Novel technology to help understand the context of physical activity and sedentary behaviour

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Abstract

When used in large, national surveillance programmes, objective measurement tools provide prevalence estimates of low physical activity guideline compliance and high amounts of sedentary time. There are undoubtedly a plethora of reasons for this but one possible contributing factor is the current lack of behavioural context offered by accelerometers and posture sensors. Context includes information such as where the behaviour occurs, the type of activity being performed and is vital in allowing greater refinement of intervention strategies. Novel technologies are emerging with the potential to provide this information. Example data from three ongoing studies is used to illustrate the utility of these technologies. Study one assesses the concurrent validity of electrical energy monitoring and wearable cameras as measures of television viewing. This study found that on average the television is switched on for 202 minutes per day but is visible in just 90 minutes of wearable camera images with a further 52 minutes where the participant is in their living room but the television is not visible in the image. Study two utilises indoor location monitoring to assess where older adult care home residents accumulate their sedentary time. This study found that residents were highly sedentary (sitting for an average of 720 minutes per day) and spent the majority of their time in their own rooms with more time spent in communal areas in the morning than in the afternoon. Lastly, study three discusses the use of proximity sensors to quantify exposure to a height adjustable desk. These studies are example applications of this technology, with many other technologies available and applications possible. The adoption of these technologies will provide researchers with a more complete understanding of the behaviour than has previously been available.

Introduction

Despite unequivocal evidence that physical activity is beneficial for health (Warburton, Nicol & Bredin 2006, Garber et al. 2011), public health strategies to date have failed to engage the majority of the population in achieving recommended levels of physical activity. Accelerometer data from national surveillance programmes have shown that only a small minority of adults are meeting physical activity guidelines; for example, in the United States just 5% of adults (Troiano et al. 2008) and in the United Kingdom just 4% of men and 6% of women achieved national guidelines (Craig, Mindell & Hirani 2009).

An emerging body of cross sectional and experimental evidence (Tremblay et al. 2011, Wilmot et al. 2012, Edwardson et al. 2012, Biswas et al. 2015, van der Berg et al. 2016) suggests that, independent of physical activity, large amounts of sedentary time may confer an unfavourable cardio-metabolic risk profile. National surveillance programmes show that adults spend the majority of their waking hours sedentary; for example, when using an accelerometer cutpoint of less than 199 counts per minute (CPM) adults spend approximately 10 hours sedentary per day in the United Kingdom (Craig, Mindell & Hirani 2009) and, when using a cutpoint of less than 100 CPM, approximately 8 hours sedentary in the United states (Matthews et al. 2008). It should be pointed out that accelerometers assess movement and that a lack of movement (i.e. time spent under 100 or 199 CPM) may not be true sedentary time spent in a seated or reclined posture (Atkin et al. 2012); however, these sedentary time figures are broadly comparable to the sedentary time figures found in a recent study conducted in the Netherlands of ~2500 participants with objectively measured posture via the ActivPAL (van der Berg et al. 2016).

This is set against a background of transitioning from labour intensive occupations to large numbers of people in sedentary occupations (Katzmarzyk, Mason 2009), leading to a

reduction of more than 100 calories per day of occupation related energy expenditure in the US over the past 50 years (Church et al. 2011). There is undoubtedly a plethora of contributing factors to this "lack of success" in increasing population levels of physical activity; for example, lack of knowledge of physical activity guidelines (Knox, Musson & Adams 2015), the disconnect between immediate effort with future reward (Hall, Fong 2007) and a lack of understanding of the behavioural context (Leask et al. 2015). One way in which the measurement of context may facilitate successful interventions is by identifying context specific correlates which can then be targeted for intervention. This paper operationally defines context as who, what, where, when and why as suggested by the sedentary behaviour taxonomy (Chastin, Schwarz & Skelton 2013).

Despite the broadness of context, the measurement of context is an understudied research area. Several questionnaires are available which collect information on the domain, such as work, leisure or travel, in which physical activity or sedentary time is accumulated; for example, the domain specific sitting time questionnaire (Marshall et al. 2010) or the international physical activity questionnaire (IPAQ) (Booth et al. 2003) . From each domain a composite measure is then calculated which provides a crude estimate of the "context" of physical activity or sedentary time. However, a review of sedentary behaviour measurement found all composite questionnaires, when compared to objective measures, to have Spearman's rho of less than 0.49 (Healy et al. 2011). Interviewer administered 24 hour recalls are able to provide a wealth of contextual information such as the domain and purpose of the behaviour (Welk, Kim 2015); however, they may be unsuitable for long term monitoring studies and can be burdensome for the participant and labour intensive for the researcher.

Similar to the measurement of physical activity and sedentary time, objective monitoring of context may be logically seen to provide a more optimal and richer measurement paradigm. Previous objective monitoring of context, in a physical activity setting, has largely utilised

Global Positioning Systems (GPS) and wearable cameras. Originally developed by the US military, GPS utilises orbiting satellites to calculate longitude and latitude coordinates to provide objective quantification of outdoor location (Maddison, Ni Mhurchu 2009). In a physical activity setting GPS has been combined with accelerometry to quantify physical activity accumulated in outdoor locations such as in green space (Lachowycz et al. 2012, Almanza et al. 2012, Evenson et al. 2013) or during active travel (Cooper et al. 2010, Rainham et al. 2012, Southward et al. 2012). However, the average individual spends 85% of their day indoors (Klepeis et al. 2001) where, due to the loss of satellite signal, GPS does not function.

This paper discusses the objective measurement of context, using example data from three ongoing studies to illustrate the utility of quantifying context. Study 1 assesses wearable cameras and electrical energy monitoring as measures of television viewing. Studies 2 and 3 utilises proximity sensors to assess indoor locations of older adult care home residents and workplace intervention exposure respectively. Data generated from these specific technologies are discussed; however, there are a host of alternate technologies available with many other possible applications. These exemplar studies, and the technologies used within them, should be viewed as illustrative of the utility of measuring specific aspects of context, but not the entire behavioural context, to add important information to current measurement paradigms.

Study 1- Concurrent validity of electrical energy monitoring and wearable cameras as measures of television viewing

Background

Television viewing is perhaps the predominate form of leisure time sedentary behaviour (Marshall, Gorely & Biddle 2006, Clark et al. 2009). Self-report data from the 2012 Health

Survey for England show that, on average, individuals engage in 2.8 hours of television viewing on a weekday and 3.1 hours on a weekend day (Scholes, Mindell 2012). Meta-analytic reviews suggest that each 1 hour per day increment in television viewing time, may be related to a 13% increased risk of childhood obesity (Zhang et al. 2015). Meta-analytic evidence in adults suggest that the relative risk of all-cause mortality is 1.33 between those in high and low television viewing categories (Sun et al. 2015), whilst the relative risk per 2 hour increment in television viewing is 1.2 for type 2 diabetes and 1.15 for cardiovascular disease (Grøntved, Hu 2011). Furthermore, television viewing is associated with unhealthy dietary behaviours in children, adolescents and adults (Pearson, Biddle 2011). The prevalence of television viewing, alongside its direct relationships with health outcomes and other unfavourable behaviours suggests that television viewing is a key domain of total sedentary time.

Usual measurement practice

Television viewing time has been assessed almost exclusively using self-reported measures which may be subject to recall and social desirability biases (Maitland et al. 2013, Bryant et al. 2007). Test-retest reliability of self-reported television viewing is predominantly moderate-to-high; however, validity is rarely assessed and can vary substantially depending on the reference measure used (Clark et al. 2009).

Novel measurement practice and exemplar data

A great deal of interest has accrued in recent years in the use of wearable cameras to assess the context of physical activity and sedentary time. The most mature and widely used wearable camera in a research setting is the Sensecam (Doherty et al. 2013a). This device is worn via a lanyard or clip on the back of the device and automatically captures a first-person point of view image approximately every 20 seconds (Doherty et al. 2013b). Given the

potential privacy concerns of image capture, an ethical framework has been proposed to guide researchers and participants in their use of wearable cameras (Kelly et al. 2013). Wearable cameras have previously been used to assess active travel and to augment accelerometer measured time spent sedentary and in physical activity (Kelly et al. 2011, Kelly et al. 2012b, Doherty et al. 2013a, Kelly et al. 2012a, Doherty et al. 2012, Kerr et al. 2013). Given the wide range of information that can be extracted from an image, wearable cameras offer the potential to simultaneously assess a number of contextual factors; however, image coding can be laborious on the researcher. The images generated by wearable cameras may therefore be suitable for assessing television viewing.

Energy monitors are small units which are plugged into electrical power sockets and collect energy usage data when the plug from an appliance is inserted into the energy monitor. Interested readers are referred elsewhere (Kulkarni, Welch & Harnett 2011) for more detailed discussion and example devices used in energy monitoring. Energy monitoring therefore offers the potential to measure when a television is switched on or off.

Both wearable cameras and energy monitoring may be able to provide a more objective measure of television viewing than self-report measures. Energy monitors provide an objective measure of when the television is switched on and the wearable camera permits objective information on whether the person is watching the television (i.e. within close proximity and facing the screen). The aim of this study is to determine the concurrent validity of these technologies as measures of television viewing.

A convenience sample of participants (n=6, 50% female, mean age 27 ± 2) were recruited with the only exclusion criteria being non-ownership of a TV. Participants television sets were fitted with a small energy meter which measured the electrical energy consumed in Watts per minute. This was used to determine if the television was switched on. Participants

wore an Autographer wearable camera attached, via a clip on the back of the camera, to the neckline of their top. The Autographer was set to medium image capture rate (up to 240 images per hour). Participants also wore a waist-worn Actigraph GT3X+-BT on their right hip collecting data at 100Hz. Participants were monitored for 24 hours but only wore the wearable camera when they were at home; this was felt necessary as this study looked specifically at television viewing time and the limited battery life of the camera may have been depleted if the camera were used outside of the home.

Ethical approval was obtained from Loughborough university ethics committee and all participants provided written informed consent to participate in the study. Camera images were coded to show whether the television was visible and the location of the participant (i.e. which room they were in). Figure 1 shows examples of images that were coded as a) watching television b) television not seen but in the living room c) not in the living room and d) un-codeable. The category "no TV but in the living room" was determined by comparison with images coded as "TV watching". If there was consistency in the features (e.g. curtains, coffee tables etc.) with the "TV watching" images but no TV actually present in the image then the image was coded as "no TV but in the living room". If there were no identifiable features (such as picture 1d) then the image was deemed to be un-codeable. Actigraph vertical axis data were processed using a cutpoint of 100 CPM for sedentary time. This cutpoint was used as it is the most widely used cutpoint to determine sedentary time (Atkin et al. 2012); however, the accuracy of this cutpoint has been questioned (Kozey-Keadle et al. 2011, Kerr et al. 2013).

Results are shown in table 1. Energy monitors showed the TV was switched on for an average of 202 ($\pm$ 14) minutes per day; however, wearable camera images showed an average of just 90 ($\pm$ 43) minutes of television viewing and a further 52 ($\pm$ 24) minutes with the participant in their living room but a television not seen in the image. The remaining camera

images were un-codeable due to a lack of identifying features (e.g. a picture of a ceiling). Of the 202 minutes, 163 ($\pm$ 11) were spent in < 100 CPM whilst 39 ($\pm$ 13) were spent in light activity.

In this very small sample, 32% of daily sedentary time was accumulated when the television was turned on; conversely, if wearable camera images are used as the measure of television viewing then 17% of daily sedentary time is accumulated whilst watching television. Wearable camera television viewing in this study is in broad agreement with previous studies using wearable cameras which have found 11% of total sedentary time is spent watching television (Kerr et al. 2013). It is possible that energy monitoring overestimates the amount of time spent watching television rather than when the television is switched on. However, it is also possible that wearable cameras may underestimate TV viewing through the participant turning their neck rather than their body depending on the position of their sofa, or slouching or lying, all of which may leave the camera pointed away from the TV. Self-reported TV viewing time was not collected in this study; however, previous self-report data from the 2012 Health Survey for England show that, on average, individuals engage in 2.8 hours (168 minutes) of television viewing on a weekday and 3.1 hours on a weekend day (186 minutes) (Scholes, Mindell 2012). This may further suggest that energy monitoring overestimates TV viewing.

Table 1. Summary statistics of energy monitoring and wearable cameras as measures of television viewing

	Participant						Mean ±SD
	1	2	3	4	5	6	
Actigraph wear time	758	760	808	800	809	834	795 ± 30

Autographer wear time	204	206	276	390	182	216	246 ± 77
Total daily sedentary time (<100 CPM)	477	579	429	416	589	599	514±84
TV on time (minutes)	185	185	215	215	208	208	202 ± 14
Camera TV shown time (minutes)	73	103	16	127	136	86	90 ± 43
Camera in living room but TV not shown (minutes)	95	59	47	36	24	51	52 ± 24
TV turned on but camera shows another room (minutes)	7	12	120	11	41	44	39 ± 43
TV turned on but image un-codeable (minutes)	10	11	32	41	7	27	21 ± 14
TV on and < 100 CPM (minutes)	157	155	159	170	184	156	163 ± 11
TV on and >100 CPM (minutes)	28	30	56	45	24	52	39 ± 13
Percentage of total daily sedentary time with TV switched on	33	27	37	41	31	26	32 ± 6
Percentage of total daily sedentary time with TV switched on and shown in camera images	15	18	4	31	23	14	17 ± 9

Figure 1. Wearable camera images showing (a) TV, (b) no TV but in the living room, (c) Not in living room, (d) un-codeable image

The high number of un-codeable images suggests that this form factor of wearable cameras (deployed on a lanyard or fixed to clothing) may be a poor indicator of television viewing. This may be partly due to the camera attachment and the resultant field of view when the individual is slouching whilst watching television which may result in the camera pointing away from the television. Therefore wearable cameras may not be suitable for identifying some recreational sedentary behaviours; this is particularly noteworthy as previous research using self-report questionnaires has found television viewing to be the most prevalent leisure time sedentary behaviour (Marshall et al. 2010). Wearable gaze cameras, often in the form of eye glasses, may be able to overcome this limitation. The added benefit of gaze cameras is that they are likely to allow for better quantification of multiple screen use.

Study 2- Measurement of indoor location of sedentary time accumulation

Background

Global positioning systems (GPS) have previously been used to assess the outdoor location of time spent sedentary or in physical activity (Wheeler et al. 2010, Rodriguez, Brown & Troped 2005); however, the majority of individuals spend the vast majority, approximately 85%, of their day indoors (Klepeis et al. 2001) where GPS cannot provide location information (Krenn et al. 2011, Maddison, Ni Mhurchu 2009). Furthermore, features and equipment within the indoor environment may influence physical activity and sedentary time (Kaushal, Rhodes 2014, Maitland et al. 2013). Several technologies, such as Bluetooth low energy (BLE) iBeacons, radio-frequency identification (RFID) and real time locating systems (RTLS), are available which are able to measure indoor location (Loveday et al. 2015); however, their use in physical activity research to date has been very limited. These technologies, particularly RFID, have been more widely evaluated in healthcare and warehousing for purposes such as asset tracking (Rousek et al. 2014) or detecting when a patient is in or out of their hospital bed (Ranasinghe et al. 2014).

Usual practice

Domain specific questionnaires are commonly used to assess behaviour performed across workplace/school, travel and home; however, these questionnaires are not able to assess important sub-domain behaviour; for example, which rooms within the workplace, school or home the behaviour occurred (Keadle et al. 2014). Wearable cameras have also been used to assess the type and context of objectively measured physical activity (Doherty et al. 2013a) and could provide a measure of indoor location if the captured image contains an identifying feature; however, this identifying feature may not always be present in the image and requires an extensive knowledge of the participants environment on the part of the image coder.

Sociometers are novel devices which incorporate an accelerometer, Bluetooth proximity sensor and audio recorder to collect data on an individual's interactions and communications (Yu et al. 2015). The validity of these devices has previously been assessed under simulated conditions within environments such as hospital emergency departments with the devices able to distinguish body movement and proximity between individuals but showing poor validity at detecting face-to-face interactions (Yu et al. 2016). Furthermore, in free living conditions the continuous recording of audio may be off putting to participants and may create an artificial environment in which participants are highly mindful of what they say.

Indoor location and sedentary time within a workplace have been measured using a RFID system in conjunction with a posture sensor; however, practical and technical challenges meant that the use of analogous system of indoor location monitoring cannot yet be recommended (Spinney et al. 2015).

Novel measurement practice and exemplar data

The following is a description of the deployment protocol used in a study of the locations in which older adults in care homes accumulate their sedentary time. Ethical approval was obtained from Loughborough university ethics committee and all participants provided written informed consent to participate in the study. Based on a systematic review of location measurement technologies (Loveday et al. 2015) a number of options were considered for use in this study. A Wi-Fi based RTLS has the advantage of leveraging existing wireless infrastructure but was deemed unsuitable for this particular study due to a lack of enterprise level Wi-Fi, necessary for RTLS to function optimally, in the care homes. Further information on RTLS can be obtained elsewhere (Loveday et al. 2015). Bluetooth low energy (BLE) iBeacons have the advantage of being relatively inexpensive and were also considered but were deemed unsuitable as they would have necessitated providing each participant with

a mobile phone for the beacon to communicate with. Therefore a different BLE system was used in this particular study and is described in more detail below.

Actigraph LLC provide the most widely used accelerometers to measure time spent sedentary and in physical activity (Strath et al. 2013). The two latest models from Actigraph (GT3X+BT and GT9X http://www.actigraphcorp.com/) are also equipped with BLE functionality allowing them to be used for proximity based indoor location tracking. This system has the advantage of measuring behaviour and location in one, wearable device. Actigraphs are initialised as "receivers" or "beacons" with beacons generally placed around the environment and receivers generally worn by the participant. Receivers and beacons then communicate via BLE to infer location.

The Actigraph GT9X was used in the present study to measure location and the LumoBack device was used to measure lying, sitting, standing and stepping time. Participants were drawn from a care home in Leicestershire, UK and required to be free of diagnosed dementia and non-bedbound. In total, 32 Actigraph beacons were deployed around the care home with 5 in resident's rooms (i.e. 1 in each room) on the wall where the door was situated facing inwards to the room and therefore away from the corridor, 12 in communal rooms with 1 beacon on each wall across 3 communal rooms (i.e. 4 beacons per communal room) and 15 in corridors with 1 beacon at each change of direction in the corridor in order to ensure that the whole corridor was covered. Beacons were placed in the centre of the wall at a height of 2.5m and unobstructed to ensure adequate BLE coverage. If an obstacle was present (e.g. a clock) then beacons were placed slightly lower to avoid the obstacle. The Actigraph receiver was worn by care home residents (n=5, 100% female, mean age 87 ± 5) on their non-dominant wrist. Actigraph receivers were initialised to collect proximity data at 10 second intervals and raw acceleration at 100Hz. Receivers were removed overnight, placed on charge by the care home staff and given back to the participants when they woke up in the morning.

Residents also wore the LumoBack posture sensor (http://www.lumobodytech.com/lumo-back/). The LumoBack (4.15 x 10 x 0.8cm, 25g) is a small posture sensor which is worn on the small of the lower back via an elasticated belt and continuously tracks the amount of time spent lying, sitting, standing and stepping via inertial sensors collecting data at a constant 25Hz (Brakenridge et al. 2016). The LumoBack has shown strong correlations in free living conditions against the activPAL in total time spent standing ($R^2 = 0.86$) and sitting ($R^2 = 0.89$) (Rosenberger et al. 2014) with a mean absolute percentage error (MAPE) of 9.5% when assessing total sitting time (Rosenberger et al. 2016). Furthermore, the LumoBack has shown excellent agreement in step counting under controlled laboratory conditions against the Optogait treadmill test (MAPE 0.2%, Intraclass correlation coefficient (ICC = 0.99) and under free living conditions against the activPAL (MAPE 0.4%, ICC = 0.99) (Kooiman et al. 2015).

Following preliminary analyses, example proximity and posture data from five care home residents are presented. Residents wore both devices for one week with data presented as average values per day. These data are taken from a larger study and used for illustrative purposes to highlight the utility of the measurement technology. Descriptive statistics of time spent in each posture, measured via the LumoBack, and each location, measured via Actigraph GT9X Bluetooth proximity, per hour are presented in Figures 2 and 3 respectively.
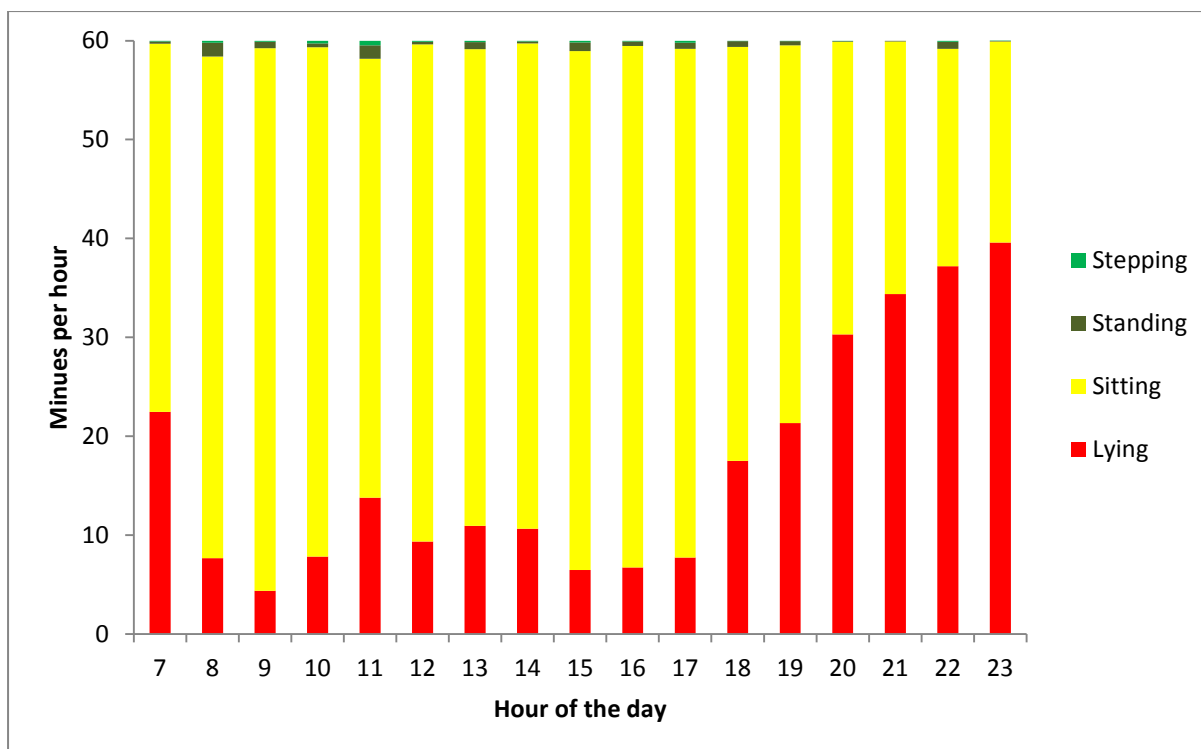
Figure 2. Hour by hour plot of LumoBack measured average behaviours of the care home residents. On average, between 7am-11pm, residents accumulated 288.2 (±11.4) minutes of lying, 720.5 (±11.2) minutes of sitting, 9.0 (±0.4) minutes of standing and 2.2 (±0.1) minutes of stepping.

Figure 2 shows that participants spent the vast majority of their day sedentary. Conversely, participants engaged in very small amounts of standing or stepping.
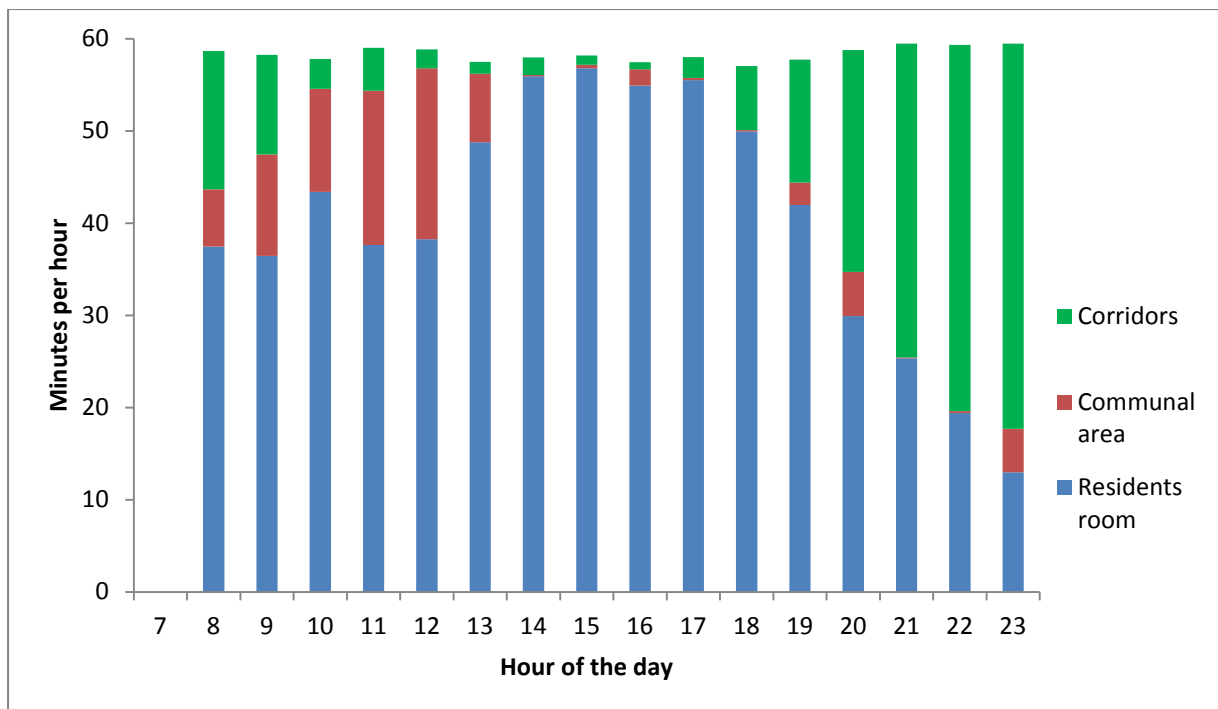
Figure 3. Hour by hour plot of resident's average location within the care home. On average, between 7am-11pm, residents accumulated 644.6 ($\pm$13.0) minutes in their own room, 86 ($\pm$5.9) minutes in communal areas and 202 ($\pm$14.0) minutes in corridors (confounded by device charging time).

Processed location data (Figure 3) showed that participants spent the majority of their waking day in their own room and more time in communal areas in the morning than in the afternoon. The large amount of time spent in corridors in the later evening reflects the fact that during the overnight period the devices were taken off so they could be charged (in the corridor charging station) rather than actual resident's location. More sophisticated analyses are currently being conducted to expand on the results.

These data provide preliminary suggestions that older adult care home residents accumulate very large (98% of time 7am-11pm) amounts of sedentary time with the majority of this time occurring in their own room within the care home. Time spent in communal areas may be important to facilitate social contact between residents. Furthermore, residents may be more likely to engage in activities (e.g. bingo) within communal areas than within their own room which, although sedentary, may convey psychological well-being benefits in this population.

The very high amount of sedentary time may reflect the functional status of care home residents as opposed to older adults who reside in their own home or an assisted living facility. Given the limited location possibilities available to care home residents, it seems worthwhile to investigate the utility of this technology in settings which may offer more location possibilities and populations which are likely to spend their time in more varied locations.

Study 3- Quantifying workplace intervention exposure

Background

Adults typically accumulate their sitting in three domains: the workplace, during leisure time and for transport (Owen et al. 2010). Many adults are now employed in sedentary occupations, such as office work (Katzmarzyk, Mason 2009). Desk-based office workers spend the majority of their working hour's sedentary (Clemes, O'Connell & Edwardson 2014, Thorp et al. 2012); it has therefore been suggested that workplaces may be an ideal setting to introduce interventions to decrease sedentary time. Interest has grown in recent years around the provision of activity permissive office equipment such as height adjustable desks and treadmill workstations, to displace sedentary time with standing or light ambulation (Tudor-Locke et al. 2014).

Current practice

A number of studies are beginning to emerge investigating the use of height adjustable desks with objective measures of physical activity and/or sedentary time (Neuhaus et al. 2014). The installation of height adjustable desks has been found, one week after installation, to reduce activPAL measured sitting by 143 minutes per day at the workplace and 97 minutes per day overall with these effects maintained at 3 month follow up (Alkhajah et al. 2012). Similar

findings have been reported elsewhere with activPAL measured sitting reducing by 73 minutes per workday and standing increasing by 65 minutes per workday (Chau et al. 2014). Conversely, other height adjustable desk studies have reported non-significant reductions in workplace sitting time unless part of a multi-component intervention (Neuhaus et al. 2014).

In order to obtain a more robust quantification of the effect these interventions have in reducing sedentary time, it is important to quantify intervention exposure (e.g. the amount of time spent using the height adjustable desk). Current methods rely on self-reported work hours to quantify this effect; however, this does not take account of working time spent away from the height adjustable desk (e.g. in meetings, at lunch, time spent accessing communal resources such as supply stores or copiers/printers).

Novel measurement practice

Objectively quantifying time spent at the height adjustable desk or treadmill workstation offers the potential to better evaluate the effects of these interventions. This quantification could be achieved via proximity monitoring between the participant and the desk, for example using small BLE stickers (e.g. http://estimote.com/). This technology currently requires the participant to carry a mobile phone which may be potentially unsuitable for some applications. In future, it is likely that this technology will be able to communicate with a smart watch or other BLE enabled device. Quantification of time spent at the height adjustable desk or treadmill workstation could also be achieved using sensors affixed under the desk (e.g. http://www.humanscale.com/landing/officeiq.cfm). However these systems generally assess whether any individual is at the height adjustable desk or treadmill workstation and may be unable to differentiate when a specific individual is there. This is clearly problematic when assessing a specific participant's intervention exposure. Given the limitations of these systems to assess height adjustable desk exposure it was deemed more

worthwhile and feasible to focus on objectively assessing office dwell time (i.e. the amount of time spent in the office) as a proxy of height adjustable desk exposure in the present study. Although imperfect, objectively assessing office dwell time to quantify intervention exposure may present a considerable improvement on the current method of self-reported work hours.

This study presents initial pilot data collected as a precursor to a recently initiated cluster randomised controlled trial (RCT) incorporating height adjustable desks and proximity based location measurement; for brevity, the main trial is described in general terms with a focus on the features most pertinent to the initial pilot data and the present paper. A detailed protocol of the main cluster RCT is available elsewhere (O'Connell et al, 2015). Briefly, the cluster RCT (Trial ID ISRCTN10967042) aims to develop and evaluate an intervention to reduce workplace sitting time over 12 months within office based UK National Health Service (NHS) employees. Guided by the behaviour change wheel (Michie, van Stralen & West 2011), the intervention incorporates environmental, organisational and individual strategies including height adjustable workstations, self-monitoring tools and other behaviour change techniques. Data will be collected at four time points; baseline, 3, 6, and 12 months. The main outcome of the study is a reduction in activPAL measured sitting time at 12 months with objectively measured physical activity and a variety of work-related health and psycho-social measures as secondary outcomes. Work related measures include presenteeism, occupational fatigue and job satisfaction. Particularly relevant to the present paper, participant's office dwell time will be measured using the Actigraph proximity feature, allowing the quantification of intervention exposure (i.e. time spent neat the height adjustable desk) in an unobtrusive manner. To the author's knowledge, this will be the first height adjustable desk intervention to include an objective measure of office dwell time as a mechanism for better quantification of intervention efficacy in reducing workplace sitting.

Summary descriptive statistics of five participants (20% female, mean age 26 ± 4), measured for one day each, from preliminary pilot testing of the system are presented here to illustrate the utility of this new measurement approach. All participants were drawn from a convenience sample of Loughborough university employees with no exclusion criteria. All participants already used a height adjustable desk in their office. Ethical approval was obtained from Loughborough university ethics committee and all participants provided written informed consent to participate in the study.

Office dwell time was measured via Actigraph Bluetooth proximity with each participant wearing a GT9X on their non-dominant wrist. Actigraph GT9X beacons were placed high and unobstructed in the centre of the same wall where the door was situated with beacons placed facing inwards to the office. The range of the Actigraph BLE signal is dependent on the environment in which they're deployed but is approximately 10-20 metres; however, BLE is obstructed by, among other things, concrete, plaster and brick which should ensure that erroneous signals received from beacons in other rooms is minimal. Time spent sedentary and upright were measured via the activPAL attached to the participant's thigh collecting data at the default rate of 20Hz. Participants self-reported their working hours with time spent sedentary and upright in and out of the office calculated during self-reported working hours (excluding self-reported lunch times). All data are presented in table 2.

Table 2. Summary statistics of sedentary and upright time accumulated inside and outside the office during self-reported working hours

	Participant					**Mean ±SD**
	1	2	3	4	5	
Sedentary time during self-reported working hours (minutes)	235	290	247	119	108	200 ± 73

Sedentary time in the office during self-reported working hours (minutes)	196	273	236	11	98	163 ± 96
Sedentary time outside the office during self-reported working hours (minutes)	39	27	11	107	10	39 ± 36
Upright time during self-reported working hours (minutes)	208	90	79	375	154	181 ± 108
Upright time in the office during self-reported working hours (minutes)	55	49	26	176	134	88 ± 57
Upright time outside the office during self-reported working hours (minutes)	139	40	53	200	19	93 ± 70

These analyses showed that using the current practice of self-reported working hours, participants accumulated 200 minutes of sedentary time at work; however, using the novel measurement practice of office dwell time, only 163 minutes of this time occurred in their office. Sedentary time during self-reported working hours in the present study is towards the lower end of previous research investigating sedentary behaviour in office workers with previous research finding office workers spend 50-75% of their working hours sedentary (Buckley et al. 2015). Nonetheless, the purpose of this study was to show that office workers do not spend all of their working hours, or indeed accumulate all of their occupational sedentary time, at their desk and the ensuring implications for assessing height adjustable desk efficacy.

These data provide preliminary indications that office workers may spend a proportion of working hours outside of their office. This has clear implications for assessing the efficacy of office based environmental interventions such as height adjustable desks. Using office dwell

time as the sedentary time denominator may therefore provide a more robust means of assessing intervention efficacy than self-reported working hours.

Discussion

This paper has briefly outlined and provided sample data for three studies, each involving contextual monitoring in conjunction with objective measurement of physical activity and/or sedentary behaviour. These studies included the use of energy monitoring and wearable cameras to quantify television viewing, the use of indoor location monitoring to assess the locations in which sedentary time occurs and the use of a proximity system to quantify office dwell time as a surrogate of exposure to a height adjustable desk

Using energy monitoring and wearable cameras to measure television viewing it was found that wearable cameras may not suitable for measuring television viewing due to a large number of pictures being un-codeable due to a lack of distinguishing features likely brought about by the mal-aligned field-of-view of the camera due to slouching postures. That being said, wearable cameras have successfully been used to assess a wide range of contextual information beyond TV viewing and, as such, are a valuable measurement tool (Doherty et al. 2013a, Leask et al. 2015, Doherty et al. 2012, Kerr et al. 2013). Energy monitoring is a feasible means of identifying when the television is switched on but not necessarily when it is being watched. For example, the participant may not be looking at the television or may be in an entirely different room.

The second use case highlights indoor location monitoring in conjunction with the LumoBack to elucidate the locations in which sedentary time occurs in older adult care home residents. This study found that older adult care home residents spend the vast majority of their waking day sedentary, on average, accumulating 720 minutes of sitting. Although previous literature using objective assessment of care home residents is scarce (Barber, Forster & Birch 2015),

this figure appears to be considerably higher than previous estimates of sedentary time among this group. For example, an accelerometer study in the UK found an average of 607 minutes per day of sedentary time among care home residents (Barber, Forster & Birch 2015). This may be due, at least in part, to differences in measurement with the use of a posture sensor in the current study rather than an accelerometer to quantify sedentary time. Location monitoring showed that on average older adult care home residents spend the majority of their day in their own rooms and more time in communal areas in the morning than in the afternoon. Time spent in communal areas may be important to facilitate social contact between residents. Furthermore, residents may be more likely to engage in activities (e.g. bingo) within communal areas than within their own room. This has important implications for intervention design.

Lastly, proximity monitoring was highlighted as a means of quantifying office dwell time as a measure of exposure to a height adjustable desk installed in the office. This is important as the success or failure of an intervention to reduce sitting time can only truly be judged by quantifying exposure to the intervention; in other words, when it is actually possible for the participant to use the desk. This is not to say that a height adjustable desk intervention with low exposure cannot be successful; for example, an individual who spends the entire working day at their desk may achieve a greater absolute reduction in sitting but an individual who spends less time at their desk could still achieve a greater relative reduction during the time that they do spend at the desk. In essence, quantifying exposure is important to more fully elucidate the intervention effect. This technology has been implemented into an ongoing study which, to the author's knowledge, will be the first to quantify the amount of time the participant spends at their desk before and after the installation of a height adjustable desk.

The three use cases outlined in the present paper provide a flavour of the value of measuring context within physical activity and sedentary behaviour research. These use cases should be

viewed as examples with many other possible applications of the measurement technologies. For example, energy monitoring could be used to differentiate when exercise equipment such as treadmills are switched off at the wall socket, on at the wall socket but off at the treadmill or on at the wall socket and on at the treadmill. This may allow inference, using the time that the treadmill is on at the wall socket and treadmill, of the type of physical activity. Similarly, indoor location can be as readily measured and equally useful in a variety of settings and populations such as childcare centres, fitness centres or individual homes. For example, the presence of a television in a young person's bedroom may be a correlate of higher screen time (Hoyos Cillero, Jago 2010); however, the strength of this correlate may be affected by the amount of time the young person spends in their bedroom. Indoor location monitoring allows for this quantification.

Similarly to measurement tools for quantifying physical activity and sedentary time, the measurement tools available to assess the context in which these behaviours occur are evolving rapidly with many tools likely to have been complemented or supplanted by newer models or tools before the research studies in which they are used reach publication. This should not discourage researchers from using contextual measurement tools; as the tools will retain their functionality in providing important contextual information. For example, one noteworthy innovation in proximity sensing is the recent miniaturisation of this technology to a smaller form factor into a "nearable" sensor (e.g. http://estimote.com/). This technology can therefore now be affixed to smaller objects such as chairs, exercise equipment or small screen equipment. This offers the tantalising possibility of quantifying the type of behaviour being performed in an inexpensive and unobtrusive manner.

Although the measurement of context can provide important behavioural information, it is not without limitations. Currently, depending on which piece of context the research seeks to assess, the participant may be required to wear an additional device(s). Wearing more than

one device may have implications for participant burden (Maddison, Ni Mhurchu 2009); however, GPS and accelerometry have successfully been used in a number of studies (Dessing et al. 2013, Klinker et al. 2014, Cooper et al. 2010) suggesting that an additional wearable, though not ideal, is not an insurmountable obstacle. Images generated from wearable cameras have been used to assess a wide range of contextual information (Doherty et al. 2013a, Doherty et al. 2012, Kerr et al. 2013); however, the labour intensive nature of image coding (Kelly et al. 2013) and potential data loss due to a relatively short battery life and lack of participant recharging among some groups, such as older adults, (Leask et al. 2015) suggest that wearable cameras are no more or less suited to assess context than other technologies. The selection of the appropriate technology is therefore likely to be research question and study population specific. For example, despite the limitations of wearable cameras, they may be the best currently available technology to concurrently assess a number of contextual factors. Conversely, if a study has a more focused requirement, for example assessing indoor location of older adults, then other technologies, such as proximity sensors, may be more suited.

The ideal tool to measure the context of physical activity and/or sedentary time is likely to possess the following features: the ability to measure the whole context, to be integrated into tools which measure physical activity and/or sedentary time so that participants are only required to wear one device, medium to long term battery life and collecting data in a manner which does not compromise participant privacy. Such a device does not currently exist and is unlikely to in the foreseeable future. Nonetheless, measuring the context in which physical activity and/or sedentary time occur can provide valuable information alongside objective measures of activity intensity and posture.

Conclusion

Wearable technologies, such as accelerometers and posture sensors, are commonly used to quantify physical activity and/or sedentary behaviour. These sensors are able to measure the volume, duration and frequency of the behaviour; however, they are unable to provide contextual information such as where the behaviour is performed, what specific behaviour is being performed and with whom. This contextual information is vital to providing greater specificity of correlates of physical activity and/or sedentary time and, thereby, allowing greater refinement of intervention strategies. Fortunately, novel technologies are emerging with the potential to provide this information. These technologies include measures of indoor location, energy monitoring of electrical appliances such as televisions and Bluetooth low energy based "nearable" sensors allowing measurement of interactions between participants and objects. This list is not exhaustive with newer technologies complementing or supplanting existing technologies at a rapid pace. The adoption of these technologies for research use will provide the behavioural researcher with a more complete picture of the behaviour than has previously been available.

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