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Health impacts of the Cambridgeshire Guided Busway

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1. Aims/Objectives:
Aims

1. To assess the magnitude, nature and population distribution of changes in the travel behaviour of commuters who travel to work in Cambridge associated with the opening of the Cambridgeshire Guided Busway

2. To identify, explore and explain the wider health impacts of any observed changes in travel behaviour, specifically in terms of changes in overall physical activity energy expenditure, wellbeing, sickness absence, and carbon emissions.

Objectives

1. To repeat the self-reported measures of shift working patterns, psychosocial constructs, travel behaviour, physical activity and general health and wellbeing collected at baseline by means of a follow-up questionnaire survey

2. To repeat the objective measurement of physical activity using accelerometers ('basic activity monitoring') in the subgroup of participants who completed this at baseline

3. To characterise the context and content of the intervention and its effects on the population by describing the geography and experience of the typical travel patterns of subgroups of participants who do, and who do not, use the busway in a longitudinal qualitative study of a further subgroup of participants

4. To quantify as precisely as possible the physical activity energy expenditure, travel and movement patterns and carbon emissions associated with using different combinations of modes of transport in an additional in-depth study of a further subgroup of participants using combined heart rate and movement sensors, global positioning system (GPS) monitors and household travel diaries ('enhanced activity monitoring')

5. To test the following specific longitudinal hypotheses:

(i) That the opening of the busway is associated with a modal shift (a change in the distribution of modes of transport used) for commuting to and from work, and for overall travel, in the intervention group significantly greater than any modal shift observed in the control group after adjusting for differences in the demographic, socioeconomic and baseline physical activity and health profile of the two groups

(ii) That a modal shift from car to bus for commuting to and from work is associated with an increase in active travel (walking and cycling) as part of the journey to work

(iii) That the observed effects on travel behaviour vary according to the demographic and socioeconomic characteristics of participants and the locations of their homes and workplaces

(iv) That the observed effects on travel behaviour are accompanied and mediated by changes in predicted mediating psychosocial constructs such as behavioural intention and habit strength

(v) That an increase in active travel on the journey to work is associated with an increase in overall physical activity energy expenditure and, as more exploratory hypotheses, with improvements in self-reported wellbeing and sickness absence

(vi) That the population distribution of the benefits associated with the intervention — whether in terms of improved access to the opportunity for active travel to work, or in terms of observed changes in active travel, physical activity or wider health impacts — favours the least well off and those with the lowest baseline levels of physical activity.

2. Background:

Physical inactivity increases the risk of many chronic diseases including coronary heart disease, type 2 diabetes and cancer of the colon.[1] Accumulating 30 minutes of moderate intensity physical activity on most days is enough to provide substantial health benefits, [2] but most adults in the UK do not currently achieve this.[1][3][4] Increasing the population level of physical activity, particularly among the most sedentary, has been described as the 'best buy' for improving public health[5] and has become a leading aim of contemporary public health policy.[6][7]

Until recently, efforts to promote physical activity have focused on promoting sport, recreation or health-directed exercise.[8] However, there is little evidence that such approaches are effective in increasing physical activity in the medium-to-long term.[9] On the other hand, there is increasing evidence that patterns of physical activity may be related to the physical environment in which people live and travel. For example, numerous studies have shown that people who live in more 'walkable' neighbourhoods tend to walk more.[10]

Most research in this field to date has been conducted in North America or Australia, and may therefore be of limited relevance to the UK. More significantly, evidence-based guidance on physical activity and the environment recently issued by NICE has drawn attention to the lack of studies examining whether changing the physical environment leads to changes in patterns of physical activity.[11] NICE has specifically identified a need for more, and more rigorous, studies of this kind involving longitudinal designs, control groups, and robust measurement of physical activity. One way of conducting such studies is to take the opportunity to observe what happens when new services or facilities are made available to a population — a comparatively underused approach to applied public health research sometimes described as a study of a 'natural experiment'.[12]

The Cambridgeshire Guided Busway

When the Cambridgeshire Guided Busway (CGB) opens in late 2009, it will be the longest of its kind in the world (www.cambridgeshire.gov.uk/transport/ thebusway). This major new piece of transport infrastructure will link towns and villages to the northwest of Cambridge with the Cambridge Science Park, the city centre and the Cambridge Biomedical Campus at the Addenbrooke's Hospital site on the southern fringe of the city, a site that is said to generate more traffic than any other in the East

of England. Buses will run on a completely segregated track along most of the route, avoiding traffic congestion both on the A14 approaching Cambridge and between the railway station and Addenbrooke's. A new high-quality bidirectional off-road cycle route will also be provided adjacent to the busway. The busway is central to the plans for the new town of Northstowe, which is to be built adjacent to the route, and the busway concept may be extended to other radial routes into Cambridge in the future.

The purpose of the busway is to make public transport journeys in this transport corridor faster, more reliable and more attractive, thereby promoting a modal shift from car travel to public transport and reducing traffic congestion, air pollution and carbon emissions.[13] These are highly desirable goals in their own right. However, the busway also has the potential to contribute to achieving the public health goal of promoting regular physical activity, which reduces the risk of chronic disease and premature death.[1] Enabling people to incorporate moderate-intensity physical activity into their daily routine can help to increase overall levels of habitual energy expenditure, especially in more sedentary groups. If commuters living near the route who currently travel to work in Cambridge by car shift to using the bus, their journey to work is likely to include a period of walking or cycling at either end of the journey.[14] Some commuters may also be motivated by the provision of a new off-road cycle route to begin cycling the entire journey to work.

Rationale and justification for this study

If it could be demonstrated that investing in new, high-quality transport infrastructure led to an increase in physical activity in the population, the cost-benefit case for future investment in similar projects would be considerably strengthened. At present, however, making this case depends on a number of assumptions or unproven hypotheses that require to be empirically tested, reflecting the fact that the relationships between infrastructural interventions and changes in behaviour, between public transport and active travel, and between active travel and overall physical activity all remain somewhat uncertain at present.[11, 15]

First, it cannot be assumed that substantial numbers of people will change their travel behaviour as predicted by the transport modelling for the busway. Although much of the route will be completely segregated from normal traffic, buses will still have to use existing roads for part of their route within the city. The Cambridge sub-region is a predominantly rural and comparatively affluent area with historically poor provision of rural public transport and a high level of car ownership in rural areas.[16, 17] Rural dwellers who already own a car and are accustomed to having to use it for many of their regular journeys may not easily be persuaded to leave their car at home, particularly if the new bus services are regarded as too expensive, too infrequent, too inflexible or too slow to compete.

Second, it cannot be assumed that people who do use the guided busway will walk or cycle more as a result. For example, a commuter working at Addenbrooke's may currently drive to work and park at an outlying car park on the site, several hundred metres from their actual place of work. If this person were to shift to the bus and be dropped off by car at the bus stop nearest to their home (so-called 'kiss-and-ride'), the increase in walking may be marginal or zero. Conversely, city dwellers who currently cycle to work may find that the new guided busway offers a more congenial

way of travelling to work and abandon regular cycling.

Third, it cannot be assumed that people who take up a more physically-active regular journey to work will become more physically active overall. The increase in energy expenditure while travelling may be counterbalanced, or even outweighed, by a compensatory decrease in other activities such as those undertaken at home (e.g. gardening) or during lunch breaks at work (e.g. walking, swimming or aerobics classes).[18]

Nonetheless, the guided busway clearly has the potential to transform travel behaviour in the corridor it serves and bring about important transport, environmental and health benefits. We therefore propose to take the opportunity presented by this 'natural experiment' [12, 18] to carry out a robust quasi-experimental study of the effects of a major infrastructural intervention on travel behaviour, physical activity and related wider health impacts that will also contribute to addressing related unresolved research questions in the field of physical activity and public health. This study will represent an important step forward in developing and demonstrating methods for the rigorous evaluation of cross-sectoral benefits of interventions, such as those outlined in new MRC guidance on evaluating complex interventions,[19] and will contribute new evidence on questions of interest not only to the public health and transport research communities, but also to employers, local authorities, NHS organisations and other stakeholders, particularly on two key unresolved questions which are topical and important for both public health and transport policy:

1. Can investment in new, high-quality transport infrastructure change the way people travel?

2. What are the wider health impacts of those changes in travel behaviour in the areas of physical activity, wellbeing, sickness absence and carbon emissions?

The key unique contributions of this study lie in:

1. Its interdisciplinary nature: the study involves a collaboration between public health, environmental sciences and transport researchers and a combination of quantitative and qualitative approaches to gathering and analysing data[20]

2. Its capacity to track changes in the population benefiting from the new transport infrastructure over time and in comparison with a control group[15][11]

3. Its robust approach to measurement: very few previous studies of transport projects have included any measure of physical activity, let alone the combination of questionnaire surveys and repeated activity monitoring proposed in this study.[15][11]

3. Methods:

a. Setting
The phase 2 study population will comprise the cohort of adults recruited in phase 1 (see below) supplemented by further limited recruitment in phase 2 of new participants meeting the same criteria to offset the loss of members of the original

cohort who leave the area between phase 1 and phase 2. The detailed inclusion and exclusion criteria for recruitment to the study remain as stated in the phase 1 protocol and subsequent approved amendments and will be applied again in phase 2 as follows.

b. Design

Overall study

A controlled observational quasi-experimental cohort study of commuters who travel to work in Cambridge, including nested in-depth quantitative and qualitative studies in subgroups of the study cohort.

Phase 1 study

The phase 1 study comprised the recruitment of the study cohort (target n~1000), a baseline questionnaire survey, baseline activity monitoring, and a set of baseline qualitative interviews. A total of 2163 people responded to the phase 1 recruitment activities and registered their willingness in principle to participate, of whom 1581 met the inclusion criteria and were invited to take part; of these, 1115 (71%) have taken part to date as follows:

- 1115 have returned a baseline survey and consent form, of whom
- 501 have also completed optional baseline activity monitoring, and
- 19 have also completed an optional baseline qualitative interview.

The target cohort sample size having been achieved, phase 1 recruitment has now ceased and phase 1 data collection is currently being wound up.

Phase 2 study

The phase 2 study — the subject of the current application — comprises the first year of follow up and will take place during 2010.

Inclusion criteria

The study population will comprise all those who work in areas of Cambridge served by the Cambridgeshire Guided Busway and live within a radius of approximately 30 kilometres. Participants' eligibility in these terms will be assessed by matching their home postcode to a list of unit postcodes that lie within the radius of the city centre that defines the study area and by asking them to identify the area of their workplace from a list as follows:

- The Addenbrooke's site (also known as the Cambridge Biomedical Campus)
- (including Long Road Sixth Form College)

- The Cambridge Science Park and Milton Road area (e.g. Cambridge Regional
- College, Cambridge Science Park, Cambridge Business Park, Cowley Road, St
- John's Innovation Centre, Milton Tesco)

- The Castle Hill area (e.g. Shire Hall)

- The Parkside and Grafton Centre area (e.g. Anglia Ruskin University, Kelsey

- Kerridge, fire station, police station)

- The railway station and Brooklands Avenue area (e.g. Cambridge Leisure,
- Cambridge University Press, Government Office, Hills Road Sixth Form
- College)

- Histon (e.g. Vision Park)

- Trumpington (e.g. Waitrose)

- Cambridge city centre (e.g. central colleges and departments of the University of Cambridge, Grand Arcade, Guildhall, Trinity Street).

This definition includes:

- All those routinely travelling to work irrespective of their employer, workplace, length of employment contract or working hours, irrespective of whether they also work at other locations, and irrespective of any disability that may limit their mobility

- Postgraduate students and clinical students in medicine, nursing, midwifery and allied health professions based at the Addenbrooke's site.

Exclusion criteria
Participants will not be eligible to participate if they:

- Are currently participating in *Get Addenbrooke's Active*, a randomised controlled trial of physical activity promotion among hospital staff which is expected to begin recruitment at some time during the period of this study, or another research study that involves measuring their physical activity

- Are resident in on-site staff accommodation associated with their workplace and therefore do not routinely commute to the site.

Recruitment of new members of the study cohort
Numerous public and private sector employers in Cambridge have already facilitated recruitment to the phase 1 study. Additional participants will be recruited through the same employers, and any other local employers who indicate a willingness to take part, using one or more of the following methods already used in phase 1:

- Announcements distributed on the investigators' behalf by employers (or institutes, units or departments within the larger employers) through their corporate email distribution lists, intranets or staff newsletters

- Posters and fliers displayed on the investigators' behalf by employers (or institutes, units or departments within the larger employers) on noticeboards staff rooms, dining rooms or other suitable locations

- Advertisements and announcements in print media such as leaflets,

community newsletters and local newspapers circulating in the area from which potential participants commute to work

- Posters and fliers displayed in public places such as health centres, libraries, community centres and public transport facilities in the area from which potential participants commute to work

- Stalls staffed by research assistants at locations and times at which a high throughput of staff or commuters is expected, such as in the hospital concourse at lunchtime, in staff car parks, or in public places elsewhere in the area from which potential participants commute to work.

Recruitment will proceed as follows:

1. The research team will negotiate with each organisation which methods of recruitment may be used within their organisation

2. Employers will be asked to distribute announcements or display posters on behalf of the research team, but will not be asked to supply the research team with mailing lists or other identifiable data concerning their workforce

3. Announcements, posters and fliers will invite potential participants to express their interest by entering their details on an online expression of interest form (www.cambridgecommutingstudy.org.uk) or by contacting the study office directly by telephone (to a freephone number) or email

4. Where research assistants are present in person, for example at a recruitment stall, potential participants will also be able to enter their details on a paper expression of interest form

5. Participants who wish to express their interest in taking part in the study will enter their contact details and very limited sociodemographic data on the online or paper expression of interest form

6. All those expressing an interest in this way will be screened for their eligibility to participate in the study. Those selected (see below) will subsequently receive a survey pack by post

7. All those who choose to return a completed questionnaire and consent form from the survey pack will be deemed to have given informed consent to participate in the study and will be entered into the phase 2 prize draw (see below)

8. Reminder survey packs will be sent to non-responders two weeks after the original mailing. No further attempt will be made to coerce non-responders into participating, except that further attempts will be made to contact participants who have not returned an activity monitor to request the return of the device.

Approach to original members of the study cohort
All members of the cohort who consented at baseline to being approached for a

follow-up study will be invited to take part in phase 2 as detailed below. Those who agree will be entered into the phase 2 prize draw to win one of eight £50 gift vouchers, which we regard as an appropriate response to the well documented decline in response rates to questionnaire surveys in health research.

Allocation of participants to intervention and control groups
Members of the cohort have been allocated to 'intervention' and 'control' groups after recruitment on the basis of their home postcodes. A similar procedure will be applied to newly recruited members of the cohort in phase 2. As described in the phase 1 protocol, an intervention area has been defined comprising a set of unit postcodes that fall within, or encroach upon, either (a) a 600 metre network distance buffer around the stops along the urban sections of the route or (b) a larger polygon encompassing the towns and villages along the rural sections of the route. Participants whose home postcode lies within this area constitute the intervention group, and those whose home postcode lies outside it constitute the control group. However, as described in the phase 1 protocol, the influence of the guided busway will not, in practice, be limited by any arbitrarily-selected distance buffer. The assumptions implicit in defining the boundaries of the intervention and control areas will subsequently be tested by:

- Comparing the results of two alternative approaches to analysis: one in which exposure to the intervention is defined *a priori* in terms of place of residence (as above), the other in which exposure to the intervention is defined *post hoc* in terms of actual reported use of the guided busway. This comparison would be somewhat similar to that between an intention-to-treat analysis and a per-protocol analysis in a clinical trial

- Entering the network distance from home to the nearest guided busway stop or access point as a covariate in analysis of the effect of the intervention on travel behaviour.

Both approaches may be viewed as a form of sensitivity analysis of the effects of the decisions made in defining the intervention and control areas, and may reveal unexpected findings about the distances participants are prepared to walk, cycle or drive to gain access to the guided busway.

c. Data collection
Phase 2 data collection will comprise three elements already used in phase 1 (questionnaire survey, basic activity monitoring and semi-structured interviews) and two new elements (household travel diaries and enhanced activity monitoring).

Questionnaire survey
Core questionnaire data will be collected from each participant using a written questionnaire distributed by post to the participant’s home or work address (whichever they have chosen to supply for study correspondence) and returned by reply-paid envelope, except that if a participant chooses to opt in to the enhanced activity monitoring study (see below), they will receive their questionnaire as part of a package given to them in person by a research assistant.

The questionnaire will be very similar to that issued in phase 1, being based on the

Recent Physical Activity Questionnaire (RPAQ) extended with additional elements as detailed below.

RPAQ has recently been selected as the preferred instrument for assessing self-reported physical activity in the enhanced component of the UK Biobank study (www.ukbiobank.ac.uk). It was developed at the MRC Epidemiology Unit and is designed to ascertain self-reported physical activity in the past four weeks in three sections: (a) physical activity at home, (b) physical activity on the journey to work and at work, and (c) recreational activity, from which physical activity energy expenditure (PAEE) and total energy expenditure (TEE) are estimated using an established algorithm. RPAQ is closely based on the previously-validated EPAQ2 questionnaire[21] developed for the EPIC-Norfolk cohort study and subsequently also used in intervention studies such as the ProActive trial,[22] but takes the past four weeks rather than the past year as its reference period. A validation study of RPAQ using healthy Cambridge volunteers aged 21–55 has shown the estimated PAEE to have relatively strong criterion validity (r=0.43) against PAEE objectively assessed using the doubly labelled water technique.[23]

The questionnaire will also include:

1. An instrument to ascertain the use of different modes of transport on the journey to and from work on each of the last seven days, closely based on a travel diary used (and shown to have acceptable test-retest reliability in terms of travel mode choice) in a previous study of active commuting on a university campus[24]

2. An instrument to ascertain all journeys undertaken on the previous day, the purpose of each journey and the time spent using each mode of transport, previously used in the M74 study in Glasgow[25] and adapted and simplified from the travel diary used in the UK National Travel Survey[26]

3. Items to ascertain the perceived characteristics of the travel environment en route to work previously used (and shown to have acceptable test-retest reliability) in the M74 study in Glasgow[25, 27]

4. Items to measure mediators of changing travel mode choices predicted by the Theory of Planned Behaviour, previously used in a public transport intervention study[28]

5. The Self-Report Index of Habit Strength applied to car use[29]

6. A new set of items on awareness, perceptions and use of the Cambridgeshire Guided Busway adapted from those used in the National Statistics Omnibus Survey

7. A new set of items on road accidents in the past three years adapted from those used in the National Travel Survey and the Scottish Household Survey

8. A single item on self-reported sickness absence in the past year, responses to which have been shown to be strongly correlated with sickness absence

objectively verified from employment records in the Whitehall study, and to have as strong an association with other measures of health as objectively verified sickness absence[30]

9. The SF-8 questionnaire for assessing general physical and mental health (adapted from, calibrated to and validated against the longer and widely-used SF-36 scale)[31, 32]

10. Standard items on selected other characteristics of participants and their households, including access to cars and bicycles, possession of a driving licence, presence of long-term limiting illness or disability, difficulty walking and self-reported height and weight, all taken or adapted from the census or established national population surveys and, in most cases, previously used in the M74 study.[25]

For existing members of the study cohort, survey packs will be posted to participants on a date in 2010 as close as possible to the date in 2009 on which they completed their baseline survey to minimise the influence of seasonal variation in travel behaviour and physical activity. Participants were advised of the intention to approach them again for these follow-up surveys in the participant information leaflet for the phase 1 study and only those who have explicitly consented to being approached again in this way will receive a follow-up questionnaire.

Household travel diaries
Existing members of the study cohort will also be given the opportunity to opt in to completing a household travel diary along with their core questionnaire survey. This will be included in the survey pack posted to all participants who indicate their willingness to receive this, except that if a participant chooses to opt in to the enhanced activity monitoring study (see below), they will receive their household travel diary as part of a package given to them in person by a research assistant.

The purpose of collecting household travel diary data is:

To explore the inter-relationships of travel behaviour within households, such

- as the influence of the need to take children to school on the way to work, or the additional opportunity for car use by other members of the household created by a commuter's decision to cycle to work and leave the car at home

- To provide more extensive travel data from which to estimate the effects of any changes in travel behaviour on overall household travel-related carbon emissions

- To provide a seven-day travel diary for the index case (main participant) in each household for comparison with contemporaneous objective measurements where these are collected (see below).

Participants (target n~400, 200 from the intervention group and 200 from the control group) will be invited to complete a seven-day household travel diary based closely on that used in the National Travel Survey[26] in addition to the core questionnaire survey. The index case (main participant) in each household will be asked to

complete the diary day by day during the seven day monitoring period with or on behalf of all members of the household. The identify of these other members of the household will not be ascertained and they will not be participants in the study as such; the study participant will report all household travel on behalf of the rest of the household.

Basic activity monitoring

Participants who completed optional basic activity monitoring in phase 1 will receive with their follow-up questionnaire an Actigraph activity monitor and an instruction and log sheet similar to those already used in phase 1, except that if a participant chooses to opt in to the enhanced activity monitoring study using an Actiheart activity monitor (see below), that will replace the Actigraph activity monitoring they would otherwise have been asked to undertake and they will not be asked to do both. Participants were advised of the intention to approach them again in this way in the participant information leaflet for the phase 1 study, and only those who have explicitly consented to being approached again in this way will receive a follow-up activity monitor. The Actigraph is a small, lightweight accelerometer that provides detailed information about the intensity, frequency and duration of physical activity and has been extensively validated in both laboratory and free-living conditions.[33] Participants will be asked to wear their monitor on an elastic waistband on the right hip during waking hours for seven days, removing it only for bathing, showering and swimming, and recording on the log sheet the times at which the monitor was removed and reattached and the reasons for removal. Participants will be asked to return their monitor at the end of the seven day period either by special delivery in a reply-paid padded envelope or by hand to the MRC Epidemiology Unit. Participants will be free to choose not to repeat basic activity monitoring at follow-up, in which case they will be asked to complete the questionnaire and to return their activity monitor unused.

Newly recruited participants in phase 2 who indicate their willingness in principle to take part in basic activity monitoring will receive a similar survey pack, except that if the number of willing volunteers should exceed the number of available monitors, the monitors will be issued to a random sample of willing participants and the remainder will receive only a questionnaire.

Enhanced activity monitoring

Prior to the start of phase 2 data collection, participants who completed optional basic activity monitoring in phase 1 will be invited to take part in an optional enhanced activity monitoring study to replace the basic activity monitoring they would otherwise have been asked to repeat in phase 2. Participants were advised of the intention to approach them again in this way in the participant information leaflet for the phase 1 study, and only those who have explicitly consented to being approached again in this way will receive such an invitation.

Participants will be invited to take part in two simultaneous forms of enhanced activity monitoring over a seven day period. These will provide for more detailed characterisation of differences both within and between the intervention and control groups after adjustment for baseline covariates. Participants will be free to opt out of either of these elements or to decline altogether. Those who accept the invitation to take part in one or both elements of the enhanced activity monitoring study will be

invited to attend a short meeting with a research assistant at the MRC Epidemiology Unit, at the Unit's outstation at the Princess of Wales Hospital in Ely, or at another convenient location such as the participant's workplace. At this meeting, the research assistant will briefly explain and demonstrate the use of the relevant monitoring tools following a standard operating procedure (SOP), answer any questions, supply the participant with the appropriate devices and questionnaires, and agree the most appropriate method for these to be returned (by hand to the MRC Epidemiology Unit, by post using a reply-paid special delivery envelope, or by a research assistant collecting them from the participant's home or workplace).

The two devices to be used in the enhanced activity monitoring study are as follows:

- Actiheart combined heart rate and movement sensors
- Global positioning system (GPS) monitors.

The purpose of collecting Actiheart and GPS data, both separately and in combination, is to maximise the precision of measurement of travel behaviour and physical activity energy expenditure (PAEE) in a subgroup of participants, thereby providing robust objectively-measured data from which to:

- Determine the (combinations of) travel modes used by participants

- Estimate the PAEE involved in using different (combinations of) modes of transport

- Test the hypothesis of activity substitution between domains (e.g. that an increase in active travel may be compensated for by a decrease in leisure-time physical activity)

- Estimate the contribution of active travel to overall PAEE and thereby estimate the effect of the guided busway on overall PAEE

- Identify the physical characteristics of the routes used by participants to travel to and from work and thereby examine associations between route characteristics and travel mode choice

- Establish the criterion validity of alternative methods of ascertaining active travel. Some participants (target minimum n~30, 15 from the intervention group and 15 from the control group) will complete household travel diaries and both elements of the enhanced activity monitoring study. Data from this overlap group will enable us to validate the estimates of active travel obtained using questionnaires, travel diaries and accelerometers against the criterion of active travel ascertained from combined Actiheart and GPS data. The purpose will be to inform the optimal choice of measurement instruments for future intervention studies of this kind, which necessarily involves a trade-off between the validity, feasibility, acceptability and cost of the various instruments available ranging from questionnaires (relatively cheap and acceptable to participants, but of uncertain validity) to combined heart rate and movement sensors (relatively expensive and somewhat less convenient for participants).

Actiheart combined heart rate and movement sensors. The Actiheart is a lightweight waterproof combined heart rate and movement sensor that clips onto two standard electrocardiogram (ECG) electrodes on the chest and measures acceleration, heart rate, heart rate variability and ECG amplitude. It has been shown to be a reliable and valid tool for measuring both acceleration and heart rate and therefore offers a more accurate assessment of physical activity energy expenditure (PAEE) than accelerometry alone, particularly for activities such as cycling which are not optimally ascertained using hip-worn accelerometers.[34] It has been successfully used in previous free-living population studies,[35] for which individual calibration is not required since a simple calibration protocol based on sleeping heart rate and gender has been shown to be adequate for free-living studies.[36]. Participants (target n~200, 100 from the intervention group and 100 from the control group) will be asked to wear an Actiheart monitor for seven days. The accelerometer component of the Actiheart will provide the equivalent of the phase 2 basic activity monitoring (Actigraph) data for these participants.[34] About 10% of Actiheart users may experience a minor skin rash associated with the chest electrode. Participants will be informed of this risk in the participant information sheet and at the time of their meeting with the research assistant, and will be asked to contact the study office by telephone or email should they experience any adverse effects while using the device.

Global positioning system (GPS) monitors. GPS monitors are used to record the spatial coordinates (i.e. latitude and longitude) of participants at ten-second intervals. The Garmin Forerunner 205 is similar to a large wristwatch, has a battery life of 10-13 hours in normal use, can store up to 4 days' worth of data in onboard memory, and does not suffer from the loss of satellite signal when in a vehicle, close to high buildings, or under tree canopy that affect some alternative GPS monitors. Participants (target n~200, 100 from the intervention group and 100 from the control group) will be asked to wear a GPS monitor during waking hours for the first four days of their enhanced activity monitoring period, switching it off at all other times and recharging the batteries overnight. This is a simple procedure with which participants in our previous research studies have shown a high degree of compliance.[35] GPS monitor technology is continually improving, and if a new model should become available before the start of phase 2 data collection that offers greater memory, convenience for participants or both (e.g. by allowing data collection to extend over seven days, or by reducing or eliminating the need for overnight recharging) we will consider substituting the new model for the Garmin Forerunner 205 (subject to verification of the quality of the data recorded by the new model) and will update the participant information sheet and instruction sheet accordingly.

Semi-structured interviews

Participants who completed a semi-structured interview at baseline will be invited to take part in a follow-up interview during 2010. Participants were advised of the intention to approach them again in this way in the participant information leaflet for the phase 1 study and only those who have explicitly consented to being approached again in this way will be invited to take part in a follow-up interview.

Following preliminary analysis of the baseline quantitative survey data, the existing pool of interview participants (those who took part at baseline) will be expanded by

inviting selected additional members of the overall study cohort (including those newly recruited in phase 2) to take part in a follow-up interview. The objective will be to gradually assemble an overall interview sample to include a mixture of men and women, different age groups, people living in different types of household (e.g. singles, couples, families), people living and working in different areas, and people using different modes of transport at baseline. A final sample of between 40 and 60 participants is envisaged, the intention being to continue sampling until saturation appears to have been reached with respect to the main research themes (in other words, a point has been reached at which key themes are being repeated in subsequent interviews and no new themes are being generated, suggesting that interviewing more participants would add little value to the data already collected).

Interviews will be conducted one-to-one in participants' homes, workplaces or other convenient locations at the participants' choice. Each interview will last for approximately 30 minutes (but may last for up to 60 minutes with the participant's agreement) and will be semi-structured using a flexibly-applied topic guide. Each interview will begin with a brief review of the notes of the participant's baseline interview (for those who took part at baseline) followed by an identification of the origin and destination of the participant's usual commuting journey, the usual route followed and the (combination of) mode(s) of transport usually used, and whether these have changed since the previous year. The researcher will then explore the reasons for these choices, the availability of alternatives, what factors influence the choice between these options, and whether these factors have changed since the previous year. The researcher will also elicit variations on the typical journey and reasons for those variations, such as the need to accommodate shift working patterns or transport children. Finally, the researcher will explore whether participants have any expectation or intention of changing their travel mode choices, the barriers to and facilitators of making such changes, and their views as to why other people may have made other choices. Each interview will be recorded using a digital voice recorder and subsequently transcribed. Field notes will also be written by the researcher during or immediately after each interview.

Sample size estimation

The sample size estimation for the overall study was given and justified in the phase 1 protocol. Briefly, an achieved overall sample size of 788 at follow−up (788 in total) is estimated to have 80% power to detect a realistic effect of the intervention in terms of a mean increase in active commuting time of 2 min/day, corresponding to an effect size (standardised mean difference or *d*) between the intervention and control groups of 0.20 using a two−sample t−test (alpha = 0.05, two−sided). With 1115 completed baseline responses already received, the study is therefore sufficiently powered according to the original sample size estimation. The aim of the new elements introduced in phase 2 (household travel diaries and enhanced activity monitoring) is to optimise the precision of measurement in as many members of the study cohort as possible. We will therefore enrol as many participants in these sub-studies as are willing to take part, subject to the limitations imposed by the number of measurement devices available for use in a given week of data collection. Should the number of willing participants exceed the number of available devices in a given week, we will issue devices to a subset of willing participants selected at random.

d. Data analysis

Quantitative analysis

Pre-coding, data entry and data cleaning

Free text data on the purposes, origins and destinations of journeys entered in the core questionnaire and the household travel diaries will be coded to pre-specified categories developed for a previous study[25] and based on those used in the analysis of the Scottish Household Survey travel diary[37] and the National Travel Survey.[26]

Questionnaires and household travel diaries will be sent by courier to a specialist company for double-entry data entry.

The dataset returned from the data entry company will be checked and cleaned using a combination of range and consistency checks and the data cleaning algorithms already established in the MRC Epidemiology Unit for RPAQ data and the baseline questionnaire survey. Actigraph, Actiheart and GPS data will be checked and cleaned using a combination of range and consistency checks and the bespoke data cleaning algorithms and software already developed by the MRC Epidemiology Unit and the University of East Anglia for these instruments.

Computation of derived variables

The following key derived variables will be computed:

- Time spent using each mode of transport for travel in general and for the journey to and from work in particular (min/day, min/wk)
- Estimated overall physical activity energy expenditure (PAEE) using the established RPAQ algorithm
- Body mass index
- SF-8 physical and mental health summary scores using the methods described in the SF-8 manual
- For those participants who have completed activity monitoring, mean daily activity counts per minute (cpm) and time spent in moderate-to-vigorous-intensity physical activity (MVPA) (>2000 cpm) (min/day).

Network distances will be computed from the centroid of the unit postcode for each participant's home address to their nearest bus stop, nearest bus stop on the guided busway, and workplace in a geographical information system (GIS) using Ordnance Survey datasets for the road network and datasets for the nodes and vectors of public transport infrastructure supplied by Cambridgeshire County Council.

The distributions of the raw and derived variables will be summarised using frequency tables or bar charts for categorical variables and histograms, means and standard deviations or medians and interquartile ranges as appropriate for continuous variables.

Outcome measures

The primary outcome measure will be the net increase in daily active commuting time (min/day) after one year, net change being defined as the average within-subject change in a given outcome measure in the intervention group minus the average within-subject change in the control group after adjustment for baseline covariates.

The secondary outcome measures will be:

1. Net increase in total active travel time (min/day)

2. Net increase in overall physical activity expenditure estimated from self-reported data (MET-hours/week based on RPAQ data)

3. Net increase in overall physical activity estimated from objective measurement (mean counts/min, and min/week spent in moderate-to-vigorous-intensity physical activity, both based on Actigraph data)

4. Net increase in wellbeing (changes in SF-8 physical and mental health summary scores)

5. Net reduction in self-reported sickness absence after (days/year).

Main analyses

The main longitudinal analyses will therefore comprise:

- Multivariate regression analysis of the effect of exposure to the intervention (i.e. access to the new transport infrastructure) on changes in travel behaviour (both to and from work, and overall) after adjustment for demographic, socioeconomic, geographical, psychosocial and health correlates of travel behaviour at baseline

- Stratified outcome analyses to examine how the effect of exposure to the intervention varies according to demographic and socioeconomic status and baseline level of physical activity

- Multivariate regression analysis of the relationship between changes in travel behaviour and changes in overall physical activity, body mass index, wellbeing and sickness absence.

Where outcome variables prove to be highly skewed or otherwise unsuitable for multivariate linear regression, they will be dichotomised and modelled using multivariate logistic regression.

Household travel diary data will be examined to explore relationships between the travel of household members using multivariate regression analysis.

Analysis of enhanced activity monitoring data

Actiheart data will be used to calculate PAEE, merged with GPS data and imported into the ArcGIS geographical information system (GIS). GPS time and positional data will be used to identify journey start and finish times, estimate velocities and predict the travel mode(s) used on journeys using a published protocol,[38] validated against the heart rate data obtained using Actiheart, and used to estimate the proportion of PAEE attributable to commuting. Adjacent GPS data points will be joined so that routes are depicted as linear features whose surroundings can be characterised using a range of indicators such as predominant land use type and 'greenness' based on detailed land use maps using a protocol developed previously.[39] These indicators will be compared with the travel mode(s) used by participants to examine associations between route characteristics and travel behaviour.

Estimation of carbon emissions

Baseline carbon footprints (kg or tonnes CO2/person/day) will be calculated from phase 1 survey data based on the distance, frequency and urban/rural character of commuting journeys computed using the GIS along with data on travel mode choice, car fuel type and engine size, and will be recalculated from follow-up survey data in phase 2 to quantify the overall impact of the intervention on carbon emissions attributable to travel. Household travel diary data will also be used to examine in more detail the wider knock-on effects on carbon emissions attributable to travel by other household members. These specialist analyses will be commissioned from the Carbon Reduction Project (CReD) in the Low Carbon Innovation Centre, a specialist unit within the School of Environmental Sciences at UEA.

Qualitative analysis

The transcripts will be checked against the audio recordings. An iterative process of content analysis will then be used to code segments of transcripts, extract related segments, identify and group themes, and identify patterns and negative cases using the method of constant comparison. Higher-order themes will mostly be derived from the topic guide, whereas the lower-order themes are likely to emerge from the data elicited in the interviews. After an initial batch of interviews, an interim descriptive account based on the content analysis described above will be discussed with the research team in order to validate emerging findings and review the recruitment strategy and topic guide before continuing with further recruitment, interviews and analysis. The identification of themes, patterns and negative cases will be validated by one other member of the study steering group reading all the transcripts to verify and, if necessary, challenge and refine the coding and analytical decisions taken.

4. Outputs and translation

The research findings will be presented at national and international scientific and professional meetings across the public health and transport spectrum and published in high-quality journals in both scientific disciplines. The applicants have a track record of successfully disseminating the results of previous research in this field through all of these routes, including papers presented at the World Health Organization Healthy Cities Conference (2003), the European Transport Conference (2003, 2004, 2006), the UK Public Health Forum (2005), the International Society for Behavioral Nutrition and Physical Activity (2006), the Campbell Collaboration

Colloquium (2007), the World Conference on Transport Research (2007) and the International Conference on Physical Activity and Public Health (2008), and papers in such journals as Transport Policy (2003), the British Medical Journal (2004, 2007), Transportation Research Part A (2005), the American Journal of Preventive Medicine (2006) and the International Journal of Behavioral Nutrition and Physical Activity (2008 x 3).

The study will also provide an excellent opportunity to address the intersectoral translational aspirations of CEDAR and the MRC Population Health Sciences Research Network (of which the MRC Epidemiology Unit is a member) and the 'applied public health research' remit of the NIHR.

At local and regional level, this will be achieved through a stakeholder forum (see below) for disseminating and discussing emerging research findings with government, health service, local authority, employer and other stakeholders. The findings will be of particular importance to the East of England because this region is the focus of substantial planned population growth and further major transport infrastructure projects are already planned or under consideration as part of initiatives such as the Cycling Towns programme, the Transport Innovation Fund, and the construction of new towns and urban extensions in the Cambridge sub-region.

At national and international policy level, the study will contribute to the emerging field of quantifying the public health benefits (including the economic benefits) of investment in high-quality transport infrastructure, notably in terms of physical activity and carbon emissions, for which little convincing empirical evidence currently exists.

We intend to report the emerging findings in outline to our participants in an annual newsletter and to provide individualised physical activity feedback to those participants who have taken part in activity monitoring in the form of a simple summary of their activity data, such as a bar chart comparing their daily activity counts to the average for their age/sex group and to current public health recommendations.

5. Stakeholder Involvement

The following stakeholders are already engaged in various ways in consulting on, supporting, facilitating, or providing advice about the study:

- Cambridgeshire County Council — Director of planning and infrastructure; head of delivery, Cambridgeshire Guided Busway
- Cambridgeshire Horizons (an arm's length body responsible for the development of new communities on behalf of the local authorities) — Director for development
- NHS Cambridgeshire — Director of public health
- Cambridge University Hospitals NHS Foundation Trust — Director of planning; planning manager; consultant occupational physician; sustainability project manager and travel plan coordinator

- NHS Sustainable Development Unit — Director
- Cambridgeshire Travel for Work Partnership — Development manager
- Senior representatives of a variety of other local employers.

Further stakeholder involvement in the study is envisaged as follows:

1. The research team will liaise with the guided busway delivery team at Cambridgeshire County Council to ensure that routine traffic monitoring and public transport patronage data collected by the local authority are taken into account in the interpretation of the research findings

2. An annual stakeholder forum will be convened, its aims being (a) to share emerging research findings, (b) to provide advice on the interpretation and translation of those research findings, and (c) to identify and exploit opportunities for collaborative engagement with the media.

6. Project Management:
Research governance
The study will be sponsored by the MRC Epidemiology Unit, Cambridge and will be conducted and managed by that institution in collaboration with the co-investigators from the University of East Anglia (UEA) and University College London (UCL) under the terms of a formal collaboration agreement. The study will be directed by a scientific committee of the principal investigator and co-investigators that will meet quarterly, to which the academic collaborators will be invited as appropriate and to which the study coordinator and researchers will report; and will be managed in the MRC Epidemiology Unit by means of a monthly operational team meeting convened by the study coordinator and co-chaired by the study coordinator and the principal investigator. The study will be conducted in accordance with relevant current MRC policies and standard operating procedures including those pertaining to informed consent, indemnity, data protection and data storage. An independent study steering committee chaired by Professor Mark Petticrew, professor of public health evaluation at the London School of Hygiene and Tropical Medicine, will meet annually in Cambridge to oversee and advise on the conduct of the study.

Indicative timetable
Ethical approval
An application for NHS research ethics committee (REC) approval for the phase 2 study will be submitted through the common Integrated Research Application System (IRAS) in November 2009.

NHS Research and Development (R&D) approval

The R&D offices for the local acute hospital trust (Cambridge University Hospitals NHS Foundation Trust) and primary care trust (NHS Cambridgeshire) have both confirmed that their approval is not required for this study.

Data collection

Participants will receive preliminary information about phase 2 and invitations to take part from March 2010 onwards. Phase 2 data collection will begin in May 2010, exactly one year after the onset of phase 1 data collection, and will continue until around November 2010.

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