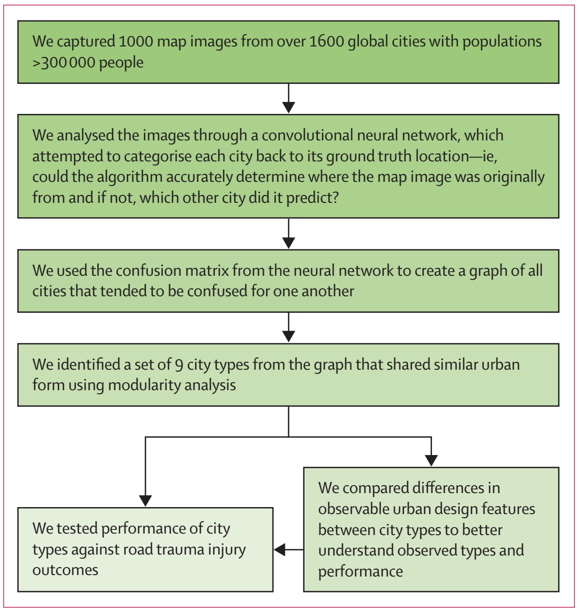

Figure 2: **Methods and analysis**

therefore assume that confused cities shared at least some common urban design characteristics observable through the extracted maps.

Identification of city types

Graph-based analysis using the Force Atlas 2 algorithm[35] was then applied to all cities in the confusion matrix that showed an aggregated weighted degree of more than 1. One outlier city, Efòn-Alààyè, Nigeria, was removed from analysis as it contained predominantly unmapped white space, which resulted in a weighted network degree 14·5 times that of the next highest city—Brussels, Belgium. This process produced a spatially representative network graph comprising 1641 cities in which groups of cities more often confused for one another in the model tended to appear closer together in the network. Conversely, those least similar (ie, cities that were rarely or never confused for one another) were represented as further apart. A modularity analysis[36,37] was then done on the graph (resolution of 1·10)[38] to identify groups comprising individual city types. Conceptually similar to cluster analysis, modularity analysis is a technique that enables potentially non-trivial community structures to be identified in connected graphs based on the extent to which graph nodes share greater connection (through shared vertices) with other nodes in their group than those outside the group. The number of modules contained within the graph was not predetermined.

City types and road transport injuries

To investigate the association between city types and burden of road transport injury, we estimated burden using data from the Global Burden of Disease study into global, regional, and national disability-adjusted life-years (DALYs).[39] Road transport injuries (International Classification of Diseases-10-CM V00-V89) were reported as DALYs lost for drivers and passengers, motorcyclists, pedestrians, and cyclists across each city type.[39] DALYs are a combination of the sum of the years of potential life lost due to premature mortality and years of productive life lost due to a disability per 100 000 population.[40] As the Global Burden of Disease data are not available at the city level, mean DALY rates were calculated for all cities within each city type based on their country level disease-burden estimates. We then produced a population-weighted estimate of total road injury burden that incorporated the influence of multiple cities and country level rate estimates from within each city type. For example, if DALYs from a particular country made up a certain proportion of the total estimated population captured within a certain city type, then total road injury burden for the contribution of cities from within said country were inflated or discounted to reflect this proportional contribution (ie, individual city population multiplied by country DALY rate per total within city-type population).

The proportion of land area dedicated to road and rail networks for cities in each city type (based on pixel colour counts from each individual city map image, 1·7 million images) was calculated and regressed on the burden of road transport injury for each city type. Risk ratios (RR) for road transport injury for each city type were estimated for varying transport modes (motor vehicle drivers and passengers, pedestrians and cyclists, and motorcyclists) and compared between city types. Using the RR and city populations, we then estimated the total DALYs lost to road transport injury for populations contained within each city type and estimated the aggregate excess DALYs lost for each city type relative to the risks associated with the lowest risk city type.

To assess the association between city type and mean road transport injury rates, 2×3 multivariate ANOVA (MANOVA) was undertaken using city type as the independent variable, and (1) driver and passenger injury rates, (2) motorcycle injury rate, and (3) pedestrian and cyclist injury rate as the dependent variables. To control for the effect of economic activity within locations, Fossil Fuel Data Assimilation System (FFDAS)[41] readings were collected at a city level and broken into quintiles (≤0·16, 0·17–0·57, 0·58–1·37, 1·38–3·23, ≥3·24). The FFDAS is a measure of fossil fuel emissions available at a global, city level scale that expresses emissions as a product of population density, per capita economic activity, energy, and carbon intensity of the economy. Although it does not measure units of per capita productivity, it can be used as a means of understanding the magnitude of variation in economic activity between locations. A univariate ANOVA was also undertaken to assess the association between city type and FFDAS on overall road trauma rates (injuries within all transport modes combined). Two cities, Chișinău, Moldova, and Basilan

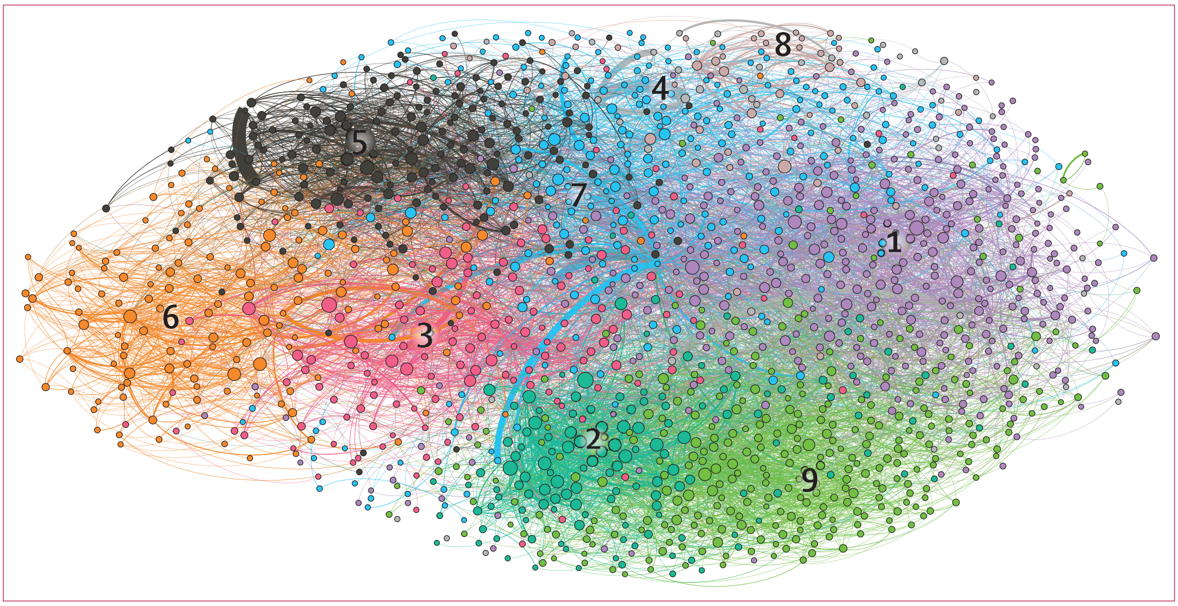

Figure 3: **Network graph of the model's confusion matrix**
Featuring all 1632 cities and identified city types identified by colour with approximate locations from one to nine (1=informal, 2=irregular, 3=large block, 4=cul de sac, 5=high transit, 6=motor city, 7=chequerboard, 8=intense, 9=sparse); a searchable version of the chart containing city names is available in the appendix (p 1).

City (including city of Isabela), Philippines, were dropped from this section of the analysis due to errors in their FFDAS measurements at their location. A high-level summary chart of the methods used in this study are provided in figure 2.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Using map images captured between between Mar 1, 2017, and Dec 24, 2018, the analysis produced a set of 17 city types represented by modules. Eight so-called outlier modules (representing just nine cities in total) were removed from further analysis leaving nine city types from 1632 cities. The nine city type modules are represented in figure 3 by different colours. Given the detail in this chart, we recommend accessing the interactive, searchable version available for download in the appendix (p 1). The list of cities included in this analysis alongside their identified urban design type is also available to download in the appendix (p 11).

Descriptive city-type titles, alongside a 3×3 panel of representative city and map images from the nine city types is presented in the appendix (p 2), while figure 4 shows the global distribution of the city types. Further details on each city type across elements associated with geographical location, characteristics of the urban design including mean block size and intersection intensity, and the estimated total population captured by cities contained within each city type are described in the appendix (p 2).

Figure 5 highlights the association between the mean proportion of land area dedicated to road and rail networks in each city type and the estimated mean DALYs lost to road transport injury. Considerable differences in the mean proportion of land dedicated to road and rail transport networks were observed across city types. For example, the high transit, motor city, and intense city types featured a combination of high percentage of land space allocated to both road and rail networks. Irregular, sparse, and informal city types contained limited land dedicated to roads or rail. Taken independently, the observed proportion of road and rail transport networks within city types measured via pixel counts showed a strong negative correlation to road transport injury. The percentage of land area dedicated to railed transport networks accounted for most of the variance ($r^2=0\cdot81$) highlighting that cities with considerable rail networks have a reduced burden of road transport injury. Although the direction of effect is similar for road transport networks, they accounted for 15% of the variance in road transport injury. Together, the combination of land area devoted to road and rail transport networks accounted for 87% of the variance in road transport injury, suggesting that the burden was lower in cities featuring both a high percentage of land dedicated to more intense road and rail networks (eg, high transit and intense cities). However, caution needs also to be taken in understanding the shape and structure of road networks as discerned by the city types (appendix p 2), not just their proportional representation.

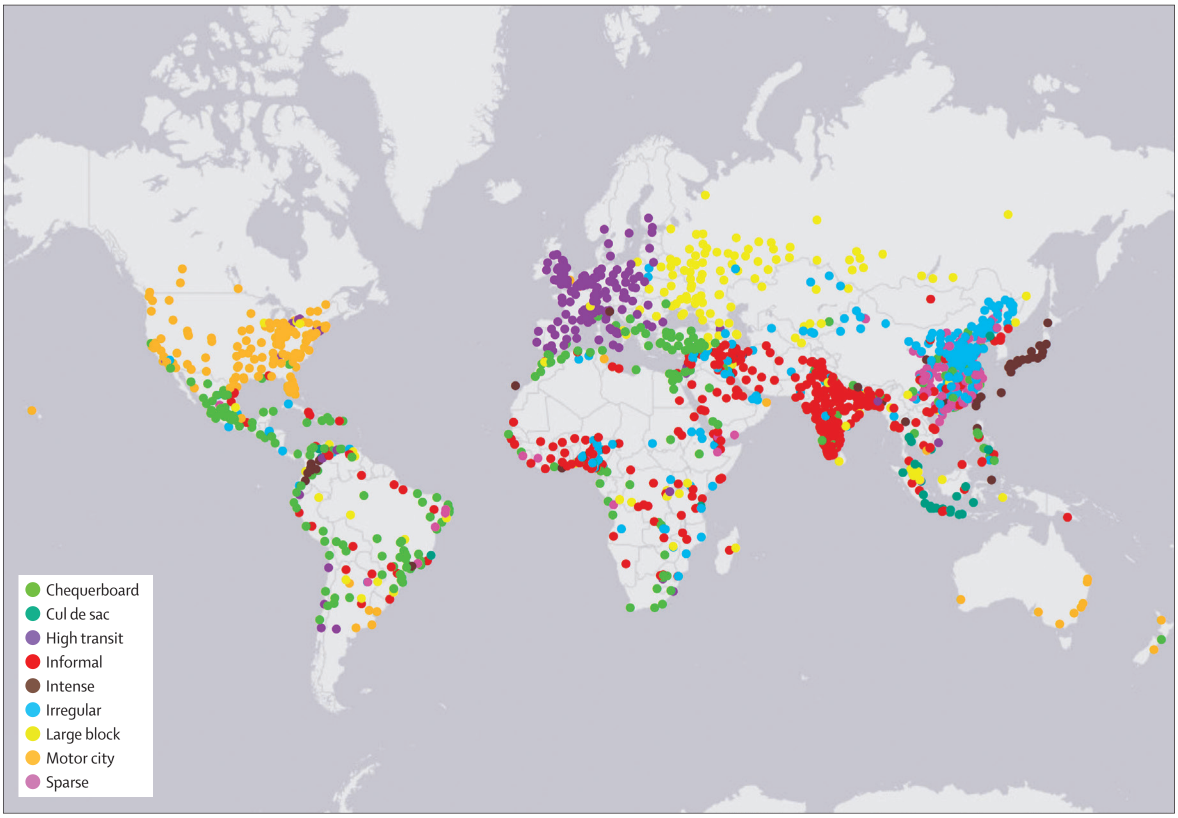

Figure 4: **Global distribution of identified city types**

The appendix (p 7) includes additional analysis showing differences in block size and shape between city types and the association between these characteristics and road transport injury rates.

Figure 6 highlights differences in the mean estimated DALYs lost to road transport injury for drivers and passengers, motorcyclists, and pedestrians and cyclists across each city type per 100 000 population. Overall, high transit, intense, and motor cities performed best, showing a reduced total burden of road transport injury (figure 6D). High transit city types were the only group that showed reduced injury burden for all road user types. By contrast, estimates for cul de sac, informal, and sparse city types with neither a high proportion of road or rail networks nor smaller block sizes performed poorly. Results of the univariate ANOVA with estimated effect sizes (η^2) showed a main effect for differences in total road transport DALYs lost per person for city type ($p<0\cdot001$, $\eta^2=0\cdot16$) and the interaction term of city type and FFDAS ($p<0\cdot001$, $\eta^2=0\cdot05$) but not FFDAS. The nature of the interaction effect showed that increases in FFDAS led to increased road transport injury within some city types but decreases within others (appendix p 9). A similar pattern of results was obtained in the MANOVA. It showed that city type was significantly associated with differences in road transport injury DALY rates across combined ($p<0\cdot001$, $\eta^2=0\cdot17$) and individual mode types (ie, motorcycle injuries ($p<0\cdot001$, $\eta^2=0\cdot07$), pedestrian and cyclist injuries ($p<0\cdot001$, $\eta^2=0\cdot31$), and driver and passenger injuries ($p<0\cdot001$, $\eta^2=0\cdot11$), and the interaction term between city type and FFDAS for total injuries was significant ($p<0\cdot001$, $\eta^2=0\cdot04$). By contrast, FFDAS was not significantly associated with road transport injury on the multivariate tests, nor associated with differences by individual transport mode ($p>0\cdot001$).

Comparison of the network graph and road injury rates among city types (appendix p 10) highlights that city types proximal to one another (in the graph) showed similar patterns of road transport injury. Motor cities were adjacent to large block, high transit, and chequerboard city types indicating similarities in urban design, but they also show concordance in the extent and nature of the burden of injury among road user categories; that is, they showed high rates of driver and passenger injuries. The mean burden of injury for motor vehicle drivers and passengers in these car-oriented city types was 406 DALYs lost per 100 000 population, or 1·53-times greater than in remaining types.

The rates of motorcycle injury showed similar links between urban design and elevated road transport injury within modes. Intense, cul de sac, sparse, chequerboard, large block, and informal city types featuring either tight street networks suited to navigation by motorcycles, and also featured in countries with comparatively high motorcycle use,[42] were located together on the network graph's right-hand side. Taken together, these city types accounted for a mean 176 DALYs lost per 100 000 population for motorcycle injury; 1·54-times greater than remaining city types. Sparse, irregular, large block, and cul de sac city types appearing in the lower right area of the graph had a combined mean of 473 DALYs lost to pedestrian and cyclist injuries per 100 000 population; 1·83-times greater than remaining city types. The RRs between various city types by road users relative to the high transit city type (city type with the overall lowest burden of road transport injury) are shown in table 1.

Table 2 uses the road transport injury RRs associated with the city types to estimate the total burden of road transport injury associated with specific city types, along with the estimated share of the total road transport injury burden attributable to city types that do not match the lowest risk, high transit, design. Based on 2015 world population estimates, the greatest total burden of road transport injury is associated with the informal, chequerboard, and sparse city types, followed by irregular and large block cities. The estimated global burden of road transport injury attributable to urban form that does not match the lowest risk example from high transit city types is estimated at more than 8·7 million DALYs per year.

Discussion

This analysis has identified nine global city types through visual classification techniques that capture the diversity of urban design related to land transport. It has shown the benefit of accessing and harnessing combined, global, standardised datasets for urban analysis alongside global health burden data. We have identified differences between city types that appear strongly associated with the magnitude and nature of road transport injury between transport modes. The study identifies city types in which the transport networks differ across multiple dimensions; from cities with intense, extensive, highly organised road and rail networks (eg, high transit, intense, and motor city types), to cities with limited, irregularly shaped road infrastructure and almost no railed public transport networks (eg, the sparse and informal city type). Further, the study has shown an ability to differentiate between city designs that cross globally accepted cultural and geopolitical boundaries and follow previously documented patterns of ethnographic dispersion and colonial settlement through continental Europe to the Americas.[43,44]

The findings highlight that urban design is strongly associated with road transport injury burden. Controlling for the influence of economic activity, a two-times difference was observed in the total estimated burden of road transport injury between the best performing city type (high transit) and the poorest performing types (cul de sac, informal, and sparse followed by chequerboard, irregular, and large block types). Together, these poorly performing city types contained close to 1·7 billion people located in areas across western China, India and Asia, South America, the former Soviet Union, and Africa. Many of the cities that fall within the specific city types are in low-income regions and are transitioning through a period of rapid development. Importantly, they are often located within countries targeted by multilateral development bank infrastructure programmes promoting road safety initiatives that do not emphasise reducing motor vehicle use through changes to urban design or land use planning.[18] Furthermore, seldom do these projects advocate investment in safer public or active transport alternatives beyond the car.[45] The limitations of tackling transport injury through a restricted lens of road safety, which places the car at the centre of transport policy while discounting investment in safer alternative transport options, are emphasised by the results presented here. Efforts to promote urban design, which

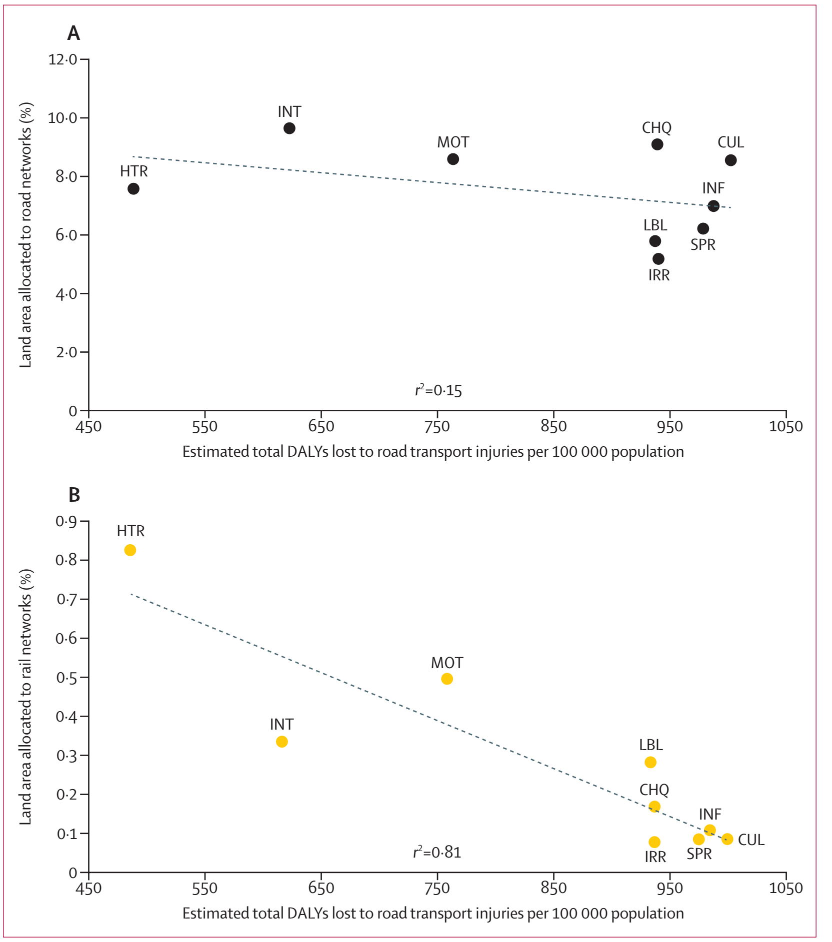

***Figure 5:* Association between city types dedicated to road (A) and rail (B) networks and DALYs lost to road transport injury per 100 000 population**
HTR=high transit. MOT=motor cities. INT=intense. CUL=cul de sac. CHQ=Chequerboard. INF=informal. IRR=irregular. LBL=large block. SPR=sparse. DALYs=disability-adjusted life-years.

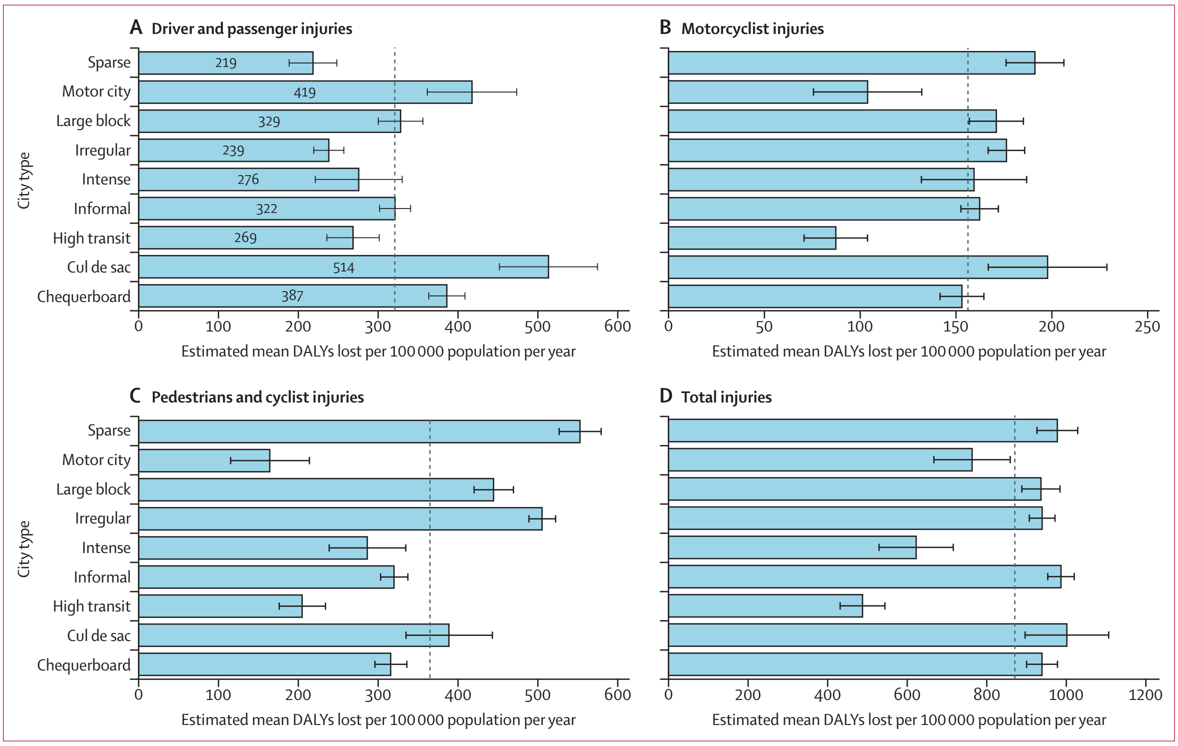

Figure 6: **DALYs per 100 000 population lost due to road transport injuries**
95% CIs are indicated. The grand mean for road user type is indicated by the vertical line. DALYs=disability-adjusted life-years.

	Driver and passenger injuries	Motorcyclist injuries	Cyclist and pedestrian injuries	Total road transport injuries
High transit*	1·00	1·00	1·00	1·00
Intense	1·03 (0·82–1·23)	1·83 (1·51—2·14)	1·40 (1·16–1·63)	1·28 (1·09–1·47)
Motor city	1·55 (1·35–1·76)	1·19 (0·87–1·51)	0·80 (0·56–1·04)	1·56 (1·37–1·76)
Large block	1·22 (1·12–1·33)	1·96 (1·80–2·12)	2·17 (2·05–2·29)	1·92 (1·82–2·02)
Irregular	0·89 (0·82–0·96)	2·02 (1·91–2·13)	2·47 (2·39–2·55)	1·93 (1·86–1·99)
Chequerboard	1·44 (1·35–1·52)	1·75 (1·62–1·88)	1·54 (1·44–1·64)	1·93 (1·85–2·01)
Sparse	0·81 (0·70–0·92)	2·19 (2·02–2·36)	2·70 (2·57–2·83)	2·00 (1·90–2·11)
Informal	1·20 (1·12–1·27)	1·86 (1·75–1·97)	1·56 (1·48–1·65)	2·02 (1·96–2·09)
Cul de sac	1·91 (1·68–2·14)	2·27 (1·91–2·62)	1·90 (1·63–2·16)	2·05 (1·84–2·27)

Data are risk ratio (95% CI). *Risk ratios relative to high transit city type.

Table 1: **Road user transport injuries and total road transport injury by city type**

features characteristics inherent in high transit and intense city types (eg, higher density road infrastructure and high rates of public transit) should also be advocated by global institutions responsible for promoting transport safety as they might better support the development and maintenance of high performing[46] transport and health systems.

Pedestrian and cyclist transport-related injury were demonstrably higher for sparse, irregular, cul de sac, and large block city types, with the risk of such injuries being two to three-times greater than in high transit cities. Patterns over the past century have shown that when cities are in earlier stages of development and motorisation, vulnerable road users who are less protected than those in motor vehicles, such as pedestrians and cyclists, are over-represented in injurious crashes.[47] The frequencies of these injuries typically increase as motorisation takes greater hold before declining again once active transport is usurped for motor vehicle use.[48] This pattern is well illustrated in China where road infrastructure once allocated for cycling has been increasingly engineered to provide greater access for motor vehicles.[49] Given the considerable health and environmental co-benefits associated with active transport,[5,50] urgent attention from low-income and rapidly motorising cities is needed to ensure these transport modes receive greater emphasis in transport, planning, and health policies.

Although the total DALYs lost to road transport injury in motor cities (a city type that reflects extensive lower density, high capacity road networks) was comparatively low, it is notable that DALYs lost among motor vehicle drivers and passengers were among the highest. Driver and passenger risk in motor cities was more than 55% greater than that of high transit cities, reflecting the car-dominated nature of regions typical of this city type (eg, North America, Australasia). Due to an orientation toward motor vehicles, rates of active transport in regions dominated by motor cities are also low,[51] which is reflected in the reduced observed burden of road transport injury among pedestrians and cyclists.

Although this study points to the association between urban design and the burden of road transport injury, it also highlights that some cities are relative outliers in relation to their reduced burden of road transport injury given their dominant city type. For example, all Australian cities fall within the motor city type and yet Australia has observed considerable success in reducing road transport injury over the past 40 years. However, much of the success is attributed to substantial investment in public education, behaviour-change, and enforcement activities[52] whose impact now appears to be waning as reductions in aggregate and per capita injuries plateau, or are even beginning to increase again.[17,53,54] The findings from this study suggest that more upstream investment in urban design that supports transport mode shift away from motor vehicles and into lower risk modes such as rail[1,4,55] or safe active transport (ie, where separated or protected infrastructure is provided)[56] can be harnessed to deliver reductions in transport injury.

We acknowledge some limitations of the results. First, although (and because) the dataset is very large and the computational effort involved is lengthy, we did not re-sample cities multiple times nor redraw the city image training and validation sets. Future work that replicates the method of sampling city images from random locations and at future dates in which urban designs alter might therefore produce small variations in input data and therefore classification results. These variations are likely to be felt most keenly at the margins of city type classifications where it is possible that individual cities only weakly connected to modules could be reclassified on the basis of small changes to the confusion matrix and hence graph network community structures. Although we do not expect this effect to be substantial to the extent that it alters interpretation of results, the robustness of the presented methods and city-type classifications will be realised over time. It is further acknowledged that contribution of individual cities to city-type road trauma rates and total DALYs lost is drawn from the country level, rather than city level rates. Though unavoidable due to the current unavailability of detailed disease data across global cities, this limitation removes within-country variation in per capita road injury risk between cities. In general, however, within-country variation of city types was low, with just 35 of 176 countries showing more than two city types and more than 50% containing just one.

Secondly, although we observe clear differences in injury rates by road users across city types, our analysis does not consider potential differential crash rates between urban and rural areas, which might pose dissimilar injury risk. High speed, low quality, and low-density roads place drivers, passengers, and vulnerable road users at higher risk due to increased kinetic energy at the point of collision. By contrast, dense, low speed networks containing more intersections could produce more crashes; however the kinetic energy transferred at the point of collision is lower, reducing the risk of injury or death should a crash occur.[57]

	Total DALYs lost to road transport injury per annum	Additional DALYs lost to road transport injury per annum, attributable to city design
High transit	883 574 (781 633–985 517)	NA
Intense	751 234 (638 663–863 805)	162 764 (59 040–239 453)
Motor city	1 834 981 (1 604 217–2 065 746)	662 301 (493 614–793 302)
Large block	1 282 407 (1 216 742–1 348 073)	614 394 (578 343–646 934)
Sparse	3 104 840 (2 942 070–3 267 613)	1 555 805 (1 470 104–1 632 968)
Irregular	2 067 793 (1 996 562–2 139 023)	994 175 (955 871–1 029 926)
Cul de sac	509 525 (455 991–563 060)	261 384 (232 251–284 976)
Chequerboard	3 669 189 (3 517 302–3 821 079)	1 765 232 (1 683 015–1 840 916)
Informal	5 333 575 (5 153 988–5 513 162)	2 698 039 (2 606 206–2 783 890)
Total	19 437 118 (18 307 169–20 567 078)	8 714 094 (8 078 444–9 252 365)

Data are n (95% CI). DALYs=disability-adjusted life-years. NA=not applicable.

Table 2: **Estimated burden of DALYs lost to road transport injury attributed to city types**

We also acknowledge that these results might be influenced by unobserved or related factors such as historic patterns of social or urban development,[17] road safety management approaches,[58] or other conditions not captured by our observations but present within cities and countries represented within each of the nine city types. Although we have included a detailed control for economic activity (FFDAS), we suggest it is important to recognise two aspects. Firstly, that economic activity shapes city design and is hence captured by maps to some extent, and secondly that although advanced city economies might provide opportunity for more public transport, safe road infrastructure, and enforcement activities, strong economies do not implement so-called safe systems policies by themselves—they remain policy and governance choices. For example, elevated total road injury burden in high-income countries (eg, Saudi Arabia, United Arab Emirates, USA), and high motorcycle injury rates in countries dominated by intense city types (eg, Japan), show that comparatively high gross domestic product (GDP) is not a sufficient condition for preventing road transport injuries nor a solution to their occurrence. This finding appears lost in contemporary solutions to road transport injury such as safe systems,[59] which can ignore the issue that economic and technological development has been the primary driver of motorised transport systems and consequent road injury in the first place. Developing economies are not necessarily experiencing high rates of road transport injury because they have comparably low GDP; they are experiencing it because GDP is increasing alongside uptake of motor vehicles.[60]

The future design of cities in which the world's seven billion city dwellers will live, work, and play will be crucial to increasing global productivity and reducing the incidence, prevalence, and costs associated with non-communicable diseases and injury. This study shows a new, replicable, scalable, and highly efficient method for understanding the characteristics of urban design with respect to health outcomes—in this example, the burden associated with road transport injury. The study highlights the opportunity for reducing the global burden of road transport injury by embracing urban designs that emphasise characteristics captured within high transit city types.

Contributors

JT conceived the manuscript and methodological design, and contributed to data collection and statistical analysis, and the manuscript text. JSW, KAN, MS, and GDPAA contributed to methodological design, data analysis, and the manuscript text. CNM, PR, JS, RS, MN, and RH contributed to methodological design and the manuscript text.

Declaration of interests

We declare no competing interests.

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