Sleep Health 1 (2015) 275–284

Contents lists available at ScienceDirect

Sleep Health

Journal of the National Sleep Foundation

journal homepage: http://www.elsevier.com/locate/sleh

Practical considerations in using accelerometers to assess physical activity, sedentary behavior, and sleep

Mirja Quante, MD [a,b], Emily R. Kaplan, BS [a], Michael Rueschman, MPH [a], Michael Cailler, BS [a], Orfeu M. Buxton, PhD [a,b,c,d], Susan Redline, MD, MPH [a,b,e,*]

[a] *Division of Sleep and Circadian Disorders, Departments of Medicine and Neurology, Brigham & Women's Hospital, 221 Longwood Ave, Boston, MA 02115*
[b] *Division of Sleep Medicine, Harvard Medical School, 221 Longwood Ave, Boston, MA 02115*
[c] *Department of Biobehavioral Health, Pennsylvania State University, 221 Biobehavioral Health Building, University Park, PA 16802*
[d] *Department of Social and Behavioral Sciences, Harvard T.H. Chan School of Public Health, 677 Huntington Ave, Kresge Building, Boston, MA 02115*
[e] *Sleep Disorders Center, Beth Israel Deaconess Medical Center, 330 Brookline Avenue, Boston, MA 02115*

ARTICLE INFO

Article history:
Received 23 April 2015
Received in revised form 3 September 2015
Accepted 3 September 2015

Keywords:
Accelerometry
Actigraphy
Sleep
Physical activity
Sedentary behavior

ABSTRACT

Increasingly, behavioral and epidemiological research uses activity-based measurements (accelerometry) to provide objective estimates of physical activity, sedentary behavior, and sleep in a variety of study designs. As interest in concurrently assessing these domains grows, there are key methodological considerations that influence the choice of monitoring instrument, analysis algorithm, and protocol for measuring these behaviors. The purpose of this review is to summarize evidence-guided information for 7 areas that are of importance in the design and interpretation of studies using actigraphy: (1) choice of cut-points; (2) impact of epoch length; (3) accelerometer placement; (4) duration of monitoring; (5) approaches for distinguishing sleep, nonwear times, and sedentary behavior; (6) role for a sleep and activity diary; and (7) epidemiological applications. Recommendations for future research are outlined and are intended to enhance the appropriate use of accelerometry for assessing physical activity, sedentary behavior, and sleep behaviors in research studies.

Introduction

Accelerometry (also referred to as actigraphy) is one of the most commonly used methods to objectively assess physical activity (PA) and/or sleep in free-living individuals.[1,2] By capturing and analyzing changes in movement, accelerometers provide an objective measure of activity frequency, intensity, and duration with minimal subject burden, which can be used to quantify PA, sedentary behaviors (SBs), and sleep-wake periods[3] and potentially to distinguish times spent in each of these activities. Accelerometry provides a wide range of summary statistics on PA such as sedentary time, light-intensity PA, moderate PA, vigorous PA, moderate-to-vigorous PA (MVPA), and total activity counts per day, as well as sleep-wake behaviors, including sleep duration, nap duration, sleep latency, sleep maintenance efficiency, sleep fragmentation, sleep onset time, sleep offset time, and sleep midpoint.[4,5] Due to their low subject burden, accelerometers are especially attractive for use in longitudinal, large-scale epidemiologic studies and intervention studies where repeated assessments are needed. Accelerometers eliminate recall and reporting biases and may provide more consistent data across population groups compared to questionnaires, which are influenced by language and literacy and reporting biases.[6]

There is established utility of using accelerometry for PA, SB, and sleep-wake estimation, as well as known limitations. Accelerometers have demonstrated adequate intrainstrument and interinstrument reliability for estimating PA and SB in controlled laboratory and in free-living conditions but have limited ability to quantify times spent in specific activities.[7] Furthermore, there are challenges when using accelerometry in research studies due to a lack of standardized procedures for identifying the spectrum of SB and PA behaviors and for defining these behaviors at different points in the life course. The American Academy of Sleep Medicine has recognized accelerometry as a valid measure to assess sleep-wake periods.[2] In comparison to polysomnography, accelerometry has reasonable validity and reliability in assessing sleep-wake patterns in normal individuals with average or good sleep quality. However, the validity appears to be lower in individuals with poor sleep quality (high amounts of wake after sleep onset) due to its relatively low specificity to detect wakefulness during sleep periods.[8] Age is another important variable that may affect the accuracy, sensitivity, and specificity of accelerometry.[8] For example, sleep efficiency declines with age,

---

[*] Corresponding author at: Division of Sleep and Circadian Disorders, Departments of Medicine and Neurology, Brigham & Women's Hospital, 221 Longwood Ave, Boston, MA, 02115. Tel.: (617)-732-4013; fax: (617)-732-4015.
E-mail address: sredline1@rics.bwh.harvard.edu (S. Redline).

http://dx.doi.org/10.1016/j.sleh.2015.09.002
2352-7218/© 2015 National Sleep Foundation. Published by Elsevier Inc. All rights reserved.

and, therefore, in older adult women (mean age, 69 years) with insomnia, accelerometry accuracy fell below 80% as the sleep efficiency measured by polysomnography fell below 73%.[9] These observations highlight the need to appropriately consider age-related differences when interpreting accelerometry studies.

Although there is some correlation between motor activity with specific sleep stages, accelerometry cannot be used to assess sleep architecture.[10]

There are many accelerometers on the market potentially suitable for use in research. Each commercially available device uses different hardware, software, and sets of algorithms to identify sleep-wake and/or activity levels. Lack of standardization limits the utility of use of these devices for use across populations and studies, such as for population-level PA surveillance.[7] Similar concerns apply when using these devices for population studies of sleep-wake patterns.

The purpose of this review is to identify several methodological questions and decisions relevant for the design and implementation of research that uses this technology, such as choice of cut-points, impact of epoch length, accelerometer placement, duration of monitoring, best approaches for distinguishing sleep, nonwear times and SB, the need for a sleep and activity diary, and epidemiological applications. A special focus is on approaches to measure activity and sleep concurrently over a 24-hour period. The latter may have especial utility for identifying potential interacting health effects of activity and sleep. This review will also identify gaps in evidence where future research is needed. Although this is not a systematic review, we conducted a comprehensive search on MEDLINE, PubMed, and Google Scholar in the English-language literature, using the following key words: accelerometer, actigraph, PA, SB, sleep, cut-points, epoch length, wrist, hip/waist, days/hours of monitoring, placement, wear time, sleep diary, activity logs, and consumer-based activity monitors. We screened articles for inclusion based upon the title and abstract of all these citations, retrieved full manuscripts of potentially relevant articles, and selected final articles for our review after thoroughly reading them. The literature search included publications through August 2015.

Technical basis of accelerometry

Accelerometers are small, wearable, and noninvasive devices designed to record motion intensity as a function of time. Most monitors use piezoelectric, piezoresistive, or capacitive sensors. Accelerative forces stress these transmitters, leading to the production of an electrical signal that is proportional to the magnitude of the acceleration force. Accelerometers can be uniaxial, usually sensitive to movements in the vertical plane, or biaxial or triaxial, with movement also detected in the anteroposterior and/or lateral planes.[11] The outputs from accelerometers are converted, filtered, and summed over a user-specified cycling period, known as an epoch, and reported as dimensionless units commonly referred to as "counts."[12] Usually, proprietary algorithms are used to convert raw acceleration data to counts. This can be problematic as the use of different filters and processing algorithms can drastically alter the output signal. Peach et al[13] suggest that open-source software be developed to allow researchers to adapt filtering methods to match the needs of their individual research projects.

Different algorithms are used to translate accelerometer counts to estimates of sleep and PA; and, in general, commercially available monitors are optimized and often only validated for either sleep or PA measurement. Generally, devices worn at the hip with sensors sensitive and oriented to vertical acceleration are used to record PA, whereas accelerometers for sleep assessment are usually worn at the wrist and contain sensors that are more horizontally oriented and, therefore, sensitive to arm movements.[14] Some newer devices are equipped with an inclinometer that reports posture and can distinguish between lying, sitting, and standing. However, there is only limited research on the reproducibility and validity of this inclinometer function.[15,16] Commonly used accelerometers for PA, SB, and sleep determination are summarized in Table 1.

Accelerometer cut-points

Analog signals transduced from the motion of accelerometers can be digitized in different ways (eg, threshold crossing, cycle count, etc), yielding different activity counts for the same underlying motion. This means that the precise physical meaning of a count can be widely different according to how the signal was digitized. Cut-points are then applied to these counts to classify ranges of PA intensity (eg, moderate-vigorous) or to distinguish sleep from wake periods. Generally, cut-points for PA are based on calibration studies with concurrent collection of energy expenditure or direct observation.[17] Sleep algorithms have been validated against polysomnography, the gold standard for sleep assessment,[8] and generally have been based on activity count thresholds or regression equations.

A number of cut-points have been proposed for estimating PA. Because patterns of PA and mechanical efficiency vary by age,[18-20] different cut-points have been developed for adults and for children across the pediatric age range. However, the range of available cut-points also reflects differences in calibration activities, criterion measures, and statistical analyses used in their derivations. Understanding the impact of different approaches for digitizing data as well as for deriving cut-points for classifying PA, SB, and sleep behaviors is important to appropriately interpret data from accelerometers, both for research and for public health interventions aimed at targeting specific populations for activity behavior change.[21] Numerous studies have described the impact of using alternative cut-points for gauging PA activity. For example, Mota et al[22] found that the percentage of children who met PA guidelines was significantly higher when using the Freedson child cut-points compared to the Puyau cut-points. Watson et al[23] used cut-points from 9 studies to estimate PA in a national adult sample ($n = 6547$). Results showed that the prevalence of meeting the 2008 PA Guidelines for Americans ranged from 6.3% to 98.3% according to which cut-point was used. Similarly, results from National Health and Nutrition Examination Survey (NHANES) 2003-2006 estimated PA intensity with 5 child-derived and 12 adult-derived cut-points and showed that cut-point selection influenced the relationship between PA and various health outcomes. For example, the percentage of participants not meeting PA guidelines among those who were obese ranged from 33.5% to 44.0%.[21]

Accelerometers are also used to identify SB, which is not simply the absence of PA but is defined as energy expenditure between 1 and 1.5 metabolic equivalents while sitting or lying.[24] A number of accelerometer cut-points have been proposed for defining SB both in children and adults. The most commonly applied cut-point for adults is a threshold of <100 counts per minute (CPM).[25,26] In children, SB cut-points vary widely, from 5 CPM to 1100 CPM.[6,27-33] Atkin et al[34] compared 4 different cut-points for SB in a large sample of children and found that estimates of sedentary time differed significantly for each cut-point. Specifically, a 2-fold increase in the accelerometer cut-point increased estimated SB by a factor of 1.2.[34] Reilly et al[1] and van Cauwenberghe et al[33] have shown that the choice of a sedentary cut-point can change estimates of SB by more than 4 hours per day in preschoolers. Moreover, the strength of the association between sedentary time and clustered metabolic risk factors varied by choice of accelerometer cut-point.[34]

The most commonly used algorithms for sleep-wake-determination for children and adults have been developed by Sadeh et al[35] and Kripke et al,[36] respectively. Some algorithms