Sleep apps and the quantified self: blessing or curse?

INTRODUCTION

A vibrating alarm from the SONY SWR10 Smartband™ wakes up the wearer not at a prearranged hour, but at the point near that hour when, according to the device's measurements, the wearer is in a state of light rather than deep sleep. This, the manual claims, helps the wearer awaken refreshed rather than sleepy. Welcome to the wonderful world of quantifying sleep with a mobile phone.

Entertainment and communication media evolve at an amazing rate. Tablet computers were adopted by a large part of the population, including children, in a matter of months (Zickuhr, 2013). The same applies to so-called smart-phones, mobile telephones that are pocket-sized computing and communication devices. These developments are so rapid that the academic and public health world has a hard time catching up. By the time studies on the uses and effects of these devices are published, they may no longer describe the current situation. And yet, it is important to stay abreast of such developments, particularly in the world of sleep medicine. Widely available, easily affordable and consumer-oriented portable devices are likely to influence how a growing number of people perceive their sleep and how they interact with sleep professionals.

SLEEP APPS FOR THE MOBILE PHONE: A PARTIAL OVERVIEW

Almost daily, new commercially available devices or software claiming to track or influence sleep duration and sleep quality emerge. Several different types exist, including so-called 'apps' that use the sensors of a smart-phone to register sleep-related data. Some apps detect the amount of movement in a bed. Such apps use the movements registered by the phone, tucked under a pillow, to estimate whether the user is in a state of wakefulness or of light or deep sleep. They offer varying degrees of analysis of sleep patterns, and some propose to wake the user at a moment that is most opportune according to the app's algorithms. Another variation of this first type claims to track sleep parameters by measuring the extent to which the user is snoring (Stippig *et al*., 2014), or the levels of sleep talking. A more sophisticated, or cumbersome, application consists of what are called 'wearable devices'. Most started as accelerometers, which attempted to count the number of steps the wearer took (Gusmer *et al*., 2014). Today they claim to be wrist actigraphs, analysing sleep by recording activity levels of the wearer. Yet another type of sleep-related apps offers the promise of improved sleep. Some do this by offering relaxation, guided meditation routines and even hypnosis. Some of the oldest sleep-related apps provide soothing sounds from nature (birds, the ocean, rain), or even customized sounds purported to stimulate healthy sleep reactions in the brain. At least one app claims to adjust the type and quantity of light emitted by the smart-phone screen to prevent any adverse effect of late-night screen use on melatonin production.

The growing number of applications, software programs and devices is hard to fathom as they change constantly. The range is limited only by the imagination of developers and the willingness of customers to pay for the service or product. The market is immense. Research2guidance, a Berlin-based company that monitors the e-Health market, estimated that around 100 000 apps existed by the first quarter of 2014. Again the rapid evolution is staggering as less than half that number existed 2.5 years earlier (Research2guidance, 2014). Research2guidance estimates the market to be worth 2.4 billion US dollars, but expects it to increase more than 10-fold to 26 billion dollars by the end of 2017. Many new developments are paid for by what is known as 'crowd sourcing', whereby future customers pledge to pay a certain sum for a product or service that has yet to enter the production stage. Producers are thus guaranteed a minimal break-even point before the first steps towards putting the finished product on the market are taken.

Little is known about the success of most apps and devices. Most are not very successful and those that are, sometimes remain so only for a limited period of time. The difference between success, lack of success and short-lived success should offer behavioural scientists and economists a whole new field of enquiry. An interesting case in point is the Zeo, a sleep-tracking device inserted on a headband that claimed to be a sleep coach. When the company behind the Zeo went bankrupt, users of the device no longer had access to replacement parts and updates. Because the algorithms and other specifications of the hard- and software had not been made public, the device lost much of its value and use for most owners (Dolan, 2013).

THE 'QUANTIFIED SELF' MOVEMENT

The move towards self-monitoring of sleep fits into a wider trend, which has been coined the 'quantified self' movement (Shull *et al*., 2014). With the aid of new technologies, an increasing number of people are counting and registering their nutritional intake, energy expenditure through exercise, and many other things. A study from the Pew Research Center estimated that seven-out-of-10 Americans were tracking health indicators, either for themselves or for a loved one. The study was conducted in 2012, and hence such data likely underestimate today's numbers. Even in 2012, 21% of the respondents claimed to use some form of technology to record and store these data (Fox and Duggan, 2013). Worldwide it is estimated that about 100 million people track some form of fitness or health data on a regular basis, even though it is difficult to distinguish which proportion of those data pertains to sleep (Research2guidance, 2014).

Advocates of the 'quantified self' trend have forwarded several reasons why widespread data tracking by consumers is beneficial. One argument has been that self-tracking increases patient involvement and that self-care empowers patients (Hansen, 2012). Others have found that just the act of monitoring behaviours can have strong motivational effects that stimulate healthy behaviours (Shull *et al.*, 2014). Yet another argument is that the trend is getting people involved in (and motivated by) research (Bartlett *et al.*, 2014). When a large earthquake hit the San Francisco Bay Area on 24 August 2014, San Francisco-based Jawbone® published a graph based on data from an undisclosed number of users (described as 'thousands') of the company's wearable armband that functions as an actigraph (Mandel, 2014). The graph showed a large peak in sudden movements at the time of the earthquake. It suggested that sleep disruption was greater for people who lived closer to the epicentre of the quake. Data from apps and devices, when shared in communities and uploaded to and gathered by those providing the technology, can be compiled into massive databases of the daily (sleep) habits of large populations. As so often is the case in debates about 'big data', proponents claim these databases hold the promise of exciting new insights.

CHALLENGES: AN AGENDA FOR RESEARCH

There is a tendency among technology enthusiasts to be overly optimistic about the positive effects of new technologies. Similarly, those critical of new developments tend to predict apocalyptic doom. It is probably more productive to treat new developments as challenges. The world of sleep medicine will have to learn how to deal with new behaviours and new data emerging from those who seek or need their help. Researchers may gain access to new types of data, making the testing of new hypotheses possible, but will also be faced with methodological challenges. Together the various aspects of these challenges offer an agenda for future research. The challenges listed here are far from exhaustive.

The first and probably most important question is that of measurement validity. If people are going to use apps and devices to assess their sleep, they need to know whether these devices have the sensitivity and specificity required to arrive at acceptable conclusions (be they comforting or alarming). The same applies to researchers who hope to find inexpensive and widely-available alternatives to the validated, but expensive and time-consuming devices they use in research and in sleep laboratories. A recent overview concluded that, to date, almost no scientific data regarding the validity of sleep-monitoring software or devices are available (Behar *et al.*, 2013). Research has shown that at least one device overestimates sleep time and sleep quality (Montgomery-Downs *et al.*, 2012). There is a lot of anecdotal evidence in the popular media of large differences in the responsivity of the devices. People who wore more than one device at the time typically report different readouts for the same reference period. A problem researchers and other analysts are faced with is that the algorithms used by the software are usually undisclosed, making it nearly impossible to examine and judge how these algorithms treat the data and arrive at conclusions. This is an important line of inquiry for at least two reasons. First, if these new developments lead to devices and software with acceptable specificity and sensitivity, this will expand research possibilities by offering cheaper solutions for sleep research. If the apps and devices offer valid information, then researchers can recruit people who already have the necessary equipment. Second, if the data are valid it means that enormous databases may become available from large groups of people who have allowed their data to be uploaded and stored by the providers of the software. One evident implication of gaining access to such data (and of the fact that such data exist at all) is that important ethical questions will arise in light of this new technological situation.

TOWARDS AN EPIDEMIC OF CHRONOREXIA?

The second question that merits consideration is what sleep apps and wearable devices are doing to the user. We need to know which type of personality is drawn towards them, what their motives are, and whether and how such devices change their sleep behaviour and their (perceptions of) sleep quality. Many apps and devices avoid being labelled as a medical device, as this would entail undergoing the rigours of approval by government agencies, such as the US Food and Drug Administration. They do, however, communicate explicit or implicit assumptions on what constitutes healthy and unhealthy sleep. We will need to study whether and to what extent the use of apps affects people's knowledge and beliefs about healthy and unhealthy sleep.

Changing behaviours and beliefs can have at least three substantial effects. First, those dealing with sleep disorders, from primary care physicians to sleep clinics, will have to adjust to a new reality where patients increasingly arrive with a self-diagnosis based on self-gathered data (Topol, 2012). Second, widespread use of sleep monitoring may have beneficial effects for people suffering from undiagnosed problems, who are made aware that something is amiss by the data they collect. However, if large groups of undiagnosed people start using such monitoring, even the most reliable of devices and algorithms are likely to produce enormous numbers of false positives. As Behar *et al.* (2013) have remarked, even a 99% accuracy level would lead to no less than 1000 false readings in a group of 100 000 users. The market projections for e-health applications suggest that the number of people likely to self-diagnose will be many times that. It is important to note that the traditional actigraphs used in sleep medicine are only deployed when a sleep professional wants more data to decide what is wrong with someone who has

reported symptoms. Finally, in the area of nutrition and fitness there has been growing interest in the phenomenon of 'orthorexia', or an unhealthy obsession with healthy behaviours such as exercise and healthy eating (Vandereycken, 2011). Some people struggle with such obsessions on their own, but in many cases orthorexia is likely to affect family members and children as well (Varga *et al*., 2014). An equivalent in the context of sleep should, perhaps, be called 'chronorexia', referring to people who develop an unhealthy and, possibly damaging, obsession with 'healthy sleeping', as measured by their devices, either in themselves or in their children.

The steady rise in self-monitoring devices and software for self-analysis of sleep may benefit many people. It will be important to study the extent to which such monitoring devices are adopted by the general public, and whether this leads to positive and/or negative outcomes. Health-care practitioners need to be aware of the existence of such applications and of their potential effect on people's self-diagnoses. Finally, researchers and health-care practitioners should be on the lookout for potential cases of 'chronorexia'.

CONFLICT OF INTEREST

No conflicts of interest declared.

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Jan Van den Bulck
School for Mass Communication Research, University of Leuven, Leuven, Belgium
Correspondence: Jan Van den Bulck, PhD, DSc, Parkstraat 45, box 3603, 3000 Leuven, Belgium. Tel.: +32-16-32-32-94; fax: +32-16-32-33-12; e-mail: jan.vandenbulck@soc.kuleuven.be

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