Introduction to the Objective Measurement of Physical Activity

Research · November 2015

DOI: 10.13140/RG.2.1.1829.3202

5 authors, including:

David A Rowe

University of Strathclyde

Soren Brage

University of Cambridge

Sebastien Francois Martin Chastin

Glasgow Caledonian University

Introduction to the Objective Measurement of Physical Activity

Written by (in alphabetical order):

Dr Søren Brage

Dr Francesca Burton

Dr Sebastien Chastin

Ms Victoria Penpraze

Dr David Rowe

Recommended citation: Brage, S., Burton, F., Chastin, S. F. M., Penpraze, V. & Rowe, D. A. (2015). Introduction to the objective measurement of physical activity and sedentary behaviour. Unpublished manuscript. DOI: [To be obtained]

Explanatory note: This document was written by the above academics with expertise in the objective measurement of physical activity. It is written as an introduction to the field of physical activity measurement, dedicated in particular to those who are new to the field.

We outline the fundamental principles that should be considered when choosing to measure physical activity using objective methods, e.g. body-worn devices. We also address a critical point that is often ignored, namely that the "outcome data" are produced at the end of a complex set of procedures applied to the initial capture of the raw data. The processes used to derive the endpoint data must be considered by researchers when drawing conclusions about their research findings.

Introduction

Recent technological advances have resulted in the development of numerous objective methods designed to measure physical activity. These methods include doubly labelled water, accelerometers, pedometers, heart rate (HR) monitors, and global positioning systems (GPS). However, the emergence of new technologies yielding different information about physical activity has proven to be a challenge, in part due to variation in the dimensions of physical activity measured by these devices and also the different approaches to data processing that are implemented. This document intends to inform those new to the field of the fundamental principles of using objective methods to measure physical activity in order to enhance the quality of data collected and research findings and conclusions that these data underpin.

Background and Evidence

Before measuring physical activity it is important to acknowledge which dimension of activity is of interest. Dimensions include *frequency* (how often physical activity is undertaken in a specified period); *intensity* (absolute or relative amount of biomechanical or metabolic cost); *duration* (number of minutes of physical activity per bout); *mode* (type of physical activity such as walking, gardening, swimming); *volume* (total amount of physical activity in a specified period); and *context* (physical activity setting such as physical or social environments) . If choosing to measure more than one dimension at a time, users should prioritise the dimension of greatest importance to help focus the choice of method.

Measuring Physical Activity.

Due to its complex and multidimensional nature, dimensions of physical activity cannot always be directly measured. Instead, proxy measures may be recorded, for example heart rate used to infer energy expenditure from a physiological response, and accelerometer count patterns to infer frequency of physical activity from the motion of the body or kinematics. The use of proxy measures to infer physical activity is a source of error for all objective measures of physical activity but the error will depend on what is measured and what activity dimension is being estimated; therefore it is important to choose an objective method or device that is most valid for your chosen dimension. There are many objective measures of physical activity (de Bruin, *et al*. 2008; Godfrey, *et al*. 2008) and Table 1 provides an overview of some more common methods and their associated error when estimating different dimensions of activity. Technological advances continue to introduce new devices for measuring physical activity: Some shoe manufacturers now include an accelerometer located within the shoe that links with smartphones to provide biofeedback when exercising and body-worn cameras enhance the contextual information provided about the physical environment that GPS offers.

Table 1: Characterisation of dimension and proxy nature of common objective measures of physical activity

		Nature of proxy measure				
		Physiological		Kinematic		Location
	Method / device	DLW	HRM	Accelerometer	Pedometer	GPS
Dimension of physical activity	Frequency	-	+	++	-	+
	Intensity	-	++	++	-	+
	Mode	-	-	+	+	+
	Time	-	+++	+++	-	++
	Volume	+++	++	++	++	+
	Context	-	-	-	-	++

Key: Not possible to estimate (-), possible to estimate but with large error (+), possible to estimate with medium level of error (++), possible to estimate with low degree of error (+++). DLW: doubly labeled water, HRM: heart rate monitors, GPS: global positioning system.

Objective measures of physical activity can be broadly classed into two categories. Firstly, some assess the overall amount (*volume*) of physical activity in a given time period yielding what is sometimes called aggregated data; doubly labelled water and most pedometers fall into this category as they only provide estimates of total energy expenditure or total step counts, respectively, over a relatively long period. Secondly, there are those devices that record time-stamped information which enables further insight into intensity, frequency, duration and pattern of physical activity; accelerometers and heart rate monitors fall into this category recording acceleration signals and heart rate on a regular basis from every few milliseconds to every minute or more. The aggregated data method offers immediate convenient data for analysis, but lacks information on temporal activity patterns that can be deduced when using the latter category.

The minimum acceptable duration of daily physical activity measurement is a common subject of debate. When screening activity data collected over a day, imposing longer minimum data collection periods (a 10-hr minimum rather than an 8-hr minimum of the awake day, for example) yields more accurate estimations of physical activity but leads to a greater likelihood of discarding data. As there is no consensus definition of a 'complete' day, it is reasonable to replicate relevant landmark research studies in order to enable comparison across studies; this is obviously not an issue with 24-hr/day monitoring protocols. The minimum number of days of data collection to estimate 'true' physical activity behaviour also has no definitive consensus, although individuals with greater variability in physical activity require longer monitoring periods (see Baranowski, *et al*. 2008). When collecting time-stamped data, for example accelerometry derived activity counts, aim to use the highest sampling resolution possible; a signal with high resolution can be downsampled during postprocessing if needed, but raw data in low resolution cannot be converted into higher time resolution signals.

Processing Physical Activity Data.

To illustrate the complexity of data processing that occurs for objective measures of physical activity, Figure 1 shows a model of information flow (adapted from Corder, *et al*, 2008). As an example, HR provides a proxy measure for physical activity energy expenditure (PAEE; Stage 1). Most HR monitors initially measure electrical potential on the surface of the skin providing a 1-lead ECG signal (Stage 2). This information is processed by the monitor, which employs an algorithm to determine heart beats (Stage 3) which can be further reduced to average heart beats every minute or heart rate (HR; Stage 4). HR can be converted to PAEE using specific equations (Stage 5). Ideally, the outcome measure accurately reflects the original physical activity dimension of interest identified at stage 1; the strength and nature of this relationship is the validity of the estimate. However, at every stage of data processing, there is potential for error to occur and the outcome measure moves further away from the original dimension; this should be considered if using methods that rely on proxy measures of physical activity. See Preece, *et al*. (2009) for further discussion of data processing.

When using time-stamped sensors a large amount of detailed data is produced that needs to be reduced, after data have been screened and cleaned. This requires handling outlier data, missing data and non-wear periods (Kang, *et al*., 2009). Many data reduction techniques are available, from simple summation to more complex measures of patterns. The choice of reduction technique depends on the physical activity dimension of interest. Regardless of which technique is used, the underlying statistical distributions of the data, and the assumptions and transformation that data have undergone during processing must be reported fully and clearly.

During data processing many commercial devices (particularly accelerometers and pedometers) use manufacturers' own algorithms to infer physical activity dimension(s) from the raw proxy data; however details of such processes are seldom made available, and the assumptions and data manipulations applied are often untraceable. A lack of transparency in the algorithms manufacturers apply makes it difficult to compare different measures of physical activity. Some researchers have developed independent programmes and software for data processing in an attempt to overcome this problem; however, this may add another variable to consider when interpreting physical activity data.

As well as data processing, challenges arise when interpreting outputs from objective measures of physical activity. Intensity of physical activity is often categorised into episodes of light, moderate and high intensity activity using predefined thresholds. At present, however, there is little agreement on what these threshold levels should be (Reilly *et al*., 2008) and as such classification of physical activity intensity into these broad categories is not always consistent. Variation in the choice of objective method to measure physical activity also makes the interpretation and comparison of data difficult (Berntsen *et al*., 2010), primarily due to the different data processing techniques and algorithms that each one uses, including those from the same manufacturer. Being transparent about the data processing employed should help in the evaluation and comparison of physical activity data.

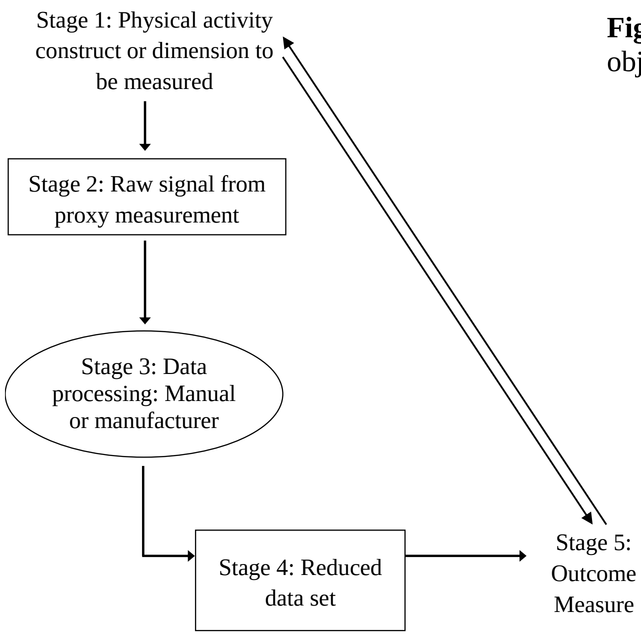

Figure 1. Model of information flow as applied to objective measurement of physical activity.

Conclusions and Recommendations

Objective measurement of physical activity is a rapidly growing field of research within sport and exercise science as well as large-scale epidemiological studies. However, this expansion has made the collection, interpretation and evaluation of physical activity data more challenging due to the variety of objective methods available and different analytic approaches applied to the outputs. The fundamental principles of physical activity measurement should be emphasised to enhance the quality of data collected. Assumptions and limitations associated with the processing and interpretation of physical activity data should not be ignored and transparency of such information is strongly recommended. We propose the following recommendations for objectively measuring physical activity:

- Clearly define and prioritise the dimension(s) of physical activity to be measured.
- Identify the proxy measure for the physical activity dimension of highest priority and select the most valid method to capture this proxy data, within the feasibility constraints of the study.
- Provide clear details of the measurement device including make, model, firmware version, and device reliability.
- Provide clear details of the monitor placement site, sampling rate, and wear instructions to participants
- Where appropriate, store all data in its most raw format and record all contextual information available.
- Provide evidence (published or pilot data) for the implemented protocol such as days and hours of physical activity measurement.
- Outline all reduction methods applied to data, including how data were cleaned, screened and outliers or missing data accounted for.
- Be transparent about algorithms applied to data, whether 'in-house' or manufacturer based, and map **all** stages of data processing. Aim to make algorithms available via open-access repositories.
- Report data on intra- and inter-subject variability, including ranges of data, standard deviation or standard error of the mean or other appropriate metrics of variability.
- Be clear about the differences between original measurement, proxy data captured and inference(s) made from these data.

References

Baranowski, T., Mâsse, L.C., Ragan, B., & Welk, G. (2008). How many days was that? We're still not sure, but we're asking the question better! *Medicine and Science in Sports and Exercise, 40,* S544-S549.

Bernsten, S., Hageberg, R., Aandstad, A., Mowinckel, P., Anderssen, S.A., Carlsen, S-H. & Andersen, L.B. (2010) Validity of physical activity monitors in adults participating in free-living activities. *British Journal of Sports Medicine, 44*, 657-664.

Corder, K., Ekelund, U., Steele, R.M., Wareham, N.J. & Brage, S. (2008). Assessment of physical activity in youth. *Journal of Applied Physiology, 105*, 977-987.

de Bruin, E.D., Hartmann, A., Uebelhart, D., Murer, K. & Zijlstra, W. (2008). Wearable systems for monitoring mobility related activities in older people: A systematic review. *Clinical Rehabilitation, 22*, 879-895.

Godfrey, A., Conway, R., Meagher, D. & ÓLaighin, G. (2008). Direct measurement of human movement by accelerometry. *Medical Engineering and Physics, 30*, 1364-1386.

Kang, M., Rowe, D.A., Barreira, T.V., Robinson, T. S. & Mahar, M.T. (2009). Cross-validation of an individual information-centered approach for handling physical activity missing data. *Research Quarterly for Exercise and Sport, 80*, 131-137.

Preece, S.J., Goulermas, J.Y., Kenney, L.P.J., Howard, D., Meijer, K. and Crompton, R. (2009) Activity identification using body-mounted sensors – a review of classification techniques. *Physiological Measurement, 30,* R1-R33.

Reilly, J.J., Penpraze, V., Hislop, J., Davies, G., Grant, S. & Paton, J.Y. (2008). Objective measurement of physical activity and sedentary behaviour: review with new data. *Archives of Disease in Childhood, 93*, 614-619.

Author Profiles

Dr Søren Brage is a Program Leader of the Physical Activity Epidemiology Programme in the MRC Epidemiology Unit, University of Cambridge. His research expertise is in the development of methods for measuring physical activity in populations.

Dr Francesca Burton is a Lecturer in Human Physiology at the University of Plymouth. Her research expertise is in physical activity and cardio-metabolic health.

Dr Sebastien Chastin is a Lecturer in Physiotherapy at Glasgow Caledonian University. His research expertise is in the analysis and handling of physical activity data outputs.

Ms Victoria Penpraze is a University Teacher in Life Sciences Human Biology. Her research expertise is in the use of accelerometers for measuring physical activity.

Dr David Rowe is a Reader in Exercise Science at the University of Strathclyde, Fellow of the American College of Sports Medicine, Fellow of the National Academy of Kinesiology, and Fellow of the Research Consortium. His research expertise is in the measurement of physical activity related to health.