Redefining Rest: A Taxonomy of Contemporary Digital Sleep Technologies

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Ben Lyall and Bjørn Nansen *

Abstract: *»Erholung neu definieren: Eine Taxonomie heutiger digitaler Schlaftechnologien«.* Digital sleep tracking has become part of everyday life via smartphones with in-built sensors, dedicated sleep tracking software, and a range of peripherals. In a context of mediatised and managed sleep, this paper seeks to schematise the scope of consumer technologies, products, and media taking shape in the sleep industry. We outline a five-part taxonomy of sleep media technology: instrumentalisation of sleep data; augmentation of bedroom material; routinisation of sleep atmosphere; hacking of sleep rhythms; and finally, modulation of neurological states. We argue these technology types amalgamate to position sleep as in-crisis, while concurrently, commodifying this problem with digital "solutions" intervening at different scales, from the brain to body to bedroom to environment. Emerging from marketing and popular media coverage are new norms of "good sleep" and "sleep hygiene," normalising a discussion of "how" (rather than "if") digital technologies can measure, datafy, optimise, automate, and bioengineer sleep.

Keywords: Sleep, mediatisation, taxonomy, self-tracking, sensors, datafication.

1. Introduction

Today, smartphones and mobile applications enable personal sleep to be monitored, measured, datafied, and visualised through metricised representations of duration, stages, latency, and quality (Williams, Coveney, and Meadows 2015; Lyall 2021). Alongside smartphones, mobile apps, and software applications, commercial developments in wearable devices and sensor-enabled and internet-connected bedroom products are operating to extend the possibilities for monitoring and mediating sleep (Liang and Ploderer

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2016; O'Neill and Nansen 2019; Nansen, Mannell, and O'Neill 2021). Within this current technological context, this paper schematises the consumer marketplace, providing a taxonomy that classifies sleep media technologies into five key domains: *instrumentalisation of sleep data; augmentation of bedroom materials; routinisation of sleep atmospheres; hacking of sleep rhythms;* and *modulation of neurological states*.

The taxonomy draws on authors' research in this area, involving data on a wide range of digital sleep-tracking products: mobile software applications, sensor and wearables devices, and "smart" bedroom technologies, as well product marketing and coverage in popular articles about sleep routines, including specialised publications for neurobiological interventions. The ever-expanding scope of sleep media and mediatisation requires a classification approach to help understand the patterns of emergent sleep practices and discourses created by novel devices and applications. Our taxonomy highlights the ways sleep is currently being reimagined as a site of malleability and meaning across sociocultural, technologic, health, and economic vectors.

The paper situates this analysis of sleep technology within a theoretical framework of mediatisation, which understands changes in social meanings and cultural practices, here of sleep, as inextricably bound to changes in communication and media technologies (Couldry and Hepp 2013; Hepp 2020). Krotz defined mediatisation as an ongoing process whereby new media technologies emerge and alter patterns of social communication and social life (2014). Thus, mediatisation captures patterns of historical transformation and contemporary constellations of media disruption. It is useful in the studying of sleep media insofar as it affords a framework for approaching the interrelations of sleep products, marketing, discourses, and their effects, as well as affording interpretive flexibility in assessing the varied types of sleep technologies people encounter, the impacts they have on sleep meanings, and practices. Ultimately, this mediatisation approach is significant for analysing how sleep technologies assemble into larger configurations of sleep as being in crisis: a label we apply based on the escalation of diagnostic problematisation of sleep to something deemed socio-politically important (Williams 2011, 2013) at the *discursive* level; the concurrent tensions of technological solutionism (Morozov 2013) at the *consumer* level, in which sleep is simultaneously threatened and amended by technology innovation; and contemporary complexities of sleep at the *population* level (Meadows, Brunton-Smith, and Ellis 2022) including the COVID-19 pandemic (Williams, Meadows, and Coveney 2021).

2. Background: The Mediatisation of Sleep

Sleep has historically been understood as an embodied state of subjective, social, and technological withdrawal from the world for the purposes of rest and recuperation (Ekirch 2001; Glaskin and Chenhall 2013). Yet, the widespread practice of sleeping with a smartphone nearby is revising these norms (Gregg 2011; Williams 2011; Littlefield 2018). Commercial sleep technologies aim to transform sleep by quantifying, customising and optimising sleep data and routines (Liang and Ploderer 2016; O'Neill and Nansen 2019; Nansen, Mannell, and O'Neill 2021), while also remediating the emergence and development of sleep technologies associated with sleep science and the sleep labs of the 20th century (Williams, Coveney, and Meadows 2015; Littlefield 2018): a period which transformed sleep from a subjective, personal experience into something known "objectively" through technologies like the polysomnogram, the development of sleep research, and the formation and formalisation of the "sleep laboratory" (Kroker 2007).

In everyday life – as in the spaces of medical sleep centres, and the contexts of laboratory studies – sleep monitoring maintains a "scientific" presentation. Over time, however, sleep's meaning has undergone fundamental shifts. Littlefield (2018, 93) summarises these as "neurological," "psychological," and "instrumental" modes, with the final category focusing on how – today – rest serves wakeful productivity (Littlefield 2018, 93). Sleep technology products exist in this instrumentalised mode, though with an ambivalence toward other models of sleep that allow for science to be co-opted: many companies market themselves based on connections to sleep science associations. At the expense of both scientific detail on how sleep is monitored (Lee and Finkelstein 2015) and how metrics are communicated to users (Ravichandran et al. 2017), most products rely on proprietary monitoring systems and metrics to promote sleep as a governable "biosocial" (Williams, Coveney, and Meadows 2015) phenomenon, transformed through a diverse range of functions: analysis of sleep data, interventions in sleep-wake routines, and the redesigning of bedrooms as "smart" environments for sleeping (O'Neill and Nansen 2019; Nansen, Mannell, and O'Neill 2021). Digital sleep products are diverse, appearing as discrete sleep "systems," as features offered by wearable hardware like the Apple Watch or Ōura ring, software applications such as "Sleep Cycle," and in a plethora of sensor-enabled pillows, mattresses, or lamps such as Philips's "Somneo" that modify bedroom spaces.

Thus, we see the remit and claims of consumer-facing sleep technologies expanding and diversifying. Through "vernacular review" (Jaakkola 2020) culture, sleep is a consistent topic of news and technology reporting, including wellness blogs, advertorials, biohacking guides, and self-help resources.

Sleep is recast as malleable and primed for transformation. An example of the mediatisation of sleep technologies appears in *The Huffington Post's* article series (2019–2020) entitled "Life: The Sleep Edition." The series featured blogs, news, product reviews, and research summaries on the topic of sleep, collectively rendering sleep as a "problem" for modern humanity: a necessary process, difficult to successfully perform around fast-paced work and social lives. Yet too, sleep is primed for diverse interventions across behavioural, corporeal, and spatial levels.

As such, we see sleep technologies operating at various scales of intervention from the biopolitical terrain of brain and body (Fuller 2018), to the datafication of daily routines and sleep regimes (Lee-Tobin et al. 2017), to the code/spaces (Kitchin and Dodge 2011) of bedroom objects and spaces, to the smart interoperation of sleep rhythms with cultural imaginaries of restfulness and wakefulness (Valtonen and Närvänen 2016). *The Huffington Post* series – one of many quasi-news, marketing-orientated "lifehacking" items published on the internet – relies on the cultural resonance of sleep-as-problem, as well as a sense of unknown created by unsettled science, and intensely individual preferences. These resonant qualities are leveraged by sleep media, which pitches ongoing self-experimentation and optimisation as the path forward: eventually, a technological solution (Morozov 2013) will prevail.

The digitisation, datafication, and mediatisation of sleep has been traced by media theorist Matthew Fuller, who outlines a complex assemblage of dormant bodies and a network of monitoring technologies (2018, 103): "a proliferating set of medial and bodily relations that are also interpolated by sensors, databases of logic, ordering, proliferation, entrepreneurial 'disruption,' user-centeredness and ideas of health and improvement."

There are competing forces at work in monitoring the dormant body, focussing attention on the intimacies of the sleeper's physiology at the same time dissecting the body into streams of digital data to be analysed and reordered according to competing biosocial demands.

The COVID-19 pandemic has intensified the mediatisation of sleep. A side effect of public health responses is an exacerbated sleep disruption. Williams and colleagues describe a biosocial "desynchronisation" (2021) from the absence of routine, and industry research shows lockdowns intensified digital device use in bedrooms, impacting sleep quality and mental health (Robbins et al. 2021). In the context of social isolation, quarantine, and lockdown, sleep has also been pressurised: re-emphasised as a site of self-care, exercised through regimentation and monitoring (Robbins et al. 2021). The same corporate actors that framed sleep as an extrinsic generator of productivity (Crary 2014; Sharma 2014; Williams 2013; Paterson 2021), were also able to advocate for self-care and contribute to the "greater good" in pandemic times. Eager to maintain their utility during lockdowns, the usual "activity"

orientation of mainstream self-tracking companies like Fitbit and Garmin was rapidly altered to incorporate sedentary self-care, rest, and sleep. Limited by functionality, these discourses tended to emphasise what companies know about users' bedtime, while making generalised connections to the impacts of un/healthy sleep patterns (Fitbit Staff 2020) or spruiking university research partnerships (Garmin 2020). Amenable to both emerging and existing concerns for human rest and recouperation, the mediatisation of sleep is diverse and iterative.

3. Research Approach

As existing social science research has noted, sleep can be modulated by technological, temporal, and sensory conditions (Berg 2017; Meadows, Brunton-Smith, and Ellis 2022). Sleep is increasingly subject to monitoring, with bodies and environments adjusted by technology. As outlined by Nansen, Mannell, and O'Neill (2021, 138), scientific literature characterises behavioural and neuro-physiological features of sleep, cycles of the body transitioning between wakefulness and sleep, whilst popular mediatisation and publications describe the environments that surround sleep, in which light, sound, and touch are altered to match or induce states of sleep or wakefulness. In both science and media, technology represents means to monitor and optimise sleep from within and without.

This paper draws on various sources of data and examples of sleep mediatisation, and presents them based on relevant case study and technology oriented methods that include elements of feature analysis of sleep products (Lyall 2021; O'Neill and Nansen 2019); visual analysis of advertising materials (Crawford, Lingel, and Karppi 2015; Wernimont 2018); as well as discourses from entrepreneurs – who regularly offer advice and technology solutions to the problems of sleep: Silicon Valley elites Musk, Zuckerberg, and Dorsey have all used social media channels to communicate sleep practices and associated technology (see Lyall 2021; Nansen, Mannell, and O'Neill 2021). These methods fit within broader mobile media and smart home research, which critically evaluate the embodiment of self-tracking technologies and the production of data about the human body and its nightly activities to manage or optimise the spatio-temporalities of sleep (Lupton 2016; Nafus 2016; Neff and Nafus 2016); as well as household sleep environments, in which bedroom systems use sensors and internet connectivity to monitor and automate spaces of sleep (Andrejevic 2020; Kitchin and Dodge 2011; Sadowski 2020; Strengers et al. 2020).

Collectively, these approaches enable us to address social and cultural questions about sleep technology, and to analyse the everyday mediation and

datafication of sleep through the available functions of sleep products. These methods analyse the content of product designs; how they claim to utilise sensors, data, and automation to monitor and modulate sleep; the corporate imaginaries of these technologies; the specialised communities (biohackers, entrepreneurs) called to action; and the wider public discourse generated by publications that review, advertise, and promote new products. Thus, this paper addresses the technology imperatives, imaginaries, and constellations surrounding the various social, commercial, and health dimensions of sleep technologies through the following research questions: 1) What are the categories or types of sleep media and technology innovation? 2) How do these types of sleep media technologies attempt to transform the meanings of personal sleep?

While using the lens of mediatisation to understand emerging sleep technologies (and practices), this paper also draws on the histories of brain monitoring technologies from Cornelius Borck (2018) and Kenton Kroker (2007). In both histories, human sleep (including states of sleep, sleep or related health disorders, and dreams) loom large: sleep is a convergent point for novel experimental scientific research methods, and quests to expand knowledge of the unconscious brain and mind. Given our interest in consumer technologies, we also draw on the work of Melissa Littlefield (2018) and her conceptualisation of the trajectory of sleep monitoring technology, which arrives at a form of "instrumental intimacy" between technologies and consumers in the domestic sphere.

Littlefield's analysis shows how sleep was once considered to be an inactive and restful state of mind but was reconfigured in the early 20th century through psychoanalytic hypotheses about sleep, dreams, and accessibility of mind into a psychological state. In the second half of the 20th century, this understanding of sleep shifted to a neurophysiological state, sleep was reconfigured and recategorized via electroencephalograms (EEG) in the 1950s and 1960s as an active state of mind, and one in which scientists (as well as laypeople) could intervene. Littlefield notes that, "what we know about sleep has long depended on the technologies we employ for its measurement and evaluation" (2018, 76). Mechanized sleep research is largely a mid-to-late-20th-century phenomenon that shifted from technologies for tracking sleep movement – (measured by a somnokinetograph), or heart rate (measured through electrocardiography [ECG]) – to tracking brain activity using an EEG. She argues that accompanying these measuring technologies were discursive shifts in the understanding of sleep. Psychoanalytic measures displaced a previous discourse around sleep as a natural but mysterious state of inactivity, into a psychological state of accessible dream states. Similarly, the EEG and sleep laboratory science transformed took sleep away from psychoanalytic speculation toward a scientific discourse of recognised electrical patterns and

stages. Crucially, these "physiological phenomenon that [are] a target of scientific measurement and therefore subject to potential modification" (2018, 76).

And, as Littlefield notes of the early 21st century, sleep monitoring moved out of the laboratory, into the homes of individuals, through a range of technologies designed to enable "the augmentation and optimisation of human sleep for the purposes of efficiency, productivity, and an instrumentally inflected sense of control" (2018, 93). Littlefield defines "instrumental intimacy" as the outcome of this discourse: a basis for physiological intervention, the likes of which have also been catalogued by Mark Paterson (2021) with regards to fatigue (and a longer history of what he calls "neuroprosthesis"). We extend notions of sleep as being instrumentalised by arguing that the current constellation of sleep technologies – featured in our taxonomy – rely on both historical and contemporary discourses and offer consumers a variety of intensities at which to engage.

4. Online Traces of Sleep Self-Tracking

The taxonomy aims to categorise consumer sleep technologies – including software applications, wearable devices, and bedroom products, and how they construct different meanings of sleep through their mediatisation. This taxonomy classifies sleep media technologies into five key domains of operation and associated meanings: *instrumentalisation of sleep data; augmentation of bedroom materials; routinisation of sleep atmospheres; hacking of sleep rhythms;* and *acoustic automation of neurological states.* We provide examples and discussion of each of these categories below.

4.1 Instrumentalisation of Sleep Data

Instrumentalisation of sleep data takes shape through the aggregation of sensors and features associated with mobile phone sleep applications, and the subsequent transformation of sleep data into forms of datafied sleep for assessing sleep quality. Focused on data, our definitional use of "instrumental" is suggestive of "*an instrument,"* rather than "*something essential."* Though many digital tools use the latter meaning as marketing for the former. The core characteristic of sleep apps is, of course, the capacity to monitor and communicate data about sleep patterns. Apps use smartphone accelerometers and microphones to sense bodily sleep data through movement or sound. Wearables add dedicated accelerometers and gyroscopes for tracking movement, with additional sensory affordances including temperature, photoplethysmography (PPG) (O'Neill 2017) and ECG (Davies 2019), which measure

blood flow and pulse by shining light through skin. These measures are a proxy for sleep quality: an algorithm looks for patterns with activity indicating lighter sleep, and stillness indicating deeper sleep (Crawford, Lingel, and Karppi 2015, 484). Sleep data is then visualised through features such as sleep graphs, sleep quality scores, or trend analyses and advice is given to users based on algorithmic calculations performed on their sleep data.

Companies are in competition to then distinguish their specific sensors technology and mode of instrumentalisation. Based on longitudinal (nightly) data points, and hidden proprietary algorithmic determinations, apps often render sleep as a "score": for example, "readiness" (on Ōura and Fitbit) or "recovery" (Whoop). One prominent example of this instrumentalisation is in Northcube AB's "Sleep Cycle," one of the most popular sleep trackers and alarm applications on Apple's App Store. Sleep Cycle users are provided with data about their sleep in the form of a "Sleep Quality" score (running from 0 to 100) (Northcube, n.d.). Here, and in many similar applications, the precise means of evaluating sleep and establishing this "quality" metric are not provided in the app. Northcube's support website however, details four key measurements: time spent in bed; time spent in "deep sleep"; "consistency" of the sleep; and number of instances in which the app registered the user as "fully awake" (Northcube 2022). Notably, these additional vague terms ("deep sleep," "consistency," "fully awake") are not provided with any further detail.

This category typifies the art of datafication, where the uncertainties and complexities of sleep are allegedly tamed by calculative interpretations. In fact, Withings "Sleep Analyser" – sold with the slogan "Know your nights. Master your days." – bears striking similarity to Quantified Self movement's catchcry: "self-knowledge through numbers" (Wolf 2010), and this is indicative of the instrumentalisation present in these applications and devices. The ambiguities of the operation and meaning of "scores" raise questions about living with and interpreting the meanings and values of such datafied information (Lupton 2016; Liang and Ploderer 2016; O'Neill and Nansen 2019), raising the ire of medical literature, where analyses of device accuracy pose issues of self-diagnosis (e.g., Bhat et al. 2015). Sleep clinicians have reported instances of "orthosomnia," where users have deemed themselves to have a sleep disorder based on becoming overly concerned with poor "sleep scores" given by their sleep trackers, and anxious that they are not producing sufficiently "optimal" sleep (Baron et al. 2017, 351).

When sleep is instrumentalised and rendered in "scores" about the quality of personal sleep, it is also very overtly linked to associated wakeful activities such as exercise and diet, which Williams, Coveney, and Meadows (2015, 1045) argue reproduces sleep as a sphere for the enactment of "optimisation" of life more broadly in terms of general health. Martin Berg (2017, 8) argues in his analysis of the aforementioned Ōura, that in addition to emphasising

optimised self-management though this mediatisation of sleep, this process of datafying sleep distances humans from viewing sleep as *experiential*: rather, it alienates user bodies "as remote, intangible and perhaps even impossible to make sense of without proper guidance from a technology that interprets, categorises and visualises these experiences in ways through which they are rendered measurable, precise and comparable." We begin with instrumentalisation of sleep – and relatively prosaic examples such as wearables – as something of a given. Digital sleep technologies universally apply an extractive mode of operation and extrinsic valuation, with more complex interventions possible (as in the categories we outline below).

4.2 Augmentation of Bedroom Materials

While personal, the logics of sleep management have been adopted into household objects, products, materials, and spatial arrangements. Bedrooms are now mediated by digital devices in both ordinary and extraordinary ways, with a range of "internet of things" (IoT) devices clambering at the bedroom door to redesign and reimagine the intimate spaces and practices of sleep. Smart household devices extend on-body instrumentalisation of sleep and – through IoT –augmenting sleep *in-space*. Eye masks, headphones, pillows, blankets, and mattresses are all examples of this extended form and "augmented" mode of sleep media. Such products leverage discourses of the smart home and IoT to – in the language of Kitchin and Dodge (2011) – transform bedrooms into "code/spaces" (Lyall 2021) in which the digital reconfigures the spatial to create optimum conditions. We provide coverage of a few objects below, that while not exhaustive, provide a sense of the scope of this augmentation.

Masks – designed to cover the eyes and in some cases, envelope the ears – provide a simple means to optimise and modulate somnolescence. Examples of these include wearables like the "Sleep Shepherd" headband, or Entertech's "Luuna" sleep mask, which augment the fabric of the mask with sensors to record map and respond to physical signals from the body or brain, such as EEG (Littlefield 2018). They also have embedded speakers to promote sleep with relaxing sounds. The acoustic and sensory dimensions of these products are discussed further in the final section of our taxonomy (acoustic modulation of neurological states). Pillows, such as the "Zeeq" smart pillow from REM-Fit incorporates motion sensors with speakers and microphones to monitor sleep, specifically targeting restlessness and snoring. It primarily communicates with the sleeping user through vibration motors: during the night this encourages them to change the position of their head and body if snoring above a certain volume threshold (dB) is detected and offers the sleeper an "intelligent" and "partner friendly" morning alarm. Using

Bluetooth, the pillow also sends data to a smartphone app, and like masks, features a wireless speaker. This smart pillow – and the project of sleep optimisation as a whole – carries extreme tensions and ironies. Objects of stillness and quiet, like pillows, are retrofitted with technology that does exactly the opposite: making noise and encouraging movement. Furthering a positionality that indicates sleep is *extrinsically* rather than *intrinsically* valuable (Berg 2017), or a means to a further outcome rather than an end in-itself, REM-Fit also sell a range of fitness equipment products. These appear to have some basic connectivity features and the company has previously experimented with producing and selling activity tracking wearables. Now seemingly defunct (the pillow's iOS and Play Store apps are no longer available for download), Zeeq represents an interesting subset of the sleep technology sector, having arrived in the marketplace as a start-up funded through the crowdfunding platform Kickstarter: the project raised over 400,000 USD by 2017 (ZEEQ Smart Pillow 2022). However, without ongoing support, smart sleep technology loses its "smarts," and might fail to deliver the promises of optimised rest.

Amping up the complexity of monitoring affordances, smart mattresses offer assessments of the entire sleep cycle. The product category is typified by "Sleep Number" (formerly Select Comfort) beds, originally marketed on the premise that individuals have specific sleep needs that could be addressed as a "sleep number" and matched to the tactile qualities of a mattress. However, the product range now includes adjustable mattress/bed systems adorned with sensors to both track and alter a range of factors surrounding sleep: both retrospective data (e.g., a sleep "score") as well as operating in a semi-automated real-time fashion (e.g., modulating mattress airflow to alter bed, and in turn body temperature). The latter occurs through heating, akin to an electric blanket, as well as tactile alterations to the mattress such as its firmness and orientation (horizontal incline). Other examples in this space include the Withings "Sleep Analyser" mat and Beddit "Sleep Monitor," which are sensor pads – inserted into bedding or pillows – to monitor sleep. The pads use ballistocardiography (BCG) to detect the micro-mechanical forces of arteries and blood vessels, mapping breathing and heartbeats like a stethoscope. These alternatives represent the smartening of otherwise "dumb" objects and herald their enrolment into systems of augmentation (Kitchin and Dodge 2011).

Many of these sensory and environmentally oriented products are discussed in terms of connected systems for the routinising sleep atmospheres in the next section. But it is worth noting here, that these products rely heavily on their non-digital materiality. That is, the comfort of furnishings such as pillows and mattresses is parlayed into the digitised materiality of smart sleep. In promotional materials for all these examples, there is a unity between qualitative comfort and the alleged quantitative record of enhanced

sleep. Unsurprisingly, these bedroom furnishings, linens, and accoutrement are available for purchase from the same vendors. While some categories in this taxonomy overhaul sleep practices, the augmented mode remains reliant on soft furnishings to smooth over the hard edges of technology.

4.3 Routinisation of Sleep Atmospheres

The routinisation of sleep atmospheres involves technology augmenting bedroom spaces as noted above but emphasises the sensory dimension of mediatisation. Sensory arrangements involve bedroom IoT systems that monitor and automate temperature, sound, and luminosity to generate sleepy atmospheres. These technologies include various combinations of sensory registers: haptic, acoustic, visual, and temporal. Tools for managing these registers appear in mobile device settings for audio "do not disturb" or "night mode" (Mulvin 2018), as well as screen brightness through Apple's "Night Shift" and Android's "Night Light" (which reduce the overall illumination of screens and/or shift the overall hue of colours displayed). Here users create schedules for sleep routines that dull audio-visual and haptic aspects of smartphones during designated periods of rest or sleep. These shifts in atmospherics build on the assumption that smartphones are inculcated in poor sleep but are also a safe option: the routinisation is simply linked to clock-time, rather than any biomedical test of sleep quality.

But more complex routinisation of sleep schedules occurs through the discourse of "sleep hygiene": in which public health guidelines offer advice for creating spaces and routines that are conducive to sleep through managing bodily comfort and warmth as well as bedroom lighting, noise levels, temperature, and so forth. Deeper than the clock, the object of intervention is the body's "natural" cycles of alertness and rest, such as hormonal and circadian rhythms, which are manipulated by changes to the spatial conditions surrounding sleep. Lighting has a further focus here, with blue light (a melatonin production inhibitor) a particular concern in sleep hygiene discourse. Lighting interventions appear in IoT and smart bedroom products, including Philips' Bluetooth-enabled "Hue" light globes and "Somneo" connected lamp, which simulate the lighting conditions of sunrise and sunset, to optimise falling asleep. Products like "Morphée" also offer to solve the problems of light by providing sound-only solutions. This product, which features mechanical knobs for an analogue aesthetic, offers "no screens, no waves." But the claim of this product – "for optimal efficiency, Morphée is non-digital" – is perhaps indicative of the wider trend in acoustic sleep media: to make sonic interventions in the atmospheres surrounding sleeping bodies, while ignoring solutionism inherent in proposing means for optimisation.

Advanced sound-based interventions target not just the smartphone but sleeping environments. This construction of sound-as-atmosphere is distinct from sound as a pathway to neurology, which we discuss later. At their most prosaic, sounds can simply be projected to drown-out background noise and interestingly, it is common for these to revive a naturalistic view of sleep through beach, rainfall, and animal (or similar) noises. More sophisticated examples, such as the "Nightingale Sleep System," block unwanted noise and replace it with a desired ambiance, what the company describes as a "sound blanket" (Nansen, Mannell, and O'Neill 2021). Here again we see the tactile imagery of warm soft bedroom furnishings, though the "blanket" is formed by projecting sound from multiple speakers in one room. Datafication here is also elevated: users are required to share environmental features of the room (via in-app survey) so that each speaker in the setup can be calibrated to best douse the room in ambient noise.

The use of "system" in product names – including the Nightingale as and the Withings product family, which is also described as a "sleep system" – suggests that the wider goals of many atmospheric products is to also engage with the forms of instrumentalisation and augmentation already discussed. An example of this integrated atmospheric approach is the "S+" by ResMed, a device that records inputs (light, noise, temperature) as well as modulating them. In addition, the device claims to use echolocation: like bats and dolphins, the system issues short pulses sound, then listens to observe how the sound rebounds from physical objects in the space. ResMed claims that the S+ has the subtlety to detect body movements in this manner, which can in turn, be used to calculate a user's sleep patterns. Importantly, the recommendations generated by the system (beyond extant forms of datafication) include suggestions for bedroom reconfiguring. Similarly, the "Pod 3" from Eight Sleep is a thin mattress cover designed to fit under a bedsheet and incorporates a plethora of sensors to collect information and make on-the-fly changes to atmospheres: heartrates, breathing patterns, bodily movement, bed temperature, and environmental information such as room temperature, humidity, noise, and light levels are all collected and used to achieve "up to 32% higher sleep quality." This product, unlike others, also projects itself forward in time; into a world where other technology is (or might be) programmed to communicate with or about the sleeping body: through "if-this-then-that" (IFTTT) software standards, Eight Sleep's products contain the instructional logics to synchronise and automate the actions of other devices and relationships between these devices in future.

Collectively, these products incorporate multiple sensors to track, analyse, and operationalise data in the pursuit of customising sleep routines and sleep atmospheres to produce conditions deemed suitable or conducive to optimal sleep outcomes. Broadly, these spatial and environmental manifestations of

relaxation share commonalities with smart-home visions of comfort: what Strengers et al. (2020) describe in the conceptual portmanteau of "pleasance," building on the Danish concept of *hygge* (Jensen et al. 2018). Spaces for relaxation (and subsequently sleep) share many qualities of the ambient intelligence of the smart-home, ultimately though, the goals of "smart" (such as ease-of-use, algorithmic prediction, and energy efficiency) are shifted from the spatial and added to the corporeal: smart applied to "sleep" rather than the home. Though as the "Pod 3" example speculates, future connections between the sleeping body and the smart home are possible and might directly hack the biology of sleep rhythms.

4.4 Hacking of Sleep Biology

Visions of customising and reconfiguring sleeping rhythms emanate from everyday smart technologies such as smart wake alarms but incorporate fringe endeavours such as transhumanist "bio-hacking" and poly-phasic sleep patterns. Biohackers deploy sensors and data monitoring to optimise and improve health, alertness, and productivity by maximising wakefulness hours (see Berson 2015, 84-99; Reagle 2019). This form of sleep media doubles down on the harmonies between people, spaces, and technologies seen in the taxonomy so far. As discussed, the rhetoric of digital devices entering a form of "sleep" or "night mode" (O'Neill and Nansen 2019; Nansen, Mannell, and O'Neill 2021; Mulvin 2018) indicates a technologization of sleep, as well as a biologizing of technology.

This was codified in the 20th century via the EEG's rendering sleep as a period of "active" brain state (Kroker 2007; Littlefield 2018), and thereafter animated by the seemingly immutable "unknowns" of the human brain (Borck 2018). This technologization has become more intensive and more pervasive through the IoT mediatisation of human sleep: neither human nor device are ever "offline" and continue to function in states of rest. Previous research on mobile app stores reveals that common features of sleep apps include a range of sleep management functions such as customisable alarm sounds, manually setting a sleep/wake time, sleep aid sounds, bedtime reminder, and smart wake up functions (O'Neill and Nansen 2019). Some of these functions move from figuring spaces or routines as sites of customisation, as described above, and instead focus more directly on the intervening into the biology and rhythms of the sleeping body.

Given the restrictions of being external to the body, these interventions are often haptic (see Paterson 2007; Parisi 2018). The Sleep Cycle app for example, which added a corollary app for the Apple Watch in 2018, offers an everyday biological intervention. Sleep is managed by the wearable: sensor data algorithmically determines a wake-up time to improve both sleep quality and

wakeful activities (Hall 2018), and Fitbit's range of wearables also offer similar haptic functions that either awaken the wearer with gentle vibrations or intervene mid-sleep to halt restlessness or snoring. Here, sleep is not just managed, but automated throughout the night, and unlike a smart mattress, the automation is managed on-the-body. Similar claims of bioengineering or "biofeedback" are claimed to be possible through sonics (including the headbands discussed) and profess to function in real-time. Examples here include "Neuvana" (2022) and "Sensate" (2022) devices, which claim to target the vagus nerve (through "micropulses" and "bone conduction" respectively) to engender calmness.

Sleep hacking "pioneers," who position sleep as a "frontier" to be overcome (Lyall 2021), extend the remit of technology through self-experimentation by moving from "monophasic" (singular) sleep to "polyphasic" (multiple short sleeps across the day and night). This alternative model of sleep has historical antecedents in pre-modern sleeping routines, which historical research has shown were often broken up into two distinct periods of rest (e.g., Ekirch 2001), as well as varied cultural patterns of sleep such as the afternoon siesta. The more recent variant, however, leans heavily on the ideas of bio-hacking perspectives and practices (Reagle 2019), and understands the body more like a computer system that can be "hacked" and "rebooted" to produce more efficient outcomes. Even proponents of this form of sleep note its difficulties and problems (Uberman Sleep Schedule 2019), but in online and traditional media coverage, less extreme polyphasic patterns are gaining a wider audience. More achievable approaches, such as a three-hour sleep in the early morning, supplemented by two half-hour naps during the day (Preston 2016) and deliberative eye-closing to achieve "offline waking rest" (Fairbank 2022), are being popularised. Even the "Morphée" (described earlier) features "napping" soundscapes designed for polyphasic forms of sleep.

Nevertheless, these sleep hacking activities promote a biopolitical refashioning of the perceived limitations of corporeality, and instead promote an ideology or vision of transhuman mastery in pursuit of productivity (Berson 2015). Other sleep biohacking sees both vitamin supplements and medicines (like the medical compound modafinil, sold as the narcolepsy treatment "Provigil" in the US) consumed in off-label ways. Here they are consumed to manipulate circadian sleep-wake rhythms to promote wakefulness, alertness, or productivity for an extended period, or to manage the conditions of fatigue or performance expectations for a range of socio-technical conditions of labour and leisure in contemporary economies. Such self-experimentation fits within the self-monitoring ethos popularised by the like of the Quantified Self, is implicit in modern working demands (Williams 2011) and is aligned with the logics of contemporary capitalism (Crary 2014; Williams 2013). Such

connections are only compounded in the products and content discussed in the final section of our taxonomy below.

4.5 Acoustic Modulation of Neurological States

Acoustic adjustments, like the other categories, are highly varied in their scientific definitions and claimed benefits. Modulations of neurological states can be either or both affect-acoustic (pleasurable relaxing sounds) or more automated psychoacoustics (sound frequencies that claim to change the pattern of brainwaves). Simultaneous bold yet nonspecific, these claims are used to sell speakers and headphones, with manufacturers (for example Bose) and sleep-specific audio products (such as the "Sleep Shepherd") offering both the auditory hardware and curated soundscapes for idyllic rest and relaxation. In the case of renowned manufacturers like Bose, an audiophile social cachet supports their specific brand of acoustic mediation.

Designer sounds might mask surrounding noise (the "sound blankets" discussed earlier) but can also promise a more sophisticated way of instructing the self (e.g., thoughts) by enrolling the entire body (i.e., posture, breath) in hypnosis, guided meditation, or sophrology (O'Neill and Nansen 2019). An example here are the various "colours" of "noise." The repetitive – often esoterically desired – sounds are a kind of background "fuzz" designed to block other sounds or directly provide relaxation. "White noise" is the sound often associated with radio static, or the sound of an appliance (such as a fan, air-conditioner, or refrigerator). However – continuing the theme of *diluted* sleep science (Littlefield 2018) – white noise is a term referring to a specific sonic spectrum. It is named by making a loose association between sound waves and light waves. Other colours in the visible light spectrum are also used to connote noise types, including pink, brown, and blue. These are often integrated into acoustic apps, and various claims are made about the moods generated by frequencies. Noise can also feature in routinisation, with sounds timed, synchronised, and modulated by (or used as) alarms (O'Neill and Nansen 2019).

Autonomous sensory meridian response (ASMR) sounds have much in common with these acoustic modulations, insofar as particular noises and soundscapes are designed to generate relaxation. The genre is popular on video streaming platforms like YouTube and Twitch, and like other forms of relaxing noise, it can be unexpected (often called "unintentional ASMR") as well as purposeful. There is an intensity of intimacy present in ASMR, generated through the closeness of sound: highly sensitive microphones are required to amplify small whispers or tapping into dynamic soundscapes. Like white noise, there is often a focus on the recreation of "mundane" (Smith and Snider 2018, 41) and otherwise overlooked sounds: the background is made

foreground. Like many forms of sleep media, ASMR also plays with science: attempting to describe a specific "tingling" sensation in scientific terms. But the phenomenon is deeply subjective, esoteric, with unsettled science. Subgenres of ASMR exist to discuss this, experimenting with sound, coaching listeners through the listening experience, and describing a lack of sensitivity to ASMR as "tingle immunity" (Smith and Snider 2018, 42).

Recently the popularity of the genre has exploded, featuring in McDonalds advertising (McDonald's Canada 2021), appearing in *Pokémon* videos (Pokémon kōshiki yūchūbu chan'neru ポケモン公式YouTubeチャンネル 2020), and forming a celebrity interview format for *W Magazine* (W Magazine 2018). But ASMR is distinct in being – as Smith and Snider (2018) have described – a *community*. In ASMR, there is a layered intimacy: not only are sounds intimate, but creators and fans have space for dialogue, and fans are bonded by their experience and ASMR and/or preferences for certain sounds. The community is also highly active, working to define the science of the sensation, to destigmatise the space, and to police the borders of the content which has variously been interpreted as sexualised, creepy, or weird (Smith and Snider 2018, 46).

Seeking a similar scientific justification for sleep modulation are "binaural beats." The alleged pathway for binaural beats, is the simultaneous transmission of different frequencies (hertz or "Hz") to the left and right ear, which "mathematically" force brainwaves to resolve the dissonance between frequencies as a *third* intermediate frequency (O'Neill and Nansen 2019; Nansen, Mannell, and O'Neill 2021): a tone dually represented as Hz and as a type of rest. Certain frequencies as promoted as desirable, purporting to induce certain states leading up to sleep (relaxed; meditative), or related to the quality of sleep (deep; filled with vivid dreams). These beats can be integrated into devices (like the Luuna mask) or sourced elsewhere: as artistic experiments shared freely on platforms like SoundCloud, examples of royalty-free background music, as music marketplace genre (e.g., "432Hz" on Apple Music), as an in-built feature of clock-radios, and of course within relaxation apps.

Increasingly, binaural beats are being pitched as digital sleeping pills (O'Neill and Nansen 2019), as part of a wider spectrum of "digital drugs." Indeed, one product – "Digipill" – promises to sonically unlock the subconscious mind (Digipill 2023). The "drugs" nomenclature is intended as an association with psychoactive substances (not with sensor-laden ingestible medicines, which also occupies the term) that ultimately aim to elicit a cognitive or emotional bodily response (Barratt et al. 2022). Distinct from the use of drugs in other recreational contexts however, survey data suggests that the dominant rationale for "digital drug" consumption is, indeed, to aid sleep (Barratt et al. 2022, 1138). Recently, the emerging and contested space of blockchain technologies – specifically non-fungible tokens (NFTs) – has seen

bespoke binaural beats developed. Beats are combined with looping visual animations, intended to be mesmerising, satisfying, and/or psychedelic, and these are bought and sold on cryptocurrency markets such as the popular NFT marketplace *OpenSea*. The additional drawcard here, beyond other binaural beats, is that the sounds are rare or even one-of-a-kind. In such spaces, digital drugs take on a level of specificity akin to design chemical "compounds" or "strains" of their tangible drug corollaries.

5. Conclusion

Across our sleep technology taxonomy, the goal, object, and experience of sleep becomes fungible: able to be crafted, communicated, bought, and sold on an oscillating register of science, spiritualism, and social status. Technology, increasingly, intersects with all three of these domains, pulling human sleep into the operations of technological solutionism (Morozov 2013). We see digital "solutions" intervening at different scales, from brain, to body, to bedroom, to environment. The consumer market for sleep technology, if still emerging as an "industry" or "sector," is a burgeoning business with significant cultural power. Troubled sleep, even if partially created by "new" technology, is not a "new" problem. The history of 20th century media technologies is one of domestication via bedroom (including alarm clocks, radios, televisions, and eventually computers). But contemporary framings are more urgent in their rhetoric: without new digital technological solutions, everyday sleep – in both its quality and its very *meaning* – exists in a state of crisis.

We have schematised the ever-growing scope of consumer technologies taking shape in the sleep industry through a taxonomy that aims to categorise sleep into five key domains of operation: *instrumentalisation of sleep data; augmentation of bedroom materials; routinisation of sleep atmospheres; hacking of sleep rhythms;* and *modulation of neurological states*. Collectively, the technologies we have mapped suggest an apparently vital path to better sleep hygiene through practices of self-care and discipline. They materialise the crisis of sleep as undermined by capitalist, consumer, and technological demands, but also paradoxically present solutions through the rampant commercialisation and commodification of sleep. Individuals are no longer the arbiter of sleep quality and are compelled to consume an ever-growing range of products to better self-manage rest, awakening, alertness, and productivity.

Despite the prominence of science and reference to academic research in marketing for sleep technology products and services, the veracity of the claims made – about data, bedrooms, routines, biohacking, and neurology – are uncertain. "Good sleep" with technology is, in fact, crafted externally: through algorithmic assessment, combined with marketing, and the

momentum generated by continual consumer participation, including crowdfunding supporters of devices, transhuman advocates, and the communities that follow ASMRtists or beat creators. Moreover, while our taxonomy has focused on the individual consumer, the enrolment of shared objects and practices into self-managed rest suggests that this growth will continue to expand and be characterised by participation in (rather than withdrawal from) households and workplaces. Already many of the sonic aspects of sleep media can be read critically – thought the likes of Sterne (2003) and Plourde (2017) – as disciplinary: seemingly combining the use of "Muzak" (used to govern mood in the context of work), with the burgeoning tracking of the labouring body (Moore 2017).

Further research could empirically explore the intersections of collective user experience and popular understandings of sleep with the growing social movements that oppose and resist emerging technological imperatives (Nansen, Mannell, and O'Neill 2021). By continuing to emphasise new means of datafication and consumption, sleep technologies are likely to continue echo existing histories: where understandings shift, merge, and attempt to erase alternative understandings of sleep (Littlefield 2018, 42) to form the latest in a long line of instrumentalised interventions.

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