Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

The 20mph speed limit policy in Bristol: analysis of speed and collisions variations

Anna Bornioli[a], Isabelle Bray[a], Paul Pilkington[a] , Emma L Bird[a]*

aCentre for Public Health and Wellbeing, Faculty of Health and Applied Sciences, University of the West of England, Bristol, United Kingdom

Abstract

Twenty mph (32.2 km/h) speed limits across urban areas are becoming a widespread tool for public health and road danger reduction in cities. They can also alleviate the burden of car travel on health variables such as road deaths and accidents, thus representing an interesting case-study for the field of transport and health. However, little is known about how the introduction of 20 mph limits affects speeds and collisions. This paper presents the findings from a novel comprehensive academic evaluation of the adjusted effects of a 20 mph sign-only city-wide intervention on vehicle speeds and collisions in Bristol, United Kingdom. A quasi-stepped wedge design analysed speeds of 36,973,090 single vehicles. Generalized linear mixed models were used to control for confounding variables in the speed analysis. Poisson regression was used to estimate variations in collisions using Police statistics. Results showed an adjusted speed reduction of 2.66 mph (4.28 km/h) over two to three years. Preliminary descriptive analyses showed that the number of injuries post-intervention was lower than pre-intervention for severe and serious injuries. In conclusion, 20mph policies have the potential to alleviate the burden of car transport on health, and future research should focus on how speed reductions affect health and wellbeing outcomes.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: 20 mph speed limit; road danger reduction; transport and health; public health evaluation.

1. Introduction

Twenty mph (32.2 km/h) speed limits are becoming an increasingly widespread tool for public health and road danger reduction in cities. They can alleviate the burden of car travel on health variables, in particular road deaths and accidents, thus representing an interesting case-study for the field of transport and health. The literature on the health benefits of 20mph limits is limited. The current paper reports the findings from the evaluation of the variations in

* Corresponding author. Tel.: +44 (0)117 32 87281
E-mail address: Anna.Bornioli@uwe.ac.uk

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY

speed and collisions following the 20mph speed limit intervention in Bristol, United Kingdom. First, we examined changes in speed before and after intervention with a quasi-stepped wedge design. Second, we run a preliminary analysis of the variations of collisions rates before and after intervention. The current paper reports the results and drafts guidelines for policy makers and recommendations for future research.

2. Body

Twenty mph (32.2 km/h) urban speed limits are becoming popular worldwide. Many local government authorities in Europe, such as that in Graz, Austria, have adopted speed reduction policies in recent years, lowering limits in urban and other residential areas to 30 km/h (ROSPA, 2017). In the United Kingdom (UK), speed limits on more than 400 (mainly 30 mph limit; 52.5 km/h) urban roads were reduced to 20 mph between 1991 and 1999 (ROSPA, 2017). Twenty mph or 30 km/h speed limits have also been introduced in some locations in Mexico (Flores, 2015), New Zealand (Auckland City Council, 2017), and the United States (Fried, 2016).

Some studies have found that 20 mph limits can be associated with public health benefits (Cairns et al., 2015; Edinburgh City Council, 2013; Bristol City Council, 2012). Improving road safety is one of the most important aspects of 20 mph policies (Jones and Brunt, 2017; Cairns et al., 2015; Bristol City Council, 2015; Grundy et al., 2009). This is in line with the Safe System and Vision Zero strategies, adopted by many countries, which seek to achieve a road traffic system that is eventually free from death and serious injury (PACTS, 2012). Speed is a key factor that can improve safety on the road (ROSPA, 2017; Elvik, 2005), and speed reduction is one of the five pillars of road safety, promoted by the World Health Organization (WHO, 2017). A 2005 systematic review concluded that speed has a major impact on the number of road traffic collisions and the severity of injuries, and that the relationship between speed and road safety is causal (Elvik, 2005). Research also indicates that at 20 mph the chance of being fatally injured is 1.5% compared to an 8% chance at 30 mph (Rosén et al., 2011).

Although the relationship between vehicle speeds and risk of death and injury is clear, less is known about how the introduction of 20 mph speed limits, particularly city-wide, affects vehicle speeds and collisions. Clearly, unless there is a reduction in speeds, it is unlikely that any public health benefits will be observed. Therefore, determining the effectiveness of interventions designed to reduce speeds is a crucial first step in any logic model that seeks to link 20 mph speed limits to improved health and wellbeing outcomes. Previous interim monitoring evaluations of 20 mph interventions on vehicle speed in the UK have found an average drop in speed between 0.9 mph and 2.2 mph (Atkins, 2010; Bristol City Council, 2012; BANES, 2017). In Bristol, an interim report evaluated changes in speed in two pilot areas where the scheme was first implemented. Results indicated that speed dropped by 1.4 mph and 0.9 mph respectively (Bristol City Council, 2012). Similarly, a report by Atkins (2010) found that in Portsmouth speeds went down by 1.3 mph following implementation of 20 mph limits. Two additional studies found a larger speed reduction: Edinburgh City Council's (2013) Pilot Evaluation found an average fall of 1.9 mph, while in 1998 the Transport Research Laboratory (TRL) reviewed reports from various sources in the UK and overseas and found that signs-only 20 mph limits were associated with an average speed reduction of 2.2 mph (TRL, 1998). However, these before-after evaluations were generally conducted over short time periods and did not control for possible confounding variables that might influence speed. In addition, these studies did not present detailed methodological accounts of how the studies were conducted, and in particular how speed was measured. To date, no comprehensive academic evaluation has assessed the adjusted effects of a 20 mph city-wide intervention on vehicle speeds over several years. The current paper reports the findings from the first such evaluation; this was a quasi-stepped wedge design that assessed the adjusted change in individual average speeds following a 20 mph sign-only intervention in Bristol (United Kingdom).

In relation to effects on road collisions, some studies have examined the effects of 20mph zones, rather than areas, on collisions. Twenty mph zones are areas where traffic calming measures have been introduced, such as speed humps, chicanes, road narrowing, planting (ROSPA, 2018). Twenty mph speed limits only consist of speed limit change without physical measures. Therefore, 20mph zones, are designed to be "self-enforcing", as opposed to 20mph speed limits (ROSPA, 2018). These studies have found that 20mph speed zones are associated with reductions in collisions (Grundy et al., 2009).

However, few studies examined the effects of 20mph speed limits on collisions. An early evaluation of 20mph limits in Scotland found a considerable drop in the number of recorded collisions per year, and a significant reduction in serious and fatal collisions (Burns et al., 2018). A 2015 systematic review of the effectiveness of 20mph speed limits

found evidence that introducing these lower speed limits reduce collisions and injuries, vehicle speed and volume, as well as improving perceptions of safety among the local population (Cairns et al., 2015). A number of local authority-led evaluations have taken place. Portsmouth, the first city in the UK to introduce a 20mph across most of the city, undertook an evaluation and reported a 22% reduction in casualties, with an average speed reduction of 1.4mph (Department for Transport, 2010). Bristol City Council evaluated the impact of introducing 20mph speed limits in two pilot areas of the city, reporting small but important reductions in average daytime vehicle speeds, an increase in walking and cycling, and strengthening public support (Bristol City Council, 2012). In Bath and North East Somerset (BANES) a recent review of their 20mph limit intervention found an overall reduction in average speeds of 1.3mph, with some reductions in road traffic collisions (Bath and North East Somerset Council, 2017). Nonetheless, most of the evidence from studies on 20mph limits to date is cross-sectional, has relatively short follow-up periods, and is potentially confounded by a range of factors. In addition to the speed analysis, the current study examines changes in collision rates before and after the 20mph intervention.

2.1 Methods

2.1.1 Intervention

In Bristol, a 20 mph limit scheme was introduced between 2010 and 2015. The intervention was implemented in seven phases across the city. After the successful implementation of a pilot phase in 2010 (Phase 1), the lower speed limit was introduced in six further phases between 2014 and 2015. The main aims were reducing road danger; making Bristol healthier, lowering road speeds and making walking, cycling and outdoor play more attractive options; and supporting and building communities (Bristol City Council, 2012). The 20 mph speed limit intervention was a signs-only policy that did not involve the introduction of any physical traffic calming measures. The lower limit was accompanied by a range of social marketing measures (using advertising and community engagement) that aimed to influence individuals' attitudes towards speed (Toy, 2012; Bristol City Council, 2018). Dual carriageways and 40 mph and 50 mph roads were not affected, and a minority of urban roads were selected to retain a 30 mph limit.

2.1.2 Monitoring

The city council undertook a comprehensive programme of vehicle speed monitoring to evaluate the introduction of the 20 mph limits. Speed monitoring sites included 106 roads in Bristol, with a mix of residential and non-residential roads, including 77 roads that changed from 30 to 20 mph limits, and 29 that retained the 30 mph limit. Automatic Traffic Counters (ATC radars; magnetic induction loops in the road surface that collect traffic counts – DfT, 2018) monitored car speeds for two weeks a year on a 24-hour, seven full-day count.

Sites were surveyed in summer and winter from summer 2014 until summer 2017. For three sites, pre-implementation data were missing due to unavailability of raw data. The authors did not take part in the planning and implementation phases of the intervention; involvement was limited to evaluation of the intervention after the monitoring data had been collected.

2.1.3 Speed analysis design

The study was a natural experiment, given that the intervention was not introduced or controlled by the researchers (Craig et al., 2012). Based on the characteristics of the available data, the chosen evaluation design was a quasi-stepped wedged trial (see Hemming et al., 2014 and Hussey and Hughes, 2007 for specification of the model). This pragmatic study design includes several clusters (areas) and several steps (phases) at which the intervention is implemented. Normally, there is an initial period in which no clusters are exposed to the intervention. Subsequently, at regular intervals each cluster is randomized to receive the intervention, until all clusters have been exposed. Data collection normally continues throughout the study, so that each cluster contributes observations under both control and intervention observation periods. This design has the advantage of reconciling robust scientific evaluations with the typical constraints of policy initiatives, such as logistical or political constraints (Hemming et al., 2015). In the current study design, each cluster was an area of Bristol, with a total of seven clusters under study (see Figure 1c in Hemming et al., 2014). Our design was a quasi-stepped wedge due to several factors. Firstly, the intervention was not randomly assigned to clusters. Secondly, whereas in a stepped wedge design the intervention is applied at regular intervals, in the current design the steps were irregular, due to political needs. Thirdly, due to the availability of raw data at the time of analysis, three areas out of seven did not have pre-intervention data, only post-intervention. Finally, not all roads in a cluster received the intervention, so in each area after the intervention had been introduced, there were some roads that retained a 30 mph limit as well as those that had changed to 20 mph limits.

A dataset was built including every vehicle monitored by the ATC radars during the monitoring period. A total of 36,973,090 observations were included in the dataset. The speed of each individual vehicle was recorded by Automatic Traffic Count (ATC) and assigned automatically to a speed bin (e.g.: 10.1-15 mph; 15.1-20 mph). Therefore, individual speeds were estimated by the middle point of each range. For example, a car that was recorded in the 10-15 mph range was coded as 12.5 mph.

Data were analyzed with SPSS23. Generalized linear mixed models were used to estimate the effect on speeds of introducing the 20 mph limit, while controlling for the effect of time variables (time of day; weekend and weekday; season; calendar year) and other confounding variables (road type: A/B roads; U roads; and clusters: 1 to 7) with fixed effects (Hussey and Hughes, 2007; Hemming et al., 2014). Time of day was included in the models as a categorical variable to control for traffic volumes (day time: 7am to 7pm; night time: 7pm to 7am). Two road types were coded: A/B roads (major roads carrying heavy to medium traffic) and U roads (unclassified roads intended for local traffic) (DfT, 2012). Preliminary analyses showed that there was a significant difference after the introduction of the intervention between those roads which changed to a 20 mph limit and those that retained the 30 mph limit. Therefore, three intervention groups were created for the purpose of the analysis: pre-intervention (30 mph speed limit), 20 mph post-intervention (roads that received the 20 mph intervention), and 30 mph post-intervention (roads that retained the 30 mph speed limit). Additional models including interaction terms were used to estimate the effect of the intervention at different times and in different clusters.

2.1.4 Collision analysis

Data regarding personal injury road collisions that have been reported to the police (known as Stats 19 data) are provided to the Council by Avon & Somerset Police. This provides details about each incident, including location, severity and contributory factors. The personal injury road collision database contains records dating back to 1990.

Eight years of data was available for road traffic casualties that occurred in Bristol, between the 1st January 2008 and 31st December 2016. Descriptive analyses were conducted comparing pre and post-intervention annual rate of injury. Additional analyses with conditional fixed effects Poisson models are also being conducted. These will be available in January 2019.

2.2 Results

2.2.1 Speed analysis

The city-wide pre-intervention mean speed was 27.1 mph. The unadjusted city-wide change in speed after the intervention was -4.7 mph in 20 mph streets and -1.3 mph in 30 mph streets. Unadjusted changes in each cluster in 20 mph streets ranged from -5.2 (Cluster 4) to -1.7 (Cluster 5). In roads that retained the 30 mph speed limit, speed decreased in Clusters 4, 6, and 7, and increased in Cluster 5.

Generalized Mixed Models assessed the effect of the intervention on speed outcomes controlling for time variables (calendar year, season, time of week, time of day) and geographical and space variables (road type, area) (Table 1). The estimated change in individual vehicle speed associated with the introduction of the 20 mph limit when controlling for confounding factors was -2.66 mph (95% CI [-2.65, -2.67]). In the roads where the speed limit remained 30 mph, there was also a small reduction in speed of – 0.04 mph (95% CI [-0.03, -0.06]). Calendar year was also included as a categorical variable in the model and the coefficients did not suggest a linear trend over time.

Table 1: Adjusted effects of 20 mph intervention and other variables on traffic speeds. From Bornioli et al., 2018

			95% Confidence Interval	
Parameter	Estimate	Sig.	Lower Bound	Upper Bound
Intercept	22.42	.000	22.41	22.44
Post-20 mph [a]	-2.66	.000	-2.67	-2.65
Post-30 mph [a]	-.04	.000	-.06	-.03
Cluster 2 [b]	2.00	.000	1.99	2.02
Cluster 3 [b]	2.29	.000	2.28	2.30
Cluster 4 [b]	2.79	.000	2.78	2.81

Cluster 5 [b]	3.27	.000	3.26	3.28
Cluster 6 [b]	5.10	.000	5.08	5.11
Cluster 7 [b]	5.69	.000	5.68	5.70
Night [c]	2.31	.000	2.30	2.31
2015 [d]	.13	.000	.12	.14
2016 [d]	-.35	.000	-.36	-.34
2017 [d]	-.42	.000	-.43	-.41
A/B roads [e]	-1.19	.000	-1.19	-1.18
Winter [f]	-.25	.000	-.26	-.25
Weekend [g]	1.30	.000	1.30	1.31
Reference category: a: Pre-intervention b: Cluster 1 c: Day (7 am to 7 pm) d: 2014 e: U roads f: Summer g: Weekdays (Monday to Friday)				

Models including interaction terms were used to analyse the effect of the intervention at specific times of day, times of week, times of year, and in the six geographical areas. During night hours (7 pm to 7 am) speed decreased by 2.43 mph in 20 mph roads (95% CI [-2.45, -2.42]) and slightly increased in 30 mph roads by 0.23 mph (95% CI [-0.25, -0.21]). Day speeds (7 am to 7 pm) in 20 mph streets went down by 2.74 mph (95% CI [-2.75, -2.73) and in 30 mph streets went down by 0.15 mph (95% CI [-0.16, -0.14]). Turning to the interaction between intervention and time of week, average speeds in weekdays in 20 mph roads decreased by 2.58 mph (95% CI [-2.60, -2.57]), while in weekend days they went down by 2.91 mph (95% CI [-2.92, -2.89]). On 30 mph roads, speeds went down by 0.23 mph in weekend days (95% CI [-0.24, -0.21]), but did not vary in 30 mph streets in weekdays (0.00; 95% CI [0.00, 0.01]). Finally, as shown by the interaction between intervention and time of year, average speeds in winter in 20 mph roads went down by 2.29 mph (95% CI [-2.30, -2.27]), while in summer they went down by 4.66 mph (95% CI [-4.69, -4.63]). On 30 mph roads, speeds decreased by 0.04 in winter (95% CI [-0.05, -0.02]) and decreased by 1.79 mph in summer (95% CI [-1.82, -1.76]) (see Bornioli et al., 2018 for full results).

2.2.2 Collision analysis: preliminary results

Analyses from Poisson regressions are ongoing. Preliminary analyses are presented below (from Pilkington et al., 2018). Table 2 reports the number of injuries in each area before and after the introduction of 20mph speed limits, on both roads to which the 20mph speed limit applied and those that retained a 30mph limit. Annual rates of fatal, serious, and slight injuries following the introduction of the 20mph speed limits are lower than the respective injury rate before the limits were introduced, thus showing an apparent reduction in the number of injuries.

Table 2: Road traffic casualties before and after the introduction of 20mph speed limits, by area. From Pilkington et al., 2018.

Phase	Injury type	Intervention period (before and after 20mph limit)	Number of months (adjusted)	Absolute number of injuries	Annual rate of injury	Difference in annual rate of injury post minus pre
Pilot (East + South)	Fatal	Before (1/1/2008 to 21/10/10)	34	2	0.71	-0.4 (-54.9%)
		After (22/10/10 to 31/12/2016	74	2	0.32	

	Serious	Before (1/1/2008 to 21/10/10)	34	49	17.29	-6.4 (-37.2%)
		After (22/10/10 to 31/12/2016	74	67	10.86	
	Slight	Before (1/1/2008 to 21/10/10)	34	550	194.12	-24.8 (-12.8%)
		After (22/10/10 to 31/12/2016	74	1044	169.30	
Central	Fatal	Before (1/1/2008 to 19/1/2014)	72	13	2.2	-0.8 (-40.9%)
		After (20/01/14 to 31/12/2016	36	4	1.3	
	Serious	Before (1/1/2008 to 19/1/2014)	72	206	34.3	-5.0 (-14.6%)
		After (20/01/14 to 31/12/2016	36	88	29.3	
	Slight	Before (1/1/2008 to 19/1/2014)	72	1874	312.3	-55.7 (-17.8%)
		After (20/01/14 to 31/12/2016	36	770	256.7	
Inner South	Fatal	Before (1/1/2008 to 10/7/2014)	78	8	1.2	-0.4 (-33.3%)
		After (11/07/14 to 31/12/2016	30	2	0.8	
	Serious	Before (1/1/2008 to 10/7/2014)	78	123	18.9	2.7 (+14.3%)
		After (11/07/14 to 31/12/2016	30	54	21.6	
	Slight	Before (1/1/2008 to 10/7/2014)	78	1076	165.5	-3.1 (-1.9%)
		After (11/07/14 to 31/12/2016	30	406	162.4	
Inner North	Fatal	Before (1/1/2008 to 28/9/2014)	81	11	1.6	-0.3 (-18.75%)
		After (29/09/14 to 31/12/2016	27	3	1.3	
	Serious	Before (1/1/2008 to 28/9/2014)	81	99	14.7	-1.3 (-9.5%)
		After (29/09/14 to 31/12/2016	27	30	13.3	
	Slight	Before (1/1/2008 to 28/9/2014)	81	829	122.8	-29.5 (-24.0%)
		After (29/09/14 to 31/12/2016	27	210	93.3	
East	Fatal	Before (1/1/2008 to 26/3/2015)	87	11	1.5	-1.5 (-100%)
		After (27/03/15 to 31/12/2016	21	0	0.0	
	Serious	Before (1/1/2008 to 26/3/2015)	87	101	13.9	-1.4 (-9.4%)
		After (27/03/15 to 31/12/2016	21	22	12.6	
	Slight	Before (1/1/2008 to 26/3/2015)	87	1173	161.8	-25.8 (-15.9%)
		After (27/03/15 to 31/12/2016	21	238	136.0	
Outer North	Fatal	Before (1/1/2008 to 18/6/2015)	89	4	0.5	0.1 (+20%)
		After (19/06/15 to 31/12/2016	19	1	0.6	
	Serious	Before (1/1/2008 to 18/6/2015)	89	61	8.2	0.0
		After (19/06/15 to 31/12/2016	19	13	8.2	
	Slight	Before (1/1/2008 to 18/6/2015)	89	567	76.4	-17.7 (-23.2%)
		After (19/06/15 to 31/12/2016	19	93	58.7	
Outer South	Fatal	Before (1/1/2008 to 22/9/2015)	93	9	1.2	-1.2 (-100%)
		After (23/09/15 to 31/12/2016	15	0	0.0	
	Serious	Before (1/1/2008 to 22/9/2015)	93	67	8.6	0.2 (+2.3%)
		After (23/09/15 to 31/12/2016	15	11	8.8	
	Slight	Before (1/1/2008 to 22/9/2015)	93	777	100.3	-2.7 (-2.7%)
		After (23/09/15 to 31/12/2016	15	122	97.6	

2.3 Discussion

The analysis has found that, following the introduction of a sign-only 20 mph limit in Bristol, UK, the average adjusted reduction of individual vehicle speeds on those roads which received the intervention was 2.66 mph (4.28 km/h) (unadjusted speed reduction: -4.7 mph; 7.41 km/h) over two to three years. In addition, it was found that the intervention appeared to have a spill over effect on the roads that remained 30 mph, which saw a general reduction of speed, though of a smaller magnitude than the 20 mph roads (adjusted speed reduction: 0.04 mph; 0.06 km/h; unadjusted speed reduction: 1.3 mph; 1.94 km/h). Preliminary analysis of collision data showed a general reduction in the number of fatal, severe, and slight collisions following the 20mph speed limit intervention. However, being the statistical analysis descriptive, final conclusions based on statistical significance cannot be drawn.

The current findings show a reduction in speed that is larger than that estimated in previous evaluations. For example, Atkins (2010) found that in Portsmouth average speeds decreased by 0.9 mph following the introduction of the 20 mph speed limit. Similarly, in Bristol preliminary analysis of the pilot scheme found that the speed decrease was between 0.9 and 1.4 mph. Nonetheless, it is possible that these discrepancies are due to methodological differences in the approach taken. In the current study, individual vehicle speeds were analysed, rather than daily average speeds, with potentially larger variances. This was also the first study to control for confounding variables and to apply the stepped wedge design. Compared to a simple before-and-after study, this design allowed a large amount of data to be analysed, and enabled a more detailed and thorough analysis of the trends. Another possible explanation for the discrepancy in speed reduction between the current study and Atkins' report (2010) is that the current study included both residential and larger roads, while Atkins's research seems to refer to residential roads only. Given that speeds are lower in residential roads, it might be that the speed reduction identified in this study was larger due to the proportion of larger roads included in these analyses, with greater scope for speed reductions. These findings are relevant for public health considering the positive health outcomes associated with lower speeds. Lower speeds have been found to be associated with fewer and less severe injuries (Elvik, 2005; Rosén et al., 2011), improved resident perceptions and social interactions (Appleyard, 1980), increased walking and cycling levels (Jacobsen, Racioppi, and Rutter, 2009) and reduced traffic noise impact (Freitas et al., 2012). The ability to introduce 20 mph speed limits over wider geographical areas, given that it is a much less costly intervention than traffic-calmed 20 mph speed zones, means that there is significant potential to address injury, environmental sustainability and wider public health goals at a town and city level (Pilkington, 2009).

It was also shown that the 20 mph intervention appeared to have a spill-over effect on the roads that retained the 30 mph speed limit, with a small reduction of 0.04 mph adjusted for confounding variables. Edinburgh City Council's (2013) Pilot Evaluation Report found that in the locations that retained the 30 mph limit, the average unadjusted fall in speed between the 'before' and 'after' speed was 0.8 mph – a figure which is close to the unadjusted drop in speed of 1.3 mph in 30 mph roads identified by the current study. The difference between the unadjusted and adjusted figures stresses the importance of controlling for external confounders, primarily for time variables.

The preliminary collision analysis showed an apparent reduction in the number of collisions post-intervention. The above changes in fatalities, serious injuries and slight injuries are marked and align with international evidence that reports that a 1mph average speed reduction in urban areas is associated with a 6.2% reduction in collisions (Allsop, 1998). Further inferential analyses will verify these trends.

2.3.1 Limitations, strengths, and future research recommendations

There are some limitations related to the current study that need to be acknowledged, and could be addressed by future research. First, pre-intervention speed data were missing for three clusters out of a total of seven. This was due to both a lack of baseline (pre-intervention) data collection, which is a common problem when evaluating changes to policy, and to the unavailability of raw speed data at analysis stage. However, the method of analysis used here allowed for use of data from all phases when estimating the effect of the intervention.

Second, in the stepped wedge design the implementation steps were not randomly assigned, as the intervention implementation phases were allocated by Bristol City Council following a core-to-periphery geographical order; as discussed above, it is possible that the order of the 20 mph speed limit implementation influenced its effectiveness. In addition, the steps were not perfectly equivalent, with some implementation dates being close and some other being more distant in time, and this might have influenced the effectiveness of the implementation. However, the current approach has attempted to mitigate these problems by controlling for both geographical area and calendar year.

Third, results are based on a sample of 106 roads across the city; it is possible that these roads might not representative of the speed trends across the city.

Fourth, speed data binning might have resulted in loss of information. However, monitoring was carried out by Bristol City Council and the authors did not have control over data collection. In addition, speed data being normally distributed, and given the large sample size, the grouping of speeds in categories should not lead to bias. Research has also shown that binned fits with bins of equal width produce unbiased results (Towers, 2014), and this was the case in the current study, with the exception of the first bin (0-10mph), which had very low frequencies.

Fifth, the relatively limited time frame (seven years) of the study represents a limitation. It is possible that over the years individual speed will decrease further, due to increased familiarity and custom to the 20 mph speed limit, or increase again towards the 30 mph limit. Therefore, it is recommended to local authorities to continue monitoring speeds to ascertain long-term effects of 20 mph limits on speeds.

Finally, no analyses on the role of socio-economic variables was run. Verifying with future research whether 20 mph speed limit interventions are more or less effective in deprived areas is of special importance. If the policy is effective in lower socio-economic areas, considering the health benefits of lower speeds (e.g. Rosén et al., 2011; Appleyard, 1980), 20 mph speed limits might become a tool to address inequalities. With this regard, a major study on the impact of 20 mph limits in 11 towns is being conducted for the Department for Transport, and those findings will add to the evidence-base on 20 mph interventions.

In conclusion, this being a non-randomised study, it is susceptible to confounding. The drop in speed cannot be fully attributable to the 20 mph intervention, and there could be other factors, other than the ones controlled for, that contributed to the reduction in speed.

Despite these limitations, this study has the strength of being the first comprehensive academic evaluation of a city-wide 20 mph intervention. Detailed monitoring was undertaken by Bristol City Council, allowing us to analyse individual car speeds, rather than average 24h speeds. This enabled a more careful evaluation, with the stepped wedge design also allowing controlling for the effect of calendar year and additional confounding variables.

The implication for policy is that, overall, the 20 mph signs-only intervention was successful in lowering motorised vehicle speeds. The analysis also identified certain areas of the city in which reductions in speed were smaller, and where further measures may be necessary. Further work should evaluate the effectiveness of a signs-only intervention with and without additional measures such as physical barriers and enforcement. In addition, the monitoring by Bristol City Council is a best practice and shows to other local authorities how a public health evaluation of a 20 mph policy can be conducted. Implementing a careful monitoring process is recommended to local authorities investing in such interventions, as this allows for the assessment of the effectiveness of the intervention and, in a second stage, its potential benefits in terms of the public health outcomes of interest, such as decreased number of collisions, increased levels of walking and cycling, and higher levels of community satisfaction and positive perceptions about the neighbourhood and city. Future research will also verify the changes in collisions pre to post introduction of the 20mph limit.

3. Conclusions

The current study has illustrated the first comprehensive academic evaluation of a city-wide 20 mph sign-only intervention on vehicle speeds and collisions. It was shown that following the 20 mph intervention in Bristol, controlling for confounding variables, individual average motorised vehicle speeds dropped by 2.66 mph (4.28 km/h) in 20 mph streets over two to three years. There was also a small decrease in speed of 0.04 mph (0.06 km/h) on those roads that retained the 30 mph limit. In addition, preliminary analyses showed a general reduction of collisions in the post-intervention period, which is being verified with further analyses. Policy makers in urban centres around the world are encouraged to implement rigorous monitoring of the effects of 20 mph speed limit interventions on vehicle speeds in order to enable a meaningful evaluation of potential public health benefits such as reduction in collisions and increased active travel. Local authorities may also wish to consider complementing signs-only interventions with additional measures such as physical barriers and/or law enforcement at specific times or in problematic locations.

References

Allsop R. MASTER Project (Managing the Speeds of Traffic on European Roads) [Internet]. Vol. 67. 1998. Available from: http://discovery.ucl.ac.uk/55439/

Atkins, 2010. Interim evaluation of the implementation of 20mph speed limits in Portsmouth [Internet]. 2010. Available from: http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/roadsafety/research/rsrr/theme4/interimeval20mphspeedlimits.pdf

Auckland Council, 2017. Wynyard Quarter and Viaduct Harbour now 30km/hr. Auckland Council. Retrieved 2018-10-26.

BANES (Bath & North East Somerset Council), 2017. Setting Local Speed Limits. A review of recent installations of 20mph area schemes (signage only). Bath and North East Somerset Council. Available from: https://democracy.bathnes.gov.uk/documents/s46582/20mph%20Zones%20Review%20Report.pdf

Bath & North East Somerset Council. "Setting Local Speed Limits " A review of recent installations of 20mph area schemes (signage only). Appleyard, D., 1980. Livable streets: protected neighborhoods?. The ANNALS of the American Academy of Political and Social Science, 451(1), pp.106-117.

Bornioli, A., Bray, I., Pilkington, P. and Bird, E. (2018) The effectiveness of a 20 mph speed limit intervention on vehicle speeds in Bristol, UK: A non-randomised stepped wedge design. Journal of Transport and Health, 11. pp. 47-55. ISSN 2214-1413 Available from: http://eprints.uwe.ac.uk/37939 '

Bristol City Council, 2012. 20mph Speed Limit Pilot Areas: Monitoring Report. 2012. Bristol City Council. Available from: https://www.bristol20mph.co.uk/wp-content/uploads/2016/06/20mph-Monitoring-Report-pilot-areas-2012.pdf

Bristol City Council, 2015. A Safe Systems Approach to Road Safety in Bristol [Internet]. 2015. Available from: https://www.bristol.gov.uk/documents/20182/34140/A+Safe+System+Approach+to+Road+Safety+in+Bristol.pdf

Burns A, Johnstone N, Macdonald N. 20MPH SPEED REDUCTION INITIATIVE [Internet]. [cited 2018 Feb 4]. Available from: http://www.gov.scot/Resource/Doc/156487/0042012.pdf

Cairns J, Warren J, Garthwaite K, Greig G, Bambra C, 2015. Go slow: an umbrella review of the effects of 20 mph zones and limits on health and health inequalities. J Public Health [Internet]; 37(3):515–20. Available from: https://academic.oup.com/jpubhealth/article-lookup/doi/10.1093/pubmed/fdu067

DfT (Department for Transport), 2010. Interim evaluation of the implementation of 20mph speed limits in Portsmouth [Internet]. 2010. Available from: http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/roadsafety/research/rsrr/theme4/interimeval20mphspeedlimits.pdf

DfT (Department for Transport), 2012. Guidance on Road Classification and the Primary Route Network 2 [Internet]. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/315783/ro

DfT (Department for Transport), 2018. Traffic counts. Accessed 16th May 2018. Available from: https://www.dft.gov.uk/traffic-counts/about.php

Edinburgh City Council, 2013. South Central Edinburgh 20mph limit pilot evaluation 2013. Available from: http://www.edinburgh.gov.uk/downloads/file/7820/south_central_edinburgh_20mph_limit_pilot_evaluation_2013

Elvik, R., 2005. Speed and road safety: synthesis of evidence from evaluation studies. Transportation Research Record: Journal of the Transportation Research Board, (1908), pp.59-69.

Flores, O. 2015. Proyecto Zona 30, por buen camino. El Debate. Retrieved 2018-10-26.

Freitas, E., Mendonça, C., Santos, J.A., Murteira, C. and Ferreira, J.P., 2012. Traffic noise abatement: How different pavements, vehicle speeds and traffic densities affect annoyance levels. Transportation Research Part D: Transport and Environment, 17(4), pp.321-326.

Fried, B., 2010. "NYCDOT Releases Landmark Ped Safety Study, Will Pilot 20 MPH Zones | Streetsblog New York City". Streetsblog.org. Retrieved 2018-10-26.

Grundy, C., Steinbach, R., Edwards, P., Green, J., Armstrong, B. and Wilkinson, P., 2009. Effect of 20 mph traffic speed zones on road injuries in London, 1986-2006: controlled interrupted time series analysis. Bmj, 339.

Hemming, K., Haines, T.P., Chilton, P.J., Girling, A.J. and Lilford, R.J., 2015. The stepped wedge cluster randomised trial: rationale, design, analysis, and reporting. Bmj, 350.

Hussey, M.A. and Hughes, J.P., 2007. Design and analysis of stepped wedge cluster randomized trials. Contemporary clinical trials, 28(2), pp.182-191.

Jacobsen, P.L., Racioppi, F. and Rutter, H., 2009. Who owns the roads? How motorised traffic discourages walking and bicycling. Injury prevention, 15(6), pp.369-373.

Jones, S.J. and Brunt, H., 2017. Twenty miles per hour speed limits: a sustainable solution to public health problems in Wales. J Epidemiol Community Health, 71(7), pp.699-706.

PACTS (Parliament Advisory Council for Transport Safety), 2012. PACTS' campaign priorities for road safety. Available from: http://www.pacts.org.uk/wp-content/uploads/sites/2/PACTS-Campaign-Priorities-201410131.pdf

Pilkington, P., 2009. Lowering the default speed limit in residential areas: opportunities for policy influence and the role of public health professionals. Injury prevention 15 (5). pp. 352-353.

Pilkington, P., Bornioli, A., Bray, I. and Bird, E. (2018) The Bristol Twenty Miles Per Hour Limit Evaluation (BRITE) Study. Project Report. University of the West of England. Available from: http://eprints.uwe.ac.uk/34851

Rosén E, Sander U. Pedestrian fatality risk as a function of car impact speed. Accid Anal Prev [Internet] 41(3) pp. 536–42. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19393804

ROSPA (The Royal Society for the Prevention of Accidents), 2017. Road Safety Factsheet. ROSPA. Available from: https://www.rospa.com/rospaweb/docs/advice-services/road-safety/drivers/20-mph-zone-factsheet.pdf

ROSPA (The Royal Society for the Prevention of Accidents), 2018. 20mph Zones and Limits. Available from: https://www.rospa.com/road-safety/advice/drivers/speed/20mph-zones-and-limits/

Towers, S., 2014. Potential fitting biases resulting from grouping data into variable width bins. Physics Letters B, 735, pp.146-148.

Toy, S., Tapp, A., Musselwhite, C. and Davis, A., 2014. Can social marketing make 20 mph the new norm?. Journal of Transport & Health, 1(3), pp.165-173.

TRL (Transport Research Laboratory), 1996. Review of traffic calming schemes in 20 mph zones. Available from: https://trl.co.uk/reports/TRL215

WHO (World Health Organisation), 2017. Managing speed. Available from: http://www.pacts.org.uk/wp-content/uploads/sites/2/PACTS-Campaign-Priorities-201410131.pdf