Cost-effectiveness of neighbourhood slow zones in New York City

Boshen Jiao,[1] Sooyoung Kim,[2] Jonas Hagen,[3] Peter Alexander Muennig[1]

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/injuryprev-2017-042499).

[1]Global Research Analytics for Population Health, Columbia University Mailman School of Public Health, New York, NY, USA
[2]Ecole des Hautes Etudes en Santé Publique, Rennes, France
[3]Columbia University Graduate School of Architecture, Planning and Preservation, New York, NY, USA

Correspondence to
Boshen Jiao, Global Research Analytics for Population Health, Columbia University Mailman School of Public Health , New York, NY, USA; bj2361@cumc.columbia.edu

Received 23 June 2017
Revised 7 August 2017
Accepted 13 September 2017
Published Online First 27 September 2017

To cite: Jiao B, Kim S, Hagen J, *et al*. *Inj Prev* 2019;**25**:98–103.

ABSTRACT

Background Neighbourhood slow zones (NSZs) are areas that attempt to slow traffic via speed limits coupled with other measures (eg, speed humps). They appear to reduce traffic crashes and encourage active transportation. We evaluate the cost-effectiveness of NSZs in New York City (NYC), which implemented them in 2011.

Methods We examined the effectiveness of NSZs in NYC using data from the city's Department of Transportation in an interrupted time series analysis. We then conducted a cost-effectiveness analysis using a Markov model. One-way sensitivity analyses and Monte Carlo analyses were conducted to test error in the model.

Results After 2011, road casualties in NYC fell by 8.74% (95% CI 1.02% to 16.47%) in the NSZs but increased by 0.31% (95% CI −3.64% to 4.27%) in the control neighbourhoods. Because injury costs outweigh intervention costs, NSZs resulted in a net savings of US$15 (95% credible interval: US$2 to US$43) and a gain of 0.002 of a quality-adjusted life year (QALY, 95% credible interval: 0.001 to 0.006) over the lifetime of the average NSZ resident relative to no intervention. Based on the results of Monte Carlo analyses, there was a 97.7% chance that the NSZs fall under US$50 000 per QALY gained.

Conclusion While additional causal models are needed, NSZs appeared to be an effective and cost-effective means of reducing road casualties. Our models also suggest that NSZs may save more money than they cost.

INTRODUCTION

As more people around the world drive, the rates of fatalities from automobile crashes are climbing sharply.[1 2] Automobiles may also contribute to the global obesity epidemic, pulmonary disease, heart disease and other health problems related to passive transport and air pollution.[3] As a result, urban planners and public health policy-makers from Sweden to Indonesia are teaming up in an attempt to find new ways to mitigate the public health threats associated with driving and ensure that pedestrians and bicycles can safely venture out on our roads.[4]

However, the speed limits, traffic cameras and road modifications that are needed to improve the safety of our roads produce regulatory and time costs for society while irking drivers. At the same time, residents do not want fast traffic in their neighbourhoods because it is a safety hazard for their children and a noise nuisance in their homes.[5] Neighbourhood slow zones (NSZs) with a speed limit of 20 mph (32 km/h) therefore provide allies for policy-makers (drivers who are also home owners) in their efforts to calm traffic.[6]

Earlier work suggests that a 1 mph reduction in speed will reduce traffic injuries by 5%.[7] Evidences from quasi-experimental studies have shown that 20 mph zones can significantly slow down the traffic speed, so as to prevent both fatal and non-fatal traffic injuries.[7–9] However, the impact of speed changes on societal costs is complex because a reduction in speed can produce shifts from fatalities to an increased incidence of debilitating injury.[10] Moreover, investments are required to implement NSZs, including signs, pavement markings, speed bumps and increased enforcement.[11] While NYC claims that NSZs have reduced crashes with injuries within these areas by over 14%, questions remain regarding the causal impacts of NSZs on mean traffic speeds, injury rates and exercise activity.[11] Given that they are both politically palatable and life-saving, 20 mph zones serve as a potentially powerful public health tool, but it is not known whether they are cost-effective.

In 2011, New York City (NYC) started establishing NSZs, in which traffic speed limit was reduced from 25 to 20 mph.[11] We ask whether it is plausible that NSZs are cost-effective, even when excluding potentially important benefits, such as their impacts on obesity and diabetes—two widely recognised health risk factors associated with neighbourhood walkability.[3 12–14]

METHODS

Overview and definitions

We built a Markov model using TreeAge Pro 2016 to evaluate the cost-effectiveness of NSZs for road casualties when compared with no NSZ (no intervention). We used NYC as a hypothetical case study and then provided sensitivity analyses on model inputs so that users can extrapolate our findings onto other contexts. Our model estimated the costs and health outcomes for a hypothetical cohort of 36-year-old New Yorkers (the median age in NYC).[15] They were followed until age 90 years or death, whichever came first. From a societal perspective, we included all costs, including construction, maintenance and reconstruction costs of NSZs, the medical costs of fatal and non-fatal traffic injuries and productivity losses due to traffic injuries. The quality-adjusted life year (QALY) was used as a health outcome measure. One QALY is roughly equal to 1 year of life spent in perfect health. To calculate the incremental cost-effectiveness ratio (ICER), we divided the changes costs associated with NSZs (including the cost of implementation, as well as savings from lower medical and productivity costs) by the additional gains in QALYs. A 3% discount rate was used following recommendations of the Panel on Cost-effectiveness in Health and Medicine.[16]

Intervention effect

To quantify the impact of NSZs on traffic injury reduction, we conducted a controlled interrupted time series analysis. The outcome measure of the analysis was the annual number of road casualties, including both fatal and non-fatal traffic injuries. We used 2009–2016 crash data published by the New York City Department of Transportation (NYCDOT).[17] The NYCDOT crash data record the date and geographic locations of fatal and non-fatal traffic injuries in NYC.

To generate the annual counts of road casualties outside of and within NSZs, we combined the shapefiles of crash data and NSZs (available on the NYCDOT website), using geographic information system software, QGIS V.2.14.10.[17]

The study time period was classified as either preintervention period (the years before NSZ implementation) or postintervention period (the years after NSZ implementation). The traffic injuries that occurred during the year of implementation were not included in the analysis for two reasons: (1) the specific start and completion dates for NSZ construction were not public available and (2) it could take time for drivers to adapt to the newly established NSZs.

To account for the potential time trend of traffic injuries in NYC, we selected one corresponding control neighbourhood for each of the NSZs. The selection criteria for matching were the following: (1) it is in the same borough with the NSZ and (2) it had a similar preimplementation time trend of traffic injuries as the NSZ. We then generated the annual count of road casualties in control neighbourhoods using the shapefiles published by New York City Department of City Planning.[18]

We performed conditional fixed effects Poisson regressions for the NSZs and the control neighbourhoods using Stata V.13. In doing so, it is possible to adjust for autocorrelation within time series.[19] We used Grundy *et al*'s approach.[8] The calendar year and NSZ were set as time and panel identification variables, respectively. We ran the regressions using Stata's command xtpoisson with the number of road casualties as the dependent variable and a dichotomous variable identifying the preintervention (coded 0) or the postintervention period (coded 1) as the independent variables. The coefficients of the independent variables represent the effect of NSZs or control neighbourhoods on road casualties.

If drivers attempt to avoid NSZs, they might increase the risk of crashes in the areas adjacent to the NSZs.[8] We conducted an additional controlled time series analysis to test this hypothesis. We randomly selected eight adjacent neighbourhoods. Then, as above, we selected a neighbourhood as control zone for each of these eight neighbourhoods and performed conditional fixed effects Poisson regressions.

Probabilities

The probabilities used as model inputs are listed in table 1. Our hypothetical cohort was exposed to the probability of traffic injury (fatal, serious and minor) and death by other causes. The age-specific mortality rate for other causes was derived from a US life table.[20] We used the traffic injury rate, the proportion of serious traffic injuries and the case fatality ratio in 2011 for NYC as the 'status quo' (no NSZs), since NSZs included in our

Table 1 Values used in the Markov model evaluating NSZs relative to the no intervention

Parameter	Base	SE/range	Distribution	Source
Cost (2016 US$)				
Cost of injury (per case)				
Lifetime medical cost due to non-fatal traffic injury	3608	902	Gamma	CDC[26]
Lifetime medical cost due to fatal traffic injury	16 265	4066	Gamma	CDC[26]
Lifetime productivity cost due to non-fatal traffic injury	6682	1671	Gamma	CDC[26])
Lifetime productivity cost due to fatal traffic injury	1 277 926	319 482	Gamma	CDC[26]
Intervention cost (per person)				
Proposed speed bumps	1.30	0.32	Gamma	Bushell *et al*[24]
Existing speed bumps	0.35	0.09	Gamma	Bushell *et al*[24]
Gateways	0.60	0.15	Gamma	Bushell *et al*[24]
20 mph markings	0.28	0.07	Gamma	Bushell *et al*[24]
Health utility decrement				
Serious traffic injury	0.45	Low: 0.36; high: 0.53	Triangular	EQ5D survey
Probability				
% Case fatality ratio of traffic injury	0.38	0.02	Beta	NYS Department of Motor Vehicles[21]
% Serious injury among non-fatal injuries	7.54	0.13	Beta	NYS Department of Motor Vehicles[21]
% Background traffic injury probability	0.15	0.01	Beta	NYC Department of Transportation[17], NYS Department of Motor Vehicles[21]
% Traffic injury reduction in the NSZs	8.74	Low: 1.02; high: 16.47	Triangular	
% Potential injury increase in control neighbourhoods	0.31	Low: −3.64; high: 4.27	Triangular	
Other				
Baseline age	36			NYC Department of City Planning[15]
Time horizon	54			
% Discount rate	3%	Low: 0%; high: 5%	Triangular	Paulden *et al*[16]
Frequency of NSZs reconstruction (every n years)	5	Low: 3; high: 7	Triangular	
Population in NSZs	518 420			NYC Department of City Planning[18]

EQ5D, EuroQol Five Dimensions Questionnaire; NSZ, neighbourhood slow zone; NYC, New York City; NYS, New York State SE, standard error

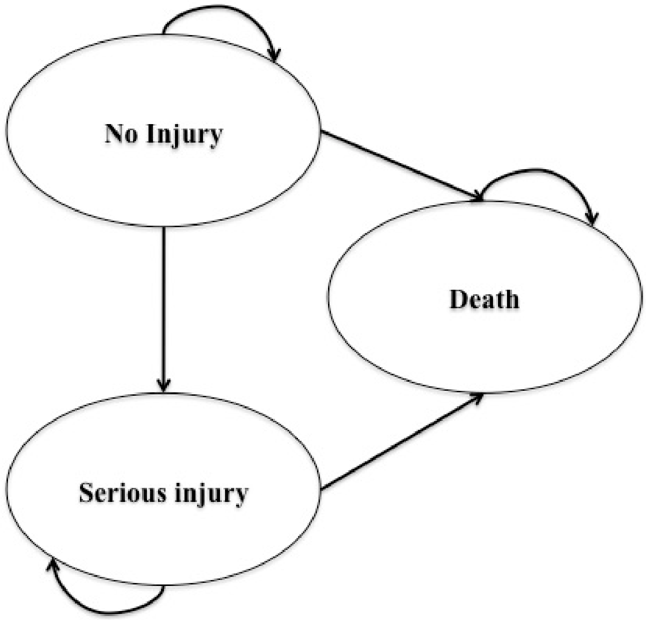

Figure 1 Markov model diagram.

study were implemented and completed between 2012 and 2015.[11 21] The NYCDOT reports the locations of road casualties in NYC, of which 1.11% occurred in NSZs (data are available in online supplementary file 1).[17] We assumed that any missing crash data were randomly distributed across roads within the city. To estimate the background traffic injury rate in NSZs, we multiplied the total number of traffic injuries in NYC by 1.11% and then divided it by the population of NSZs.[22]

Costs

The monetary costs were adjusted to constant 2016 US$ using the Consumer Price Index of New York City (see table 1).[23] NYCDOT reported the number of gateways, 20 mph markings and speed bumps, which are the main components of the NSZs in NYC.[11] The Claremont and the Westchester Square NSZs were excluded because data on modifications were not available. We obtained the unit costs of gateway signs and speed bumps from a study that provided estimates.[24] These estimates included engineering, design, mobilisation and installation costs. We approximated the cost of 20 mph marking using a published estimate of the cost of a school crossing marking.[24] We assumed that all the components of NSZs in NYC would be reconstructed every 5 years, the ideal rate of street resurfacing.[25] The cost of resurfacing existing speed bumps was included for the reconstruction, but not for the first-time implementation.

We used the medical costs and productivity losses due to fatal and non-fatal traffic injuries reported by CDC.[26] For medical costs, we only included the costs of hospitalisations or treatments in emergency departments for non-fatal injuries, as the outpatient costs were not available and were likely to be very small relative to other costs.

Quality of life

We assigned no loss of health-related quality of life (HRQL) to minor injuries, since the period of suffering is typically quite short. For those with serious injury, we estimated HRQL by asking two experienced paediatric orthopaedists at Columbia University to fill out the EuroQol Five Dimensions Questionnaire (EQ-5D). Each paediatric orthopaedist has experience following people with serious injuries over the course of their life. These senior physicians were asked to provide subjective assessments of the impact of the 'average' child hospitalised for vehicular injury with respect to that individual's lifelong mobility, self-care, usual activities, pain/discomfort and anxiety/depression. The two five-level EQ-5D (EQ5D-5L) instruments yielded scores of 0.64 and 0.47 (an average value of 0.55) for those permanently injured in a crash.

Decision analysis models

The Markov model incorporated three major health states: no injury, serious injury and death. The model diagram is presented in figure 1. The hypothetical cohort started from the health state of no injury. They were exposed to the risk of fatal and non-fatal traffic injury and age-specific risk of death due to causes other than injury. If the simulated participants died, they exited the model. Non-fatal injury could be either minor or serious. If the simulated participants were seriously injured, they would stay in the health state of serious injury and constantly lose health utility for the rest of their life cycles. We also assumed that the simulated participants who suffered minor injuries would recover after a year. Our model had two arms: NSZs and no intervention. The life cycle in our model was 1 year, and we employed half-cycle corrections. We also conducted a series of one-way sensitivity analyses, along with a Monte Carlo simulation to test the reliability of the model.

RESULTS

Intervention effect

We included all the 26 NSZs implemented from 2012 to 2015. The total numbers of road casualties were 3460 in

Table 2 Number of road casualties in NSZs and their control neighbourhoods by year

NSZ/control neighbourhood	2009	2010	2011	2012	2013	2014	2015	2016
NSZs implemented in 2012 (4 NSZs)	67	67	72	–	68	58	60	56
Control neighbourhoods for 2012 NSZs	178	170	177	–	191	170	177	162
NSZs implemented in 2013 (9 NSZs)	121	129	122	120	–	115	111	120
Control neighbourhoods for 2013 NSZs	583	594	603	567	–	565	559	572
NSZs implemented in 2014 (5 NSZs)	134	136	147	140	154	–	137	130
Control neighbourhoods for 2014 NSZs	401	403	418	426	415	–	417	404
NSZs implemented in 2015 (8 NSZs)	161	178	172	178	173	179	–	155
Control neighbourhoods for 2015 NSZs	640	658	646	656	643	676	–	712

The road casualties in implementation years of NSZs were not included in the analysis.
NSZ, neighbourhood slow zone.

NSZs and 12 783 in control neighbourhoods. The road casualty data for NSZs and control neighbourhoods are available in online supplementary file 1 and summarised in table 2. Our interrupted time series models show that 2011 road casualties in NYC fell by 8.74% (95% CI 1.02% to 16.47%) in the NSZs but increased by 0.31% (95% CI: −3.64% to 4.27%) in the control neighbourhoods.

To assess the impact of drivers avoiding NSZs, we used road casualty data for neighbourhoods adjacent to NSZs and their control zones. There were 3864 casualties in adjacent neighbourhoods and 4488 in control zones. The data for this analysis are available in online supplementary file 2. In the adjacent neighbourhoods, there was a 5.77% (95% CI −1.49% to 13.04%) traffic injury reduction, which was not significantly different from a reduction of 5.06% (95% CI −1.44% to 11.55%) in their control zones.

Model results

The predicted costs and QALYs gained are summarised in table 3 (values rounded). NSZ implementation resulted in US$15 savings per resident compared with the status quo arm. For each NSZ resident, 23.924 QALY was gained over their lifetime as a result of NSZ implementation, which was 0.002 QALY higher than the predicted gain from the no intervention arm.

Sensitivity analyses

We ran sensitivity analyses for all parameters used in the model, and the results for the most influential variables are shown in table 4. NSZs remained cost-saving across the range of all variables. When the productivity losses due to fatal injury was assumed to be 30% lower than the base value, the incremental cost savings decreased to US$10 per resident. When we assumed that the case fatality ratio, background traffic injury probability and traffic injury reduction in NSZs were overestimated, adjustment to this resulted in smaller amount of cost savings: US$10, US$9 and US$9 per resident, respectively.

Based on the results of the 10 000 simulations of probabilistic sensitivity analysis, we found that a 95% credible interval of the incremental cost was from −US$43 to −US$2, and that of incremental effectiveness was from 0.001 to 0.006. There was a 97.7% chance of the NSZs being cost-effective if US$50 000 per QALY gained was chosen as the threshold of willingness-to-pay.

DISCUSSION

We find that NSZs are an effective and cost-effective means of reducing road casualties. Our effectiveness results are in line with previous quasi-experimental studies conducted in London.[7–9] However, our effect size was much smaller than that claimed by the NYCDOT. This is likely because the data for that study came from 2012, when only four NSZs had been implemented and only 1-year postintervention data were available for analysis.[11]

Table 3 The cost, incremental cost (2016 US$), QALYs gained, incremental QALYs gained and ICER of NSZs versus no intervention

	Cost	Incremental cost	QALY	Incremental QALY	ICER
NSZs	196	–14	23.924	0.002	Cost saving
No intervention	210		23.922		

ICER, incremental cost-effectiveness ratio; NSZ, neighbourhood slow zone; QALY, quality-adjusted life year.

In the USA, the cost of medical care and productivity losses linked to traffic injuries exceeded US$80 billion every year.[26] Our models suggest that NSZs appear to be a cost-effective—possibly even cost saving—way to improve population health. Two previous economic evaluations conducted in London also showed that 20 mph zones can yield net benefits.[27 28] Additionally, they suggest that the net benefits are larger in high-casualty areas relative to low-casualty areas. Our one-way sensitivity analysis implies the same; we find that an increase in the probability of traffic injury within a given NSZ would save more money.

Very few public health interventions and only a handful of medical interventions actually save both money and lives.[29] Moreover, when multiple sources of parameter uncertainty are included, there is only a 2.3% chance of observing an ICER as high as US$50 000/QALY gained. Even at this cost, NSZs fall well within the range of investments that American's find acceptable.[30] While the cost savings and gains in healthy life are small (about equal to one life saved every 2–3 years in NYC), the loss of healthy lives to preventable causes is a priority under NYC's Vision Zero initiative.[31]

While traffic-calming measures are broadly accepted in many European countries and Japan as necessary inconveniences to combat global warming, obesity, diabetes and injury prevention, they are quite difficult to implement in many other places.[32] Even NSZs that are limited to residential neighbourhoods can be challenging to implement due to driver complaints. Our study highlights the need for larger public education campaigns about the health and economic threats posed by automobiles in a world that is both rapidly urbanising and has one billion (and counting) vehicles on the road.[33]

Our study suffers from a number of limitations. Foremost, given the lack of causal estimates specific to NSZs, we rely on estimates from a single interrupted time series analysis in NYC. However, there is a large literature, including causal studies, supporting various components of NSZs as impacting mean traffic speeds and crash rates. For example, speed humps and posted speed limits have been shown to reduce traffic speeds,[32 34–38] and these are core components of the NSZs we study. Likewise, traffic speed is associated with crash risk and is causally linked to one's risk of injury or death.[10 32] Another consideration is that we did not model the complex systems dynamics of implementing

Table 4 One-way sensitivity analyses, NSZs versus no intervention

	Incremental cost (2016 US$)		Incremental QALY	
Parameters	Low	High	Low	High
Productivity loss due to fatal injuries (low: –30%; high: +30%)	–10	–19	0.002	0.002
% Case fatality ratio of traffic injury (low: –30%; high: +30%)	–10	–19	0.002	0.002
Utility loss due to serious traffic injury (low: –30%; high: +30%)	–15	–15	0.002	0.003
% Traffic injury in NSZs (low: –30%; high: +30%)	–9	–20	0.002	0.003
% Traffic injury reduction in the NSZs (low: –30%; high: +30%)	–9	–20	0.002	0.003

NSZ, neighbourhood slow zone; QALY, quality-adjusted life year.

NSZs. It is plausible that NSZs can produce virtuous or harmful cycles in which drivers either slowly adapt to slower speeds or lash out against them, thereby jeopardising other traffic calming measures. Our model was also limited by a lack of secondary outcomes data. Because it is difficult to estimate the psychological well-being, exercise impacts and pollution impacts associated with slower traffic, we included only the costs and benefits of injury reduction. On the other hand, while traffic calming has been shown to increase cycling and walking,[39 40] it can also potentially increase driving time and therefore time sitting along with automobile pollution. Since we find that NSZs save money and lives, adding these additional savings would strengthen our already robust findings.

Our analysis suggests that NSZs save money and lives in NYC. This is encouraging news, especially considering the effects that slow-speed zones can have in terms of improving traffic safety. There may be additional benefits to these zones, such as increasing the comfort of residents and the safety of pedestrians and bicyclists. These possible cobenefits of slow zones should be explored in future research, and such variables could be included in future analyses. Road safety changes such as NSZs could have a huge positive impact on population health globally, as well as the environment and human settlements. Our analysis indicates that the health improvements of such interventions could come at a very reasonable cost, perhaps ranking among vaccines in terms of their cost-effectiveness.

What is already known on this subject

- Neighbourhood slow zones (NSZs) with a speed limit of 20 mph have been implemented in New York City (NYC) to prevent traffic crashes.
- NYC claims that NSZs have reduced crashes with injuries within these areas by 14%.

What this study adds

- We demonstrate that NSZs save money and lives.
- Road causalities did not increase in the areas adjacent to NSZs.

Acknowledgements The authors thank Dr Zafar Zafari and Dr Zohn Rosen for their input and contributions to the study.

Contributors BJ: substantial contributions to the conception or design of the work, analysis or interpretation of data for the work and drafting the work and revising it critically for important intellectual content; SK: substantial contributions to interpretation of data for the work and drafting the work; JH: substantial contributions to the conception or design of the work and revising it critically for important intellectual content; PAM: substantial contributions to the conception or design of the work and drafting the work and revising it critically for important intellectual content. All authors: final approval of the version to be published.

Funding This study was funded by Global Research Analytics for Population Health at the Mailman School of Health, Columbia University. All the authors have approved the final manuscript for submission.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 Nantulya VM, Reich MR. The neglected epidemic: road traffic injuries in developing countries. *BMJ* 2002;324:1139–41.
2 Murray CJ, Lopez AD. Mortality by cause for eight regions of the world: global burden of disease study. *Lancet* 1997;349:1269–76.
3 Rundle A, Neckerman KM, Freeman L, *et al*. Neighborhood food environment and walkability predict obesity in New York City. *Environ Health Perspect* 2009;117:442–7.
4 Noland RB. Traffic fatalities and injuries: the effect of changes in infrastructure and other trends. *Accid Anal Prev* 2003;35:599–611.
5 Loukaitou-Sideris A. Is it safe to walk? 1 neighborhood safety and security considerations and their effects on walking. *J Plan Lit* 2006;20:219–32.
6 World Health Organization. Global status report on road safety 2013: supporting a decade of action. 2013 http://www.who.int/violence_injury_prevention/road_safety_status/2013/en/ (accessed 01 March 2017).
7 Webster DC, Layfield RE. *Review of 20 mph zones in London boroughs*. Wokingham, UK: TRL Limited, 2003.
8 Grundy C, Steinbach R, Edwards P, *et al*. Effect of 20 mph traffic speed zones on road injuries in London, 1986-2006: controlled interrupted time series analysis. *BMJ* 2009;339:b4469.
9 Li H, Graham DJ. Quantifying the causal effects of 20 mph zones on road casualties in London via doubly robust estimation. *Accid Anal Prev* 2016;93:65–47.
10 Mohit B, Rosen Z, Muennig PA. The impact of urban speed reduction programmes on health system cost and utilities. *Inj Prev* 2018;24:262–6.
11 New York City Department of Transportation. Neighborhood slow zones. http://www.nyc.gov/html/dot/html/motorist/slowzones.shtml (accessed 10 Jan 2017).
12 Lovasi GS, Grady S, Rundle A. Steps forward: review and recommendations for research on walkability, physical activity and cardiovascular health. *Public Health Rev* 2012;33:484–506.
13 Doyle S, Kelly-Schwartz A, Schlossberg M, *et al*. Active community environments and health: the relationship of walkable and safe communities to individual health. *J Am Plann Assoc* 2006;72:19–31.
14 Frank LD, Sallis JF, Conway TL, *et al*. Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. *J Am Plann Assoc* 2006;72:75–87.
15 New York City Department of City Planning. New York City population—population fact http://www1.nyc.gov/site/planning/data-maps/nyc-population/population-facts.page
16 Paulden M, O'Mahony JF, McCabe C. Discounting the recommendations of the second panel on cost-effectiveness in health and medicine. *Pharmacoeconomics* 2017;35:5–13.
17 New York City Department of Transportation. Vision zero data feeds http://www.nyc.gov/html/dot/html/about/vz_datafeeds.shtml - crash (accessed 05 Jan 2017).
18 New York City Department of City Planning. Neighborhood tabulation areas. https://www1.nyc.gov/site/planning/data-maps/open-data.page
19 Armstrong BG, Gasparrini A, Tobias A. Conditional poisson models: a flexible alternative to conditional logistic case cross-over analysis. *BMC Med Res Methodol* 2014;14:122.
20 Arias E, Heron M, Xu J. United States life tables, 2012 2016. https://www.cdc.gov/nchs/data/nvsr/nvsr65/nvsr65_08.pdf (accessed 21 Jan 2017).
21 New York State Department of Motor Vehicles. Summary of New York City motor vehicle crashes 2011–2012. https://dmv.ny.gov/statistic/2011nyccrashsummary.pdf (20 Jan 2017).
22 New York City Department of City Planning. Census blocks 2010. http://www1.nyc.gov/site/planning/data-maps/open-data/districts-download-metadata.page.
23 U.S Bureau of Labor Statistics. *Consumer price index overview table—New York-New Jersey 2017* https://www.bls.gov/regions/new-york-new-jersey/data/xg-tables/ro2xg01.htm (accessed 20 Jan 2017).
24 Bushell MA, Poole BW, Zegeer CV, *et al*. Costs for pedestrian and bicyclist infrastructure improvements. 2013 http://activelivingresearch.org/costs-pedestrian-and-bicyclist-infrastructure-improvements-resource-researchers-engineers-planners (accessed 20 Jan 2017).
25 New York City Department of Transportation. Street and roadway construction. http://www.nyc.gov/html/dot/html/infrastructure/construction.shtml.
26 Centers for Disease Control and Prevention. Web-based injury statistics query and reporting system. 2010 https://www.cdc.gov/injury/wisqars/ (accessed 27 January 2017).
27 Peters JL, Anderson R. The cost-effectiveness of mandatory 20 mph zones for the prevention of injuries. *J Public Health* 2013;35:40–8.
28 Steinbach R, Cairns J, Grundy C, *et al*. Cost benefit analysis of 20 mph zones in London. *Inj Prev* 2013;19:211–3.
29 Tufts Medical Center. The CEA registry. http://healtheconomics.tuftsmedicalcenter.org/cear4/Resources/LeagueTable.aspx (accessed 01 Mar 2017).
30 Muennig P, Bounthavong M. *Cost-effectiveness analysis in health: a practical approach*: John Wiley & Sons, 2016.
31 City of New York. *Vision zero action plan* 2014 http://www.nyc.gov/html/visionzero/pdf/nyc-vision-zero-action-plan.pdf.
32 Kim E, Muennig P, Rosen Z. Vision zero: a toolkit for road safety in the modern era. *Inj Epidemiol* 2017;4:1.
33 World Health Organization. Number of registered vehicles. http://www.who.int/gho/road_safety/registered_vehicles/number/en/ (accessed 01 Mar 2017).

34 Fitzpatrick K, Krammes RA, Fambro DB, *et al*. Design speed, operating speed and posted speed relationships. *ITE J Journal* 1997;67:52.
35 Harkey DL, Robertson HD, Davis SE. *Assessment of current speed zoning criteria*. Hapeville, GA: Transportation Research Board, 1990.
36 Parker JM. *Effects of raising and lowering speed limits on selected roadway sections*. Washington, DC : Federal Highway Administration, 1997.
37 Zaidel D, Hakkert AS, Pistiner AH. The use of road humps for moderating speeds on urban streets. *Accid Anal Prev* 1992;24:45–56.
38 Tester JM, Rutherford GW, Wald Z, *et al*. A matched case-control study evaluating the effectiveness of speed humps in reducing child pedestrian injuries. *Am J Public Health* 2004;94:646–50.
39 Morrison DS, Thomson H, Petticrew M. Evaluation of the health effects of a neighbourhood traffic calming scheme. *J Epidemiol Community Health* 2004;58:837–40.
40 Pucher J, Dijkstra L. Promoting safe walking and cycling to improve public health: lessons from The Netherlands and Germany. *Am J Public Health* 2003;93:1509–16.