The effectiveness of a 20 mph speed limit intervention on vehicle speeds in Bristol, UK: a non-randomised stepped wedge design

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Abstract

Twenty mph (32.2 km/h) speed limits across urban areas are becoming a widespread tool for public health and road danger reduction globally. Determining the effectiveness of these interventions on motorised vehicle speeds is a crucial first step in any logic model that seeks to associate 20 mph speed limits to improved health and wellbeing outcomes. However, little is known about how the introduction of 20 mph limits affects speeds. 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. This is based on a natural experiment that took place in Bristol, UK. Applying a quasi-stepped wedge design, speeds of 36,973,090 single vehicles, recorded by Automatic Traffic Counts before and after the 20 mph intervention, were analysed. Generalized linear mixed models were used to control for confounding variables. Results showed an unadjusted speed reduction of 4.7 mph (7.41 km/h) and an adjusted speed reduction of 2.66 mph (4.28 km/h) over two to three years. Some variability due to time variables was detected, with speed reductions being larger during night time, at weekends, and in summer months. The roads that did not receive the 20 mph intervention also saw a small reduction in speed (0.03 mph). The findings indicate that the 20 mph intervention was successful in lowering individual vehicle speeds. Policy makers are encouraged to implement a careful 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.

Keywords

20 mph speed limit; road danger reduction; traffic speed; stepped wedge trial; United Kingdom; public health evaluation.

Highlights

1. Novel evaluation of the adjusted effects of a 20 mph city-wide intervention on vehicle speeds;
2. Speed reduced by 2.66 mph in 20 mph streets;
3. Roads that retained the 30 mph limit saw small speed reductions;
4. Policy makers encouraged to monitor pre-post speeds for public health evaluations.

1. INTRODUCTION

The introduction of 20 mph (32.2 km/h) speed limits across urban areas is becoming an increasingly widespread tool for public health and road danger reduction globally. 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). The first UK city-wide implementation was in Portsmouth in 2007, followed by Bristol (2010), Edinburgh (2017), and London (2017), with other cities now adopting or considering the policy. 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). Examining the effects on road safety alone, Cairns et al.’s (2015) umbrella review showed that 20 mph limits are effective in reducing casualties. Turning to the wider public health benefits of 20 mph limits, research has found that 20 mph limits can improve safety perceptions of residents (Cairns et al., 2015). Some preliminary grey research has also found that 20 mph limits are associated with increased walking and cycling

(Bristol City Council, 2012); however, Cairns et al.'s (2015) umbrella review did not detect a clear effect on walking and cycling levels.

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. 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).

2. METHODS

2.1 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.

2.2 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 (Figure 1). 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.

2.3 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 randomised 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 (Figure 1; 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.

Cluster	1-Pilot																
	2																
	3																
	4																
	5																
	6																
	7																
Data		*Data not collected*									*Data unavailable*	*Data available to research team*					
Season		Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Year		2009	2010		2011		2012		2013		2014		2015		2016		2017

Note:
Light grey = Pre-intervention data (all roads 30 mph)
Dark grey = post-intervention data (mixture of 20 mph and 30 mph)

Figure 1: Quasi stepped wedge design

Table 1 summarises the characteristics of the roads surveyed. The majority of these roads (72.6%) received the 20 mph limit; of these, 61.0% were local roads (U roads).

Table 1: Roads surveyed by cluster

	Cluster							
Road type	1	2	3	4	5	6	7	Total
20 mph roads	6	20	12	12	14	8	5	77 (72.6%)
30 mph roads	1	2	3	4	3	6	10	29 (23.4%)
Total roads surveyed	7	22	15	16	17	14	15	106 (100%)
Large 20 mph roads (A and B)	4	12	2	3	6	3	0	30 (39.0%)
Local 20 mph roads (U)	2	8	10	9	8	5	5	47 (61.0%)
Total 20 mph roads	6	20	12	12	14	8	5	77 (100%)
Large 30 mph roads (A and B)	1	2	2	1	2	3	0	11 (37.9%)
Local 30 mph roads (U)	0	0	1	3	1	3	10	18 (62.1%)
Total 30 mph roads	1	2	3	4	3	6	10	29 (100%)

2.4 Analysis

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 analysed 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; Hemmings 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.

3. RESULTS

3.1 Descriptive statistics on speed (unadjusted results)

Table 2 displays average speeds before and after intervention. 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.

The analysis of percentiles categories (Table 2) shows that post intervention in 20 mph roads more drivers lied in lower speed categories compared to pre-intervention levels, with some exceptions in Clusters 6 and 7. Table 2 also shows that compliance improved following the intervention. Before the intervention, 69.5% of vehicles respected the speed limit in 30 mph roads city-wide, compared with 77% post-intervention. The percentage of vehicles traveling below 20 mph also increased, and more than doubled in Clusters 4, 6, and 7, and city-wide. After intervention, 85% of drivers reduced their speed in 20 mph roads in Clusters 4, 5, 7, and city-wide.

Table 2: Unadjusted average speeds before and after intervention by cluster

		Percentiles categories				Mean			Compliance measures	
Cluster	Period	Median category (mph)	%	85th percentile category (mph)	%	Mean	Standard Deviation	Unadjusted change in mean speed	% vehicles within 20 mph	% vehicles within 30 mph
City Wide	Pre-intervention	25.1 - 30	34.4	30.1 - 35	20.4	27.1	6.8		12.0	69.5
	Post (20 mph)	20.1 - 25	34.3	25.1 - 30	7.8	22.4	6.7	-4.7	32.5	89.4
	Post (30 mph)	25.1 - 30	35.5	30.1 - 35	16.4	25.8	6.6	-1.3	15.0	77.0
1	Pre-intervention	-		-		-	-		-	-
	Post (20 mph)	20.1 - 25	36.2	25.1 - 30	10.6	19.5	5.5	-	51.2	98.0
	Post (30 mph)	20.1 - 25	34.0	25.1 - 30	26.2	22.0	6.7	-	32.2	92.2
2	Pre-intervention	-		-		-	-		-	-
	Post (20 mph)	20.1 - 25	32.3	25.1 - 30	18.2	21.6	7.0	-	39.3	89.8
	Post (30 mph)	25.1 - 30	35.0	30.1 - 35	7.7	23.5	6.1	-	22.0	90.7
3	Pre-intervention	-		-		-	-		-	-

	Post (20 mph)	20.1 - 25	37.1	25.1 - 30	20.0	21.7	6.3	-	35.5	92.7
	Post (30 mph)	25.1 - 30	42.0	30.1 - 35	17.2	25.9	6.2	-	13.0	78.6
4	Pre-intervention	25.1 - 30	40.8	30.1 - 35	31.2	28.4	6.0		7.1	59.8
	Post (20 mph)	20.1 - 25	32.9	25.1 - 30	25.8	23.2	6.8	-5.2	35.5	92.7
	Post (30 mph)	20.1 - 25	36.2	25.1 - 30	35.6	24.3	5.7	-4.1	13.0	78.6
5	Pre-intervention	25.1 - 30	35.5	30.1 - 35	13.6	24.8	6.3		18.0	82.9
	Post (20 mph)	20.1 - 25	35.7	25.1 - 30	28.1	23.1	6.2	-1.7	26.2	90.0
	Post (30 mph)	25.1 - 30	35.8	30.1 - 35	16.9	26.7	6.4	1.9	10.1	74.6
6	Pre-intervention	25.1 - 30	33.6	30.1 - 35	20.7	28.0	7.1		10.1	65.2
	Post (20 mph)	20.1 - 25	31.0	30.1 - 35	11.7	24.4	7.1	-3.6	25.2	81.5
	Post (30 mph)	25.1 - 30	36.2	30.1 - 35	21.9	27.5	6.9	-0.5	10.9	66.9
7	Pre-intervention	25.1 - 30	32.8	35.1 - 40	11.4	29.1	6.3		6.1	56.4
	Post (20 mph)	25.1 - 30	33.2	30.1 - 35	14.5	25.6	6.1	-3.5	15.2	79.4
	Post (30 mph)	25.1 - 30	33.4	30.1 - 35	28.9	28.6	6.5	0.5	9.9	57.8

Note:
- pre-intervention data not available

3.1.1 Average speeds and temporal variables

Table 3 shows city-wide mean speeds at different times of day before and after the intervention. For roads which were subject to the 20 mph limit, the unadjusted speed reduction was greatest in the off-peak daytime (-4.89 mph); among roads which retained a 30 mph limit, the reduction was greatest in the PM peak time (-1.64 mph). The largest speed reductions took place in daytime hours outside of the morning peak period in both 20 mph and 30 mph roads.

Table 3 also shows weekday and weekend trends. The speed reduction was larger during weekends than weekdays, both in 20 mph and 30 mph roads. Finally, seasonal trends show that while pre-intervention average speeds were higher in summer months compared with winter months, the 20 mph appeared to be more effective in summer months, with a reduction of 8.42 mph on 20 mph roads.

Table 3: Unadjusted average speeds before and after intervention by time variables

	Intervention	Mean speed	Standard Deviation	Difference post to pre
Day/night				
AM peak	Pre-intervention	26.1	7.3	
	Post (20 mph)	21.8	6.8	-4.3
	Post (30 mph)	25.2	6.9	-0.9
PM peak	Pre-intervention	26.1	6.8	
	Post (20 mph)	21.4	6.8	-4.7
	Post (30 mph)	24.4	7.1	-1.7
Day off peak	Pre-intervention	26.8	6.6	
	Post (20 mph)	21.9	6.4	-4.9
	Post (30 mph)	25.4	6.3	-1.4
Night off peak	Pre-intervention	28.5	6.7	
	Post (20 mph)	24.1	6.6	-4.4
	Post (30 mph)	27.5	6.5	-3.4
Weekday and weekend				
Weekday	Pre-intervention	26.75	6.86	
	Post (20 mph)	22.20	6.77	4.5
	Post (30 mph)	25.65	6.74	1.1

Weekend	Pre-intervention	28.36	6.49	
	Post (20 mph)	22.52	6.74	5.8
	Post (30 mph)	26.97	6.46	1.4
Winter and summer				
Winter	Pre-intervention	26.79	6.78	
	Post (20 mph)	22.20	6.80	-4.5
	Post (30 mph)	25.60	6.77	-1.1
Summer	Pre-intervention	30.97	6.45	
	Post (20 mph)	22.57	6.65	-8.4
	Post (30 mph)	26.06	6.64	-4.9

3.2 Generalized Linear Mixed Models (adjusted results)

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 4). 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]). Table 4 also shows that speeds pre- and post-intervention were lower in Cluster 1 (baseline) compared with the remaining clusters, higher at night time compared with daytime, lower in U roads compared with A or B roads, lower in winter than in summer, and lower during the weekend than during the week. Calendar year was also included as a categorical variable in the model and the coefficients did not suggest a linear trend over time.

Table 4: Adjusted effects of 20 mph intervention and other variables on traffic speeds

Parameter	Estimate	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval 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 (Table 5). 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]).

The speed variation also differed between clusters (although it could not be estimated for Clusters 1 to 3 due to lack of pre-intervention data). In 20 mph streets, the decrease in speed ranged from 1.89 mph (Cluster 5; 95% CI [-1.91, -1.98]) to 5.92 mph (Cluster 4; 95% CI [-5.96, -5.88]). In 30 mph streets, speed decreased in most areas but increased by 2.04 mph in Cluster 5 (95% CI [-2.02, -2.06]).

Table 5: Interaction terms estimated from additional adjusted models [a]

Parameter	Estimate	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Model 1				
Night * Post-20 mph	-2.43	.000	-2.45	-2.42
Night * Post-30 mph	.23	.000	.21	.25
Night * Pre-intervention	0[b]	.	.	.
Day * Post-20 mph	-2.74	.000	-2.75	-2.73
Day * Post-30 mph	-.15	.000	-.16	-.14
Day * Pre-intervention	0[b]	.	.	.
Model 2				
Weekend * Post-20 mph	-2.91	.000	-2.92	-2.89
Weekend * Post-30 mph	-.23	.000	-.24	-.21
Weekend * Pre-intervention	0[b]	.	.	.
Weekday * Post-20 mph	-2.58	.000	-2.60	-2.57
Weekday * Post-30 mph	.00	.509	-.00	.01
Weekday * Pre-intervention	0[b]	.	.	.
Model 3				
Winter * Post-20 mph	-2.29	.000	-2.30	-2.27
Winter * Post-30 mph	-.04	.000	-.05	-.02
Winter * Pre-intervention	0[b]	.	.	.
Summer * Post-20 mph	-4.66	.000	-4.69	-4.63
Summer * Post-30 mph	-1.79	.000	-1.82	-1.76
Summer * Pre-intervention	0[b]	.	.	.
Model 4				
Cluster 1 * Post-20 mph	-2.63	.000	-2.65	-2.61
Cluster 1 * Post-30 mph	0[b]		.	.
Cluster 2 * Post-20 mph	-2.16	.000	-2.17	-2.15
Cluster 2* Post-30 mph	0[b]	.000	.	.
Cluster 3 * Post-20 mph	-4.48	.	-4.49	-4.47
Cluster 3 * Post-30 mph	0[b]	.000	.	.
Cluster 4 * Post-20 mph	-5.92	.000	-5.96	-5.88
Cluster 4 * Post-30 mph	-4.93	.000	-4.97	-4.89
Cluster 4 * Pre-intervention	0[b]	.	.	.
Cluster 5 * Post-20 mph	-1.89	.000	-1.91	-1.88
Cluster 5 * Post-30 mph	2.04	.000	2.02	2.06

Cluster 5 * Pre-intervention	0[b]		.	.
Cluster 6 * Post-20 mph	-3.38	.000	-3.40	-3.36
Cluster 6 * Post-30 mph	-.47	.000	-.49	-.45
Cluster 6 * Pre-intervention	0[b]	.	.	.
Cluster 7 * Post-20 mph	-3.26	.000	-3.28	-3.24
Cluster 7 * Post-30 mph	-.42	.000	-.44	-.40
Cluster 7 * Pre-intervention	0[b]		.	.

a. Controlling for Clusters, Night/Day, Calendar year, Road type, Season, Weekend/Weekday.
b. Reference category

4. 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, and that the speed reduction was larger at specific times of year/week/day. 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). Finally, the change in speed varied significantly between areas, with a larger reduction in the innermost areas of the city, where the intervention was implemented earlier than other areas. Importantly, the descriptive analysis has shown that compliance to the posted speed limit improved following the intervention in both 20 mph and 30 mph roads. 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).

The analysis also revealed that speeds reduced to a greater extent at specific times of the week and the year. On 20 mph roads, the intervention was associated with a larger speed reduction during weekends compared with weekdays. Similarly, the speed reduction was larger in summer months compared with winter months. This could be due to the fact that during weekends and in summer months vehicle speeds were higher before the intervention, thus there was more scope for a speed reduction.

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.

In addition, differences between areas in the effectiveness of the intervention have emerged, with the average speed reduction in 20 mph roads ranging between 1.9 and 5.9 mph among geographical clusters. These differences might be explained by several factors. First, the topographical structure of the clusters; the outermost clusters (Clusters 6 and 7) saw a smaller speed reduction than more centrally located areas (Clusters 3 and 4). However, due to the fact that data for pre-intervention speeds in three areas were missing, it was not possible to verify this hypothesis. Second, it is possible that the effectiveness of the intervention might have been influenced by the order in which it was implemented. Finally, there are additional factors that might have influenced these differences, for example the socio-economic background of each neighbourhood. However, socio-economic variables were not part of the analysis and this remains a topic that warrants future research. In addition, it should be noted that Cluster 5 represents an exception to these trends. Despite being a relatively central area of Bristol, similarly to Cluster 4, and receiving the 20 mph speed limit implementation before Clusters 6 and 7, the speed reduction in 20 mph roads was substantially smaller than in other clusters following the intervention – however it should be noted that in Cluster 7 only five 20 mph roads were surveyed. Importantly, 30 mph roads in Cluster 5 did not see a speed reduction, with the cluster being the only one where speed increased in 30 mph roads. Other reports have also suggested that in Cluster 5 public support for the 20 mph speed limit is weaker (Pilkington et al., 2018); this highlights the importance of influencing individuals' attitudes for the effectiveness of policies that aim to change travel behaviour (e.g. Lyons et al., 2008).

4.1 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 differences identified in average speed reduction at specific time periods highlight the importance of controlling for times of day or traffic volumes, rather than looking at average 24h speeds.

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.

5. CONCLUSIONS

The current study has illustrated the first comprehensive academic evaluation of a city-wide 20 mph sign-only intervention on vehicle speeds. 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, the effectiveness of the policy was found to vary depending on time and space variables. 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.

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