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Quantifying the physical activity energy expenditure of commuters using a combination of global positioning system and combined heart rate and movement sensors

Silvia Costa [a], David Ogilvie [a], Alice Dalton [b], Kate Westgate [c], Søren Brage [c], Jenna Panter [a,*]

[a] MRC Epidemiology Unit and UKCRC Centre for Diet and Activity Research (CEDAR), School of Clinical Medicine, University of Cambridge, Cambridge, UK
[b] Norwich Medical School and UKCRC Centre for Diet and Activity Research (CEDAR), University of East Anglia, Norwich, UK
[c] MRC Epidemiology Unit, School of Clinical Medicine, University of Cambridge, Cambridge, UK

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ABSTRACT

Background. Active commuting may help to increase adults' physical activity levels. However, estimates of its energy cost are derived from a small number of studies which are laboratory-based or use self-reported measures.

Methods. Adults working in Cambridge (UK) recruited through a predominantly workplace-based strategy wore combined heart rate and movement sensors and global positioning system (GPS) devices for one week, and completed synchronous day-by-day travel diaries in 2010 and 2011. Commuting journeys were delineated using GPS data, and metabolic intensity (standard metabolic equivalents; MET) was derived and compared between journey types using mixed-effects linear regression.

Results. 182 commuting journeys were included in the analysis. Median intensity was 1.28 MET for car journeys; 1.67 MET for bus journeys; 4.61 MET for walking journeys; 6.44 MET for cycling journeys; 1.78 MET for journeys made by car in combination with walking; and 2.21 MET for journeys made by car in combination with cycling. The value for journeys made solely by car was significantly lower than those for all other journey types ($p < 0.04$). On average, 20% of the duration of journeys incorporating any active travel (equating to 8 min) was spent in moderate-to-vigorous physical activity (MVPA).

Conclusions. We have demonstrated how GPS and activity data from a free-living sample can be used simultaneously to provide objective estimates of commuting energy expenditure. On average, incorporating walking or cycling into longer journeys provided over half the weekly recommended activity levels from the commute alone. This may be an efficient way of achieving physical activity guidelines and improving population health.

Introduction

Physical inactivity is the fourth leading cause of global mortality, and the World Health Organization, the United Nations and numerous national governments now view the promotion of physical activity as a public health priority (Department of Health, 2011; United Nations, 2011; World Health Organisation, 2000). Incorporating walking and cycling into commuting journeys is one way of increasing physical activity that may be more easily adopted and maintained in everyday life than some other forms of activity (Department of Health, 2011). Epidemiological studies suggest beneficial effects of active commuting on cardiovascular risk independent of other physical activities (Hamer & Chida, 2008), and modelling studies suggest that the health benefits of a shift towards active travel greatly outweigh the harms (Woodcock et al., 2009; Woodcock et al., 2013). However, accurate estimates of the metabolic cost associated with different commuting patterns in free-living conditions are required to quantify the health impacts of interventions aimed at changing travel behaviour (Shephard, 2008).

To derive such estimates, information on the intensity, duration and frequency of activities is required, but capturing this information is notoriously difficult. Self-reported measures are subject to recall and social desirability bias, and objective measures are often only available in small samples (Shephard, 2003). The physical activity compendium provides estimates of the metabolic cost (in metabolic equivalents, MET) for a range of different activities, sometimes from several studies. Estimates are given with and without assumptions about speed, gradient, and other factors which would influence metabolic cost, such as walking with or without a load. The compendium has been updated as new studies are published and new codes added (Ainsworth et al.,

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[*] Corresponding author at: MRC Epidemiology Unit and UKCRC Centre for Diet and Activity Research (CEDAR), School of Clinical Medicine, University of Cambridge, Box 285, Cambridge Biomedical Campus, Cambridge, UK.
E-mail address: jrp63@medschl.cam.ac.uk (J. Panter).

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2000; Ainsworth et al., 2011). However, the source publications for the estimate of energy expenditure for walking to work are either old or based on self-reported measures which have been validated in laboratory studies (Taylor et al., 1978), whilst the estimate for cycling to work uses objective data from a single study with a relatively small sample (de Geus et al., 2007). Evidence from more studies would therefore give greater confidence in the compendium estimates for these activities. These limitations equally apply to the quantification of energy expenditure of travel behaviours at the lower end of the intensity spectrum, such as travelling by public transport or car (Bandyopadhyay & Chattopadhyay, 1980). Thus, whilst walking or cycling parts of a longer journey made by motor vehicle may be encouraged for health reasons, the extent to which these active stages of the journey contribute to overall energy expenditure in an otherwise sedentary journey is uncertain.

The widespread availability of global positioning system (GPS) devices and physical activity monitors means that objective data can now be collected in free-living conditions without the need for direct observation (Krenn et al., 2011). We therefore aimed use this combination of measures to quantify the metabolic cost of physical activity associated with the use of different modes and combinations of modes of transport for commuting.

Methods

Study setting and participant recruitment

The Commuting and Health in Cambridge study protocol and recruitment procedures have been reported elsewhere (Ogilvie et al., 2010). Briefly, 1164 adults aged 16 years and over who lived within 30 km of the centre of Cambridge, UK and travelled to work in the city were recruited in 2009, predominantly through workplaces via emails, recruitment stands and advertisements. The city of Cambridge lies approximately 80 km northeast of London and has a generally flat topography, a large student population and the traffic congestion in its historic city centre. The surrounding rural area includes smaller towns as well as a large number of small settlements.

Data collection

Further information on the sample and data collection methods are given elsewhere (Panter et al., 2014). Briefly, in 2009 and 2010, participants completed a questionnaire to assess personal characteristics and travel behaviours, and a subsample were invited to wear accelerometers ($n = 714$) (ActiGraph, Pensacola, FL, USA) for seven days (Yang et al., 2012). One year later, the subsample who had provided valid accelerometer data ($n = 550$) were invited to complete a follow-up questionnaire and travel diary and to wear combined heart rate and movement sensors (Actiheart; CamNtech Ltd, Cambridge, UK) and GPS (BT-Q1000X; QStarz, Taipei, Taiwan) devices. Each participant attended an appointment with a research assistant where they gave written informed consent, had their height and weight measured for the computation of body mass index (BMI) (weight divided by height squared), and were asked to wear both devices for seven consecutive days and to complete the travel diary over the same period. Ethical approval was obtained from the Hertfordshire Research Ethics Committee (reference numbers 09/H0311/116 and 10/H0311/65).

Objective measures

The Actiheart combined acceleration and heart rate sensor (AccHR) is a lightweight (10g) waterproof device that clips onto two standard electrodes attached to the chest. It has been shown to be a valid and reliable tool to assess activity, providing a more accurate assessment of energy expenditure than accelerometry alone (Brage et al., 2005). The devices were set to continuously collect data at either 60-second epochs (in 2010) or 15-second epochs (in 2011). The GPS receivers were set to record the spatial coordinates of their location every five seconds. Participants were asked to wear these on an elastic waist belt during waking hours and to recharge them each night.

Travel diary

Participants completed a seven-day prospective travel diary (Appendix 1), in which they recorded the start and end time of each journey and all modes of travel used. The diary was closely based on that used in the UK National Travel Survey (Stratford et al., 2003).

Sample

As in our previous method development paper (Panter et al., 2014), this analysis required objective locational data to be processed to identify commute journeys and times. We randomly selected a subsample of the 182 participants who had both objective and travel diary data on commuting in either 2010 or 2011, aiming to achieve a minimum of 50 journeys for the most commonly reported types of commuting journey in the sample. These were journeys made by car only; bus journeys, with or without walking or cycling to or from the bus stop; journeys made by car in combination with walking, or with cycling combined; and journeys made by walking only, or by cycling only. However, we were unable to obtain 50 journeys made only by walking because commuters living in the same immediate area of the city as their workplace had been excluded from recruitment to the cohort. We use the term ‘journey’ here to refer to the entire trip between home and work regardless of the number of modes of transport used. We use the term ‘mode of transport’ to refer to car, bus, cycling or walking, and ‘combination of modes’ to refer to the use of multiple modes within a journey, for example when a commuter drives from home to a park-and-ride facility and uses public transport, walks or cycles the remainder of the journey (Panter et al., 2013). To be included in analysis, participants had to provide (i) valid and complete GPS data reflecting usual journeys between home and work (see *Data processing*); (ii) synchronous GPS and AccHR data and complete travel diary information on at least three days; and (iii) plausible heart rate and acceleration values.

Data processing

GPS data are increasingly used to study physical activity behaviour worldwide (Taylor et al., 1978) and as a result there are calls for standardised systems to process these data. A web-based application, known as PALMS, has been developed to process GPS data in a more standardised way and shown to be valid (Carlson et al., 2015). However, it currently requires data to be uploaded to a server held in the US. This may not be compatible with the Data Protection Act – the legislation that governs the use of personal data in the UK – which limits the export of identifiable data outside the European Economic Area. We therefore developed our own procedures which are described in detail here.

(i) Defining commute times on each journey from GPS data

GPS data were visually inspected in ArcGIS (version 10.0) to identify the start and end times for each journey to or from work. The start time was defined as the first five-second epoch after which participants left either their home or the outline of their workplace building, and the end time as the last five-second epoch before they reached the corresponding destination. Because journeys did not always begin at the start of a ‘clock minute’ (e.g. precisely at 10:00:00), the first and last clock minute of each journey were excluded to avoid misclassifying non-commuting activity as part of the journey. This ensured that metabolic cost data included in our calculations were drawn from the journey itself. We identified whether participants had travelled to or from work via an intermediate destination such as a school or shop (either visible on background mapping in ArcGIS, or reported in the travel diary) and remained there for more than five minutes without a reported change in mode. By examining GPS data, we were able to exclude the time spent at such intermediate destinations to more accurately reflect the metabolic cost of the journey itself. Both direct and indirect (‘via’) commuting journeys were included in analysis, to reflect the varied habitual commuting patterns of the study population. However, ‘via’ journeys were excluded if they included an intermediate destination more than 100 km from work or home. Further technical details of the processing and cleaning of GPS data are published elsewhere (Panter et al., 2014).

(ii) Extracting and processing energy expenditure data

Heart rate data were pre-processed (Stegle et al., 2008) using a simple individual calibration of heart rate based on sleeping heart rate, age and gender (Brage et al., 2007). Marginal metabolic cost was estimated using branched equation modelling (Brage et al., 2004) but translated to standard METs by adding 1 MET for each minute. We summarised AccHR data in one minute epochs and annotated each trace with the journey start and end times from GPS, as described above.