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Estimating Personal Physical Activity from Transport

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Abstract

A substantial and growing proportion of people in developed countries are overweight or obese. Personal physical activity protects against weight gain and obesity. Personal physical inactivity has been linked to a number of common and increasing prevalent health problems such as cardiovascular disease and a number of chronic diseases such as cancer (colon and breast), diabetes mellitus, osteoporosis and depression.

Accelerometers can be used to objectively measure a person's incidental, intermittent physical activity such as short walks. They also enable movement to be monitored inside buildings that is often not recorded and is difficult using other technologies such as Global Position Systems (GPS). Accelerometers allow comprehensive analysis of physical activity bouts. They also have low subject burden, not having to rely on the memory of individuals and are unobtrusive, and allow recording over multiple days. However, accelerometers do not accurately record physical activity associated with cycling.

GPS can be used to estimate personal energy expenditure from cycling since the speed and duration of movement is logged. However, GPS does not provide data at some locations such as inside buildings, urban canyons, or tunnels due to weak signals from satellites.

Transport is a major activity type and common form of personal physical activity. This paper describes procedures for integrating GPS and accelerometers to estimate personal physical activity arising from transport. It provides experimental evidence using data from one subject and suggests that this method has potential for further investigation.

1. Introduction

1.1 Health and Personal Physical Activity

The lifestyle of persons living in the large cities of the developed world is becoming increasingly sedentary, with a large proportion of people's non-sleeping time spent sitting or in low intensity activity.

Personal physical inactivity has been linked to a number of common and increasing prevalent health problems such as cardiovascular disease and a number of chronic diseases such as cancer (colon and breast), diabetes mellitus, osteoporosis and depression (Haskell et al, 2007; Bouchard et al, 1994 and Blaire et al, 1999). Physical inactivity is also one of the avoidable major risk factors for heart disease (American Heart Association, 1996).

By improving personal physical activity through active transport, the development of chronic diseases like diabetes and cardiovascular disease can be delayed or/and prevented, resulting in significant personal, social and economic benefits. There is strengthening evidence supporting the benefits of personal physical activity for the community as a whole. The National Public Health Partnership update on evidence for physical activity and health, Getting Australia Active II (Bull et al 2004) quotes a recent Danish study that showed cycling to work reduces mortality risk, providing clear and positive evidence regarding active commuting.

With commuter bicycle use in cities such as Melbourne dramatically increasing, and Bauman et al (2008) estimating that commuter cyclists currently save the economy $72.1 million per year in reduced health costs, there are is strong justification for investment in research to measure the health benefits from increased use of both of the main modes of active transport. The overall direct gross cost of physical inactivity on the Australian health budget in 2006/7 was 1.49 billion dollars according to a recent study by Econtech (2007).

Many countries have developed health guidelines that provide recommendations regarding the desirable levels of personal physical activity. The current Australian physical activity guidelines are, to “Put together at least 30 minutes of moderate-intensity physical activity on most, preferably all, days” (Department of Health and Ageing, 1999). Health guidelines can generally be achieved with only a moderate amount of cycling and walking per day that can be incorporated into the journey to work (Shepherd, 2008).

Improved methods for monitoring physical activity allow the links between energy expenditure gained from transport and the elements of the ecological model of physical activity to be explored, including the individual, physical environment, social as well as policy and regulatory factors (Sallis et al, 1998). The procedures presented in this paper can be used to estimate how much transport is contributing to total energy expenditure as well as determining whether or not the health standards are being met. This information can be used to develop programs for promoting active transport specifically targeted to underrepresented groups based on personal factors such as gender and age or local areas. The effects of new transport infrastructure such as bike lanes and bike parking facilities can also be evaluated.

1.2 Transport and Personal Physical Activity

Transport is a major type and common form of physical activity. Active transport is described as any form of transport that is human-powered (Healthy Living Unit, 1993). Common forms of active transport includes non-leisure walking and cycling (Berrigan et al. 2006). Li and Rissel (2008) indicated that the people who used active transport for their journey to work were the least likely to be overweight or obese after taking into account leisure-time physical activity. Walking and cycling are simple and cheap means of transport available to a substantial proportion of society Active transport time allocation allows for personal physical activity to be built into a daily lifestyle and time budget.

1.3 Physical Activity Analysis

Sport and recreation, work, household based tasks and transport are four common types of broad categories of activities where persons undertake physical activity. Timed bouts of personal physical activity participation are generally represented by frequency, intensity and duration. There are defined levels for the categories in each dimension (Esliger and Tremblay, 2007). Over a day, physical activity can also be characterized by when it occurs, time of day (temporal) and where it occurs spatial (indoors or outdoors).

1.4 Traditional Survey Methods

There are numerous surveys that are administered to quantify the amount of physical activity that is undertaken in daily activity by an individual. Self reporting is a common way of gaining details. For example The Active Australia Survey (Australian Institute of Health and Welfare, 2003) includes several questions relating to the frequency and duration of walking for recreation and transport, using survey thresholds such as at least 10 minutes of walking over a weekly period.

Conventional travel surveys (self completion questionnaires or interview surveys) can be used to estimate the amount of time spent walking and cycling. The Victorian Integrated Survey of Travel and Activities (VISTA), a household survey, is an example of a large scale transport survey that was recently conducted in Melbourne (DOT, 2009).

Geocoding of stops allows direct distances to be estimated for trip stages, but the actual distance travelled depends on the paths travelled which are not generally provided and must be estimated. For home based trips, distances are also difficult to estimate since the exact location of households are not accurately presented due to privacy reasons. It is also difficult to estimate the intensity of physical activity from walking and cycling from travel surveys since the times and locations recorded are also not generally very accurate. As well short trips are often under-reported.

2. Modelling Personal Physical Activity

2.1 Estimating Physical Activity Levels (PALs)

Estimating energy expenditure for an individual over an extended period is a complex and challenging task. A simple method has developed for determining PALs is based on personal attributes such as age, height, weight and gender as well the duration and metabolic rate of activities undertaken (Gerrior et al, 2006). Relationships can be used to estimate the physical activity levels of a person over a daily period (See Appendix A).

The basal energy expenditure of a person is the basic energy requirement to sustain life. The intensity of physical activity for each specific activity undertaken is represented by a Metabolic Equivalence of Task (MET) which accounts for the energy consumption expressed as a ratio of the resting or sitting metabolic rate.

Daily physical activity levels (PALs) can be determined by estimating the total energy expenditure, expressed as a multiple of the basal metabolic rate. It is recommended that average PALs should be above 1.6 (AICR, 2007). A number of categories have been determined by the Food and Nutrition Board (2005) for PALs.

2.2 Identifying METs for travel modes

To estimate the physical activity level for a person over a period of a day it is necessary to determine the metabolic equivalent tasks (MET) for each of the activities undertaken. Ainsworth et al, (2000) presented 605 METs for 21 activity categories at a variety of intensity levels. The reported METs range from 1 for riding in a car or truck to 18 for running at 17.4 km/h.

For walking, a total of 43 METs were presented at various speeds, purposes and loads carried (Ainsworth et al, 2000). Cycling can be for leisure, work or sport at various levels of intensity and speeds.

3. Measuring Tools

3.1 Accelerometers

Accelerometers are portable monitors that measure movement in terms of acceleration, which can then be used to record body movements to estimate physical activity level bouts over an extended period. Acceleration signals are recorded for each spatial axis (anterior-posterior, medial-lateral and vertical) at high frequency over a range of acceleration levels. For example, a three axis accelerometer, “Alive Heart Monitor” with a sampling frequency of 75 Hz with an acceleration range of -2.7 to 2.7g was used to detect walking activity for a cardiac rehabilitation program (Bidargaddi et al, 2007). Tri-axial accelerometers record counts for each dimension whilst uni-axial accelerometers combine movement counts over all dimensions.

Acceleration is detected as an external force which reflects the energy cost of physical activity. Piezoelectric sensors and seismic mass measure compression upon acceleration generate a voltage signal proportion to acceleration. Accelerometers can be mounted on a person’s waist, close to the centre of the mass to provide information on overall physical activity.

Accelerometers have the ability to objectively measure incidental, intermittent PA such as short walks. Accelerometers measure dynamic activities such as walking, ascending stairs, descending stairs, jogging and running. They also enable movement to be monitored inside buildings that is often not recorded and is difficult using other technologies such as GPS.

Accelerometers are becoming smaller, cheaper, and easy to use and are now feasible for large scale health surveys. This allows monitoring of physical activity in the field, out of the laboratory. Accelerometers allow comprehensive profiling of physical activity over an extended period (Esliger and Tremblay, 2007). They also have low subject burden, not having to rely of the memory of individuals and are unobtrusive, and allow recording over multiple days. Accelerometers record the frequency, duration and intensity of physical activity, objectively. This data can be used to estimate energy expenditure and physical activity levels.

However, accelerometers have some limitations in monitoring physical activity during transport. No information on the context or source of physical activity is recorded. To link the count data to transport or other types of physical activity generally needs to be manually recorded in a diary. Although there has been models developed for determining the type of physical activity mode (Pober, 2006; Bidargaddi, 2007; Veltink, 1996) from accelerometer data and combined with GPS devices (Troped, 2008) these procedures are not yet widely used by practitioners. They do not measure load bearing, so the energy used for items carried is not included.

Subjects may also increase their physical activity levels because of monitoring although surveys of a week's duration are recommended to reduce the potential for this bias. Compliance in wearing the devices over many days can also be an issue. A major weakness of accelerometers with respect to measuring physical activity from active transport is that when worn on the waist that they do not accurately record the physical activity associated with bicycle riding.

3.2 Global Position Systems (GPS)

Global Position Systems (GPS) allow the time and location of mobile devices to be recorded electronically. In-vehicle navigation systems are a common application of GPS. Data from GPS devices can be used to estimate energy expenditure from walking and cycling since the speed and duration of movement can be determined.

However, there are a number of challenges relating to the application of GPS to estimate the levels of physical activity from transport such as determining the mode and purpose of the trip as well supplementing data that cannot be recorded at some locations due to weak signals (Stopher et al 2008).

GPS data does not indicate what transport mode a person has used. Techniques for automatically determining the mode of transport are the focus of ongoing research. The purpose of the trip or the activity undertaken at the end of the trip is also not recorded by GPS. This limits the understanding as to why trips were undertaken and the nature of activities at the destinations. Research is currently being undertaken to develop methods for automatically analysing the data collected from GPS (Stopher et al, 2008). Algorithms are required for identifying separate trips as well as determining trip purpose and travel mode used.

In urban areas it is common for the signals from satellites to be interrupted due to interference from obstructions such as buildings, tunnels and electricity cables. GPS devices have difficulty receiving signals when they are, inside or near buildings, underground or near overhead electricity cables. Such situations are common when persons are travelling in urban areas. It is also common for GPS devices to take some time (eg. several minutes) to determine the location of the device when it is turned on. This can limit the ability of GPS to accurately record short trips (eg. walks) as well as discouraging users to accurately track their movements because they need to wait before starting their short journeys.

4. Research Method

4.1 Estimation Procedure

A procedure for estimating the physical activity gained from transport using accelerometer, GPS and travel diary data is presented:

Step

1. Determine whether transport was undertaken or not for each time period (minute).
2. Determine the mode of transport undertaken for each time period when engaged in transport.
3. Determine the appropriate MET for activities undertaken in all time periods.
4. Calculate basal energy expenditure, total energy expenditure and activity energy expenditure.
5. Calculate the percentage of total activity energy expenditure gained from transport.
6. Check (and where necessary hypothecate data) so that the time-geography plot over a 24 hour interval has no missing data cells
7. Aggregate the duration of physical activity by intensity levels to determine whether the health guidelines are being achieved and how much transport contributes to this.

Information from a number of sources such as GPS and accelerometer data or a travel diary can be used to determine what periods involved transport and what modes were used.

Methods have been developed to indicate the mode of travel from GPS and these have a high degree of accuracy (Stopher et al 2008). Using induction, bicycle trips are identified using simple rules associated with bicycle ownership, average speed and deviation from the street network. However, there are still challenges in accurately determining when trips start since devices can take several minutes for geo-referencing satellites to be detected and on occasion for short trips a signal may not be received.

METs can be estimated directly from the activity counts recorded by the accelerometer for all activities except cycling. Identifying the appropriate MET for monitoring periods for transport by cycling, involves estimating the travel speed. This can be done analysing the GPS data.

Total PALs can be estimated using the relationships presented by Gerrior et al (2006). To calculate the contribution of transport to PALs, the energy expenditure over periods when walking and cycling for transport occurred were aggregated and compared with other periods by separating these components.

4.2 Application, Discussion and Results

This section describes how the estimation procedure can be implemented in practice. A subject wore an accelerometer (while awake) and GPS device (while cycling) for seven continuous days.

In this example an Actigraph accelerometer was used. The Actigraph records activity counts (4 milli G’s per sec.), summed over an epoch (eg. 1 minute). It can also estimate the number of interval steps in each epoch. The Actigraph accelerometer has been used in a number of health studies such as the US National Health and Nutrition Examination Survey (NHANES) (CDC, 2011).

Data from the Actigraph accelerometer is downloaded to a personal computer using a cable with a USB connection. The Actigraph is worn with an elastic belt on the hip. When a standard 1 minute epoch is used with step mode it has a memory capacity of 180 days (Actigraph, 2008). It has a battery that allows up to 14 days of data to be recorded without recharging. Activity counts have been linked to intensity categories and METs. Linear interpolation was used to convert activity counts to METs. Recorded counts are aggregated over an epoch (eg. 1 minute interval). Movement can be classified in intensity categories (eg. sedentary, light, moderate and vigorous).

A procedure for converting the GPS data to METs from bicycle trips was developed. Data was collected using a GPS data logger sports watch (GlobalSat, 2006). A text file containing the location coordinates (longitude and latitude), time interval between observations and instantaneous speed was downloaded to a PC for each cycling trip. The interval time was set at 1 second, but this can vary depending on the quality of the signal between the device and the satellites. Average speeds were determined for each minute for the duration of the cycling trips. The averaging accounts and allows for the slowing down and stopping at intersections. The average speeds per minute were then converted to METs based on published studies.

A brief overview of the transport and activities that consumed energy expenditure that were recorded in an activity diary is provided in Table 1. Further work on producing algorithms for automatically detecting the transport mode and activities being undertaken from accelerometer and GPS data would also alleviate the need for diary to be manual recorded.

Table 1 Major activities involving energy expenditure

Day	*Transport*	*Activity*
Tuesday	Cycling: home ↔ work (8 km)	Exercises (10 minutes) Mowed lawns at home (30 minutes)
Wednesday	Cycling: home ↔ work (8 km) Walking: to/from meeting (4 km)	Exercises (10 minutes)
Thursday	Cycling: home ↔ work (8 km) Walking: to/from meeting (2 km)	Exercises (10 min.) Tennis: singles (90 minutes)
Friday	Cycling: home ↔ work (8 km)	Exercises (10 min.)
Saturday		Tennis: singles (200 minutes)
Sunday	Cycling: home ↔ church (14 km)	
Monday	Cycling: home ↔ meeting (16 km)	Exercises (10 min.)

Combing data from the GPS for cycling trips with the accelerometer data, a profile of activity counts and cycling speeds over a daily period can be produced (Figure 1). This shows the daily physical activity profile gained from the accelerometer and GPS for the subject for the Wednesday. This graph highlights the activity counts obtained from the accelerometer for exercises (around 7am) and walks around 1pm and 5pm. Such data can be used to estimate

Physical Activity Levels (PALs) as well as checking that health guidelines are being achieved. A daily profile of METs can be produced by combining the activity counts obtained from the accelerometer with the speed data obtained from the GPS (Figure 2).

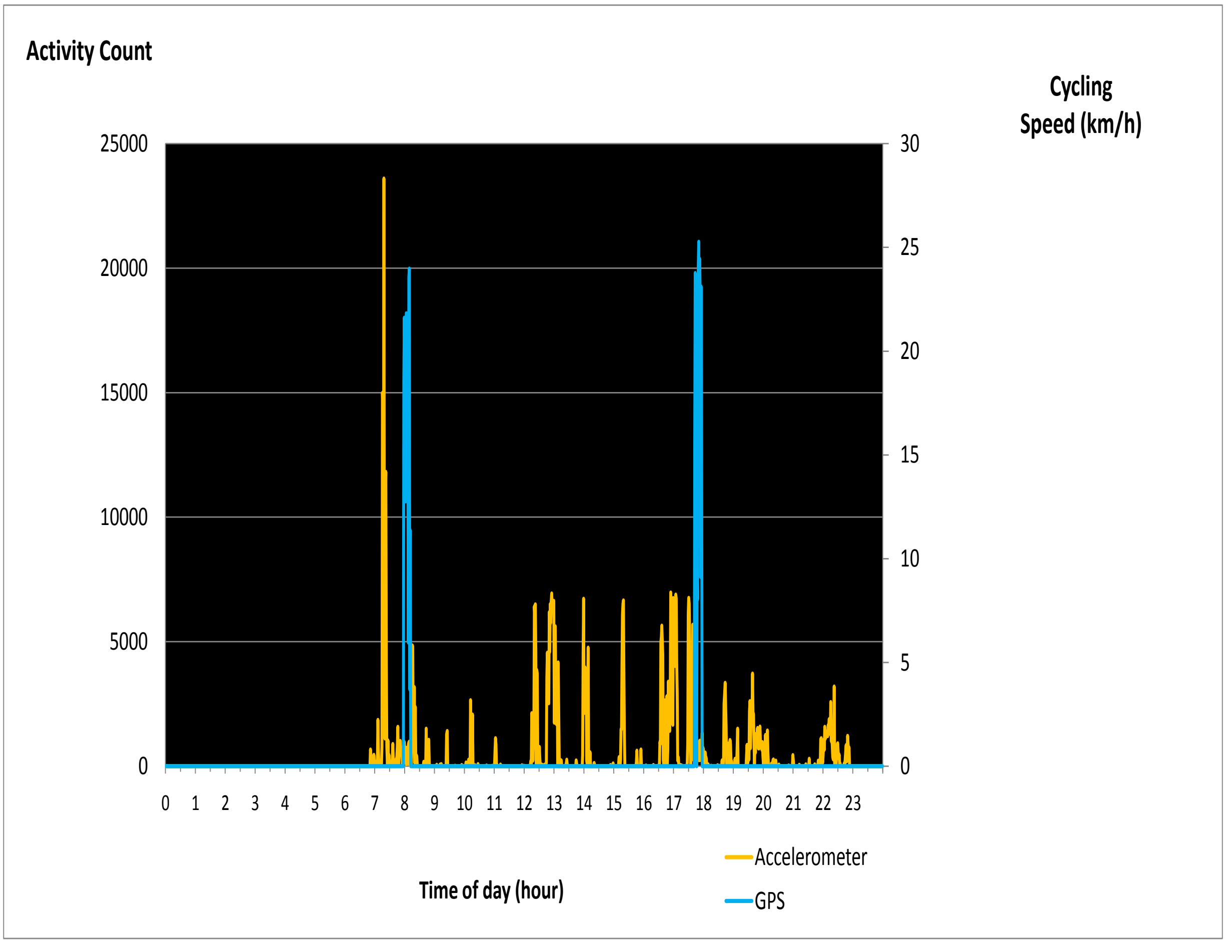

Figure 1 Activity Count and Speed Profile for cycling trips (Wednesday)

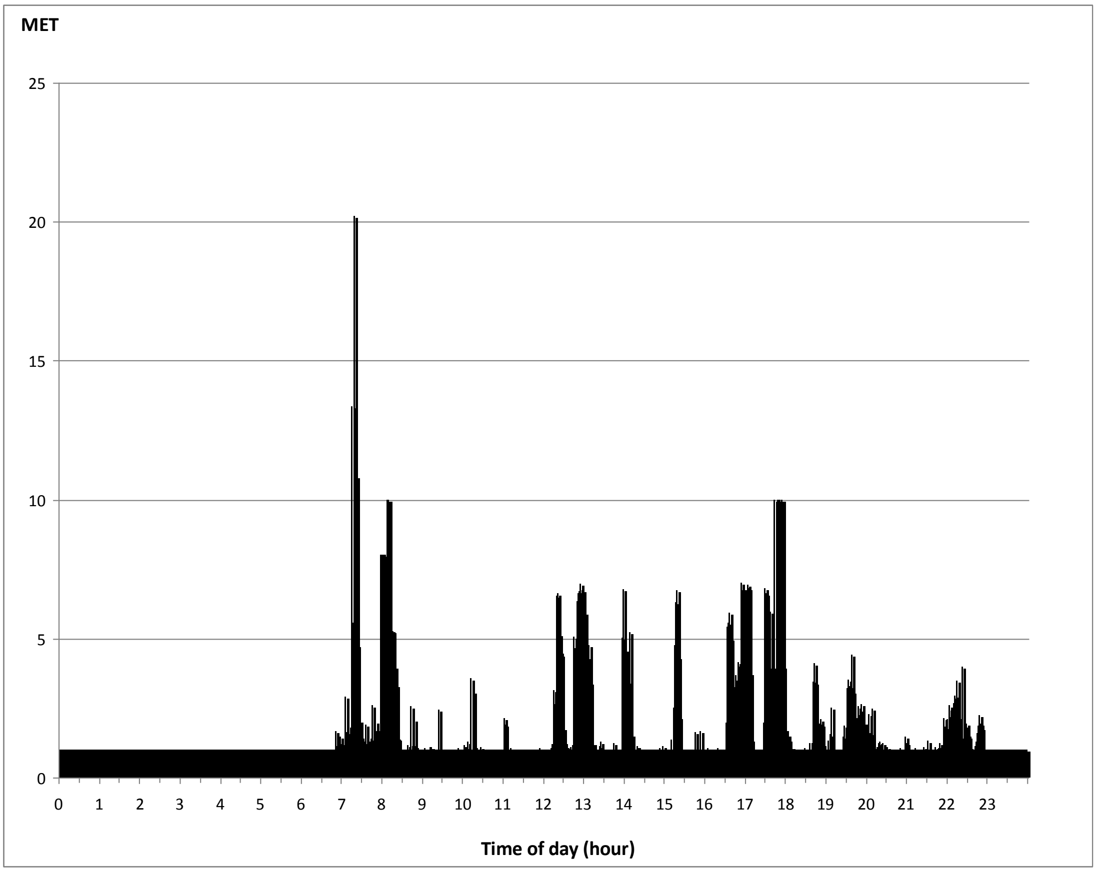

Figure 2 MET Daily Profile (Wednesday)

Using the relationships presented in Appendix A, the energy expenditure levels were determined. For example on the Wednesday, the Physical Activity Level (PAL) was estimated to be 1.77 (Active) and the estimated basal, activity and total energy expenditure are presented in Table 2.

Table 2 Estimated Energy Expenditure (Wednesday)

	Kcal.
Basal Energy Expenditure (BEE)	1,568.92
Activity Energy Expenditure (AEE)	1117.86
Total Energy Expenditure (TEE)	2686.77

Data from accelerometers and GPS can be combined to determine the physical activity levels and energy expenditure for each day over a weekly period (Figures 3 and 4).

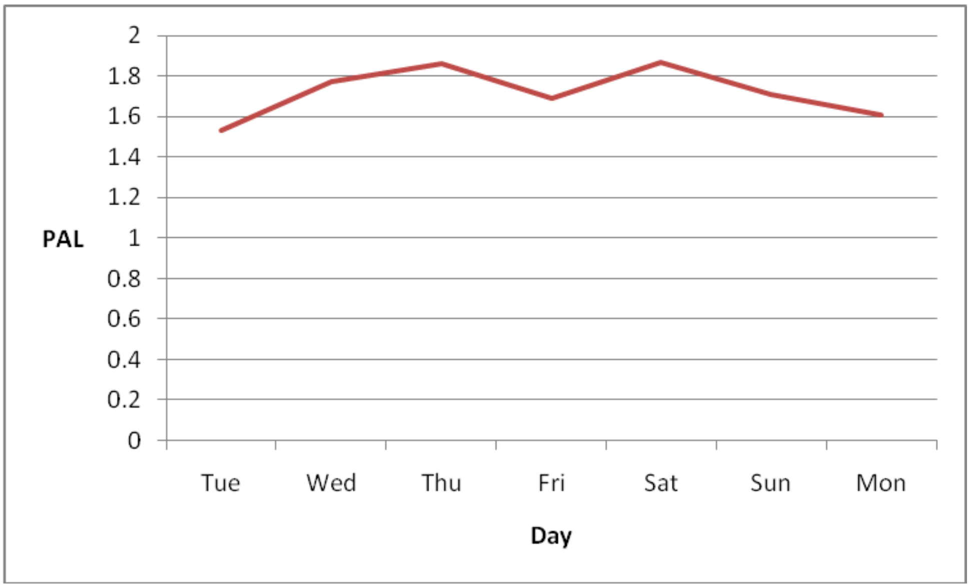

Figure 3 Daily PALs

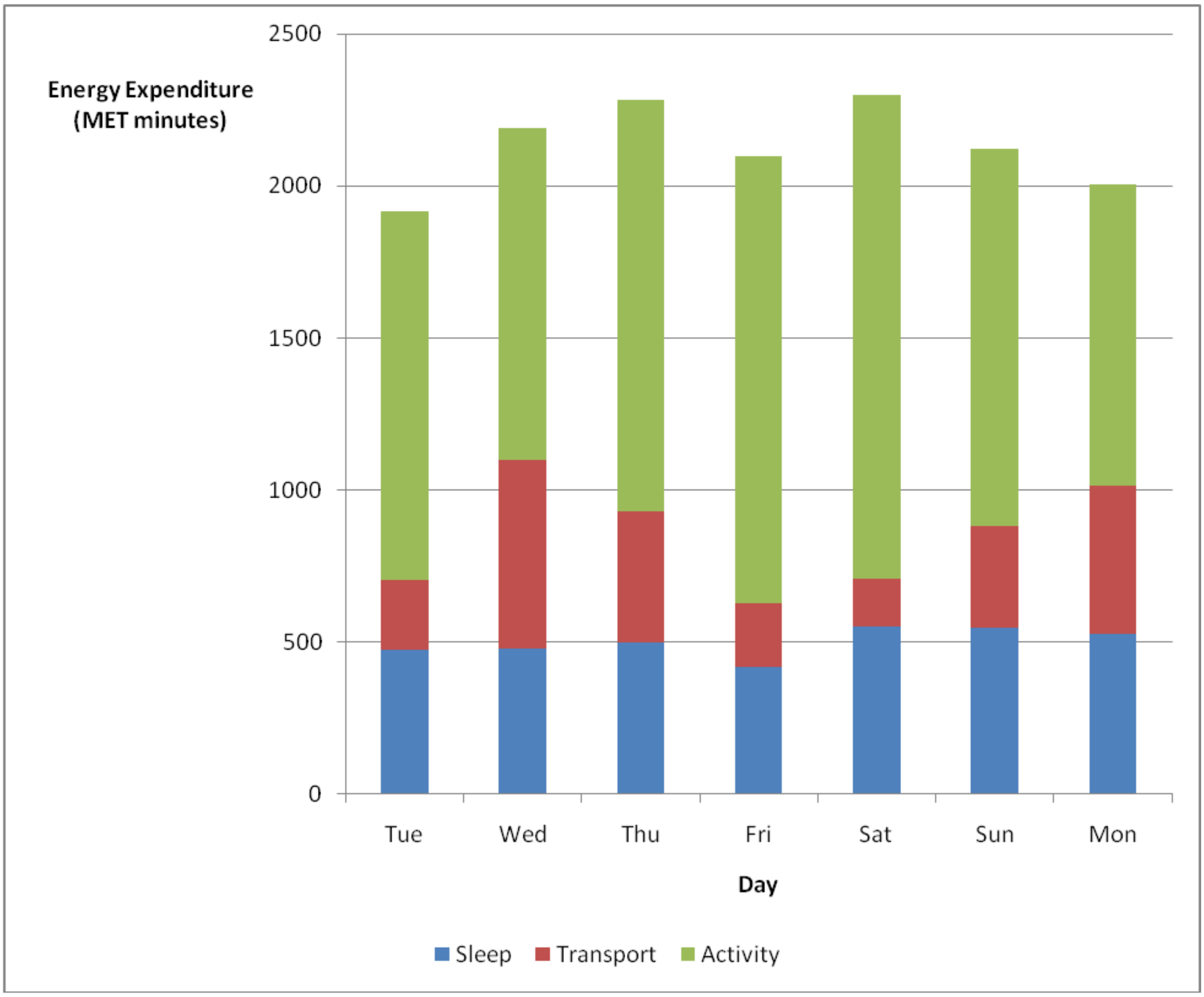

Figure 4 Energy Expenditure per day from Transport and Other Activities

The number of days per week with greater than 30 minutes of at least moderate intensity PA as well as the total amount of moderate and vigorous PA can be determined to check if the health guidelines are being achieved. In this case, the PA from obtained solely from transport satisfies both the US and Australian health guidelines (Table 3). Here, transport contributes a substantial proportion of the total amount of physical activity undertaken.

Table 3 Weekly Duration of PA by Intensity and Source (minutes)

Intensity Category	*Transport*	*Other*	*Total*
Light	288	9000	9288
Moderate	212	395	607
Hard	97	24	121
Very Hard	40	24	64
TOTAL	637	9443	10080

For this subject, transport achieves a significant amount of medium and intensity physical activity but varies considerably over the week (Figures 5 and 6).

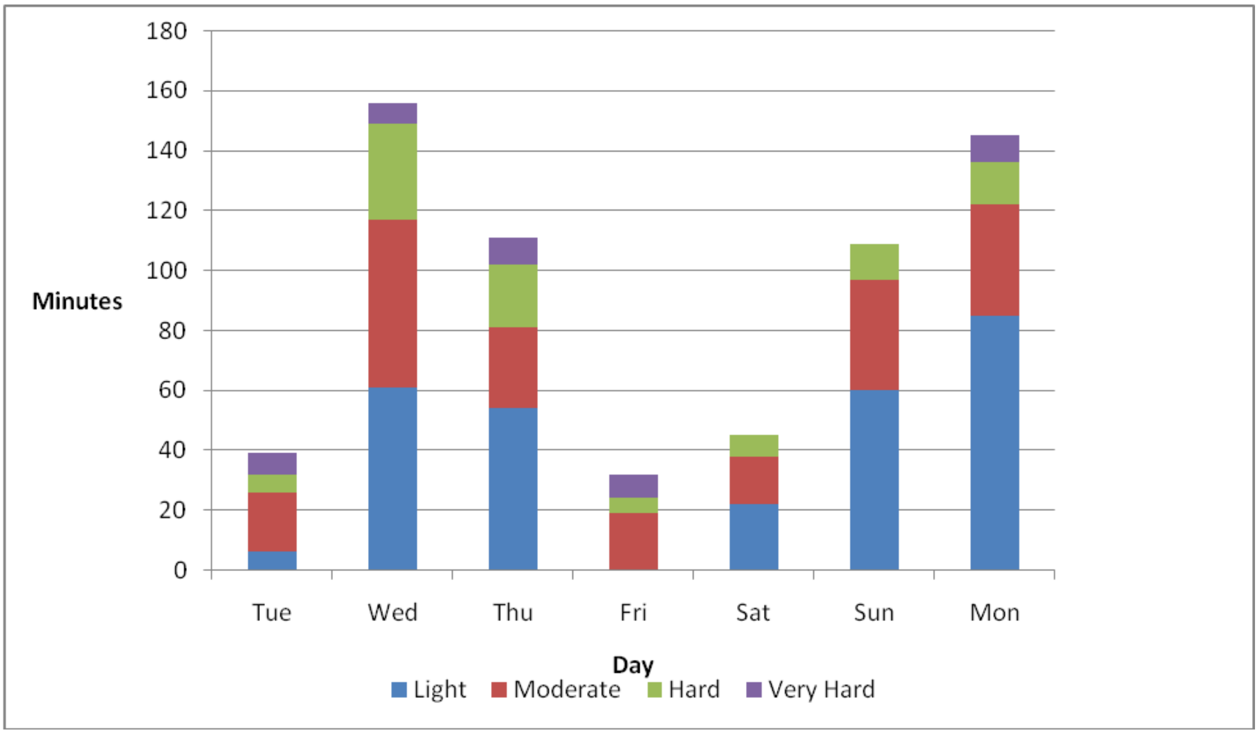

Figure 5 Intensity of Physical Activity from Transport per day

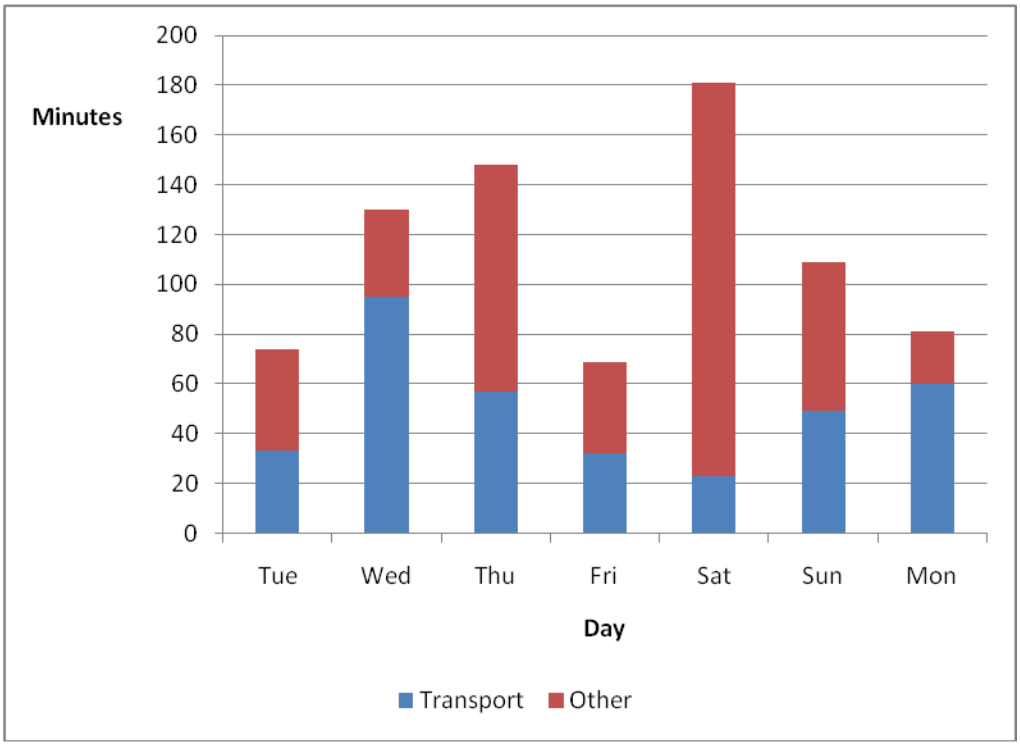

Figure 6 Duration of Moderate and Vigorous PA per day from Transport and Other Activities

Transport typically does not include walking inside buildings. However, the amount of walking within buildings can be quantified and analysed by combining diary data the identify periods spent inside with time interval step counts recorded by the Actigraph accelerometer.

Here, it was assumed that walking was undertaken when the step count exceeded 30 steps per minute. The number of steps undertaken inside can account for a substantial amount of the total steps performed each day (Figure 7). In this case, the number of steps undertaken inside exceeded those undertaken outside for two days of the week. Walking inside was predominately of light intensity PA but some moderate intensity and small periods of hard intensity were recorded (Figure 8).

The recording of personal physical activity is critical to intervention for behaviour change programs that encourage higher MET rates for building users to use stairs instead of lifts. The awareness of health benefitting time use potential in buildings is also important for designers to locate a building’s high usage locations such as toilets, water coolers and lifts away from entrances to encourage more walking within buildings.

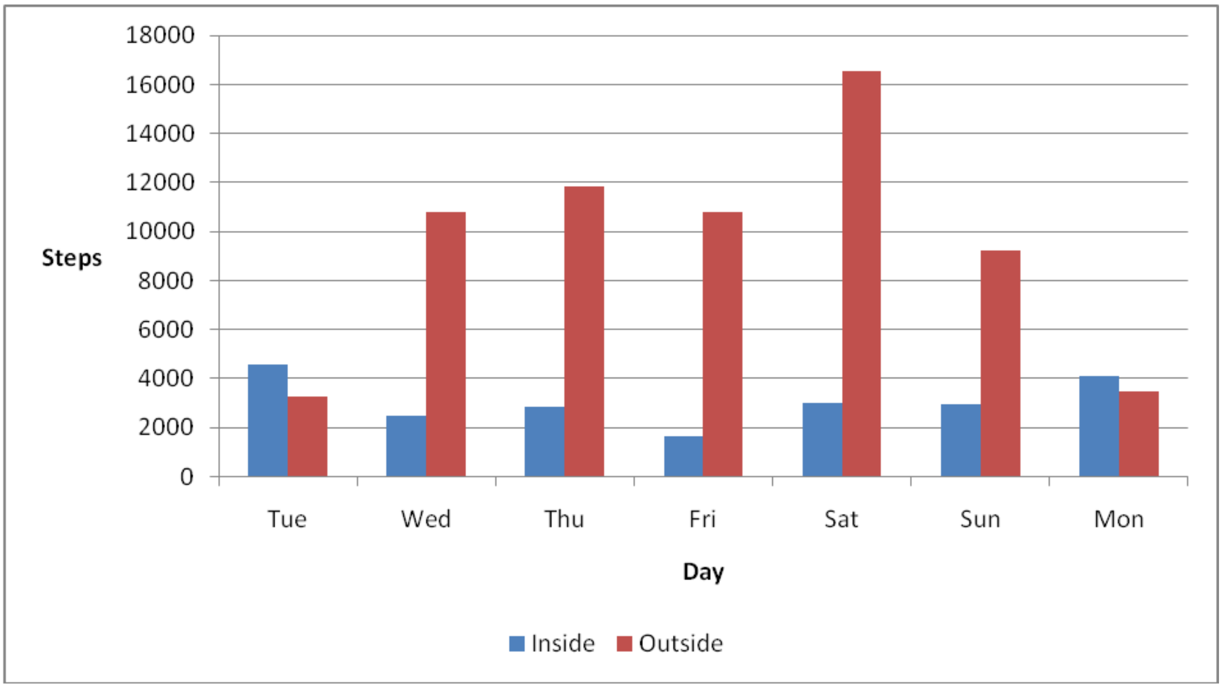

Figure 7 Steps undertaken inside and outside

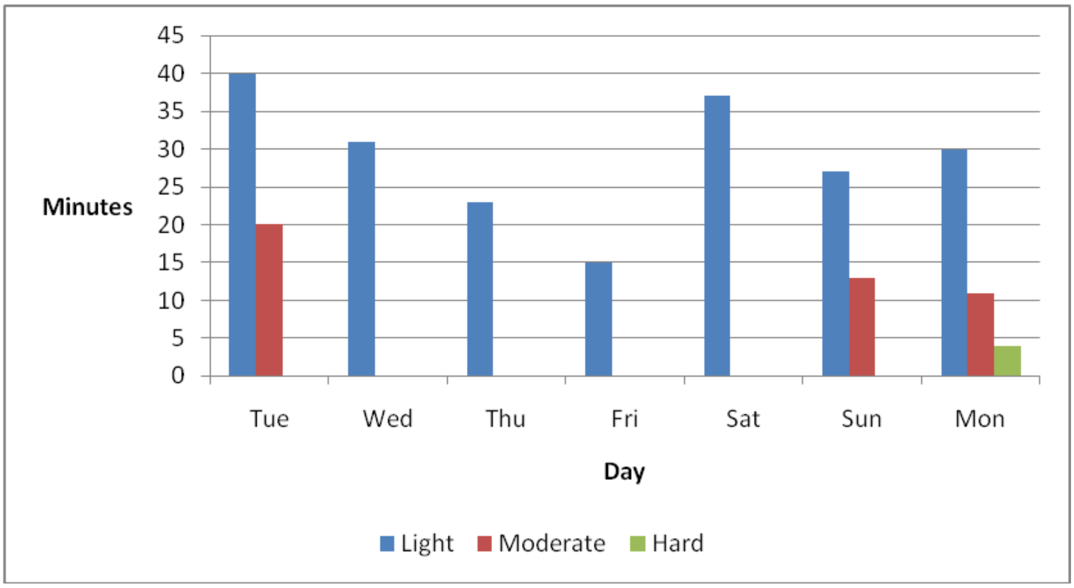

Figure 8 Duration of Walking inside by intensity

5. Conclusions

Active transport offers a simple and practical means of gaining physical activity to reduce the risk of obesity and chronic diseases such as diabetes and cardiovascular disease which are becoming increasing prevalent in modern society. Recent developments in accelerometers and GPS allow physical activity levels to be monitored objectively over an extended period.

This paper has presented procedures developed for integrating accelerometer and GPS data to assist in analysing the physical activity patterns of individuals. The contribution of active transport to personal energy expenditure can be investigated. Such procedures provide a practical means of determining whether the health guidelines for an individual are being achieved or not as well as allowing the health benefits of active transport to be explored.

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Appendix A

Relationships (1)-(6) are based on those presented by Gerrior et al (2006) and can be used to estimate the physical activity levels of a person over a daily period.

$$\boldsymbol{BEE_i} = \begin{cases} 293 - 3.8\boldsymbol{a_i} + 456.4\boldsymbol{h_i} + 10.12\boldsymbol{w_i} \quad \boldsymbol{if}\ \boldsymbol{g_i} = \text{male} \\ 247 - 2.67\boldsymbol{a_i} + 401.5\boldsymbol{h_i} + 8.6\boldsymbol{w_i} \quad \boldsymbol{if}\ \boldsymbol{g_i} = \text{female} \end{cases} \tag{1}$$

$$\Delta\boldsymbol{PAL_{ij}} = \frac{[(\boldsymbol{MET_j} - 1) \times (1.15/0.9) \times \boldsymbol{d_{ij}}]/1440}{\boldsymbol{BEE_i}/(0.0175 \times 1440 \times \boldsymbol{w_i})} \tag{2}$$

$$\boldsymbol{PAL_i} = 1.1 + \sum_j \Delta\boldsymbol{PAL_{ij}} \tag{3}$$

$$\boldsymbol{PA_i} = \begin{cases} 1.14\ \boldsymbol{if}\ 1.4 \le \boldsymbol{PAL_i} < 1.6 \\ 1.27\ \boldsymbol{if}\ 1.6 \le \boldsymbol{PAL_i} < 1.9 \\ 1.45\ \boldsymbol{if}\ 1.9 \le \boldsymbol{PAL_i} < 2.5 \end{cases} \tag{4}$$

$$\boldsymbol{TEE_i} = \begin{cases} 364 - 9.72\boldsymbol{a_i} + \boldsymbol{PA_i}(14.2\boldsymbol{w_i} + 503\boldsymbol{h_i}) \quad \boldsymbol{if}\ \boldsymbol{g_i} = \text{'male'} \\ 387 - 7.31\boldsymbol{a_i} + \boldsymbol{PA_i}(10.9\boldsymbol{w_i} + 660.7\boldsymbol{h_i}) \quad \boldsymbol{if}\ \boldsymbol{g_i} = \text{'female'} \end{cases} \tag{5}$$

$$\boldsymbol{AEE_i} = \boldsymbol{TEE_i} - \boldsymbol{BEE_i} \tag{6}$$

Where,

$\boldsymbol{BEE_i}$ = basal energy expenditure for person *i* over a 24 hour period (kcal)

$\boldsymbol{a_i}$ = age of person *i* (years)

$\boldsymbol{h_i}$ = height of person *i* (metres)

$\boldsymbol{w_i}$ = weight of person *i* (kg)

$\boldsymbol{g_i}$ = gender of person *i* (‘male’ or ‘female’)

$\boldsymbol{MET_j}$ = metabolic equivalence of task for activity *j*

$\boldsymbol{d_{ij}}$ = duration of activity *j* for person *i* (minutes)

$\boldsymbol{\Delta PAL_{ij}}$ = energy expenditure of activity *j* for person *i*

$\boldsymbol{PAL_i}$ = physical activity level

$\boldsymbol{PA_i}$ = physical activity coefficient

$\boldsymbol{TEE_i}$ = total energy expenditure for person *i* over a 24 hour period (kcal)

$\boldsymbol{AEE_i}$ = activity energy expenditure person *i* over a 24 hour period (kcal)