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Title:
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Date:
2019-06-03

Citation:
Nansen, B. & O'Neill, C. (2019). Sleep mode: mobile apps and the optimisation of sleep-wake rhythms. First Monday, 24 (6), pp.na-na. https://doi.org/10.5210/fm.v24i6.9574.

Persistent Link:
https://hdl.handle.net/11343/311346

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PEER-REVIEWED JOURNAL ON THE INTERNET

Sleep mode: Mobile apps and the optimisation of sleep-wake rhythms

by Christopher O'Neill and Bjorn Nansen

Abstract

This article contributes to the critical analysis of sleep and its technological mediation by analysing how sleep is modulated through mobile applications. Drawing on an analysis of the features in the most popular sleep apps in the Apple App store, this paper investigates the dominant types of sleep apps available for everyday use. We analyse how their functions implicate sleeping bodies within new patterns of management and optimisation. We show how sleep apps remediate the monitoring technologies of the sleep science lab to make claims of accuracy and efficacy. However, the analysis also reveals how sleep apps go beyond simply monitoring sleep patterns by directly intervening in and mediating sleep-wake rhythms. This occurs through two key acoustic features common within sleep apps — 'smart wake up' alarms and 'brainwave entrainment' sound frequencies. We show how these features operate to organise transitions between waking and sleeping states. In doing so, we argue that these functions draw on histories or genealogies of both acoustic media and sleep science in the attempt to optimise the practices and rhythms associated with sleeping bodies.

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Introduction

Sleep is increasingly a targeted site of daily monitoring via Internet technologies, including mobile and wearable devices, Internet of Things-enabled products for the bedroom, and personal data collection and visualisation. These sleep-specific media are underpinned by the spread and normalisation of wider Internet economies and cultural practices of self-tracking and datafication — the transformation of daily life into digital information.

Alongside personal practices of sleep tracking there is a growing scholarly interest in the socio-cultural and political implications of mediating sleep. These studies are resituating and complicating the traditional locus of sleep research within science and medicine. As Arber, *et al.* note "sleep ... is more than a shared biological universal. How, where, and when we sleep also depends on the type of society in which we live" [1]. The how, where, and when of our sleep has been studied from a range of anthropological, sociological, and historical perspectives (see Hsu, 2017). However, it has yet to be the subject of sustained critical analysis within Internet, media, or communications studies (*cf.*, Fuller, 2018).

In one sense, this is not unexpected, given sleep's detachment from the everyday social interaction that defines media studies research. Yet, in another sense, this gap is surprising, given the increasing critical attention within media studies on political implications of digital technologies for intervening in biological rhythms (*e.g.*, Lupton, 2016). As such, there is a growing need to examine and understand how sleep technologies mediate practices of sleep as part of the wider digital monitoring, communication, and management of personal health and well-being.

This paper contributes to this research by analysing how sleeping practices are monitored and configured through sleep-related mobile Internet applications. Drawing on an analysis of the features in the most popular sleep apps in the Apple App store, this paper investigates the dominant types of sleep apps available for everyday use. We analyse how their functions implicate sleeping bodies within new patterns of management and optimisation. We show how sleep apps remediate the monitoring technologies of the sleep science lab to make claims of accuracy and efficacy. However, the analysis also reveals how sleep apps go beyond simply monitoring sleep patterns by directly intervening in and mediating sleep-wake rhythms (see Hassoun and Gilmore, 2017). This occurs through two key common acoustic features within sleep apps — 'smart wake up' alarms and 'brainwave entrainment' sound frequencies. We show how these features operate to organise transitions between waking and sleeping states. In doing so, we argue that these functions draw on histories or genealogies of both acoustic media and sleep science in attempts to optimise the practices and rhythms associated with sleeping bodies.

Connected and sleepless

It appears that sleep, or lack of it, has reached a point of crisis in contemporary culture. Spanning medical and popular sleep science (see Walker, 2017), through to self-help literature and popular news coverage (see Boden, *et al.*, 2008; Williams, *et al.*, 2010), disturbed sleep is viewed as an epidemic. This condition is often attributed to modern capitalist society and digital technologies. Jonathan Crary (2013), for example, argues that the essentially unproductive nature of sleep has informed its systematic disavowal. He argues that accordingly the differences between the rhythms of technology and human life have been elided:

> One seemingly inconsequential but prevalent linguistic figure is the machine-based designation of 'sleep-mode'. The notion of an apparatus in a state of low-power readiness remakes the larger sense of sleep into simply a deferred or diminished condition of operationality and access. It supersedes an off/on logic, so that nothing is ever fundamentally 'off' and there is never an actual state of rest. [2]

The mobile phone, with its capacity to encroach on personal and domestic life, has symbolised these commercial forces of perpetual unrest (see Gregg, 2011). And yet, mobile phones have also become essential to social communication, entertainment, and leisure activities, through developments in social media, streaming platforms, and of course the rise and proliferation of the mobile app economy (Goggin, 2011). Smartphones, then, are positioned on the leading edge of these disruptions. As mobile, connected, and embodied devices, their bedtime use is not unexpected. However, the prevalence of sleeping with a smartphone is increasingly raised as a public health concern, especially for younger people. Venn and Arber (2008) argue that teenagers are seeing increasingly poor sleep, tied to feelings of stress and anxiety and amplified by the use of mobile phones in the bedroom, "[t]he combination of interacting with social networks, usually via mobile phones, worries and their frequently phase-delayed sleep cycle, left many of the young adult children talking of being 'totally exhausted', 'very, very tired', and even 'depressed'." [3].

Nevertheless, the central role of mobile phones is part of a broader narrative about the detrimental impacts of the Internet and digital technologies in the production of disturbed sleep. Media studies research in this area remains under-developed. Matthew Fuller (2018) has extended this discussion to situate the contemporary mediation of sleep embodied in personal sleep tracking within the rich phenomenological experience and historical aesthetics of sleep. He argues that the current meanings and practices associated with sleep have been reduced to "a proliferating set of medial and bodily relations ... interpolated by sensors, databases and targets, themselves composed by the imaginaries of logic, ordering, proliferation, entrepreneurial 'disruption', user-centredness and ideas of health and improvement." [4]

This work highlights how broad cultural, economic, and technological forces have wreaked havoc with sleep patterns and rest, normalising fatigue as a widespread social symptom. And yet, in turn, prevailing narratives of sleep are framed through a lens of self-management. Tracking the development of tensions around sleepiness discourse and public health, Kroll-Smith and Gunter (2005) analysed newspaper representations of sleep deprivation, including campaigns against 'sleepy-driving', and the emergence of

workplace sleep advisory firms such as Alertness Solutions — an organisational consultancy firm specialising in 'fatigue management'. They argue that a 'new truth' has emerged around sleepiness, in which "sleepiness is a risky, dangerous state of partial consciousness; moreover, the sleepy person is accountable for controlling this somatic condition and avoiding its potential for harm." [5]

Customising and choreographing sleep

Despite contemporary Western society appearing to largely undervalue sleep, Simon Williams (2011) describes a contradictory public discourse framed around personal intervention and optimisation in managing sleep hygiene. Here, individuals are both compelled and empowered to self-manage their daily rhythms of sleep and rest, primarily by consuming an ever-growing range of products and services from the sleep industry. Arber, *et al.* similarly argue that two key and yet seemingly contradictory trends in recent discourses on sleep are identifiable; "On the one hand, it would seem that work ethics have left us all 'negating sleep,' while on the other hand, a burgeoning sleep business has developed that seeks to sell us sleep-promoting products." [6]

Such interventions move beyond a straightforward problematisation or medicalisation of sleep, instead figuring sleep as a site of everyday 'customisation'. Visions of customising sleep extend from organisational and management solutions, through to more fringe endeavours such as transhumanist 'bio-hackers'. These sleepers operationalise poly-phasic sleep patterns, deploying sensors and data monitoring to optimise health, alertness, and productivity by maximising wakefulness hours [7]. At one extreme, these approaches connect with the emergence of the Quantified Self movement that seeks "self-knowledge through numbers" (Wolf, 2010). Others respond to the growing yet prosaic demand "to reduce the tension, or increase the 'fit', between our bodily need for sleep and our age old chronobiological rhythms that govern it (*i.e.*, our biological or circadian clocks) and the escalating around-the-clock demands and dictates of social time in the 24/7 society." [8]

Sleep is configured as increasingly malleable by a growing sleep industry, which now pursues the development of a range of mobile applications for personal management of sleep practices. There has been an explosive growth and development of digital products within the sleep industry that see the potential of mobile applications as personal behavioural tools for optimising everyday sleeping practices and quality (Liang and Ploderer, 2016). Here, the medical concern for how mobile *devices* disrupt sleep is supplanted by an ideology of innovation in which mobile software *applications* are envisaged as able to produce better sleep through sleep management functions including notifications and alerts, sleep tracking and monitoring, and relaxation therapies to encourage good sleep 'hygiene'.

Medical sociology work by Williams, *et al.* (2015), highlights the historical significance of both technological and cultural shifts in sleep monitoring technologies. They note that personal sleep monitoring was enabled by technologies that moved outside the

scientific and medical institutions of the sleep lab or hospital, and into everyday life through the development of wearable devices, mobile phones, and Internet applications. In the twentieth century the mediation of sleep was characterised by what Kenton Kroker (2007) describes as the attempt to know "the sleep of others" — the transformation of sleep from a subjective, personal experience into something which could be represented "objectively", known and rendered into a scientific object through technologies like the polysomnogram, the development of sleep research, and the formation and formalisation of the sleep lab. Williams, *et al.* (2015) argue that cultural practices of self-tracking sleep have returned attention to the "sleep of ourselves", albeit as a knowledge of sleep which is understood through the lens of sleep science technologies and values. They observe the irony, that "the very information and communication technologies which elsewhere are criticised or demonised by experts as the enemy of sleep — no computers or texting in the bedroom for instance — are in this case transformed or touted as the aid or ally of sleep." [9]

This ambiguity surrounding mobile phones and the disruption of sleep is then coupled with a discursive ambiguity over the value of sleep and potentials for its optimisation in contemporary society.

Sleep-tracking cultural research

The medical sociology approach of Williams, *et al.* (2015) is helpful in critically analysing the dispersal of medical technologies, knowledge, and authority from sleep labs to private homes and bedrooms. The analysis of sleep's digitisation offered by Williams and colleagues is helpful for positioning the mediation of sleep within wider socio-cultural shifts. However, Williams, *et al.* have not analysed sleep *apps* in detail, leaving room for further critical analysis.

In this paper, we build on the critical insights offered from these scholars. We move from their broad theoretical and sociological analyses by offering a more applied analysis of the specific mobile sleep apps available to consumers. We critically examine how their features and functions shape the meanings, practices, and rhythms associated with sleeping bodies.

There are a number of studies within medical and health literature, which as part of a wider trend towards studying mobile applications, have focused on the use of sleep apps in the contexts of personal health and well-being. These are largely concerned with questions about their metrological and diagnostic value or validity (see Behar, *et al.*, 2013; Bhat, *et al.*, 2015; Lee-Tobin, *et al.*, 2017; Lorenz and Williams, 2017; Stippig, *et al.*, 2015) and their potential for encouraging better sleep hygiene within a public health agenda (see Van den Bulck, 2015). However they largely ignore more critical and cultural questions about the everyday mediation and datafication of sleep. This gap is also noted by Deborah Lupton, who writes that, "despite this rapid expansion of a novel method of providing software programs to mobile device users, as yet very few critical social analyses of mobile apps have been published." [10] Lupton suggests a critical

perspective for analysing apps as 'sociocultural artefacts', in which "the technical affordances of apps structure the ways in which they are used and the meanings that are ascribed to them." [11]

We aim to draw on this perspective by analysing how everyday sleeping practices are monitored and configured through the available features of sleep apps. We examine these apps in terms of their specific functions, asking how these affordances shape sleeping bodies into new patterns of management and optimisation. This analysis reveals a diverse range of functions for tracking and analysing sleep patterns, as well as features to promote relaxation and rest. In doing so, we show how sleep apps remediate the monitoring technologies of the sleep science lab to make claims for accuracy and efficacy. Yet, the analysis also reveals how sleep apps go beyond simply monitoring sleep patterns. Sleep apps also directly intervene in sleep-wake rhythms through two key acoustic features: the 'smart wake up' alarm function, and 'brainwave entrainment' sound frequencies. We argue that these features suggest that sleep apps should be understood not only in terms of the monitoring or customisation of one's sleep schedule, but also as media which seek to reconfigure and optimise the value and experience of sleep.

Coding sleep apps

This analysis follows Lupton's (2014) methodological suggestion for studying mobile health and medical apps as sociocultural artefacts. This approach seeks to understand how aspects of app content, including app descriptions, screenshots, categories, developers, and appeals to authority produce "various types of capabilities and responsibilities" [12]. We undertook a feature and case study analysis of the most popular sleep apps on the Apple App store. This method was aimed at documenting the dominant features, the possibilities afforded by their functions, and the implications of app operations for managing and modulating sleep.

The preliminary aspects of this investigation involved categorising the most popular sleep apps on the Apple App store. The App Store was selected as it is one of two major app marketplaces, along with the Google Play store, and because it provides easily searchable and accessible information about the features of apps available for download. On 10 August 2017 we searched using the word 'sleep' and recorded the details of the first 100 search results, of both free and paid apps, returned by the App store. The top 100 search was chosen because it reflects the most popular apps by user download at a particular moment. While only a snapshot, the scope of apps included enables a large enough sample to reach saturation in coding across sleep app features.

The 100 apps were coded into distinct categories of sleep apps, and it was determined that the 100 results fell into the following categories — Sleep Cycle Monitoring, Relaxing Sounds, Hypnosis and Meditation, Babies, and Miscellaneous. *Sleep Cycle Monitoring* apps were defined as apps for which the primary purpose was to monitor the quantity and quality of the user's sleep. *Relaxing Sounds* apps were defined as apps

for the which the primary purpose was to relax the user and/or lull them to sleep through the use of soundscapes and/or sound loops. *Hypnosis and Meditation* apps were defined as apps for which the primary purpose was to promote either a hypnotic or meditative state through the use of either audio loops and/or guided audio sessions involving spoken instructions. There was some crossover in terms of function between the *Relaxing Sounds* and *Meditation and Hypnosis* categories; the distinction between these categories was made on the basis of whether their primary function was to encourage relaxation and sleep *or* meditation and hypnosis. The *Babies* category consisted of a handful of apps designed either for monitoring the sleep patterns of young children, or providing lullabies designed for encouraging them to sleep. The *Miscellaneous* category consisted of several alarm clocks touted as being especially loud or "annoying", a heart rate monitor app, and an app which projected a"pulsing blue ... light" onto the user's bedroom wall at night, supposedly in order to calm the user to sleep.

Of these the majority fell into the first two categories, with 27 of the apps being marked as *Sleep Cycle Monitoring* apps compared to 49 being marked as *Relaxing Sounds*. There were 12 *Hypnosis/Meditation* apps, six *Babies* apps, and six *Miscellaneous* apps. The two dominant categories were then selected for further analysis, and coded through an analysis of their features, including cost, developer, and types of functions. These features were determined through an analysis of the description of the apps and through an examination of the screen-shots provided by the app developers in the App store. Following the app feature analysis, we selected a key example from each of the dominant sleep app categories, Sleep Cycle Monitoring and Relaxing Sounds, for case study analysis. The apps selected were Northcube AB's *Sleep Cycle Alarm Clock* (hereafter *Sleep Cycle*), the most reviewed sleep cycle app on the app store, and ilBSoft's *Relax Melodies P*: sleep sounds, white noise and fan (hereafter *Relax Melodies*), the most popular of the Relaxing Sounds apps. These two apps were downloaded and used for a period of three months by the researchers, to gain a more in depth understanding of the operation of the features. The analysis in this paper is focused on the app feature analysis, paratextual material from developer Web sites, and case study data to supplement the feature analysis as a way of elaborating upon the app's functionality.

Sleep cycle monitoring — Key features

Within the Sleep Cycle monitoring category of sleep apps, the features listed from app descriptions fell into four main categories. *These included: sensor capabilities (accelerometer, microphone, heart rate, snore recorder, mood recording); sleep data visualisation features (sleep graph, sleep quality score, sleep debt, trends analysis); sleep data synchronisation functions (data export, lifestyle data sync, social media sync); and sleep management functions (customisable alarm sounds, manually set sleep/wake time, sleep aid sounds, bedtime reminder, smart wake up)*.

The core feature characterising Sleep Cycle monitoring apps is, of course, the capacity to monitor and communicate data about sleep patterns. The sleep-cycle monitoring apps use either the phone's accelerometer (10 out of 23 [13]) or its microphone (13 out of 23) to track either movement or sound. These measures are taken as a proxy for sleep quality, the key principle being that more activity indicates lighter sleep, while stillness indicates deeper sleep.

The use of wearable sensors to measure variations between rest and movement, known as actigraphy, has been used by sleep specialists for measuring sleep quality in the home since the 1990s. In everyday and personal health monitoring contexts, it is an alternative to the more scientifically precise sleep laboratory monitoring known as polysomnography. Polysomnography requires patients to enter a sleep laboratory and to be monitored by over a dozen sensor technologies. While considered the 'gold standard' of sleep monitoring research, polysomnography is nevertheless inconvenient for the patient as well as expensive. Actigraphs have the benefit of being cheaper and usable in the home. While not able to measure sleep stages with the same precision as polysomnography, medical grade wrist worn actigraphs are sufficiently accurate to be used in the diagnosis of sleep disorders (Stone and Ancoli-Israel, 2017).

Sleep cycle monitoring apps extend this tradition of dispersed sleep monitoring. However none of the apps made clear how the accelerometer or microphone enabled iPhone sleep-activity monitors actually function — neither on the App store description page, or within the app itself. The Sleep Cycle app description explains only that "Since you move differently in bed during the different phases, Sleep Cycle can use the microphone or accelerometer in your iPhone to monitor your movements and determine which sleep phase you are in." (Sleep Cycle, 2017a)

Sleep data is visualised via graphs which purport to map the user's sleep cycles. The average healthy human goes through several 90-minute sleep cycles over the course of the night — beginning with the low arousal threshold of Stage 1 sleep, ideally lasting from one to seven minutes, before moving on to the deeper Stage 2 sleep, then into Stages 3 and 4 of deeper slow wave and then REM (rapid eye movement) sleep, before returning to lighter stages of sleep again, and then repeating the process, with longer periods of REM sleep as the night progresses. The Sleep Cycle sleep graph, for example, visualises the progress of the user's sleep progress, from 'Awake' to 'Sleep' to 'Deep Sleep' and back again over time (see Figure 1).

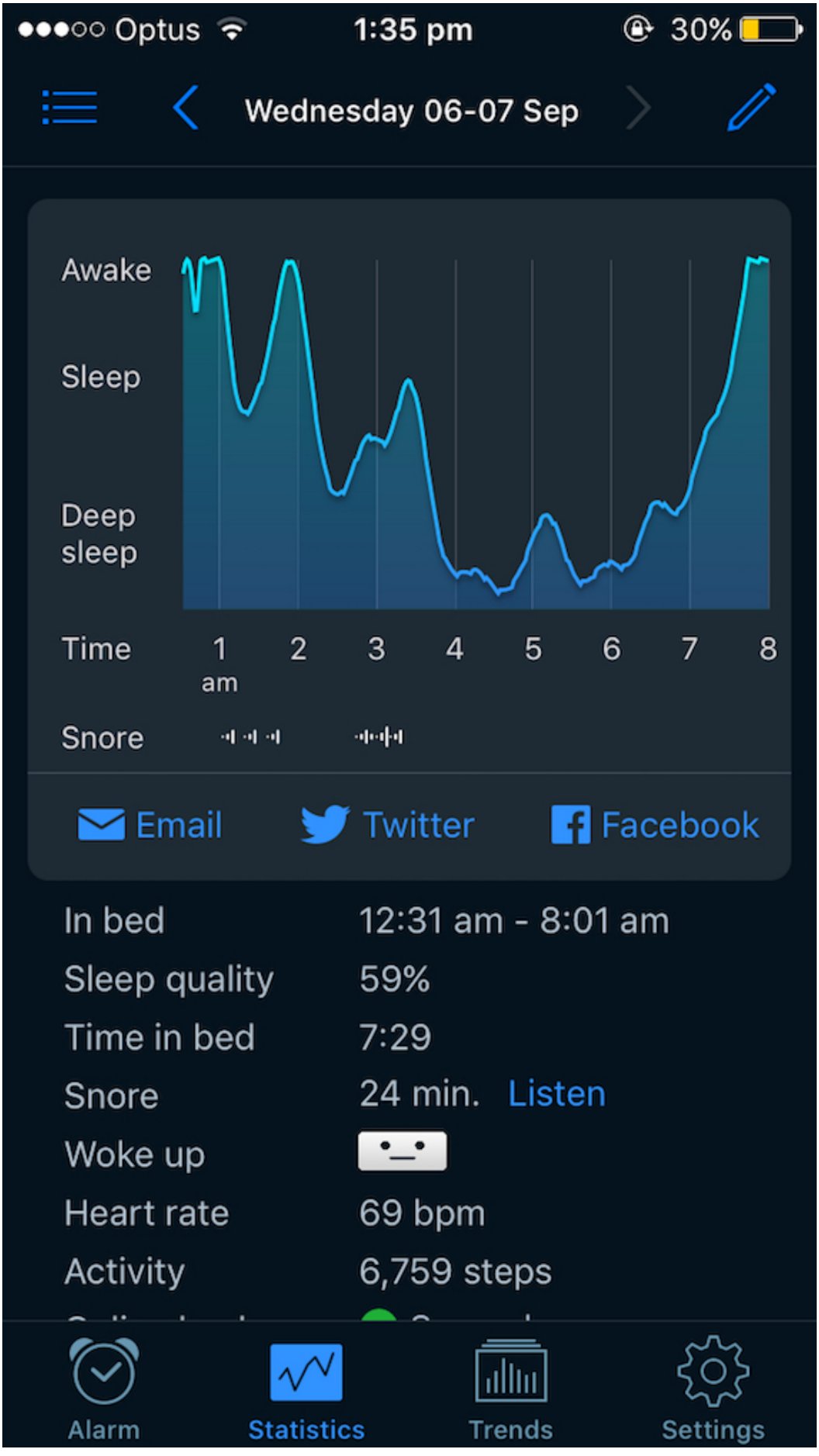

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Sleep quality
59%
Time in bed
7:29
Snore
24 min.
Listen
Woke up
Heart rate
69 bpm
Activity
6,759 steps
Alarm
Statistics
Trends
Settings

Figure 1: Screenshot of Sleep Cycle app sleep quality graph.

In addition, Sleep Cycle users are also provided with data about their sleep quality in the form of a 'Sleep Quality' score, which is a number given out of a possible score of 100. The means of evaluating this score are not given in the app, but the app's Q and A page notes that sleep quality is based on four measurements: amount of time spent in bed; amount of time spent in deep sleep; consistency of the sleep; number of times that the app registered you as fully awake (Sleep Cycle, 2017b). Clearly, the ambiguities of the operation and meaning of a 'Sleep Quality' score raise questions about living with and interpreting the meanings and values of such 'mundane data' (Lupton, 2017; Pink, *et al.*, 2017), produced through such everyday contexts of sleep monitoring. Within the medical literature, discussion and analysis often revolves around the question of accuracy of home sleep measuring tools and their effect on patient's self-diagnosis (*e.g.*, Bhat, *et al.*, 2015). The potential for inaccuracy of the apps is obviously of concern for users, especially given that our analysis of the Sleep Cycle apps in the app store revealed that 14 out of the 23 apps analysed emphasised the 'precision' or 'accuracy' of the apps. Sleep clinicians have begun to report the phenomena of patients becoming overly concerned with the 'sleep scores' given by their sleep trackers, and potentially overly anxious that they are not producing sufficiently 'optimal' sleep [14].

Sleep Cycle monitoring apps incorporate sleep data synchronisation functions, with 14 of the 23 apps surveyed also allowing for users to sync their sleep data with other activity trackers (see Figure 2). Sleep Cycle, for example, uses this data to produce graphs and data reports to alert the user as to how their lifestyle choices affect their sleep quality. These reports are then graphed through a dashboard interface to enable comparative personal sleep tracking across different temporal scales (weeks, months), and in relation to a variety of other lifestyle factors.

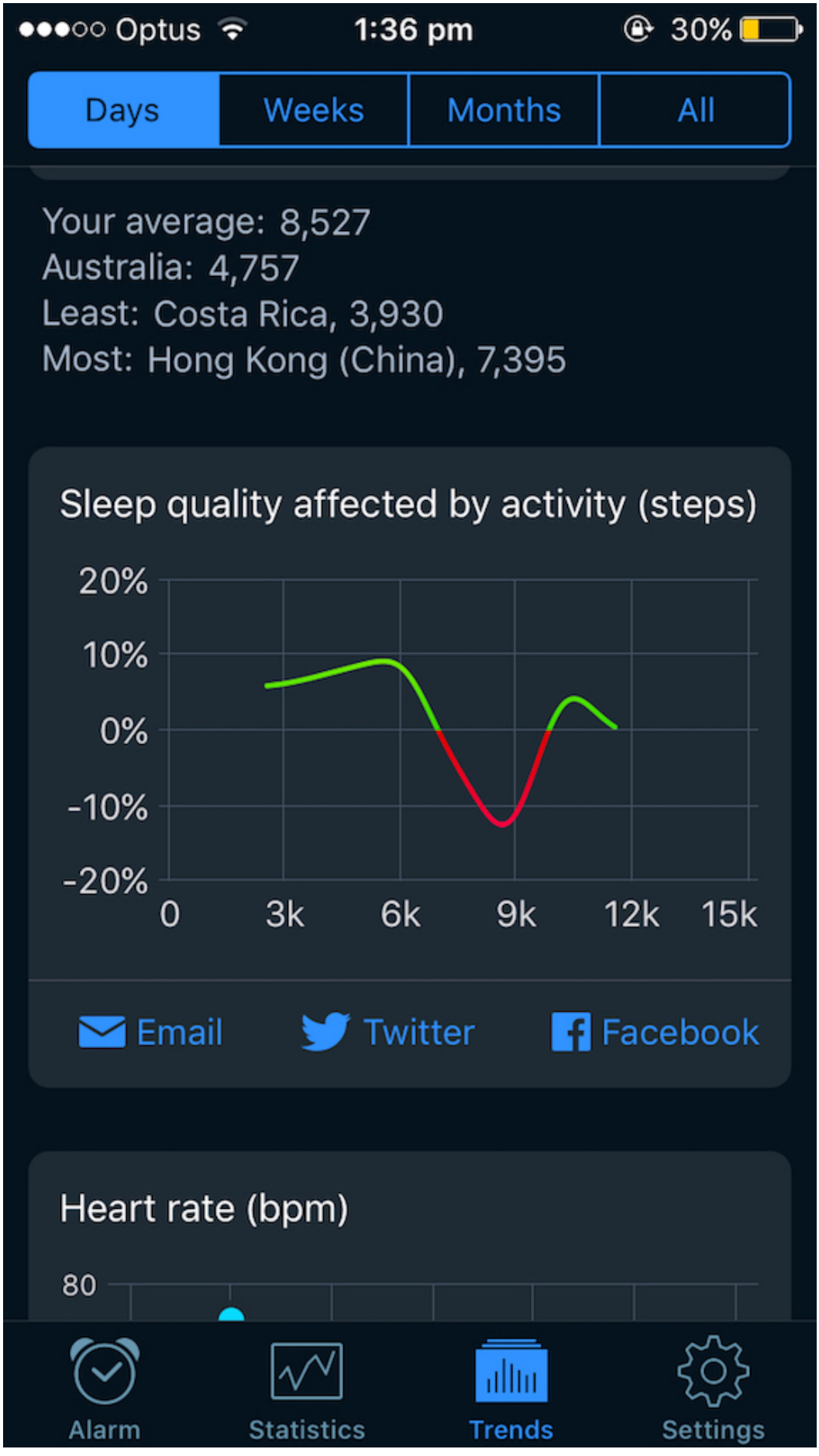

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Days
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Your average: 8,527
Australia: 4,757
Least: Costa Rica, 3,930
Most: Hong Kong (China), 7,395
Sleep quality affected by activity (steps)
20%
10%
0%
-10%
-20%
0
3k
6k
9k
12k
15k
Email
Twitter
Facebook
Heart rate (bpm)
80
Alarm
Statistics
Trends
Settings

Figure 2: Screenshot of Sleep Cycle quality graph synced with activity tracking data.

In this way a user's sleep quality is directly tied to their wakeful activities and daily routine. Williams, *et al.* [15] have noted that it is this capacity for correlation which reproduces sleep as a new sphere for the enactment of self-management, as sleep "becomes yet another site for 'improvement' or 'optimisation' in terms of performance and health, a form of optimisation or enhancement that is enacted well beyond the clinical sphere". In a strange irony, however, no apps mention functions for syncing mobile phone usage tracking with sleep quality. This erases the implicit tension of the smartphone/sleep nexus, in which mobile phones often castigated by sleep experts as so detrimental to sleep hygiene are here positioned as the remedy for poor sleep habits.

Smart wake up: Optimising the rhythms of sleep

Whilst the key features of sleep tracking apps analysed above are, in many ways, to be expected and fit within wider studies of tracking and datafication technologies, a novel and more radical feature emerged from this analysis within the category of sleep management functions. The Sleep Cycle monitoring apps incorporated a range of management functions, often set manually to enable personalised and customised reminders or sounds relating to going to sleep or waking up (*e.g.*, customisable alarm sounds, manually set sleep/wake time, sleep aid sounds, bedtime reminder). A significant extension of sleep management functions, however, is the algorithmically determined 'smart wake up' feature — 19 of the 23 apps examined incorporated this aspect into their design. Sleep Cycle describe their smart wake up function as:

> a wake-up phase (30 minutes by default) that ends at your desired alarm time. During this phase Sleep Cycle will monitor signals from your body to wake you softly, when you are in the lightest possible sleep state.

Several of the apps incorporating a smart wake up feature promised the user that they would "wake up refreshed"; with 16 of these 19 apps purporting to help the user awake more refreshed, alert, rested, or energised. While the sleep tracking trends offered indirect suggestions for improving the general quality of a user's sleep, the 'smart wake up' feature of these apps claimed to directly produce a sense of well-being in the user. The 'smart wake up' feature, then, extends from assisting with sleep management to automating sleep-wake rhythms. Going beyond measurement, these apps offer a more

direct ‘intervention’ into the timing of the user’s wake up at the most optimal point within the phases of the sleep cycle.

The ‘smart wake up’ offers an interesting divergence from the medical genealogy of the sleep trackers. While the sleep monitoring functions of these apps can be seen to remediate the earlier sleep actigraphs, there does not seem an equivalent to the ‘smart wake up’ technology as a medical tool. An early American patent for a ‘smart wake up’ technology was granted in 1999 to George Halyak, for a “user responsive sleep monitoring and awakening device”. As Halyak explained in the introduction to the patent:

> Sleep difficulties are growing more and more common in the modern world. Few people in the industrialized world wake up “cleanly”, that is to say instantly, fully, and comfortably. Hectic schedules, late office hours, meals grabbed at odd times ... all of these can lead to disturbed or erratic sleep.

In this understanding then we can see that ‘waking up smart’ is positioned as an affective remedy to the stresses and disruptions of modern life. Historically the injunction to ‘rise and shine’ has constituted a disciplinary technique by which one “[learns] to suppress or control one’s bodily desires, feelings and inclinations” [16], the urge to linger in bed, to sleep in, to hit the snooze button. These apps maintain the compulsion to exert a form of control over the structure of the wake-up process. However, the ‘smartness’ of the app indicates a shift from disciplinary self-mastery to a more distributed and adaptive form of delegated monitoring and optimised intervention.

Whereas the correlation between tracking sleep quality and waking activity serves to extend sleep self-management across the length of the entire day, beyond the ‘normal’ bounds of the sleep duration (*i.e.*, the time of sleep itself), the ‘smart wake up’ delegates authority to the app for modulating sleep rhythms in order to produce a ‘clean’ wake-up. If the sleep trackers are concerned with tracking the cyclical times of the day, our circadian biorhythms, the ‘smart wake up’ feature attempts to divine and/or produce a precise moment in optimising sleeping and waking rhythms.

Sonics for sleep — Key features

The Relaxing Sounds apps are defined as apps of which the most prominent feature is the use of sound loops or ‘soundscapes’ designed to relax users and lull them to sleep, or else work as a stimulus to meditation. 34 of the 45 [17] apps in the category allowed for some degree of customisation on behalf of the user. At a minimum this would involve being able to adjust the sound levels of the sound loops, though frequently this also included ‘blending’ different sounds with one another as well. The most popular of the Relaxing Sounds apps, ilBSoft’s *Relax Melodies*offered extensive custom mixing capacities. Users could combine up to 12 different sounds, including atmospheric

sounds like ‘Rain’, ‘Ocean’, ‘Night’, ‘Campfire’, more melodic sound loops like ‘Humming’ (featuring a woman humming the melody of ‘Brahms’ Lullaby’), ‘Pachelbel’s Canon’, ‘Sweet Hour Prayer’ (a guitar melody), as well as signal noises like ‘Brown Noise’ and ‘Pink Noise’ (see Figure 3).

Within the ‘Relaxing Sounds’ category of sleep apps, the features listed from app descriptions were less focused around sleep data and its tracking, synching, and visualisation, and instead organised around the customisation of sounds to mediate sleep practices. These were coded according to four distinct categories: *soundscape affordances* (relaxing sounds, loops, custom mix (channel and volume), background mode, guided relaxation programs, relaxing images/videos); *social sharing* (sharing mixes); *sleep management functions* (bedtime reminder, sleep timer (fade out after given time), dark mode/brightness adjustment, alarm clock);
and *psychoacoustics* (binaural beats, monaural beats, isochronic tones, ‘brainwave’ entrainment frequencies).


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Ocean
Winds
Flute
Rain
Birds
Music Box
Lounge
Piano
Pause
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Add Favorite
Sounds
Meditations
Favorites
Timers
More

Figure 3: Screenshot of *Relax Melodies* customisable soundscape feature.

Binaural beats: Modulating the frequency of sleep

As with the Sleep Cycle tracking apps, many of the features in the Relaxing Sounds apps category were to be expected in offering affordances for personalised relaxation. But, again, emerging from this analysis was a novel and critical feature based on the notion of brainwave entrainment through the use of 'binaural beats'. These purportedly use differing sound frequencies to induce certain sleeping states.

Whilst binaural beats are less about optimising sleep rhythms than the 'smart wake up', they share a similar approach in using acoustic media features for their operation — smart alarms for waking, binaural beats to fall asleep. Such sleep acoustics can be traced through a different trajectory of media theorisation than dominant critical theories of datafication and self-tracking underwritten by numbers or visualisations. Instead they demonstrate the continued cultural significance of 'audible' technologies for materially shaping our environments and perception (see Sterne, 2003). Jonathan Sterne's audible past, for example, emphasised how the technical function of transducers did not just inscribe sound waves into electrical currents, but fundamentally "the history of sound reproduction ... transform[ed] the human body as an object of knowledge and practice" [18]. Sound reproduction required learning a set of specialised practices that shaped hearing in various social contexts, from the surgery to the dance floor.

This history of *perceptible media* and its industrialisation, however, takes on new resonances in the contexts of contemporary sleep apps and the use of sounds for physiologically modulating the frequencies of neural-electrical activity. Binaural beats commonly feature as a function within a range of customisable soundscape affordances on popular sleep apps for helping to promote relaxation. *Relax Melodies* offered, as with seven of the other apps surveyed, 'binaural beats', as well as, along with four of the other apps surveyed, 'isochronic tones', to be blended with the soundscapes. Binaural beats work by simultaneously transmitting different sound frequencies in each ear using headphones — the binaural. The physiological response of the brain is to resolve the two frequencies by producing brainwave frequencies at a rate of hertz (Hz) based on the mathematical difference between the Hz of the two frequency tones — the beat [19]; see Figure 4). Isochronic tones are short pulses of sound which repeat a certain tone at regular intervals. Because they do not require two separates tones to be listened to in each ear they can, unlike binaural beats, be listened to without headphones.

In sleep apps the aim is to produce lower frequency waves of brainwave activity, such as delta (approximately one to four Hz) and theta (approximately four to eight Hz) frequencies, which are associated with relaxed, meditative, and sleeping states [20]. For example, the *Relax Melodies* app offers several frequencies of binaural beats, which play beneath the 'relaxing' soundscapes produced in the app. These include: 2.5 Hz to produce 'Dreamless Sleep', four Hz to produce REM 'Dream' states, five Hz to produce 'Deep Meditation', and eight Hz to produce 'Pre-Sleep'.

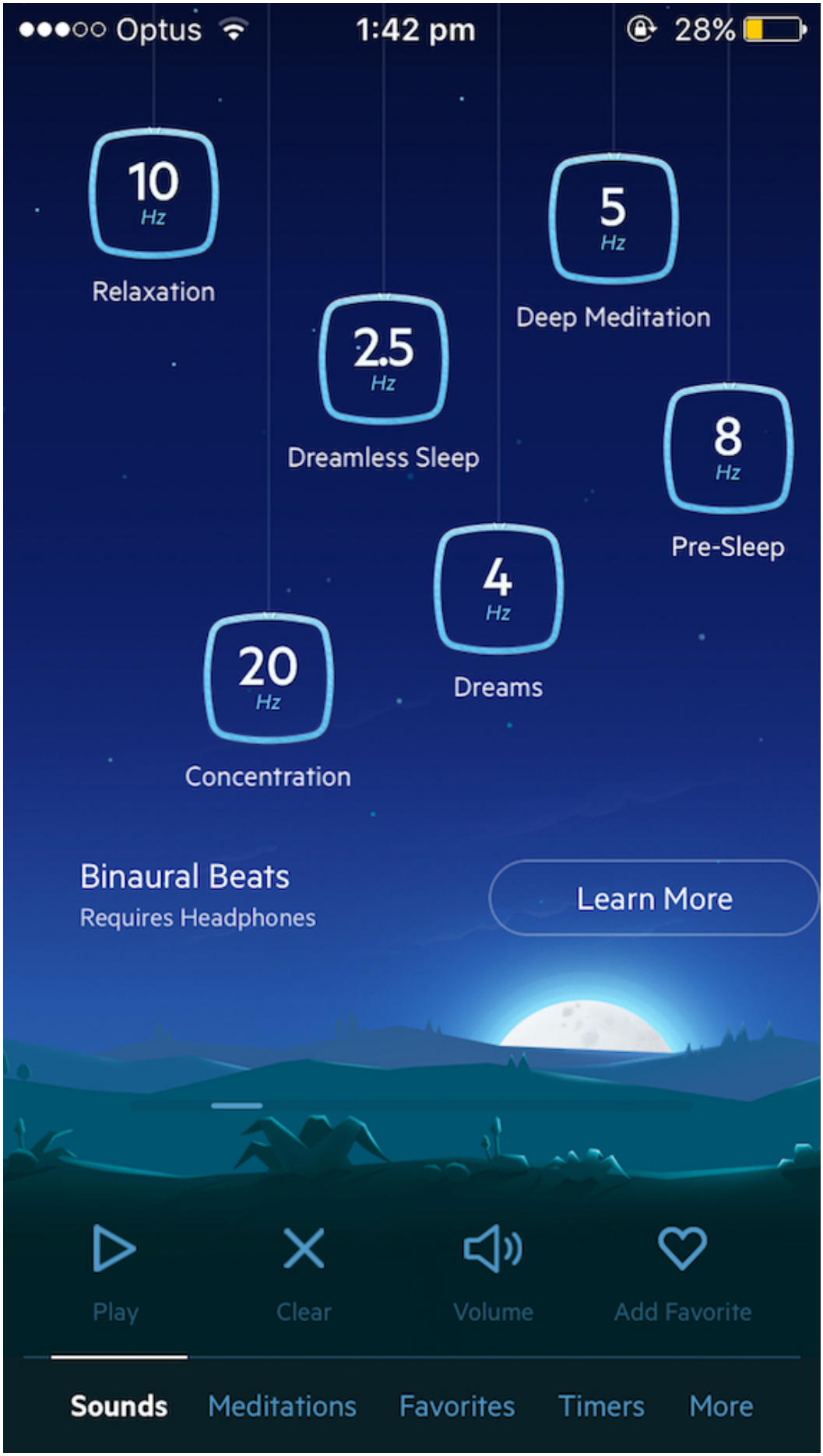

Optus
1:42 pm
28%
10 Hz
Relaxation
5 Hz
Deep Meditation
2.5 Hz
Dreamless Sleep
8 Hz
Pre-Sleep
4 Hz
Dreams
20 Hz
Concentration
Binaural Beats
Requires Headphones
Learn More
Play
Clear
Volume
Add Favorite
Sounds
Meditations
Favorites
Timers
More

Figure 4: Screenshot of *Relax Melodies* binaural beats function.

In researching the history of binaural beats, "one oscillates between science and pseudoscience, theory and conspiracy theory, unnamed 'official' sources and crystal healers, history and clandestine history" (LaLiberty, 2017). The human brain emits different frequencies of brain waves when in different psychological states. It has been claimed that listening to certain frequencies of binaural beats can alter the frequency of brainwaves produced by the brain — a psycho-acoustic phenomena referred to as 'brainwave entrainment'.

Alternative medicine practitioners have long claimed that it is possible through brainwave entrainment to induce the precise states of consciousness associated with these brainwave frequencies. However, the scientific justification for these effects of binaural beats appears unclear at best. LaLiberty places binaural beats and their associated discourses of psychological benefit within a history of other sound technologies which position the listener at an affective level. The music produced by the Muzak Corporation for example, piped into workplaces and shopping centres, "functioned to stabilize the sonics of these spaces, conditioning the consumer and worker by inducing moods conducive to consumption and production and arousing their bodies to synchronous labor with its rhythms" (LaLiberty, 2017). LaLiberty sees binaural beats as operating within a similar discursive space: "in the explicit reliance on psychoacoustic phenomena, the discourse around binaural beats speaks to a desire to condition the affective body by psychoacoustically 'entraining' sympathetic resonances in neural-electrical activity" (LaLiberty, 2017).

The psychoacoustic aspect of the binaural beats function in sleep apps aims to modulate brainwave frequencies in order to induce sleep. The user attempts to cede conscious psychological volition to the direction and guidance of the app itself. As with the smart wake up function, there is again a delegation of the work involved in entraining the body towards a given state of somnolence. However, binaural beats more directly intervene into the physiological interior of corporeal optimisation. One app, 'Digipill', even equates the app's use to that of a drug experience, advising users to "Download a pill, remove all distractions, sit back with some headphones, and listen" (Digipill, 2018). Its creators argue that the app will "help you to unlock your subconscious in order to change your mood, perception, or even your behaviour" (Digipill, 2018).

Within the contexts of sleep apps, the use of binaural beats holds out the promise of a safe and effective sonic sleeping pill. Here we see the 'binaural beats' function operating to coordinate the user's sleep through a neurological focus. The difference between 'deep sleep' and 'pre-sleep' in this conception is not an absolute difference between sleep and wakefulness, but rather a difference in the frequency or intensity of neurological output. And in this dream of delegation and intervention, we can observe a shift in the register of mobile app affordances. There is a shift from the burden of self-

management via datafication and monitoring to a passive neurological modulation that organises the self in a cybernetically oscillating operation of transmission-reception, signal-noise, on-off.

Conclusion

This paper has sought to question how sleep is structured and mediated through sleep apps. We have pursued a close reading of the features and affordances of mobile sleep apps. This was initially to situate the monitoring of sleep amidst broader media cultures of personal tracking and self-management. This close analysis demonstrates, however, that sleep apps have evolved well beyond simply tracking sleep, incorporating forms of sleep rhythm optimisation and brainwave frequency modulation. This in turn entails a more direct and delegated role for the digital mediation of sleep. In doing so, these apps both extend and depart from the institutional spaces and technologies of sleep science to carve out new intensities in digitally modulating personal sleep practices.

Our key contribution in this analysis has been to demonstrate that contemporary sleep monitoring technologies allow for both a greater degree of 'customisation' over one's sleep at the same time as they delegate key elements of this customisation away from the intentionality of the user. In seeking to produce greater 'ease' in the process of waking up or relaxing before falling asleep, we can discern a novel affective component to the management of one's sleeping and waking routine. These sleep apps do not solely allow customisation or optimisation of personal sleep practices. They also serve to intervene in defining how users understand and enact these practices through functions promoting a 'clean wake up' or 'pre-sleep' brainwave entrainment. Rather than analysing these apps then in terms of whether they promote healthy or pathological sleeping practices *per se*, we have drawn attention to how these apps serve to produce novel experiences and rhythms of sleeping, driven by acoustic affordances.

Rather than questioning whether sleep is simply inhibited or encouraged by internet-enabled media devices, Hassoun and Gilmore (2017) argue for the necessity of engaging more closely with the ways "bodies drift and flow through overlapping fields of sleep and wakefulness, as well as how technologies try to routinize these ever-changing qualities of sleep" [21]. This article has contributed further to this mode of investigation by providing more granular detail regarding the types of mediation contemporary sleep apps are offering than has previously been considered in media or sociological analyses. We demonstrate that while sleep apps certainly provide a means for the greater configuration of sleep practices and their correlation with wakeful activity, they also provide a means for what we describe as a digital delegation of sleep practice to the apps themselves. It is in this analysis then that we can begin to understand how contemporary sleep practice is both given value and organised through the novel affordances of mobile sleep apps.

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Notes

1. Arber, *et al.*, 2012, p. 223.

2. Crary, 2013, p. 13.

3. Venn and Arber, 2008, p. 125; see also Power, *et al.*, 2017.

4. Fuller, 2018, p. 103.

5. Alertness Solutions, 2005, p. 349, emphasis in original.

6. Arber, *et al.*, 2012, p. 229.

7. See Berson, 2015, pp. 84–99.

8. Williams, *et al.*, 2013, p. 41.

9. Williams, *et al.*, 2015, p. 1,049.

10. Lupton, 2014, p. 607.

11. Lupton, 2014, p. 611.

12. *Ibid.*

13. Whilst 27 apps were coded as sleep cycle monitoring, four of these were bundled with other tracking apps, and the sleep tracking features were not available in the app descriptions. Hence, numbers cited in this section are for a total of 23 sleep cycle tracking apps.

14. Baron, *et al.*, 2017, p. 351.

15. Williams, *et al.*, 2015, p. 1,045.

16. Williams, 2011, p. 29.

17. Whilst 49 apps were coded as Relaxing Sounds apps, four of these were bundled with other tracking apps, and the sleep tracking features were not available in the app descriptions. Hence, numbers cited in this section are for a total of 45 sleep cycle tracking apps.

18. Sterne, 2003, pp. 50–51.

19. Oster, 1973, p. 94.

20. Brainwave speed is measured in Hertz (cycles per second) and divided into five bands delineating slow, moderate, and fast waves (Beta, Alpha, Theta, Delta and Gamma). Each frequency has its own set of characteristics representing a specific level of brain activity, with slower brainwaves associated with feeling tired, slow, sluggish, and higher frequencies associated with feeling alert, or wired.

21. Hassoun and Gilmore, 2017, p. 104.

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Editorial history

Received 27 November 2018; accepted 23 May 2019.



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Sleep mode: Mobile apps and the optimisation of sleep-wake rhythms
by Christopher O'Neill and Bjorn Nansen.
First Monday, Volume 24, Number 6 - 3 June 2019
https://firstmonday.org/ojs/index.php/fm/article/download/9574/8045
doi: http://dx.doi.org/10.5210/fm.v24i6.9574