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Perceptions of road traffic conditions along with their reported impacts on walking are associated with wellbeing

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ABSTRACT

We examined the associations between road traffic conditions, walking, and positive mental wellbeing among survey participants in four urban neighbourhoods in England bisected by busy roads (N = 708). Sequential models were fitted, examining the associations between objective and perceived traffic conditions (volume and speed); between perceived traffic conditions and the ability to walk locally and use busy roads; and between the perceptions of traffic conditions, ability to walk locally and use busy roads, and wellbeing. Our study had three main findings. Firstly, perceptions about traffic volumes and speeds were formed jointly and depend on traffic composition and on how the speed of traffic varies during the day and relates to historical and reference values. Secondly, participants who perceived the traffic volume as heavy and the traffic speed as fast were more likely to report that the traffic conditions were a barrier to their walking locally and that this was a specific reason why they avoided the busiest road in their area. Thirdly, the participants classed as having the worst combination of perceptions of road traffic conditions, and the reported impacts of them on their walking, had on average, significantly lower wellbeing (Model 1: $p = 0.009$, Model 2: $p = 0.002$), independently of other factors such as demographics and location.

1. Introduction

Increasing evidence suggests that living close to busy roads is associated with lower levels of walking (Giles-Corti and Donovan, 2002) and with lower wellbeing (Brereton et al., 2008; Yamazaki et al., 2005; Gundersen et al., 2013). However, no empirical studies to date have integrated these two separate research strands in such a way that sets out the potential pathways through which living close to busy roads may undermine wellbeing through the intermediate link of walking (Mindell and Karlsen, 2012). For example, a recent study in Glasgow found that the construction of the M74 motorway led to lower levels of wellbeing among local residents (Foley et al., 2017a) but not through any change in their active travel behaviour (Foley et al., 2017b).

These potential pathways linking busy roads, walking, and wellbeing have been identified under the theme of “community severance”. The hypothesis is that high levels of motorised traffic, and/or traffic moving at high speed, can represent physical and psychological barriers to the movement of pedestrians (Anciaes et al., 2016; Mindell et al., 2017). These barriers can become a major source of stress for residents in the surrounding areas (Yang and Matthews, 2010). The negative impact of motorised traffic on pedestrian movement may also manifest through suppressed walking trips. This is confirmed in the literature reviews of Saelens and Handy (2008) and Jacobsen et al., (2009), who found a consistent association between high traffic volumes and speeds of traffic and low levels of walking.

This reduction in the ability to walk limits the levels of physical activity among the affected population, not only because walking is a physical activity in itself, but also because the need to cross busy roads may discourage the use of green spaces, with an effect on levels of park-based physical activity (Koohsari et al., 2013; Kaczynski et al., 2014). The reduction of physical activity is then related with poorer health and wellbeing (Penedo and Dahn, 2005; Reiner et al., 2013). The substitution of walking trips with trips by motorised modes may also impact wellbeing. For example, there is evidence to suggest that travel satisfaction and wellbeing are higher for individuals who walk (or cycle) to work, compared with those who use motorised modes (Friman et al., 2013; Olsson et al., 2013; Martin et al., 2014).

However, the suppression of walking trips due to the presence of motorised traffic may not be compensated by trips through other modes of transport, if individuals do not own a private car or if public

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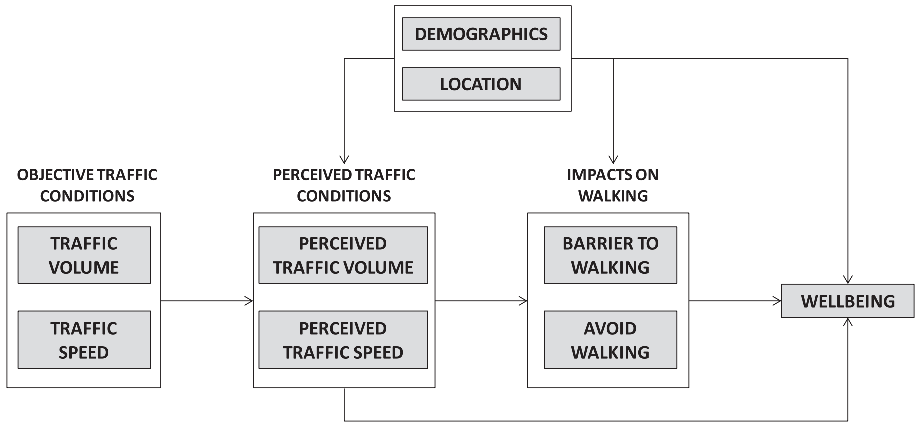

Fig. 1. Framework of analysis.

transport is not available or is not accessible in their local area. In these cases, severance caused by motorised traffic prevents residents from making all the trips they would like to do, which affects the type and frequency of their out-of-home activities and their overall satisfaction with daily travel (Bergstad et al., 2011, 2012; Friman et al., 2017, 2018). The reduced connectedness caused by the barriers posed by busy roads may then result in limited access to employment, education, and health care, possibly contributing to social exclusion (SEU, 2003; Currie et al., 2010; Stanley et al., 2011) and to restrictions to the realisation of "one's true potential" (De Vos et al., 2013).

There is also a strong evidence base on the negative impact of motorised traffic on social networks. Residents in areas around roads with high traffic volumes and/or fast speeds tend to have fewer contacts in their neighbourhoods and make fewer trips across the road (Appleyard and Lintell, 1972; Appleyard et al., 1981; Hart and Parkhurst, 2011; Sauter and Huettenmoser, 2008). This reduced social or community connectedness is also linked to poor health and lower levels of wellbeing (Holt-Lunstad et al., 2010; Moore et al., 2011; Mohnen et al., 2014).

Despite these developments, there remains little evidence on the existence of a link between living close to busy roads and wellbeing via the negative impacts of busy roads on walking. There are three possible reasons for this gap in evidence. Firstly, the associations linking motorised traffic, walking, and wellbeing can vary according to demographics and location. For example, Gundersen et al. (2013) found that women living in areas with high traffic density had significantly poorer physical health than women living in other areas, but no such association was apparent among men. It is also likely that the negative social impacts of motorised traffic disproportionately affect older people and individuals with mobility restrictions (Tournier et al., 2016). Those impacts also depend on the distance that people live from busy roads and on the presence of crossing facilities. For example, Lassière (1976) found that the effect of residential proximity on a number of outcomes, including the familiarity with the area across a busy road and the number of trips and levels of local social activity, decreased with the distance people lived from the road.

Secondly, researchers have often looked at a single aspect of road traffic conditions (either speed or volume). However, individuals may have different perceptions regarding traffic volume and speed (Anciaes et al., 2017). They may also form joint perceptions of these two aspects. For example, Hine (1996) showed that the impact of traffic volume on suppressed walking trips depended on traffic speeds. Perceptions about one particular aspect of motorised traffic may also influence perceptions of the others: in a study using photographs to elicit preferences for a range of scenarios for crossing the road, volume and speed were identified as the determining factors for the preferred choices, even when participants were only shown sets of scenarios where only the road design and pedestrian infrastructure varied (Montel et al., 2013).

Thirdly, analyses using objective and self-reported assessments of the built environment have tended to yield different associations with walking (Lin and Moudon, 2010; Ettema and Schekkerman, 2016; Kent et al., 2017). For example, Troped et al. (2017) found evidence of associations between objective characteristics of the built environment and walking; however, perceived characteristics did not mediate those associations. The lack of associations between traffic conditions and walking can therefore arise because the perceptions local residents form about road traffic conditions diverge from the "real" traffic conditions (as measured through objective data).

In this paper, we investigate the chain of associations linking motorised traffic with both walking and the wellbeing of local residents in four urban neighbourhoods in England bisected by major roads. Our main novel contribution is to focus specifically on traffic conditions and examine this postulated chain of associations via an integrated framework. In doing so, we also examine two other related issues to fill the gaps in the current literature. First, we use separate indicators of traffic volume and speed in order to examine which particular aspect is more strongly associated with walking and with wellbeing. Second, we compare objectively measured indicators of motorised traffic conditions with local residents' perceptions of those conditions.

Fig. 1 below shows the integrative framework which guided the analyses set out in the paper. Firstly, we postulated a relationship between objective attributes of busy roads (traffic volume and speed), and local residents' perceptions about those attributes. Secondly, we expected that negative perceptions of road traffic conditions could in turn manifest as a perceived barrier to walk in the local area (i.e. as a factor reducing the amenity value of walking trips) and/or could negatively impact on actual walking behaviour through the suppression of walking trips. The perceptions of road traffic conditions, along with their reported impacts on walking could then in turn influence levels of wellbeing. In addition, this postulated chain of associations was expected to hold independently of other factors such as demographics and location (assessed by the distance local residents lived from the road they identified as the busiest in their local area).

The main hypothesis of the present study was that the negative impact of busy roads on wellbeing varies according to (1) perceptions about the road traffic conditions **and** (2) the reported impact of those conditions on walking. More specifically, our hypothesis was that: (1) local residents who perceived the volume of traffic as 'heavy' and the speed of traffic as 'fast' **and** (2) who reported negative impacts of traffic (e.g. as a barrier to walk locally and as a reason to avoid using the busiest road) had lower wellbeing, on average, than those residents who did not share those perceptions or who did not report being affected by traffic. Our framework emphasizes that the traffic conditions in local neighbourhoods do not necessarily impact negatively on the wellbeing of all residents. Heavy traffic volumes and/or fast traffic speeds (as captured by objective data) may not impact on wellbeing if

Fig. 2. Case study areas.

residents do not actually perceive the traffic volume as heavy or perceive the traffic speeds as fast. Likewise, heavy traffic volumes and/or fast traffic speeds may not impact on wellbeing if residents do not perceive them as representing a physical and/or psychological barrier to their ability to walk locally, or if they do not influence their use of busy roads.

2. Methods

2.1. Case study areas

The study was conducted in four areas in England bisected by busy roads, two inside London (Seven Sisters Road [SSR] and Finchley Road [FR]), and two outside London (Stratford Road in Birmingham; Queensway in Southend-on-Sea) (Fig. 2). These areas were chosen after analysing data from a number of potential case study areas on road characteristics, traffic volumes and speeds, pedestrian infrastructure, and land use. All four roads are classified as 'A Roads' (the highest level in the road hierarchy) by the UK Department for Transport. The roads inside and outside London had 6 and 4 lanes for motorised traffic respectively. Barriers prevent pedestrians from crossing in some places along Finchley Road and Queensway. Finchley Road and Stratford Road are busy high streets with many shops. Seven Sisters Road bisects a residential area, with very few shops located alongside it. Queensway separates residential areas from the town centre. The four study areas were defined to include all addresses within walking distance (400 m) from the busy road or within the catchment area of the stations and major facilities on that road.

2.2. Objective measurements of traffic conditions

Objective traffic data along the four roads described above and other main roads was collected from data published by the Department for Transport (traffic volumes) and accessed through INRIX Roadway Analytics™ (traffic speeds). For a small number of minor roads not covered by the two datasets, additional data was collected from a video survey using fixed cameras at key locations in the study area (Anciaes and Jones, 2017). A series of variables was calculated for each road section. For traffic volumes, the variables calculated included: the annual average 16-hour traffic volumes (6 AM–10 PM), the proportion of peak-time traffic (7–10 AM and 4–7 PM), and the proportions of heavy goods vehicles (HGVs) and buses. For traffic speeds (km/h), the variables calculated included the 'reference' speed (i.e. the theoretical speed in free-flow conditions) and the daily median and maximum speeds in two scenarios: 'current' (during the month that the questionnaire survey was conducted – see Section 2.3 below) and 'historical' (since January 2014). A series of ratios and differences between these variables was also calculated.

Street audits were conducted to map the links available to pedestrians (pavements and cut-throughs), the location and type of pedestrian crossing (signalized crossings, footbridges, and underpasses), and the existence of physical barriers preventing pedestrians from crossing (such as walls or guard railings).

A series of variables were then calculated using a geographic information system, including: (1) the street network distance from each participant's home address to the nearest point on the road they reported in the questionnaire survey as being the busiest in their local area; (2) the distance of the detour from that point to the nearest potential crossing point (i.e. point without any physical barriers preventing pedestrians from crossing, with or without formal crossing facilities); (3) the traffic conditions at that potential crossing point (measured by the indicators of traffic volumes and speeds described above); and (4) the existence of formal pedestrian crossing facilities within specified maximum distances from the nearest point on the road. This was further disaggregated by the type of crossing facility: any type, signalized crossings, and grade-separated (footbridges or underpasses). Fig. 3 shows an illustrative example of the variables we calculated.

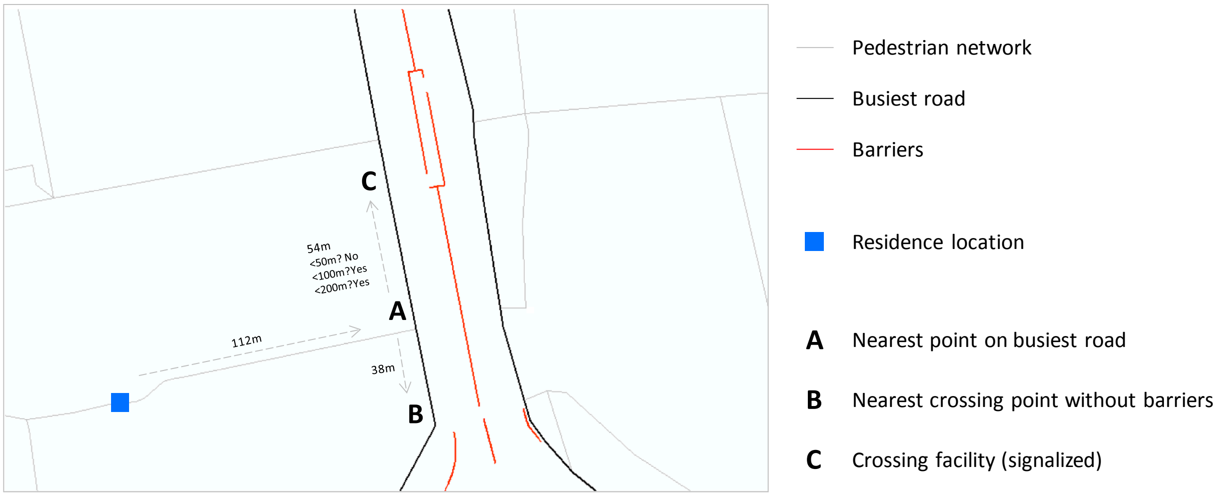

Fig. 3. Example of calculation of spatial variables. *Notes:* Firstly, we measured the street network distance from the participant's home address to the nearest point on the road they reported as being the busiest in their local area (Point A); a distance of 112 m. Secondly, we measured the distance of the detour from that point to the nearest potential crossing point without barriers (i.e. the distance from Point A to Point B); a distance of 38 m. Thirdly, the traffic volumes and speeds for this participant were assessed at Point B. Fourthly, we measured the presence of formal pedestrian crossing facilities (shown as Point C) within specified maximum distances (50 m, 100 m, or 200 m) from the nearest point on the road (Point A); a distance of 54 m. This was further disaggregated by the type of crossing facility; in this case a signalized crossing.

2.3. Questionnaire survey

We developed a self-completion questionnaire to assess residents' perceptions and behaviour in relation to the local road network (Scholes et al., 2016). The surveys in the four sites were conducted between November 2014 and June 2016. The fieldwork in each site lasted for about one month. Advance letters and accompanying information sheets were posted to 300–450 randomly selected non-commercial addresses in each study area. Interviewers then visited each selected address to recruit one adult participant per household, leaving the questionnaire for participants to complete later. A male and a female were recruited from alternate households, where possible. Participants received a £10 gift voucher as a token of appreciation. Overall, 57% of households completed the questionnaire. The survey was approved by the University College London Research Ethics Committee.

The achieved sample for the present study comprised 708 participants: 65 in London Seven Sisters Road, 178 in London Finchley Road, 182 in Southend, and 283 in Birmingham. The sample size for Seven Sisters Road was smaller than the others because the area is enclosed by non-residential land uses (a park, water reservoirs, and a canal). The population living beyond these land uses was not sampled as the local residents living there faced additional physical and/or psychological barriers to pedestrian movement that were not present in the other areas.

Participants were asked to identify the busiest road in their local area (defined as 'everywhere within a 20 min walk or about a mile of your home') and to rate the volume ('light', 'average', or 'heavy') and speed ('slow', 'average', or 'fast') of the traffic on that road. Participants were also asked whether the volume or speed of traffic, or poor pedestrian infrastructure (pavements and paths), affected their ability to walk around their local area.

Participants who did not live on what they reported as the busiest road were asked whether they avoided walking along or crossing that road. Participants who lived on what they reported as the busiest road were assumed to walk along/cross their own road. Participants who reported that they avoided the busiest road were asked to indicate whether the reason was the volume or speed of traffic, poor pedestrian infrastructure, or other. Participants could select more than one answer.

Positive wellbeing was measured using the shortened version of the Warwick-Edinburgh Mental Well-Being Scale known as SWEMWBS, a widely used instrument for measuring wellbeing, which was found in prior empirical work to have robust measurement properties, including satisfying the condition of strict unidimensionality (Stewart-Brown et al., 2009). SWEMWBS captures positive wellbeing using seven statements about participants' experiences over the previous two weeks on a five-point scale. The seven statements are 'feeling optimistic about the future', 'feeling useful', 'feeling relaxed', 'dealing with problems well', 'thinking clearly', 'feeling close to other people', and 'been able to make up my own mind about things'. The five points in the response scale are 'none of the time' (scored 1), 'rarely', 'some of the time', 'often', 'all of the time' (scored 5). Similar to previous analyses we confirmed that the overall SWEMWBS had acceptable internal reliability among the achieved sample (Cronbach's alpha $\alpha = 0.86$). In accordance with the already established unidimensional nature of the scale, we summed the scores to obtain an overall score, range 7–35. Higher scores indicated higher wellbeing.

The survey also included existing validated questions on demographics, self-reported health, disability, and longstanding illness, adapted from the Health Survey for England (Craig and Mindell, 2014). Neighbourhood social capital was measured using an instrument containing questions where participants were presented with nine pairs of contrasting statements about their neighbourhood and indicated which were closer to how they felt about their local area (Stafford et al., 2003). Answers were scored from 1 (most negative) to 7 (most positive). Summed scores of the instrument have been shown to correlate in the expected direction with health outcomes such as physical functioning (Breeze and Laing, 2008) and wellbeing (Toma et al., 2015). We confirmed that the overall scale had acceptable internal reliability among our sample (Cronbach's alpha $\alpha = 0.76$). Scores from the 9 questions were summed to obtain an overall score, range 9–63. Higher scores indicated higher neighbourhood social capital.

Participants were grouped in a stepwise fashion according to their questionnaire responses. Firstly, participants were grouped into four mutually-exclusive categories according to their perceptions of the volume and the speed of traffic on the busiest road (i.e. 'not heavy – not fast', 'not heavy – fast', 'heavy – not fast', and 'heavy – fast'), hereafter referred to as $\mathbf{A_1}$. Secondly, participants were grouped into four categories according to the reported impacts of the volume or the speed of traffic on the busiest road on their ability to walk to places locally (no/yes), and on whether they reported avoiding walking along or crossing the busiest road because of those reasons (no/yes), hereafter referred to as $\mathbf{A_2}$. Cross-classification of $\mathbf{A_1}$ and $\mathbf{A_2}$ resulted in 16 mutually-exclusive and exhaustive categories comprising the perceptions, and the reported impacts, of the volume and the speed of traffic on the busiest road, hereafter referred to as $\mathbf{A_{1,2}}$.

2.4. Statistical analysis

Descriptive statistics for all variables were computed for the sample as a whole and for each case-study area. These are summarized using percentages for categorical variables, and the mean and standard deviation (SD) for continuous variables (objective traffic conditions, neighbourhood social capital, and wellbeing). Averages of traffic volumes and speeds were also computed for participants grouped according to their combination of perceptions ($\mathbf{A_1}$). The average wellbeing scores for participants grouped according to the combination of all responses about the busiest road ($\mathbf{A_{1,2}}$) were compared with the national average using a one-sample *t*-test; the national average was calculated from Health Survey for England 2013 data (Craig and Mindell, 2014). An ANCOVA test was used to compare the average wellbeing scores across the four areas after adjustment for all the other key survey items.

Following our analytical framework (set out in Fig. 1), we examined the postulated chain of associations through fitting a sequence of statistical models. Based on the literature, possible variables to adjust in our modelling included age, neighbourhood social capital, street network distance to the reported busiest road, and other demographic characteristics. Case-study dummy variables were used as proxies for the characteristics of the road design (e.g. the number of lanes and the presence of a central reservation) and other site-specific characteristics (such as need to cross the road and quality of local public transport).

2.4.1. Model 1: Perceptions of the traffic conditions on the busiest road (A_1)

First, we modelled the associations between the objective measurements and the participants' perceptions about the traffic conditions (volume and speed) on their reported busiest road. Multinomial logistic regression was used to analyse the association between a number of predictors and the four-category outcome variable $\mathbf{A_1}$, which classified participants according to their perceptions of the volume and the speed of traffic on the busiest road (i.e. 'not heavy – not fast', 'not heavy – fast', 'heavy – not fast', and 'heavy – fast'). The reference group was 'not heavy –- not fast', i.e. participants who perceived the traffic volume and speed as 'light/average' and as 'slow/average', respectively. The main hypothesis we tested was that participants living near sections of the reported busiest road with the worst objective traffic indicators are the most likely to perceive the traffic volume as 'heavy' and/or the traffic speed as 'fast'.

The predictor variables to potentially retain in the final model included: the objective indicators of traffic volume and speed, detour to the nearest crossing point (i.e., location without physical barriers), availability of formal pedestrian crossing facilities, case-study area, demographics (age and others), neighbourhood social capital, network distance to the busiest road, and perceptions about whether the pedestrian infrastructure (pavements and paths) affected their ability to walk locally. We extended the model to include more complex relationships between the objective measures and participants' perceptions. The 16-h traffic volume was entered in the model using a squared term (to capture non-linear associations) and was also multiplied by the median traffic speed (to capture interactions between the two aspects of volume and speed).

2.4.2. Model 2: Reports of impacts of road traffic on walking (A_2)

Second, we modelled the associations between participants' perceptions about road traffic conditions on the busiest road (volume and speed), captured in $\mathbf{A_1}$, and the reported impacts of them on their walking. We used multinomial logistic regression to model the four-category outcome variable ($\mathbf{A_2}$), which classified participants according to these possible impacts: i.e. whether traffic volumes or speeds affected their ability to walk locally, and whether they reported avoiding walking along or crossing the busiest road for that reason (i.e. 'no – no', 'no – yes', 'yes – no', and 'yes – yes'). The reference group was 'no – no': i.e. participants who reported that the volume or speed of traffic did not affect their ability to walk locally, and that they did not avoid using the busiest road because of it. The main hypothesis tested in our analysis was that participants who perceived the traffic volumes and speeds as 'heavy' and 'fast' respectively would be those most likely to report negative impacts of traffic on their walking.

The predictor variables to potentially retain in the final model included the perceived traffic conditions on the busiest road ($\mathbf{A_1}$), detour to the nearest crossing point (i.e., location without physical barriers), availability of formal pedestrian crossing facilities, case-study area, demographics (age and others), neighbourhood social capital, network distance to the busiest road, and perceptions about pedestrian infrastructure (pavements and paths).

2.4.3. Model 3: Wellbeing

Our final step involved using a linear regression model to analyse the associations between a number of predictors and wellbeing. The main explanatory variables were the grouping of participants according to the combination of responses about the road traffic conditions and the reported impacts of those conditions on walking ($\mathbf{A_{1,2}}$). This allowed us to test how the wellbeing scores related to each possible combination of the four aspects we are interested in (i.e. perceived traffic volume and traffic speed, and reporting traffic as a barrier to walking and avoiding busy roads). Other predictor variables to potentially retain in the final model included the case-study area, demographics, neighbourhood social capital, and network distance to the busiest road.

We fitted two models: Model 1 contained all variables; Model 2 retained only those variables that were statistically significant at the 10% level. We examined our analyses for problems due to multicollinearity using variance inflation factors (VIF); plots of residual versus predictor scores were examined for problems due to heteroscedasticity.

3. Descriptive analysis

Table 1 shows the descriptive statistics for the objective road and traffic conditions at the nearest crossing point on the road that participants reported as the busiest (i.e. point B in Fig. 1). Overall, 57% of participants lived within a street network distance of 200 m of the busiest road. The proportion of participants with a detour from the nearest point on the road to the nearest non-barrier pedestrian crossing varied across the case study areas; this proportion was considerably higher in Southend (56%) due to the presence of guard railings along some stretches of the road. More than half of the overall sample (58%) had access to a crossing facility (of any type) within 50 m from the nearest point on the road; 50% had access to a signalized crossing facility. These proportions were lowest in London Seven Sisters Road.

The average 16-hour traffic volumes (6 AM–10 PM) in the two London areas exceeded the volumes which the UK's Department for Transport (DfT) suggests that roads create "severe severance" of communities (16,000 vehicles per day) (DfT, 1993). Traffic volumes in the two non-London areas were in the upper half of the interval suggested by DfT as "moderate severance" (8000–16,000 vehicles per day). The traffic speeds for each scenario (reference, current, and historical) were lower in the two London areas than in Southend and Birmingham. Overall, the objective data suggests that traffic conditions are more congested in the London case studies, as the difference in traffic volumes between the London and non-London case studies is more than proportional than the difference in traffic capacity (6 lanes vs. 4 lanes). This leads to lower traffic speeds on average in London. In addition, the two London road sections selected for our study are relatively short,

Table 1
Road and traffic conditions at nearest point on the busiest road, by case-study area.

		All	London (SSR)	London (FR)	Southend	Birmingham
N		**708**	**65**	**178**	**182**	**283**
Network distance to busiest road (metres, %)	0–49 m	17	32	16	21	11
	50–199 m	40	45	29	37	49
	200–399 m	26	23	20	29	29
	≥400 m	17	0	35	13	12
Detour to crossing point (without barriers) (metres, %)	0 m	59	100	54	44	63
	1–49 m	37	0	35	49	37
	≥50 m	5	0	11	7	0
Availability of crossing facilities (metres, %)	0–50 m	58	26	75	66	48
	0–100 m	78	63	96	75	72
	0–200 m	93	98	99	90	89
Availability of signalized crossing facilities (metres, %)	0–50 m	50	22	66	46	48
	0–100 m	72	58	93	57	72
	0–200 m	87	94	98	73	89
Traffic volume: Mean (SD)						
16-h Volume		21,303 (13,284)	28,848 (5856)	39,138 (10,072)	14,281 (6192)	12,868 (5408)
% Peak-time		39.1 (2.0)	41.3 (0.4)	36.1 (1.3)	40.6 (1.1)	39.4 (0.5)
% HGV		2.7 (1.2)	4.1 (0.8)	3.0 (0.4)	2.3 (0.9)	2.3 (1.3)
% Bus		3.3 (2.0)	4.4 (0.9)	4.8 (1.1)	2.4 (2.5)	2.7 (1.5)
Traffic speed (km/h): Mean (SD)						
Reference		38.1 (11.8)	30.0 (1.7)	32.6 (2.1)	41.4 (10.0)	41.4 (15.1)
Current (median)		25.6 (9.8)	22.0 (2.2)	23.4 (1.8)	35.4 (9.4)	21.6 (10.0)
(maximum)		38.6 (12.4)	29.0 (2.0)	32.5 (2.7)	43.2 (10.5)	41.7 (15.5)
Historical (median)		28.0 (9.5)	24.8 (2.0)	24.5 (2.3)	34.4 (9.2)	26.9 (11.4)
(maximum)		40.3 (12.7)	31.1 (1.8)	33.7 (2.4)	44.4 (10.8)	44.0 (16.0)

Notes: SSR: Seven Sisters Road, FR: Finchley Road, SD: Standard deviation, HGV: Heavy goods vehicles. Reference: theoretical speed in free-flow conditions; Current: daily average during month the questionnaire survey was conducted; historical: daily average since January 2014.

with traffic lights at both ends and in the middle, contributing to their lower average speeds.

Table 2 shows the summary statistics for the key survey items. 54% of participants were female; 31% were aged 55+ years. 19% reported having a disability or long-term illness that limited their mobility, and 7% rated their health condition as 'bad' or 'very bad'. Overall, the demographic characteristics of the samples are reasonably well aligned with the demographic characteristics of urban areas in England. As a result, the findings of our analyses are not generalizable to rural areas in England or to urban areas worldwide. Furthermore, non-response bias may have weakened to some extent our ability to generalise from our sample of residents' to the population of residents' in each case study area. The summary statistics also revealed some differences between the four areas: for example, the proportion of participants with no qualifications was much higher in the two non-London areas. The London Finchley Road sample also comprised a higher proportion of older participants and had a higher average neighbourhood social capital score. A separate analysis of covariance (ANCOVA) test revealed that the four areas differed significantly in average wellbeing ($p < 0.01$) after adjustment for all the other key survey items. Wellbeing scores were highest in London Seven Sisters Road and were lowest in Southend (26.7 and 25.8 respectively).

In terms of perceptions of traffic, 73% and 52% of participants reported the traffic volume and speed as 'heavy' and as 'fast', respectively (Table 2). With regards to the impacts of traffic, just over half (52%) reported that the traffic on the busiest road affected their ability to walk locally, and 27% reported that they avoided walking along or crossing it. These proportions were highest among the Birmingham sample (67% and 40% respectively).

Across the sample as a whole, we computed the average levels of 16-h traffic volume and current median speed for each of the 4 joint categories of participant perceptions (Table 3). These analyses revealed three main findings. Firstly, for a given perception of the speed of traffic (i.e. either fast or slow/average), the average 16-h traffic volume was higher for participants who reported the traffic volume as heavy than for those who reported the volume as light/average. Secondly, among the participants who reported the traffic volume as heavy, the average median speed was considerably higher (24.7 km/h) for those who reported the speed of traffic as fast than for those who reported slow/average speed (23.1 km/h). Thirdly, for those who reported the volume as light/average, the average median speed was slightly higher for the participants who reported the speed of traffic as slow/average (29.8 km/h) than for those who reported the speed of traffic as fast (29.3 km/h). In summary, these results suggest that perceptions of traffic volume are broadly consistent with objectively measured volume, but perceptions of traffic speed depend not only on speed but also on volume.

Table 4 shows the number of participants and the average wellbeing score for the grouping of participants according to the combinations of responses about the perceived traffic conditions and the reported impacts of those conditions on walking ($\mathbf{A}_{1,2}$). It should be noted that some groups have small sample sizes. The group that perceived the traffic volume as 'heavy' and the speed of traffic as 'fast' and that reported those traffic conditions as a barrier to walking locally and as a reason to avoid the busiest road represented 9.4% of the sample (67 participants) and had a significantly lower wellbeing score than the national average (23.4 versus 26.1; $p < 0.001$). This suggests that perceptions of the worst road traffic conditions, along with their negative impacts on walking, correlate negatively with wellbeing.

4. Model results

4.1. Perceptions of the road traffic conditions on the busiest road

Table 5 shows the odds ratios (OR) and accompanying 95% confidence intervals (95% CI) estimated from the multinomial logit model

Table 2
Key questionnaire survey items by case-study area.

		All	London (SSR)	London (FR)	Southend	Birmingham
N		**708**	**65**	**178**	**182**	**283**
Gender (%)	Female	54	60	54	52	54
Age (%)	18–34	27	37	28	24	27
	35–54	42	42	34	45	46
	55–64	14	12	12	13	15
	65–74	9	5	13	11	7
	≥75	8	5	13	7	6
Lives alone (%)		20	15	28	30	10
Length of residence in the area (years, %)	< 1	6	12	6	9	4
	1–4	16	23	21	13	12
	5–19	36	45	38	35	34
	≥20	42	20	35	44	51
Qualification levels (%)	Degree	34	42	58	24	23
	Other education	38	46	26	45	39
	No qualifications	29	12	16	31	39
Employment status (%)	Employed	48	46	54	50	43
	Unemployed	9	14	6	8	11
	Retired	20	12	28	23	15
	Student	6	8	6	4	5
	Other	17	20	6	15	25
Number of cars in household (%)	0	41	62	46	52	26
	1	45	29	46	39	52
	2 or more	14	9	9	9	22
Disability/illness affecting travel (%)		19	20	13	19	22
Reported health condition (%)	Very good	29	31	40	23	25
	Good	44	45	39	48	44
	Fair	20	17	18	20	22
	Bad	6	8	2	8	7
	Very bad	1	0	1	2	2
Perceived traffic volume on busiest road (%)	Light	3	8	2	4	1
	Average	24	25	19	37	19
	Heavy	73	68	80	59	80
Perceived traffic speed on busiest road (%)	Slow	7	9	6	5	8
	Average	41	40	41	45	37
	Fast	52	51	53	50	54
Walking locally affected by traffic (%)		52	38	36	48	67
Walking locally affected by poor pedestrian infrastructure (%)		32	23	13	46	36
Avoid busy road due to traffic (%)		27	20	11	24	40
Neighbourhood social capital	Mean (SD)	41.2 (9.7)	39.6 (9.9)	45.6 (8.4)	38.2 (9.4)	40.8 (9.6)
Wellbeing (SWEMWBS)	Mean (SD)	26.2 (5.0)	26.7 (4.6)	26.3 (4.5)	25.8 (5.2)	26.2 (5.2)

Table 3
Average traffic volume and speed, by participant perceptions.

Perceived volume of traffic	Perceived speed of traffic	Average 16-h traffic volume	Average current median speed (km/h)
Light/average	Slow/average	18,323	29.8
	Fast	19,049	29.3
Heavy	Slow/average	22,217	23.1
	Fast	22,419	24.7
All		21,303	25.6

Table 4
Number of participants and average wellbeing score by group.

Perceived volume of traffic	Perceived speed of traffic	Report traffic as a barrier to walking?	Report avoiding busy road because of traffic?	N	Wellbeing (Mean, SD)
Light/average	Slow/average	No	No	79	26.5 (5.2)
			Yes	14	24.2^{--} (3.8)
		Yes	No	39	27.7^{++} (5.3)
			Yes	24	26.1 (5.0)
	Fast	No	No	11	23.5^{--} (7.5)
			Yes	6	27.3 (3.7)
		Yes	No	13	27.5 (4.7)
			Yes	4	25.0 (3.4)
Heavy	Slow/average	No	No	77	26.6 (4.1)
			Yes	20	26.3 (4.2)
		Yes	No	67	27.1^{+} (5.3)
			Yes	17	25.2 (4.5)
	Fast	No	No	99	26.4 (4.2)
			Yes	36	25.8 (4.3)
		Yes	No	135	26.4 (5.2)
			Yes	67	23.4^{---} (5.6)
All				708	26.2 (5.0)
National average					26.1 (4.3)

Notes: p-values from a one-sample *t* test comparing wellbeing scores with the national average. Significance levels: above average $^{+++}$1%, $^{++}$5%, $^{+}$10%; below average: $^{---}$1%, $^{--}$5%, $^{-}$10%.

relating the predictor variables to the four-category outcome variable $\mathbf{A_1}$, which classified participants according to their perceptions of road traffic conditions. An odds ratio above/below 1 indicates an increase/decrease in the odds of being in a particular category of the outcome variable versus the reference category (volume of traffic 'not heavy', speed of traffic 'not fast') resulting from a one-unit increase in the predictor variable (or for a specific category compared to the reference), holding the other predictors in the model constant. Model fit statistics are also reported.

Significantly higher odds of participants perceiving the traffic volume on the busiest road as 'heavy' and the traffic speed as 'fast' (versus not heavy and not fast) were associated with three objectively measured attributes of speed: higher ratios between current/historical and historical/reference median speeds; and a larger difference between the current maximum and median speeds. Higher odds were also associated with one attribute of traffic volume: the proportion of road traffic being HGVs. Lower odds were associated with a one-unit increase in current median speed, and the proportion of road traffic being buses. Participants aged 75 years and over, with a reported disability affecting travel, who had lived in the locality for > 5 years, and who reported that the quality of the pedestrian infrastructure affected their ability to walk locally also had significantly higher odds of being in the 'heavy – fast' category (Table 5; column 6).

Significantly higher odds of participants perceiving the traffic volume as 'heavy' but the traffic speed as not fast (i.e. 'slow/average') were associated with two objectively measured attributes of traffic speed: higher ratios between current/historical and historical/reference median speeds. The association between the odds of participants perceiving only the volume of traffic on the busiest road as heavy and the objectively measured traffic volumes was not linear. The negative relationship is progressively smaller (and eventually positive) as traffic volumes or traffic speeds increase. Participants who reported that the pedestrian infrastructure affected their ability to walk locally had higher odds of being in the 'heavy – not fast' category (Table 5; column 4).

Significantly lower odds of participants perceiving the traffic speed on the busiest road as 'fast' but the volume as not heavy (i.e. 'light/average') were associated with one attribute of objectively measured traffic conditions: the proportion of road traffic being buses. Lower odds were also associated with having access to a signalized crossing facility (< 50 m of the nearest crossing point), being in current employment, and being aged 65–74. Participants without any formal educational qualifications had higher odds of being in the 'not heavy – fast' category (Table 5; column 2).

4.2. Reports of impacts of road traffic on walking

Table 6 shows the odds ratios (OR) and 95% confidence intervals (95% CI) estimated from the multinomial logit model relating the predictor variables to the four-category outcome variable $\mathbf{A_2}$, which classified participants according to whether their perceptions of the volume or speed of traffic on the busiest road affected their ability to walk locally, and whether they reported avoiding walking along or crossing the busiest road for that reason.

Participants who perceived the traffic volume as 'heavy' and the speed of traffic as 'fast' had significantly higher odds of reporting these traffic conditions as a barrier to walking locally, and that they avoided using the busiest road (versus not perceiving traffic conditions as a barrier and not avoiding that road). Participants with a reported disability which affected their travel also had higher odds of being in the 'yes – yes' category; higher values of the neighbourhood social capital score, and being a student, were associated with lower odds (Table 6; column 6).

Participants who perceived either the traffic volume as 'heavy' or the traffic speed as 'fast', or both, had significantly higher odds of reporting these traffic conditions as impeding their ability to walk to local places but to not report avoiding the busiest road. Living closer to the busiest road was also associated with higher odds of being in the 'yes – no' category; having a short distance from the nearest crossing point to a crossing point without physical barriers (< 50 m) and being aged

Table 5
Model of perceptions of traffic.

	Outcomes (A_1)					
Volume	Not heavy		Heavy		Heavy	
Speed	Fast		Not fast		Fast	
	OR	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Areas						
Seven Sisters Road	0.44	(0.04, 4.89)	**0.12*****	**(0.03, 0.50)**	0.33	(0.08, 1.34)
Southend	0.38	(0.02, 9.62)	**0.10****	**(0.02, 0.65)**	0.47	(0.08, 2.78)
Birmingham	0.47	(0.02, 12.2)	0.84	(0.16, 4.48)	2.75	(0.51, 15.0)
Age group						
18–34	1.13	(0.45, 2.79)	0.64	(0.37, 1.11)	0.70	(0.42, 1.18)
55–64	0.28	(0.05, 1.44)	0.92	(0.44, 1.90)	1.12	(0.57, 2.17)
65–74	**0.06****	**(0.01, 0.63)**	0.49	(0.18, 1.36)	1.28	(0.56, 2.93)
≥75	0.21	(0.02, 2.10)	1.65	(0.49, 5.56)	**2.82***	**(0.94, 8.49)**
Other demographics						
Disability affecting travel	0.83	(0.24, 2.89)	0.97	(0.47, 2.01)	**1.97****	**(1.06, 3.67)**
In area more than 5 years	1.38	(0.53, 3.60)	1.33	(0.77, 2.28)	**2.26*****	**(1.34, 3.81)**
No qualifications	**3.90*****	**(1.55, 9.84)**	0.64	(0.36, 1.16)	0.78	(0.46, 1.32)
Employed	**0.25*****	**(0.10, 0.64)**	0.86	(0.51, 1.46)	0.99	(0.61, 1.62)
Affected by poor pedestrian infrastructure	1.00	(0.39, 2.54)	**1.64***	**(0.95, 2.84)**	**2.08*****	**(1.27, 3.41)**
Crossing points						
Signalized crossing (< 50 m)	**0.28****	**(0.10, 0.77)**	0.89	(0.53, 1.48)	1.07	(0.67, 1.73)
Traffic volume						
16-h traffic volume (1000 s)	0.89	(0.60, 1.33)	**1.36****	**(1.03, 1.79)**	0.90	(0.69, 1.15)
Volume^2 (10^8 s)	1.20	(0.74, 1.94)	**0.77***	**(0.56, 1.06)**	1.27	(0.93, 1.71)
% HGV	0.90	(0.36, 2.23)	1.20	(0.71, 2.05)	**2.49*****	**(1.45, 4.27)**
% Buses	**0.68****	**(0.49, 0.95)**	0.90	(0.74, 1.10)	**0.75*****	**(0.63, 0.89)**
Traffic speed (km/h)						
Current median	0.90	(0.78, 1.04)	1.01	(0.91, 1.12)	**0.90****	**(0.82, 0.99)**
Current/historical median	1.06	(0.95, 1.17)	**1.09*****	**(1.02, 1.16)**	**1.08*****	**(1.02, 1.14)**
Historical/reference median	1.03	(0.88, 1.21)	**1.09***	**(0.99, 1.21)**	**1.16*****	**(1.06, 1.27)**
Current maximum-median	0.96	(0.80, 1.15)	1.04	(0.94, 1.16)	**1.11****	**(1.00, 1.22)**
*16-h traffic volume * median speed*	1.13	(0.53, 2.43)	**0.47****	**(0.26, 0.86)**	1.03	(0.60, 1.74)
N	708					
Initial log-likelihood	−836					
Final log-likelihood	−722					
Mc Fadden's R^2	0.14					
Count R^2	0.54					
Adjusted Count R^2	0.14					

Notes: Multinomial logit model. LR(df = 66) = 227.6, $p < 0.001$. Base category of outcome: volume of traffic 'not heavy', speed of traffic 'not fast'. Significance levels: ***1%, **5%, *10%. Reference categories: case study area (London Finchley Road), age (35–54), disability affecting travel (no), living in the area (5 years or less), education (had at least one formal qualification), employment status (not employed), affected by poor pedestrian infrastructure (no), crossing facilities (no signalized crossing facilities within 50 m of the nearest crossing point). All variables identifying distance to the busiest road were statistically insignificant and were removed from the final model. Goodness of fit statistics: The McFadden R^2 is the percentage reduction in the log-likelihood for the final model compared with the intercept-only model. The Count R^2 is the percentage of correct predictions. The Adjusted Count R^2 is the percentage of correct predictions beyond what would be correctly predicted by assigning the most frequent outcome to all observations.

55–64 was associated with lower odds (Table 6; column 4).

Participants who perceived the traffic speed as 'fast' (regardless of how they perceived the volume of traffic) had significantly higher odds of reporting that they avoided using the busiest road but that these traffic conditions did not impede their ability to walk locally. Participants with a reported disability which affected their travel also had significantly higher odds of being in the 'no – yes' category. Having no formal qualifications and no access to a car was associated with lower odds (Table 6; column 2).

4.3. Wellbeing

Table 7 shows the coefficients from the linear regression model with wellbeing as the outcome variable. Model 1 retained all variables identifying case study area, age, street network distance to the reported busiest road, and group classifications. Model 2 included only the variables that were statistically significant at the 10% level. Model fit statistics are also reported. The small value of the maximum VIF (2.4 in Model 1; 1.9 in Model 2) indicated the absence of any significant collinearity between the predictor variables. No patterns were observed in the variance of prediction errors when plotting the residual vs. predicted wellbeing values, suggesting the absence of heteroscedasticity.

In the full model, participants who reported the traffic volume as 'heavy', the traffic speed as 'fast', that these traffic conditions impeded their ability to walk locally, and that they avoided using the busiest road in their area had, on average, a significantly lower wellbeing score (Model 1: coefficient = −2.13; 95% CI: −3.73 to −0.52; p = 0.009) than those in the reference group (traffic volume: 'not heavy'; traffic

Table 6
Model of impacts of traffic.

		Outcomes (A_2)					
Traffic as barrier to walking		No		Yes		Yes	
Traffic as reason to avoid busiest road		Yes		No		Yes	
		OR	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Areas							
Seven Sisters Road		2.80	(0.81, 9.67)	0.58	(0.27, 1.22)	1.11	(0.33, 3.76)
Southend		**5.16*****	**(1.97, 13.5)**	**1.76****	**(1.01, 3.07)**	1.60	(0.65, 3.95)
Birmingham		**9.57*****	**(3.81, 24.0)**	**3.35*****	**(1.96, 5.73)**	**9.63*****	**(4.28, 21.7)**
Age group							
18–34		1.03	(0.52, 2.01)	0.81	(0.49, 1.33)	1.47	(0.75, 2.89)
55–64		0.48	(0.19, 1.21)	**0.54****	**(0.29, 0.99)**	1.04	(0.49, 2.23)
65–74		0.43	(0.12, 1.61)	0.82	(0.41, 1.65)	1.32	(0.55, 3.21)
≥75		0.65	(0.17, 2.56)	0.84	(0.38, 1.84)	1.16	(0.42, 3.22)
Distance to busiest road							
0–49 m		0.54	(0.18, 1.56)	**6.42*****	**(3.18, 13.0)**	0.70	(0.24, 2.05)
50–199 m		0.65	(0.30, 1.41)	**2.79*****	**(1.51, 5.16)**	1.26	(0.58, 2.74)
200–399 m		0.70	(0.32, 1.54)	1.73*	(0.90, 3.32)	1.05	(0.46, 2.38)
Other demographics							
Disability affecting travel		**2.09***	**(0.96, 4.56)**	1.19	(0.67, 2.11)	**4.01*****	**(2.13, 7.55)**
No qualifications		**0.50***	**(0.24, 1.07)**	1.37	(0.85, 2.20)	1.28	(0.71, 2.30)
Student		0.63	(0.18, 2.17)	1.01	(0.44, 2.30)	**0.11****	**(0.01, 0.95)**
0 cars		**0.58**	**(0.31, 1.07)**	0.77	(0.51, 1.16)	0.77	(0.45, 1.32)
Neighbourhood social capital		0.98	(0.95, 1.01)	0.99	(0.97, 1.01)	**0.94*****	**(0.91, 0.97)**
Crossing points							
No barriers (detour < 50 m)		0.68	(0.38, 1.23)	**0.50*****	**(0.33, 0.75)**	0.88	(0.51, 1.52)
Perceived traffic (A_1)							
Heavy volume	*Fast speed*						
No	Yes	**4.55****	**(1.32, 15.6)**	**2.52***	**(0.93, 6.74)**	1.54	(0.39, 6.03)
Yes	No	1.52	(0.67, 3.45)	**1.82****	**(1.04, 3.19)**	0.64	(0.29, 1.40)
Yes	Yes	**2.57****	**(1.23, 5.36)**	**3.19*****	**(1.90, 5.33)**	**2.08****	**(1.09, 3.96)**
N		708					
Initial log-likelihood		−897					
Final log-likelihood		−755					
McFadden's R^2		0.16					
Count R^2		0.51					
Adjusted Count R^2		0.20					

Notes: Multinomial logit model. LR(df = 57) = 284.1 ($p < 0.001$). Base category of outcome: ability to walk locally is not affected by traffic, and traffic is not a reason to avoid walking along or crossing the busiest road. Significance levels: ***1%, **5%, *10%. Reference categories: London Finchley Road, age 35–54, distance to the road ≥ 400 m, no disability affecting travel, had at least one formal qualification, not a student, 1 or more cars, detour to reach a point without barriers ≥ 50 m, perceived the volume and the speed of traffic as not heavy and as not fast, respectively. For interpretation of goodness of fit statistics see Table 5.

speed: 'not fast', reported no barriers to walking, and did not avoid using the busiest road) after adjustment for the other predictor variables. The equivalent regression coefficient was lower but remained statistically significant in the reduced model (Model 2: coefficient = −1.96; 95% CI: −3.18 to −0.74; p = 0.002).

Residing in London Finchley Road, being female, living alone, and reporting bad or very bad health were factors significantly associated with lower wellbeing. Participants aged 18–34 or 65–74, residing within 50 m or more than 200 m from the reported busiest road, having a university degree, being currently employed, and scoring higher on the neighbourhood social capital scale were factors significantly associated with higher wellbeing.

5. Discussion

5.1. Synthesis

There is growing evidence that living close to busy roads is associated with lower levels of walking and with lower wellbeing. However, this evidence has been gathered mainly from two separate research strands which to date have seldom been integrated. In the present study we attempted to decompose the chain of associations through which motorised traffic conditions may reduce the wellbeing of local residents living close to busy roads by looking at the empirical associations between objectively measured and subjectively perceived traffic conditions, the perceived negative impact of these traffic conditions on walking, and positive mental wellbeing.

Our main finding (Table 7) was that the survey participants who perceived the traffic volume as 'heavy' and the traffic speed as 'fast', and who reported these as a factor affecting their ability to walk locally and that they avoided using the busiest road due to those conditions, had a significantly lower wellbeing score than those who did not report these perceptions.

Furthermore, we found a significant association between the subjective perceptions of road traffic conditions and the reported negative impacts of these on walking (Table 6). More specifically, we found that the joint perception of the traffic volume as 'heavy' *and* the traffic speed as 'fast' was associated with the reported impacts of these as being a

Table 7
Models of wellbeing.

				Model 1		Model 2	
				Coefficient	*95% CI*	*Coefficient*	*95% CI*
Constant				**18.7*****		**19.2*****	
Areas							
Seven Sisters Road				**1.40***	**(−0.03, 2.82)**	**1.48****	**(0.14, 2.83)**
Southend				**1.22****	**(0.14, 2.30)**	**1.31****	**(0.29, 2.34)**
Birmingham				**1.39*****	**(0.36, 2.43)**	**1.56*****	**(0.61, 2.51)**
Age group							
18–34				**0.98****	**(0.12, 1.83)**	**0.68***	**(−0.12, 1.47)**
55–64				0.90	(−0.18, 1.98)		
65–74				**2.02*****	**(0.65, 3.40)**	**1.68*****	**(0.42, 2.94)**
≥75				0.60	(−0.88, 2.07)		
Distance to busiest road							
0–49 m				**1.23***	**(−0.04, 2.52)**	**0.88***	**(−0.05, 1.81)**
50–199 m				0.37	(−0.69, 1.44)		
200–399 m				**0.96***	**(−0.16, 2.08)**		
Other demographics							
Female				**−0.82****	**(−1.53, −0.11)**	**−0.71****	**(−1.41, −0.02)**
Lives alone				**−1.20****	**(−2.14, −0.26)**	**−1.01****	**(−1.92, −0.10)**
Degree				**1.64*****	**(0.84, 2.44)**	**1.63*****	**(0.85, 2.41)**
Employed				**0.73***	**(−0.08, 1.53)**	**0.72***	**(−0.04, 1.48)**
Health: bad				**−2.24*****	**(−3.72, −0.75)**	**−2.28*****	**(−3.73, −0.83)**
Health: very bad				**−2.82***	**(−5.75, 0.11)**	**−3.01****	**(−5.91, −0.10)**
Neighbourhood social capital				**0.13*****	**(0.09, 0.17)**	**0.13*****	**(0.09, 0.17)**
Perceived traffic and impact ($A_{1,2}$)							
Heavy volume	*Fast speed*	*Barrier to walking*	*Avoids road*				
No	No	No	Yes	−1.58	(−4.23, 1.06)		
No	No	Yes	No	1.04	(−0.77, 2.85)		
No	No	Yes	Yes	−0.54	(−2.68, 1.61)		
No	Yes	No	No	−2.19	(−5.13, 0.76)		
No	Yes	No	Yes	0.32	(−3.54, 4.17)		
No	Yes	Yes	No	1.06	(−1.70, 3.82)		
No	Yes	Yes	Yes	0.26	(−4.49, 5.01)		
Yes	No	No	No	−0.13	(−1.59, 1.34)		
Yes	No	No	Yes	−0.71	(−3.01, 1.60)		
Yes	No	Yes	No	0.55	(−0.98, 2.09)		
Yes	No	Yes	Yes	−0.37	(−2.84, 2.10)		
Yes	Yes	No	No	−0.28	(−1.66, 1.11)		
Yes	Yes	No	Yes	−0.64	(−2.48, 1.20)		
Yes	Yes	Yes	No	−0.18	(−1.49, 1.14)		
Yes	Yes	Yes	Yes	**−2.13*****	**(−3.73, −0.52)**	**−1.96*****	**(−3.18, −0.74)**
N				708		708	
R^2				0.16		0.16	

Notes: Linear regression models. $F(32, 675) = 5.09$, $p < 0.001$ (Model 1), $F(14, 693) = 10.5$, $p < 0.001$ (Model 2) Significance levels: ***1%, **5%, *10%. Reference categories: London Finchley Road, age 35–54, distance to the road ≥400 m, male, does not live alone, does not have university degree, not employed, health condition as fair, good or very good, perceives both traffic volume as not heavy and speed as not fast and does not report any traffic impact (either as barrier affecting ability to walk to local places or as a specific reason to avoid walking along or crossing the busiest road).

barrier to walking locally *and* as a specific reason to avoid the busiest road.

Our findings also showed that the associations between traffic conditions and walking extended beyond these combinations (Table 6). For example, perceiving the speed of traffic as 'fast' but the volume as not heavy (i.e. 'light/average') was associated with reporting one of the negative impacts of road traffic on walking, but not both. Likewise, perceiving the traffic volume as 'heavy' but the speed of traffic as not fast (i.e. 'slow/average') was associated with one of the negative impacts of traffic on walking – as a reported barrier to walking locally – but was not associated with avoidance of the busiest road.

In addition, we found that the joint perception of the traffic volume as 'heavy' *and* the traffic speed as 'fast' was associated with a number of objective indicators of traffic volumes/speeds, including the proportion of HGVs in the total traffic volume, and how the current median speed related to the historical and the reference (free-flow) median speeds, and with the current maximum speed (Table 5).

Overall, our study demonstrated that the use of a single aspect of traffic conditions (volume or speed) will not capture the full negative impacts of motorised traffic on walking and on the wellbeing of local residents living close to busy roads. This finding was reinforced by our results which showed that the groups most likely to perceive the speed of traffic on the busiest road as being ‘fast’ were different to those perceiving the traffic volume and speed as being both ‘heavy’ and ‘fast’ respectively (Table 5).

Finally, we found that the street network distance that participants lived from the busiest road was not significantly associated with their perceptions about the traffic conditions (Table 5). Living closer to the busiest road was associated, however, with reporting that the traffic was a barrier to being able to walk to local places, independently of perceptions of traffic volume and speed (Table 6). Living closer to the busiest road was also independently associated with higher wellbeing (Table 7), possibly reflecting unobserved influences such as accessibility to shops, transport nodes (stations and bus stops), and other facilities.

Our findings add further knowledge to the previous studies which observed a link between wellbeing and proximity to main roads (Brereton et al., 2008; Yamazaki et al., 2005) or traffic volumes (Gundersen et al., 2013). The present study emphasized the role of the perceptions that local residents have about different aspects of road traffic conditions in mediating the links between living close to busy roads and wellbeing. Our findings also provide evidence suggesting that busy roads correlate negatively with wellbeing through the intermediate effect on walking, reinforcing the “community severance” hypothesis that was formulated in the 1970s but had never been confirmed in empirical studies (Mindell and Karlsen, 2012).

5.2. Policy implications

Our analyses of wellbeing (Table 7) suggest that policy interventions aimed at addressing the well-established links between busy roads and the wellbeing of local residents living close to busy roads should aim to reduce both the volume and the speed of traffic in order to reduce their impact as physical and/or psychological barriers to walking and as a specific reason for people to avoid walking. Similarly, our analyses of the reported impacts of the subjectively perceived traffic conditions on walking (Table 6) suggest that it is the joint perception of the ‘heavy’ traffic volume and the ‘fast’ speed of traffic that correlates with reporting the traffic as a barrier to being able to walk locally and as a reason to avoiding using busy roads. Effective transport policies designed to increase walking levels therefore must simultaneously reduce both traffic volume and speed. Reducing both could be achieved by a combination of policies, for example, economic or regulatory policies to reduce the use of private cars and promote alternatives, thus reducing traffic volume, and at the same time imposing speed limits or using traffic calming measures to reduce traffic speed.

Our analyses also showed specific associations between a number of objectively measured traffic conditions and subjective perceptions of those conditions (Table 5). Traffic composition (the proportion of traffic being HGVs) and various indicators of traffic speed (higher ratios between current/historical and historical/reference speeds; and a larger difference between the current maximum and median speeds) were significantly associated with survey participants jointly perceiving the volume and the speed of traffic as ‘heavy’ and as ‘fast’, respectively. Road traffic policies should therefore prioritize the reduction of HGV traffic and the reduction of traffic speeds at the times of the day when they are highest, or on the particular sections of roads where the average speed exceeds the levels local residents would expect from historical values (i.e. from their previous experience) and from reference values (i.e. from the characteristics of the road).

Finally, our analyses showed that the perceptions of traffic volume were associated with a number of objective measures of traffic speed and vice-versa (Table 5). Reducing the daily volume of traffic at the times of the day when the traffic moves fast, for example, may improve residents’ perceptions about the volume of traffic. In addition, improving the quality of pedestrian infrastructure (e.g. pavements and paths) or adding new signalized crossing facilities might counteract the negative perceptions of road traffic conditions, even in the absence of reductions in the volume or speed of daily traffic.

Overall, the findings of this study emphasize that policies to improve walking levels need to attend more explicitly to the impact of motorised traffic on pedestrians and to the specific characteristics of that traffic. For example, the UK government's latest strategy on walking (UK DfT, 2017) mentions the role of traffic calming measures to reduce traffic speeds, as well as the improvement of pedestrian crossing facilities to minimize pedestrian-motor vehicle conflicts. However, the strategy does not explicitly call for a reduction in traffic volumes.

6. Strengths and limitations

The major contribution of this study was to integrate separate strands of research by using an integrated framework to examine the associations between traffic, walking, and wellbeing. We also filled gaps in the current literature by highlighting the importance of joint perceptions of traffic volume and speed and their influences on walking and on wellbeing. Although the overall sample size of our study was reasonable, we may have lacked sufficient statistical power to detect differences between subgroups. Nevertheless, our results provide persuasive evidence that the combination of negative perceptions of road traffic conditions and the reported impacts of them on walking negatively correlate with wellbeing.

The study also has a number of limitations. We looked at a generic scenario of motorised traffic affecting walking in the local area. However, we did not examine all the features of the walking experience that might influence perceptions about traffic, for example the quality of crossing facilities (including provision for people with disabilities or restricted mobility), waiting times at signalized crossing facilities, problems caused by temporary road works, the conditions along the routes people take to the busiest road, and the busiest road’s design characteristics (e.g. number of lanes and the presence of a central reservation) which, as previously mentioned, are only partially captured in our analyses by the dummy variables indicating the case study area in which participants lived.

The negative impacts of traffic on walking were also narrowly defined in our study in terms of general ability to walk locally and avoidance of the busy road. However, traffic may have wider impacts through influencing the overall number of walking trips made, the total amount of time spent walking, and the choices that residents make over the destinations, routes, and time patterns of walking trips. In addition, the impacts of traffic probably depend on trip purpose. It is likely that non-essential walking trips of a recreational or social nature are more sensitive to traffic conditions than essential trips (e.g. for commuting), due to greater flexibility for adapting travel behaviour. It should also be noted that while we tested separate associations between impacts on walking and perceptions of traffic and between these perceptions and objective traffic conditions, an alternative approach, with possibly different results, would be to test the associations between impacts on walking and the extent to which perceived traffic conditions diverge from the objective conditions.

The need to place some of the key survey items into a specific spatial and temporal context also reduced our ability to capture the full scope of impacts of traffic. For example, we defined the local area in our study as being ‘everywhere within a 20 min walk or about a mile of your home’. However, residents’ perceptions of their local area could be either self-defined neighbourhoods or ‘activity spaces’, which include not only the area where they live but also the places where they go on a daily basis (Tribby et al., 2017). In addition, in comparison to the full

14-item instrument (WEMWBS), the shortened 7-item version (SWEMWBS) used in our study captures a more restricted definition of wellbeing as it mainly encompasses hedonic items (happiness and life-satisfaction), excluding the eudaimonic items that refer to people's psychological functioning, social relationships, and sense of purpose (Ng Fat et al., 2017). As with the full instrument, the list of statements in the SWEMWBS refers to feelings and thoughts over the previous two weeks, which are not necessarily representative of individuals' habitual mental wellbeing.

The survey sample and choice of case study areas also limited the scope of our work. Our study focused on persons aged 18 years and over. However, previous studies have shown that traffic impacts negatively on the independent mobility of children (Hillman et al., 1990). The choice of urban case studies also meant that we were unable to provide a full insight of the associations between road traffic conditions, walking, and positive mental wellbeing, as it is possible that these associations are stronger in rural areas (Poole, 2003). There is also evidence that the associations between built environment and walking vary in space (Feuillet et al., 2016), and as such estimating average associations across study areas may mask variations within each area.

Our study was cross-sectional, therefore we cannot rule out the possibility of reverse causation; our findings must also be interpreted with caution due to the inevitable problem of residual confounding. Road traffic conditions may be associated with wellbeing via other indirect pathways such as being capitalized in house prices and rents, or influencing land-use or types of housing in the areas surrounding busy roads. These effects may then lead to changes in the socio-economic composition of the population in those areas, resulting in stronger associations between proximity to busy roads and the residence location of population subgroups typically vulnerable to lower wellbeing such as lower income groups.

Finally, the datasets available to use in this study – in particular the items captured by the survey questionnaire – restricted our choice of analytical strategy. Our approach, using a sequence of three regression models, is a simplification, as we modelled wellbeing as a function of combinations of perceptions of traffic and its impacts on walking. A more complex alternative would be a structural equation model (SEM) using multiple indicators of interlinked latent variables. SEM has been used for example to study the relationships between use of motorised transport modes and life satisfaction (De Vos, 2018). Linear regression was used in our study as previous empirical work confirmed that the wellbeing scale satisfied the condition of strict unidimensionality (Stewart-Brown et al., 2009). Furthermore, SEM typically relies on the assumption that the observed variables are measured on a continuous scale, while in our study the participant perceptions and reported impacts of traffic on walking were only captured by single items with limited response options. The greatest challenge for this type of research is then to collect datasets and define methods that take into account the multiple associations between all the relevant variables.

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