Sleep Planning with Awari: Uncovering the Materiality of Body Rhythms using Research through Design

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ABSTRACT

With the increasing adoption of body tracking technology, users are able to collect bio-data which designers struggle to make legible or actionable. This work focused on increasing this technology-mediated bodily understanding through exploring the material properties of the body rhythms that govern the sleep behaviours being tracked.

Building from a workshop with non-normative sleepers, we reframe sleep tracking to be about understanding and manipulating body rhythms. We explore these rhythms through the RtD process of designing the Awari alertness-forecast and scheduling application in four iterations. This resulted in three non-exclusive categories of rhythmic influence: *Slow & Cyclical*, *Pressure & Release*, and *Anchored*. Through a better understanding of how they interact, their inertia, and their material properties for interaction we encourage the design of technology to shape, and be shaped, by the complex rhythms of life. We discuss ways in which this can democratise medical-models, and make actionable complex bodily processes.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in collaborative and social computing**; • **Applied computing** → *Health informatics*.

KEYWORDS

Sleep, Self-tracking, Health Informatics, Personal Informatics, Speculative Design, Research Through Design

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1 INTRODUCTION

Understanding and designing with how technology influences our lived bodily experiences is advancing not only through the dissemination of new sensing technology [5, 20], but also through the increasing amount of work looking to understand qualitatively, in both the first and third person, how technology can and should influence our bodily processes and their place within our everyday lives [28, 34, 61, 63, 68].

Increasingly, built on technology with roots in the medical domain, these systems are centred around sensors and act as a way of keeping track of changes to the measurements they provide. The adoption has been accelerated by the idea of the *quantified self* [39]: that change can be achieved through acting on an understanding of data that quantifies the human experience, and that there is an optimum measurement in each dimension. This relies on the assumption that presenting data to users will lead them to draw inferences compatible these goals [40], which is often scaffolded by only providing *"ready-made insights"* rather than supporting the users' self-refection over more complex interactions within the data [11]. This approach can leave the user stranded, not knowing how to 'improve' one's score [36], while understanding that this is the goal the system encourages, in turn leading to dropping engagement [75]. With this work, we instead demonstrate how systems can move from passive data hoarding to active tools in the process of changing body rhythms. We do this by presenting three different types of rhythms, and their related opportunities and constraints for technology-supported change, drawn from exploring the case of *sleep* through a series of workshops and the design of the system *Awari*.

The system presents a web-based interface where users can explore possible outcomes from decisions on the timing of sleep and wakefulness through interacting with an alertness prediction. This system is built on personal sleep data and multi-objective reinforcement learning. It was initially built as the result of a participatory user study on non-normative sleepers. These participants, for different reasons, sleep outside the normal '7-9 hours at night' schedule. Sleeping outside the norm naturally results in people taking action to change when they sleep – which prompted the reframing of sleep tracking to be about the actions taken to influence sleep and wakefulness.

We pair the design of the system with the insights drawn from those sleeping outside of normal schedules to both support the design around rhythms of sleep and alertness in Awari, but also to provide a resource for designing for influencing other body rhythms. Through a research-through-design process, we present three non-exclusive categories of rhythmic influence: *Pressure & Release, Slow & Cyclical,* and *Anchored*. We present the ways in which they can, and cannot, be adjusted and the impact that different interventions can have on how each rhythm plays out. We do this by returning to the initial participants, exposing the different types of influence that can be exerted upon these complex systems. We group these

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around the *social (work & leisure)*, *physiological (chemical & physical)*, and the *psychological (will & goal setting)*. Through a better understanding of the interplay between the types of rhythm, their inertia, and how influence can be designed, we see how tracking technology can support timing decisions and render trajectories of what the decisions entail. In discussion, we bring up the ways in which this can be seen as a democratisation of medical models, a way to influence behaviour better and combat the stresses of modern life, and a method for designs that include more diverse bodies, personalities, and ways of living. As such, we posit that those designing in this space should aim for a deeper, more holistic understanding of the assemblage they are designing.

This paper's contributions are twofold. First, this work contributes by reframing sleep-tracking technology from passive retrospection to future alertness trajectories. Second, we present this case study on the materially of designing for and with the complex assemblage that is technologically enhanced sleeping practice. Sleep, and the data generated in relation to sleeping practice, encompasses the corporeal, social, and computational. By this, we mean the combination of the social, physiological, personal, and computational influences that come together when attempting to design *actionable* sleep-related systems. We situate sleep as one example of the range of complex, interconnected, and technologically obfuscated bodily rhythms that influence – and are influenced by – our everyday lives. The assemblages interacted with when designing for sleep are, in many ways, similar to those of hunger, emotion, thirst, ageing and work [57].

2 BACKGROUND

2.1 Sleep in society

Our sleep practices are heavily influenced by the culture in which we find ourselves. Historically, many cultures have included sleep patterns and practices that differ from what may be seen from a modern, western context as the norm; such as bi-phasic sleep [71] – where two segments are separated by an hour or more of nightly wakefulness; segmented sleep, consisting of naps such as Siestas [42]; or the frequent and normalised micro naps called *inemuri* in Japan [56]. When and how sleep happens is highly social. Prioritising sleep can be seen as sign of laziness, with sleep being seen as unwelcome 'dead time' [41], and those who are productive are often shown to achieve success at the expense of sleep [72]. Yet, much of this modern cultural encoding of what it means to sleep at certain times and places is itself challenged by the needs of modern life, which relies heavily on nightshift workers such as 'blue light' personnel[1], delivery workers and transport personnel, each with work and corresponding sleep rhythms outside the norm. Modern life also provides more opportunities for living outwith the common rhythms of society, a change that historically started with the artificial light and has led up to today's possibilities of remote and asynchronous work and online mediated social activities.

In this work, we focus on learning from both the experiences of non-normative sleepers and through designing for them. For many with a normative schedule, sleep processes are taken for granted. When waking and sleeping times are standardised around common work and social patterns, then there are fewer actions taken to influence them from which an understanding of their properties and limits can be drawn. The focus on non-normative sleepers in this work provides more opportunities to understand changing and planning sleep in context. This gives us an insight into the active practices of taking action to influence when and how to sleep, and reasoning about how much sleep is needed to meet different work and social obligations. The participants recruited for the workshops presented here fall outside what is deemed normal sleep practice in the highly normative, western, 9-5 working cultures in which they live. Their work schedules, extensive use of naps, and attitude to sleep can also be seen as 'non-normative' in relation to the expectations embedded in sleep-adjacent technology today. Yet, while the participants' relation to sleep can be considered 'marginal practices' [37] or those of extreme users [24], they do provide new perspectives to think outside the boundaries of existing technology [37].

2.2 Sensing of body rhythms

The decisions that frame everyday life are both influenced by and continually influencing the pace of bodily processes. This complex system is often seen through the lens of the *rhythms* of everyday life. Efforts people make to shape their bodily processes to better meet societal expectations and personal goals present the opportunity to understand what actions are available, and the influence they can have.

The body has a certain beat to it, following the biological circadian rhythm, slower seasonal changes, and the weekly social schedule. These rhythms are described as one of the fundamental characteristics of living matter [45] and are inherently captured by most body-tracking applications. As these tracking technologies grow in coverage and complexity, they describe users' bodily and sensory experiences in ways that incorporate these rhythmic tendencies – even if they are not explicitly presented to the user.

Recently, tools for tracking and quantifying bodies through data from various sensors have begun to focus on such rhythms [5, 20]. Body processes have been explored in several different domains, from fitness tracking [76], food tracking [38], to the increasing line of work around technology and the female body [60], including fertility and menstruation tracking apps [46]. In line with discussions on gender, Helms work on the design space around intimate processes humorously and critically discusses the space for technology to manage urination [23]. In the field of sleep, tracking has been made more available through leveraging smartphone sensors [10, 12], sleep environment tracking [32] or even personal radar systems [47]. Tracking rhythms specifically has been successful for the company Sleep Cycle[2] in their use of alarms timed to fit the rhythms of the users' sleep sessions, other efforts include work on computing circadian rhythms through smartphone usage [1, 3].

The designs presented to users are commonly built on the principle of progress through linear goals, but often focus on measurements of hard-to-control behaviours such as sleep phases [49]. This can lead to the user not knowing how to improve their scores [36]. Fiore-Gartland [19] defined this difference in expectations as data valences, encompassing tensions – such as the differing expectations of the actionability of the data – between developers,

[1]Such as police, ambulance, and fire service personnel

[2]https://www.sleepcycle.com/

healthcare workers, and end users. Linear goals have been shown to be efficient in encouraging behaviour change through following structured and actionable plans, particularly when the task in not too complex and connected to specific, bounded behaviours such as not smoking for 6 months [58]. In this paper we explore the design space of more dynamic and continuous change, where goals and context are fluid, by drawing forward possible future choices and trajectories. For many types of behavioural change the goal is not 100% adherence to a specific routine, diet, or pattern of thought. Rather, it is to influence the rhythms and norms of everyday life – be they around sleep, diet or other behavioural patterns – towards a goal set by the user. As such, these rhythms should be understood and manipulated rather than ignored and resisted.

2.3 Research through design materials

In developing an actionable understanding of traditional material, such as a novel fabric [27], designers explore its physical properties by twisting, pulling, and getting a 'feel' for how it will behave under different conditions [22]. For traditional materials and to a designer experienced in designing with an array of similar resources, this may be a relatively quick process. However, where that design revolves around digital and composite materials [66], there has been a turn towards understanding how a 'direct experience' [74] can be engineered to allow the designer to build the tacit understanding of the processes, structures, and relationships that are 'invisible on the surface' as the material is interacted with [70]. This design process builds on 'reflection in action' with continuous feedback and communication with the material [54].

Ozenc et al studied the challenges with the 'immateriality' of software, developing a tool to support coders/designers' ability to have a '*conversation with the material*' which they saw as being blocked by the problem-solving orientation of the development process [44]. Understanding and designing with materials that have complex, partially-hidden, and opaquely-influenced actions and reactions has resulted in a range of tools and methods. These span from the technology-driven – such as the slew of work on understanding machine learning as a material for design [15] – to the socio-technical assemblages of movement with technology [22], digital monetary exchange [17], working with metadata [43], voice user interfaces [59], or as in our case working with biodata [25, 26, 64].

We argue that tracking bodily processes is one of the ways users, as 'life designers,' can influence and shape their bodies through exposing when and how they can take actions to change their life rhythms "*aimed at changing existing situations into preferred ones*" [55]. Through understanding the material properties of body rhythms, through digital representations, we hope to provide the tools for designers and developers to engage beyond metrics and linear progression that the 'problem-solving orientation' of designing for and with tracking may engender.

3 WORKSHOPS

This work is underpinned by a series of workshops and interviews with a range of participants with differing relationships to sleep; from nurses working night shifts, bar-personnel to polyphasic sleepers. The workshops and interviews were conducted over the course of the design process and largely focused on the challenges in the context of sleep in the participants' lives.

3.1 Method

We recruited a total of 17 participants (13 male, with an average age of 28), initially to 4 participants through social media (via Facebook), then used snowball sampling (through word of mouth, Discord groups and social media) to increase the number and diversity of participants. This resulted in four workshops, each with 2-3 participants, and six interviews. The initial two workshops involved bar personnel and people who were frequently up at night gaming, and the following two workshops included nurses and bar personnel. The interviews included polyphasic sleepers and bio-hackers with a variety of occupations (including software developers and bar security staff). The quotes below show which group the respective participant belonged to by from the participant prefix. For example, B1 would be a quote from *Bar Personnel* number 1, with N meaning *Nurse* and P meaning *Polyphasic sleeper*.

During these sessions, the participants shared their attitudes toward sleep. First, the participants discussed their sleep practices through drawing their sleep schedule and describing any personal challenges with sleep. In this way the workshop placed the participants in the role of non-normative sleep experts. Secondly, the participants explored challenges to sleep through the use of extreme personas [14]. These personas were constructed through 'lurking' [21] on Reddit in communities found through a search for sleep and shiftwork-related content that identified four relevant subreddits[3]. For the last activity, the participants worked together to ideate solutions to a selection of these challenges. This section was inspired by the 'magic machines' method [7], in that participants were asked to envisage machines that would influence sleep practice without having to worry about how it would work. They were asked to speculate on the embodiment of these systems and the interfaces that would be presented to the sleeper and others in their lives. The final part of the workshop involved interacting with and/or discussing the current (at that time) version of the Awari system. The first iteration, described below in §4.1, was experienced by six people over 2 workshops. The second iteration (§4.2) was introduced in the following two workshops with four participants and was discussed during the interviews. In the third (§4.3) and final iteration (§4.4), data was collected from the first author and combined with generated data to support the development of the interaction and visualisation to fit the outcomes of the previous workshops and interviews. Each of these steps was a way of grounding the participants' ideas of actions on sleep, first through personal experiences, then through extreme contexts, and lastly through the lens of technological solutions, including Awari.

These sessions resulted in over 700 minutes of recorded discussions and interviews. All the data was anonymized, and conversations were transcribed and translated when necessary to English by the first author. The data was then coded using a hybrid coding approach [18]. The analysis was framed around learning from 'marginal practices' [37] to provide new perspectives on the use of technology from outliers or extreme users [24].

[3] r/nursing, r/polyphasic, r/Biohackers, r/GetOutOfBed

3.2 Outcomes

This work started with an open-ended question of how technology can increase users' agency over sleep decisions, especially for those who already sleep outside of traditional patterns. The initial question we posed was '*how can we make sleep trackers more actionable, especially for those who sleep outside the norm?*'. We drew from the stories and descriptions of the participants to understand some of the core challenges in living, or continuously restructuring one's awake time, outside of traditional waking hours. This was essential in understanding the requirements of 'agency' over sleep, as these participants represented a core user group who actively and repeatedly modify their sleep patterns. Following the analysis, we structured the discussions of actions and agency into three categories of influences.

3.2.1 Biochemical influences on sleep. The participants employed many different tactics in maintaining and making sure that their sleep was sustainable. The clearest type of influence that the participants focused upon were biochemical influences. Naturally, many of the discussions were oriented towards known sleep-influencing substances that postpone the need for sleep, such as coffee and tobacco. One participant described how getting acclimatised to working late shifts at a bar was done through these influencing substances: "*Well, you lived on coffee and caffeine pills. And nicotine*" (B4). Another set of substances were used to increase their control over starting sleep onset. Such as the use of melatonin, medications, or other supplements: "*A lot easier when I add glycin, or melatonin, or CBD, then I get a lot better cool-down curve*" (B6). Participants also discussed removing or changing when they ingested some influencing substances to ensure the sleep timing that the wanted. In discussions with the polyphasic sleepers, coffee was generally avoided, and they discussed controlling other factors that influence the biochemical processes in the body such as "*light, food, physical activity, even socialization. Kind of ramping those things down toward the end of my day, and when I start the day*" (P1). In a general sense, some participants discussed how their metabolism influenced, and was influenced, by a changing sleep pattern. One participant in particular, working late in bar, described that hunger interfered with his attempts at falling asleep when he chose: "*At times I have had to get out from bed because it [hunger] has been so hard that I cannot fall asleep.*" (B3)

3.2.2 Cognitive and physical bodily agency. In discussion, the participants also differentiated between being bodily tired and mentally drained. In the context of working in bars, the participants said stated that after a shift, one is not as tired mentally as physically, as "*you have been running around like crazy*" (B4). Or, even if one is tired, the stress from work and the stress of being unable to sleep as much as htey would like between shifts can keep one up. One key factor in making challenging work schedules achievable was trying to remove will from the equation. From the point of wake up: "*I try almost literally to jump out of bed. Point of no return. Sometimes do push-ups to kickstart the nervous system*" (B2) to the approach of one's work: "*you go in, if it is a long work weekend, very, very, bodily*" (B!).

3.2.3 Social challenges to sleeping differently. Most challenges in living outside of normal schedules come down to dealing with the social isolation it caused and being misaligned with others' rhythms of life. When it came to making appointments, whether with a doctor, one's landlord, or with friends and family, the participants described missing most events due to it being necessary for them to be asleep while others would normally schedule these events. Even arranging to meet when one is not working and awake is difficult, as such planning takes time and effort which can be in short supply between shifts: "*and your time awake is limited, then your proneness of arranging social plans is not as good*" (N1). Yet others expend this effort, changing and planning sleep with social goals in mind – such as the description from one participant who, together with their partner, scheduled rigid nap schedules to increase their time together: "*What we try to do is maximise the time together*" (P1). Another participant described that he arranged his sleep later in the day to have more time to interact with their social group online. All of whom mostly worked nights, to "*jump in and buzz, and play a bit after work*" (B3) until the morning after one's shifts.

3.2.4 Goals for tracking. From the discussions and themes, we identified three requirements for a system to support interaction with sleep rhythms.

(1) Adaptable goals that support the competing motivations around sleep. For our participants, it was never just about optimising sleep. On some days, sleep may be of the highest priority, while on others, social events, maximising time with family or work efficiency are prioritised.
(2) Flexible temporal representations of sleeping and waking hours. Many participants in the workshops expressed that their sleep often happened during the daytime, that the transition between night and day was not as clear, or that segmented sleep was not supported: "*A lot of the algorithms seem to be trained for 8 hours sleep sessions, so people who sleep segmented and things like that, the sleep trackers just don't know what to do with it*" (P1).
(3) A focus on the outcome, rather than the quality, of sleep. For many participants, it was never about catching great sleep. Many descriptions, such as those in 3.2.2, accounted for tiredness being a reality to negotiate. The focus was on being alert when needed, or at times, just to fit any sleep into one's schedule.

3.3 Reframing

The system was originally to be developed through a traditional participatory user-centred design process. However, the workshops inspired us to use the development of the system as a way to articulate the material properties of the complex entanglements of events, people and processes that constituted the view of 'sleep' that our participants developed in order to make it malleable. We articulate this shift through the use of Zimmerman's concept of 'reframing' [78].

Through these participatory design workshops and interviews, the focus of the design was *reframed* to focus on how one can design sleep technology to aid future *planning* of ones *alertness*. This question is a 'reframing' of what technology can do for people who sleep in alternative ways – where alertness is often the main goal of caring for sleep and when one needs to plan ahead around activities (such as work) at odd hours (such as night time). This

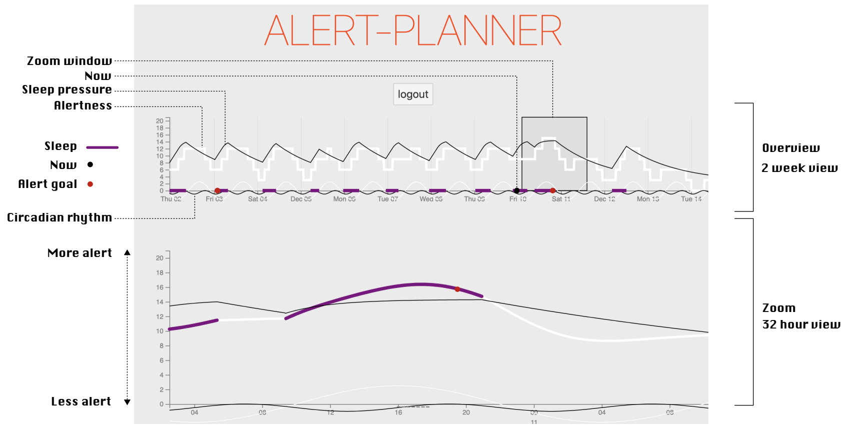

Figure 1: Awari's static model, but when experimenting with user added future sleep sessions

research output is not only defined by the initial study of people but also subsequently the establishment of this new framing and, finally, the development of a new design prototype that responds to this new problem formulation.

4 DESIGN OF AWARI

Awari is a web interface where users can explore predictions on how actions influence their future alertness. We designed Awari to explore future interactions between users and their sleep data. The ambition is to build an interaction that strengthens the user's *agency* over their lives through an intelligible and actionable presentation of body processes, building on their personal data collection. We designed the prototype through a series of iterations, using our own self-tracked data and the outcomes from the design process as guides. Each iteration was tested and explored as part of our workshops or with researchers as outlined in 3.1 following a traditional RtD process. As such, the workshops were in parallel with the development, so the earlier workshops included discussions of the earlier phases of Awari and the later ones in the later phases. The constraints of data access and model training meant that most participants experienced the system based on generated sleep data. Our process is presented in four defined steps, each building on the previous one. In describing our design and development process, we focus on meeting the ambition of user agency and what each iteration teaches about the underlying material properties of the assemblage of interconnected processes, pressures, and priorities manipulated when interacting with sleep.

4.1 Static model

The initial designs of Awari focused on creating an interface that moved the focus of the interaction with sleep data from being on the quality and length of sleep sessions to a representation of their alertness at any given point during the day. The goal was to change the perspective to one that puts emphasis on the current day the user is living, rather than the nights leading up to it.

In order to do this, the system needed access to users' past sleep data. This was done through the Google Health API, providing verified and sensor-agnostic sleep detection data. The Awari server, running Flask on Python3 for data collection and processing, presented the users' sleep data through a Svelte and *D3.js* based interface.

As the focus of our design was the shift toward alertness, we explored ways to estimate alertness from the users' sleep data. The Three Process Model of Alertness [79] was chosen and implemented on the server. This model is the result of extensive previous research and has been used in the study of sleep schedules in shift work [29] and road-crash prediction [80]. It can be used to estimate current, past, and future alertness based on a user's circadian rhythm and the timings of their past sleep.

This model, however, relies on an estimation of the user's circadian rhythm that was not directly compatible with the varied sleep schedules of our participants. Instead of developing an automated solution to extrapolate an approximate rhythm from collected data, for this first iteration, we allowed the user to freely set and change their circadian rhythm to match their sleeping patterns. As a side effect, this allowed them to freely experiment with different lengths and timings of circadian rhythms and visualise how changes in the timing of their sleep would influence their alertness over the day.

These interactions were built primarily from the viewpoint of a cyclical model of sleep. However, through the development of and interaction with the prototype, it was clear that this did not capture the complexity of the sleeping practices of our participants. It also did not give the interactional flexibility to reflect the reality of how they attempted to manage alertness and sleep along with the other pressures of everyday life. In fig. 1 we show the prototype, where users could change the rhythms through the console in the browser. This version also featured an attempt at letting users schedule sleep – an interaction that we found hindered the exploration of multi-day alertness forecasting.

4.2 Stochastic model

Our first iteration opened up the design space of rhythmic influence over sleep – yet, it lacked the flexibility and complexity of planning future sleep to meet a specific outcome the user may have. Instead

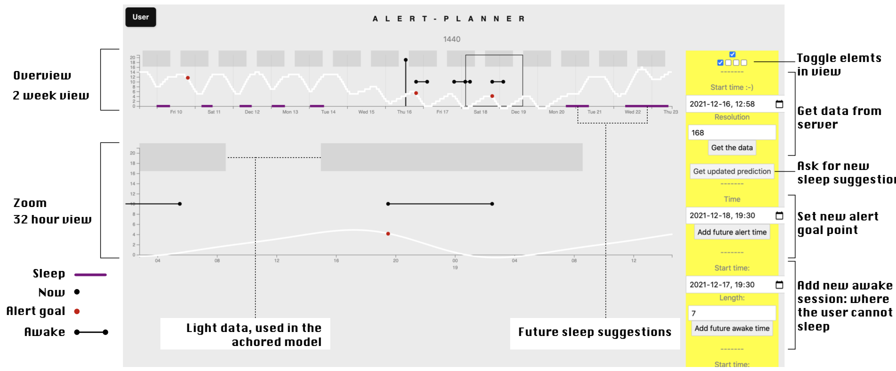

Figure 2: Awari with a stochastic brute-force sleep planner

it relied on the user being able to reflect on an imagined future based on their past actions and interactions with sleep.

The initial goal in designing the second iteration was to allow the user to project their sleep schedule into the future, experimenting with sleeping times to explore how that would change their alertness in upcoming days. However, given the varied sleep schedules that our users dealt with simply repeating the past sleep sessions on the following days was not a viable solution and expecting the user to manually input the times in which they expect to sleep was unwieldy and inaccurate. What the prospective users of this system did have, through work and social calendars, was a representation of the times in which they were planning to be awake.

This matched the overall goals of our re-framing of sleep tracking to be about alertness, and the reflections from the workshops that much of the planning participants discussed was in terms of the events that required them to be awake. For this system to cater for trajectories of alertness, it follows that it should reflect this orientation towards planning based on scheduled events. We formulated this interaction to be that the user would be able to change their alertness goals and add requirements for when they needed to be awake – if not necessarily particularly alert.

We implemented a stochastic method of finding suitable sleep patterns based on simple metrics. The user could add sessions when the user needed to be awake (shown as black barbells in Fig 2), as well as 'alert points' (shown by red dots) where the user prioritised being as alert as possible. The system then tested random patterns[4] that conformed to the Three Process Model implemented for the previous iteration. In the last model, the interaction focused solely on the influence of the circadian pattern. With this model, the influence of 'sleep debt' moved from being a constant to a changeable and dynamic material. Sleep debt is modelled as a pressure for sleep that built up steadily while the user was awake and was released unevenly as sleep progressed, allowing alertness to be influenced by sleep over multiple days. The system then picked the schedule with the least overlap of sleep on times the user needed to be awake and the highest alertness at the chosen 'alert points'. This system, albeit simple, lets the user both mould their circadian rhythm and adjust their tolerance to sleep pressure over multiple consecutive days.

The results of the scheduling algorithm when presented with more complex sleep patterns represented in our target user group quickly became unfeasible. While it was able to adjust to some amount of non-normative sleeping, it was too simplistic to meet the users' many goals of attempting to normalise their sleep as much as their schedules would allow. The random search for different solutions gave highly varied ways of reaching alertness at the highlighted time points – but it did not take into account the preference of specific sleep patterns over others. For a solution that expanded on the goals, both accounting for the circadian rhythm and the pressure, we needed a deeper model for planning.

4.3 Reinforced model

To incorporate more complex user goals and constraints, the third iteration of the system moved from the stochastic model to using a multi-objective model-based reinforcement learning algorithm. Multi-objective learning algorithms can be trained on multiple complementary and competing conditions. This allowed us to represent a range of goals the users had, balancing sleep, alertness, and their work and social responsibilities. Multi-objective model-based reinforcement learning has previously been used as part of a real-time decision support tool, specifically for policymakers during the COVID pandemic [69]. The ability to manipulate competing constraints and goals and see the resulting impact on the modelled behaviour in real-time supported the iteration of policy decisions that influence viral spread. This pattern of interaction matched the goal of allowing the user to tweak multiple 'motivation' parameters that directly influence the reward function of the algorithm attempting to schedule their sleep.

Internally, we brainstormed motivations that would capture the essential aspects of daily sleep planning for our prospective users. Drawing on previous literature and from the comments of our participants in the workshop, we settled on two main features.

First, we implemented an estimation of the current state of the user's circadian rhythm based on the past weeks' sleep data. This model was based on the calculations carried out in response to the Munich ChronoType Questionnaire for Shift-Workers (MCTQ^{Shift})[5] [30] and, as such, is designed to be responsive to changing and irregular sleep patterns. To preserve user agency over the modelling of their

[4]with a weighting towards longer sleep sessions

[5]A questionnaire to assess the chronotype based on users shift-work schedule

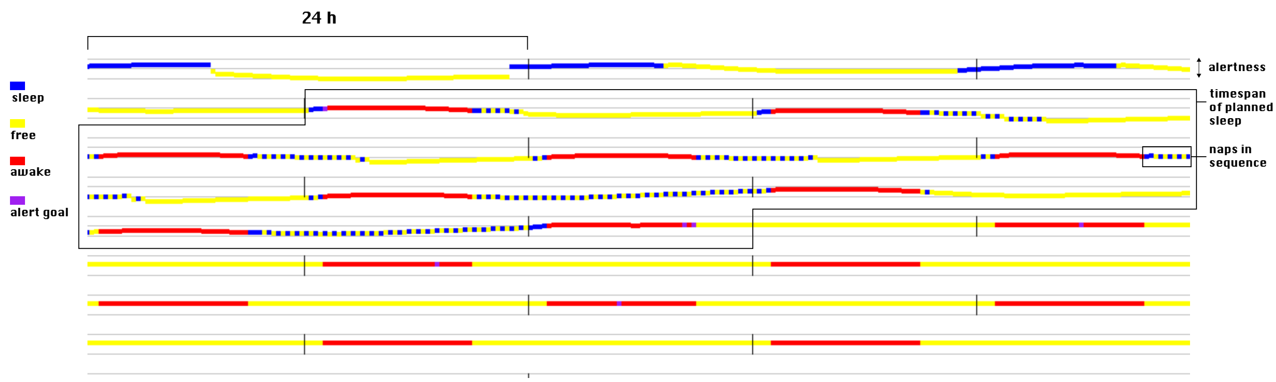

Figure 3: The live tracked planning from the training system.

drifting circadian rhythm, we allowed users to set their preferred 'chronotype.' This weighted the algorithm accordingly, preferring to the extent they chose an 'early' or 'late' skew to their waking time in relation to the other constraints on their sleep and alertness.

Second, we wanted the system to look at the alertness over the course of the whole day instead of only focusing on the alert points. To do this, the sleep pressure being high when the user was *awake* was a negative reward for the algorithm and was a positive reward to times when the user was *asleep*. We also introduced a 'tolerance' parameter to adjust the threshold of what amounts of sleep pressure resulted in these algorithmic rewards, allowing the user to set what they perceived as being too tired.

One issue that emerged from this solution was that the algorithm took advantage of the pressure-reduction model of sleep debt. As the amount of 'benefit' of a sleep session, in relation to the reduction of sleep debt, is modelled as decreasing over time the algorithm attempted to maximise the number of going-to-sleeps. This resulted in schedules packed with micro-naps as we can see in figure 3. Each line represents the shift between days, blue lines are the sleep schedule, red the work schedule, and blue dots are naps – with the extent of the algorithm's suggestions outlined in black. This highlighted a material property of the processes that we were attempting to manipulate that was not captured entirely by the cyclical model of the circadian sleep processes and the pressure and release model of sleep debt.

4.4 Anchored model

In the fourth iteration, we addressed the underlying problem that resulted in the algorithmic optimisation via micro-naps with a third, complimentary sleep process model.

It was apparent that our system was agnostic to the shifts between being awake and asleep. Yet, these shifts involve rhythmic processes of sleep onset and waking, with their own timings and influence on future action. One such influence was that modelling the processes of sleep onset and waking as uninterruptible by each other enforced a minimal distance between naps.

We built on the research on sleep inertia, the drowzy feeling of waking up – which is reported to last up to two hours [62]. Yet it is apparent that every onset or waking is not of equal length. The time between waking and participating in another activity can be, to an extent, compressed through choice or necessity. Time spent on sleep onset may be influenced to be shorter by overall sleep debt or to be longer by any number of stimuli from light to mental or physical exercise. And as utilised in the sleep cycle alarm clock, this inertia is said to be related to 'ultradian rhythms' in the sleep: by rhythmic sleep session. This also was discussed by the pool of polyphasic sleepers in our participant tool, where they reference that these basic-rest-activity cycles expand into wake hours [33]. This could be modelled with care, using the more sophisticated sleep cycle sensing capabilities of modern trackers, but in an effort

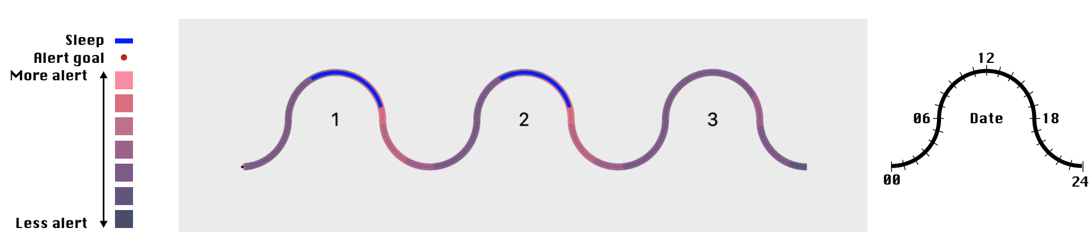

Figure 4: A new view that depicts the days as waves, used to show a whole month, shows in Fig 5

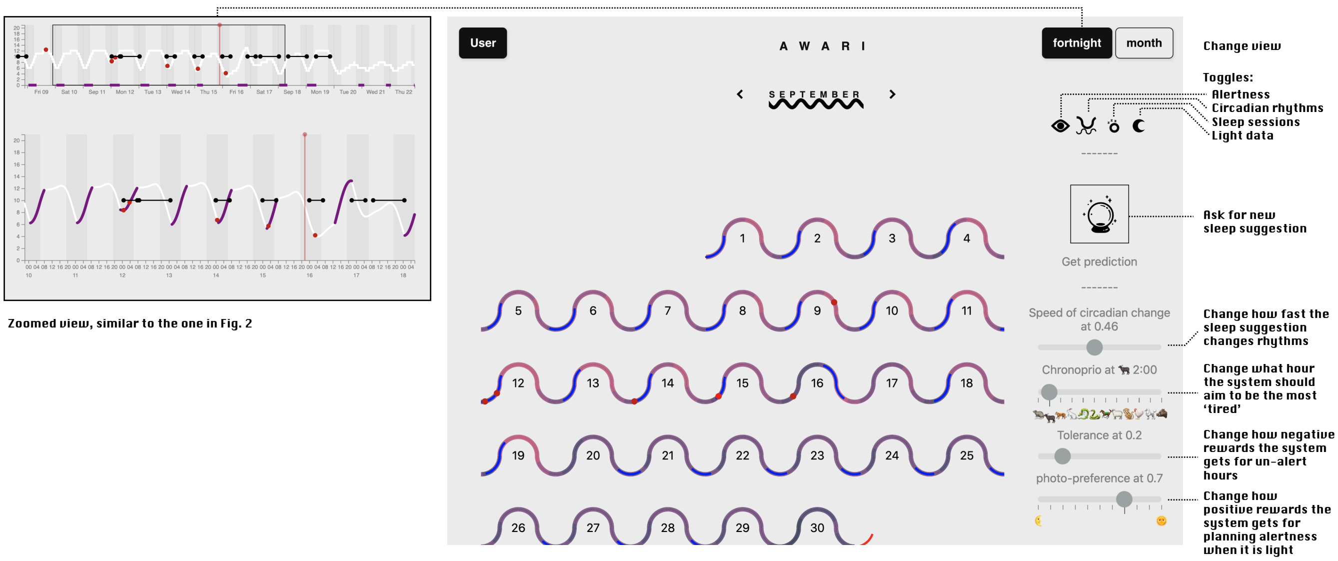

Figure 5: The system at the last stage

to stay tracking-agnostic, we decided to utilise a strict model of two hours of inertia.

These influences on sleep onset and waking highlighted that the algorithm was also ignorant of the daily and seasonal rhythms of light exposure. This influence was one of several actions that were seen to either anchor or impact the onset and waking curves of the sleep schedules of our participants. The most discussed in the context of working shifts at bars, after light exposure, were those of meal timing and the use of supplements to aid either sleep or alertness .

For this version, we used users' locations to retrieve sunrise and sunset times and combined this with a parameter of 'photo-preference' to allow the user to indicate their personal affinity to this influence on their sleep and alertness. This parameter was used to scale the impact that light or dark would have on the waking or sleep onset curves and the reduction of alertness from being awake. This meant that a higher value would influence the algorithm to prefer sleep onset in the dark, and waking and being awake in daylight hours.

To address the seasonal changes in rhythms, we sketched different ways to adapt the visual feed-forwards to a longer perspective. We decided on a design that draws the days as wave curves (see Fig 4). This view can portray the whole month while keeping the convention of sleep sessions marked in blue and 'alert points' as red dots, with the alertness level as a gradient (lighter purple values as more alert and vice versa). The curve shape follows the conventions of a 24-hour clock face that shows the rhythms of the days and keeps the boundaries between days ambiguous.

While the same modelling as for the light was not implemented for the processes of hunger or metabolising the various stimulants and sedatives mentioned by the participants, the system could easily be expanded if provided with suitable rhythmic data.

This final system featured all of the interactions explored in the design process. At each login, the latest sleep data is processed. The interaction with the planner requires the user to input when they need to be awake, and mark when they aim to be alert. Through adjusting the four parameters (tolerance, preferred chronotype, speed of change, and photo-preference) the system provides sessions of sleep together with the corresponding predicted alertness. Two views allow for shifting between long-term monthly overviews (see fig. 5), bi-weekly and weekly detailed views (shown on the left). By adjusting the parameters (annotated on the right side in the figure), removing sleep by expanding wake hours, and setting new goals, the resulting system was able to plan and visualise the vast majority of the sleeping schedules described in the workshop.

5 MATERIAL PROPERTIES OF BODY RHYTHMS

Based on the workshops and the design research described above, in this section we expose the different types of rhythms that govern processes such as sleep, as well as the different ways in which they can be influenced. We see parallels in many other attempts to track and influence aspects of our lived experiences. Instead of treating the body as an isolated machine and tracking its progression through a series of metrics, we propose that the lens of rhythms entangled with the personal, familial, and societal actors in our lives will aid in shaping interactions that can support informed and empowering change.

5.1 Rhythms

This section breaks down the process of changing alertness into three different rhythms. Each stems from models and perspectives of how bodies change over time, though this section analyses how

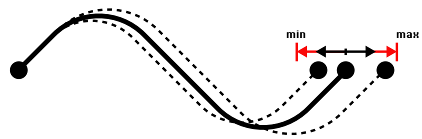

Figure 6: Each day the rhythm changes, but only to a certain extent

these rhythms can be understood in terms of users' actions over these changes. We express this by describing the material properties that can be rendered through design. Understanding the material properties of life rhythms provides opportunities for interventions that can aid in the planning and reasoning around resilient changes to one's life and body rhythms.

5.1.1 Slow and cyclical. One view of the body through the lens of the rhythms that influence it is of a slow, drifting, periodic system. This view of bodily processes as a combination of being slow to change slow and cyclical in nature was the first method we developed by which users could explore body rhythms. It is well documented that the body's processes follow the body clock, oscillating over a day, naturally entrained to follow the sun and reinforced by the matching socially constructed norms and routines [2].

One property of such rhythms is the period over which it takes place. When discussing body rhythms, these can be split into those less than a day (*ultradian* rhythms, such as the heartbeat), more than a day (*infradian* rhythms, such as the menstrual cycle) and *circadian* rhythms which approximate a 24 hour period. As illustrated in Fig 6, the period of these rhythms is open to manipulation – to some extent. Each underlying process has a maximum and minimum period to which it can be entrained, developing a *new normal* period for that rhythm going forward. Beyond the limits of entrainment, there are temporary periods to which someone could adhere to but to which they would be unable to normalise to. The tension between these limits can be seen in the exploration of different sleeping patterns of polyphasic sleepers, and to a lesser extent, those experimenting with different ways to 'flip flop' between night and day schedules [31].

We can express this as a change as a vector, as there is not only a direction, but also a speed of change which can be measured over multiple periods – as we can see in Fig. 7. This speed of change also has limits. In this work, following sleep science research [16], we limited the maximum change to 1 hour per period, with periods generally being circadian. However, such maxima are contextually and personally dependent, and in a controlled setting, can be further enhanced [13]. Such change may not only be the result of active attempts at intervention. In the context of sleep this is described by *zeitgebers* – factors that influence the period of sleep rhythms, such as light exposure, that continuously adjust the duration of the cycles. This means that there can also be a *minimum* amount of change that can be experienced in a cycle.

The notion of the speed of change and the inertia that must be overcome is sourced, in part, from the participants of the workshops. Most participants expressed in different ways how shifting between schedules is one of the greatest challenges in non-normative sleep. So, while the body's rhythms cannot shift from day-shift to night-shift from one day to the other, people can, and do, shift their schedule in this way. But this shift in schedule, can be exhausting and lead to imbalances in alertness in the days following the change. Alternatively, such a daily rhythm can be set as a goal and gradually entrained over a week or more. This would result in shorter or longer periods during the adjustment to the new schedule, then a return to the previous periodic length of the cycle.

In the initial version of the system, the user was left exploring and projecting freely how different circadian rhythms would have resulted in alternative alertness over the day. In order to incorporate the participants' idea of the body's resistance and inertia to changing its clock we limited the possible change over a period, the overall period of the rhythm. This gave an interaction closer to the users' experience of cyclical time representing their drifting 'chronotype'. Encoding the experience that the rhythms of the body may change more slowly than we desire them to, as those who have experienced jet lag can attest to.

This exposes the material properties of cyclical rhythms, such as the circadian rhythm that influences sleep – that there is a certain speed of change that can be accommodated by the process, that cycles can be truncated or elongated only so far, and that the limits for sustaining such changes in a period are less than can be accommodated temporarily. For sleep, we see this in challenges in being able to sleep even when tired, or to wake on time when jet-lagged. Influencing other cyclical rhythms can also be seen to be bound, to a lesser or greater extent, by this inertia. Shifting the timing of meals, for example, will adjust the cyclical process of hunger onset but can be influenced much more strongly by social cues than sleep could be [8].

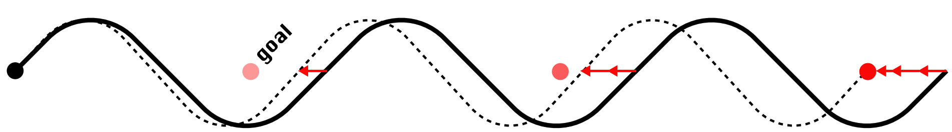

Figure 7: The change is slow, and rendered over several days

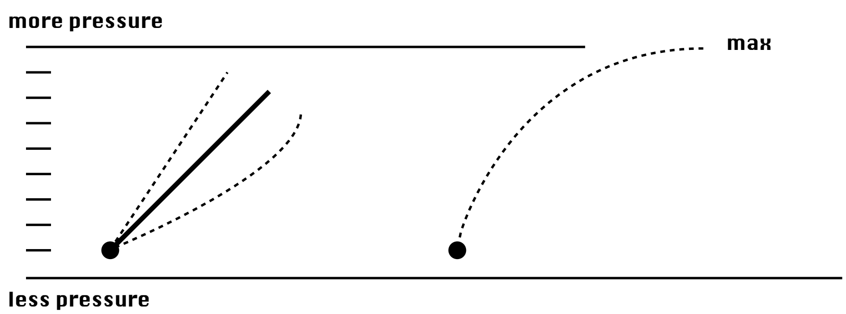

Figure 8: Pressure raises differently depending on what rhythm is modelled, with a limit of maximum pressure.

5.1.2 Pressure and release. The pressure and release rhythms are perhaps the most intuitive ways of understanding sleep. The longer one is awake the higher the pressure to sleep becomes, until one sleeps and some or all of that pressure is released. In our Awari system, this is represented through an implementation of a model of homeostatic pressure. The way in which this pressure is built each consecutive waking hour is modelled on the body's accumulation of *adenosine*, and its' release during sleep on the depletion of *glycogen*. The body accumulating and releasing pressure is a natural part of regulating homeostatic processes that, in different contexts, behave differently. To expand on the materiality, we break these down into the two systems of pressure and release.

The increase in pressure can be seen as a combination of the rate at which it is increasing, and the current level of that pressure. As illustrated in Fig. 8 these rates can differ and are not necessarily expressed linearly – as in the case of sleep. While the accumulation rate of biological tiredness is more difficult to influence, other rhythms that follow the same pattern can be more malleable. The physical sensing of stretching of one's bladder can be influenced in minutes by the consumption of liquids [65], and the pressure of oxygen depletion on the respiratory system felt when holding one's breath can be dramatically increased through physical exercise.

There are extents to the pressure in such biological systems; we describe these in terms of the maximum beyond which the agency of the person feeling that pressure is overridden by the biological imperative to release and the minimum below which there is no perceptible change in the amount of pressure felt.

In the model used for Awari, the rate of accumulation stagnates as it reaches a maximum level of tiredness. Building and keeping pressure comes with some discomfort, but the level at which the experience of the pressure moves from awareness to discomfort varies. As described in Chapter 4.3, Awari gave the users the option to adjust this tolerance. This value defines how sensitive the system should be to the users' short-term tiredness for the overall success of a schedule. By raising the tolerance, the user lets the system find more uncomfortable and tiring, but possibly faster, ways to adjust the schedule. This is a real dilemma in the planning of shifting sleep for night shifts, as while some level of short-term discomfort can be seen as unavoidable many expressed the difficult choice of increasing that discomfort to experience it over a shorter period, or lowering the maximums but increasing the number of periods of tiredness.

Another essential characteristic of these rhythms is the actions that can be taken to *release* of this pressure. As illustrated in Fig. 9, the release rate can result in different final pressure levels, and happen over different time scales. Yet these actions of release, be they sleeping to release tiredness or eating to release hunger, are dependent on both their outcome and the ability to perform them on the current state of the pressure of the rhythm. There is a certain range of pressure along which actions can be taken – when there is no tiredness pressure at all sleeping may be impossible. The difficulty of taking that action will decrease as the pressure of tiredness increases. Similarly, the results of the same action may result in different changes in pressure depending on the starting level. At a high level of hunger, the act of eating a meal would result in a larger change to the pressure than eating that same meal when the level is low. For sleep, the rate of the decrease in pressure can also be influenced to an extent by traditional 'sleep hygiene' practices that promote deep, uninterrupted periods of sleep or by the consumption of sedatives and stimulants.

Together these expose how one can open these material properties of pressure and releases rhythms for design. The, biologically bound, flexibility in both the timings and rates of accumulation and release as well as the differing levels where pressure moves over to discomfort can be modelled. In the timing of actions to release pressure, one can endure (to a certain extent) a higher level of pressure and move the timing later, illustrated by the moving of the red action dot down or up along the pressure curve. This also influences the rate at which the pressure is released and the ease with which the action can be taken. This results in the build up of pressure also increasing agency, as it makes it easier for the user to choose when to release it. This creates a property of asymmetry, being easier to move timings forward rather than backwards. As in cases of night-shift, and as presented by the model, it takes a certain timing to prepare for 'releasing' the built-up sleep pressure to be able to sleep at a time conducive to being rested for a night shift, as pre-work sleep has a higher success rate if one is tired. And even yet so, missing a cycle can result in destructive interference – often experienced by involuntarily falling asleep too early when adjusting jet lag.

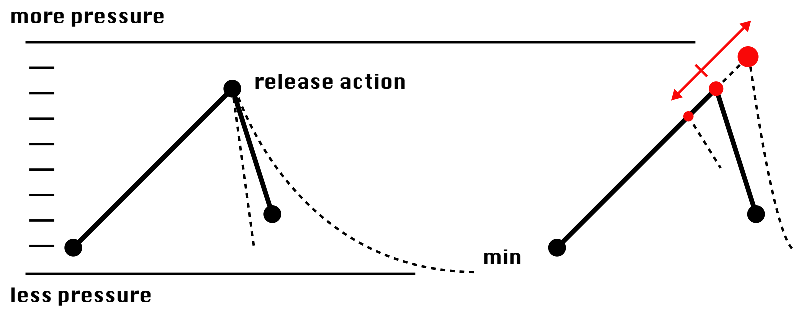

Figure 9: Pressure release is the result of actions, such as falling asleep. In sleep a higher pressure is connected to a faster release.

5.1.3 Anchored. We were challenged by the combination of the above rhythms resulting in solutions which included repeated fast shifts between naps and being awake. This pointed out properties of sleep which were not captured in rhythms above, yet would be necessary to include to meet our design goals. We expand our system of expressing these relations between the different states as a third type of *anchored* rhythm.

In sleep, this type of rhythm is can be seen in the relationship between the 'anchors'[6] of being awake to being asleep, with the rhythmic routines including anchoring actions of sleep onset and waking up connecting to each one. In expressing the properties of this process, the rhythm can be described as the distance of the change undertaken and the time over which the process happens, shown by the height and length in Fig. 10. These properties are relational, to some extent, as the greater the distance – the further the user's state must change from its current level of wakefulness to being asleep – the longer the onset time will be to have a successful transition.

In between, we can scaffold and segment the process through introducing more anchoring actions. This sequence of anchoring actions can be described as the individual's *ritual* in this rhythm. This ritual can be modified, as many of our participants tried to do with their waking and sleeping routines in order to influence these transitions, however, the rhythmic and entrained nature of these rituals means that there are material properties of the rhythm which should be understood in order to suggest successful manipulations.

The anchoring actions that comprise the scaffolding of the ritual can be removed in an attempt to decrease the length or complexity of the ritual; however, as the scaffolding of the ritual is removed the success of the change itself can be jeopardised. Adding actions to the ritual can be seen as a way to increase the effectiveness of the scaffolding and improve the chances of the transition being successful at the expense of taking more time. These actions themselves have prerequisite states and constraints. As an example, one participant reported refraining from caffeine, tobacco, and "*stressful confontations*" (B6) in the final hours of his working shift in order to be able to shorten his sleep onset ritual. This allowed him to reduce the steps that would be necessary for successfully transitioning to sleep by both lowering the distance of the transition and increasing the effectiveness of the actions he did take as part of his ritual.

The actions themselves can be elongated or contracted, as can the time between them. But the rhythm can only be extended up to a certain point. Anchoring actions too far apart may not connect to constitute the scaffolding of the trajectory required for the ritual

[6]As in the anchor points defining paths in vector graphics

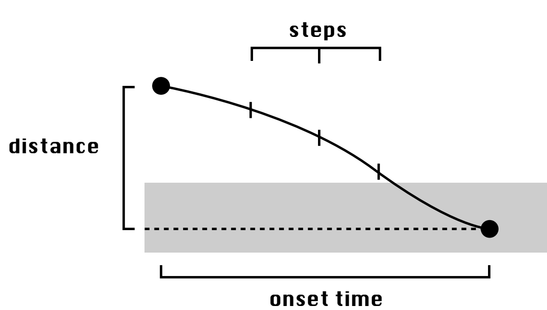

Figure 10: The onset is anchored in the steps from being awake to falling asleep

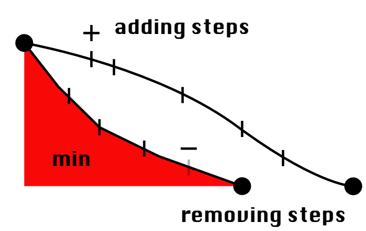

Figure 11: These steps can be extended, added, removed or squeezed to some extent – forming the onset curve

to succeed; similarly, actions taken simultaneously or too close together may cause interference (be they part of the ritual or not). Fig. 11 shows the action space of designing for anchored rhythms. These transitions are scaffolded by the ritual of supporting anchoring actions, minimally bound by the amount of scaffolding needed to make a transition of that magnitude successful. They are also maximally bound by the influence of the interdependent scaffolding actions over time, and the users' ability to exclude external interference with the ritual.

In understanding the material properties of an Anchored rhythm, we must examine the freedom of the anchoring actions, in that some – such as taking a homoeopathic supplement or taking a warm bath – may have different social, spatial and temporal constraints than others.

5.2 Influences

In our presentation of the material properties of the three types of rhythm above the ways in which they can be controlled were focused on the agency of the users. In this section, we unpack the different scales of entanglements that any designed intervention should be aware of – and could take advantage of – with the goal of providing actionable change that can be enacted by end users. We draw from the themes that emerged from discussions with the non-normative sleepers and analyse them in relation to technical interventions by highlighting decisions in the design process.

This section is informed by the discussions from the workshop and we analyse the themes that emerged in relation to the three rhythms that are designed for.

5.2.1 Social. Probably the most important, and most commonly overlooked from the lens of technological intervention, influence on body rhythms is that of the social environment of the user.

Actions regarding the body are highly culturally bound. When and where it is appropriate to perform actions such as sleeping, eating, washing, urinating or defecating are prescribed by a myriad of written and unwritten rules. These rules are partially dependent on the space the body inhabits, the other bodies in that space and the relationships between them. When designing technology to influence bodily processes one must be cognizant of the plurality of bodies and their individual entangled relationships with and within the space that they inhabit. Ignoring such practical social constraints on the end user will either results in non-compliance with the actions the technology presents to meet the user's goals, or non-use of the technology in question by those for whom the actions are incompatible with their social landscape. As expressed by one participant working night shifts as a Nurse, "*.. the difficulty is not in being awake at night, it is everything else around it*" (N1).

This means that through choice or necessity, users may not be in a social environment where the recommendations of technology to optimise the change in their body rhythms are actionable at that time. Taking sleep as the primary example in this case, suggesting that naps be built into a commute in order to meet alertness goals may be something that would be socially acceptable in Japan for most users, acceptable in western Europe for male users but less so for those of other gender presentations, and unacceptable in North America. Beyond social constraints on particular actions, the continued activity of keeping up social connections can also be more important than the advice of a system or the goals of changing or conforming to body rhythms. The phenomenon of 'social jet lag' [73] documents the systematic prioritising of social obligations over sleep. One implication is that working life should always be prioritised over both. Another implication is that any attempts to enact change to the timing and rhythms of daily life should be compatible with changing social obligations and priorities of the user. In the RtD process, we adapted the social planning through always prioritising the 'awake' sessions, and letting the sleep suggestion be formed around the scheduled requirements for the users. This takes the stance for social scheduling before sleep – but still places the responsibility on the user to schedule these requirements. In developing new systems that let users render their future alertness, the system could provide this support in scheduling future social opportunities: in finding timings, and helping users in making informed decisions on how to change their schedule to accommodate social, sleep schedule breaking, events.

5.2.2 Chemical and Physical. While social constraints and opportunities exert perhaps the strongest influence, the most discussed as actionable influences are those centred around chemical or physical changes to the body.

Of the chemical influences, the most discussed was caffeine. This included influence it had on the sleep and alertness rhythms of the person drinking it, as well as the pressure and release rhythm of satiation and withdrawal felt by those that use it regularly. Not all of the chemical influences on body rhythms come with their own rhythm, instead their results can be seen as they influence one or more ongoing rhythm in the body. Medical and herbal sedatives, for example, can be used to decrease or increase the length of sleep onset – making it easier and quicker to fall asleep. They can also be used to simulate an increase to sleep pressure, allowing the user to release it and fall asleep at a chosen time without having to 'manually' build up the amount of awake-time that would normally require.

However these interventions can be made physically, as well as chemically. In earlier work [31] we reported on those who hack their sleep engaging in timed physical activities, for example bathing at particular temperatures at particular times before sleep, in ways that would construct the scaffolding of their sleep onset ritual. Another common physical intervention, and one that was incorporated into the model for Awari, was that of light exposure. While the influence of various spectra of light on sleep is still under active research – there is evidence to support that the isolation from certain wavelengths (such as blue or ultraviolet) can increase perceived sleep quality and onset [35] and some to showing little to no influence of exposure [6] – the longer term influence of the seasons on body rhythms, and the short term impact on waking latency of exposure to direct sunlight were both mentioned as influences to be managed or used in the workshop.

Such chemical and physical influences do not only impact the scaffolding of anchored rhythms. In cyclical rhythms, such influences can be seen to influence overall timing. For example, the changing of light exposure timing due to the changing seasons influences the circadian rhythm to peak later or earlier in response. These are not binary relationships, however, and when designing to take them into account, the other material properties of the rhythms (such as inertia) should be included.

In designing technological interventions in this space, it is difficult to ignore the chemical and physical influences that users may choose to implement when attempting to design a system that accurately reflects the real-world practice of users. However, the position of the designer, developer, and/or researcher administering such an intervention must be taken into account. By choosing to include some chemical or physical influences over body rhythms and not others, the values of the designer (and the social, cultural and economic influences that shape the values they are able to enact in their role) are made concrete. These values are then given relevance and weight by proxy of the relationship between the user and the constellation of institutional brands, other users in their network, and possibly the researcher themselves.

In summary, physio-chemical influences can be taken advantage of by users to influence their body rhythms and these actions can either be encouraged as part of a planned change, expected and reacted to by tracking and planning systems without being suggested as tools for change, or ignored and treated as either noise in the data or peculiarities of the individual's rhythmic processes. The changes can be seen as influencing the rate of pressure buildup in Pressure and Release rhythms, adjusting the timing of Anchored rhythms, and influencing the oscillation time of Cyclical rhythms. Yet all these changes are complimentary to the material properties outlined above.

5.2.3 Psychological and Will. In the perspective of alertness models such as the one Awari is based on, the relationship between the body and the mind is portrayed as one where the body forms the conditions for the mind, falling into the debatable view of their being a 'body-mind divide' – but despite this positioning, it does highlight that this is a highly symmetrical relationship.

Whether this takes the form of mental exhaustion, as discussed by the participants in §3.2.2, or as the desire to stay up to play one more game, watch one more episode, or simply to not sleep, these currently technologically untrackable states of mind play a massive role in the rhythms we discuss.

On a shorter times scale, people can decide to 'power through' – to some extent – their normal limits on the amount of pressure they would normally endure in a pressure & release rhythm, to shorten an anchored rhythm beyond what would normally be comfortable, or to live at odds to a cyclical one. In a tired state, one can still find focus – all be it temporarily.

Will also plays a role in the slower changes. Attempting to change behaviour is something that ultimately starts with a wilful choice. People are not changing their behaviour because of tracking technology,*"but they are using tracking technology because they want to change"*[51]. Yet, for many, that choice must be made repeatedly in order for the change to be enacted. A user must decide to get out of bed early each and every time they do so, and while traditional tracking-based gamification such as streaks and badges may help in providing some extra extrinsic motivation, the choice must still come from the user.

This presents a set of complexities and flexibilities in the tracking of body rhythms, and one of the key points in making a system: When the goal is a trajectory of continuous change, this can be better achieved when the body rhythms being interacted with are in sync with the users' actions as this can potentially reduce the amount of will required.

This presents two points for design with body rhythms. The first is that, while there may be limits set in the model by the user as to pressures that are endurable, inherent inertias, and the scaffolding necessary to enact some rhythms, these do not have to be taken as hard-limits in the system. In some cases, presenting possible future rhythms where the user would be forced to 'power through' in order to meet conflicting goals might be the outcome that the user desires. On the other hand, if the future rhythms are shown to be systematically breaching the limits the user may be drawn into a reflection of those goals and encouraged to explore other possibilities and priorities.

The second point is that design must recognise that change requires continuous reaffirmation of the desire to meet those goals by continuing to perform the actions to enact that change. Not only that, it must recognise that not every choice is equal, and that in some contexts the adherence to the goals may require much less willpower than in others. Encouraging reflection on variations in the untracked labour that following a change plan requires, and if possible connecting those variations back to the rhythms and their changing trajectories themselves, holds the potential to enhance agency and use overall.

6 DISCUSSION

6.1 Exploring hackable future

Self-tracking practices often have great engagement initially, but even successful adaptation turns over time into a passive gathering of data. By letting the technology track, we leave this task to the system, and we let it do its job. To actually engage with the system, requires us to break from the "tracking" to "noticing" [11]. Awari makes concrete an approach that extends the "noticing" from past, to present, then to extended future trajectories.

Expanding bio-feedback into the future-tense has been discussed recently in the context of rethinking behaviour change technology. Rapp et al. [48] challenged passive and mechanical systems suggesting that they "*could make available tools for exploring the future consequences on behavior*" – strengthening users' agency by informing them about possible versions of their '*future life*'.

The goal is to encourage consequence-free exploration of *what ifs* – similar to the commitment-free yet aspirational exploration through travel site recommendations in that they provide the ability to explicitly add goals, preferences and constraints while taking advantage of learned behaviour through their recommendation algorithms. The further one moves from the norm as defined by the recommendation algorithm, the more important it is to include *feed-forward* interaction to allow users to encompass the unpredictable rhythms and multi-factorial obligations of their lives without the need to explicitly express them.

By building such feedforward systems around the different types of rhythms of everyday life, such as those exposed in this paper, a system can provide a graspable extrapolation of the complexity that may arise in the future from changes implemented in the near term – and in making such extrapolation graspable, it is also made tractable to a user as something that they can reason about and explain to others.

So much of the body-adjacent technology we live with today provides raw data combined with algorithmically obscured inferences upon which it becomes increasingly difficult to build meaningful change. Yet, the desire for change is what drives many to these technologies, which can result in this unrealised motivation latching on to the arbitrary optimisation of tracked numbers – resulting in oxymoronic situations such as users staying up at night worrying about how to get a better score on their sleep health ratings. Rapp et al. point out that behaviour change technology needs to empower the user by developing their knowledge of the complexities that surround the behaviour they want to change, making the representations more holistic and continuous in order to ensure that the user internalises the control they have over the outcome [48].

In realising this, we propose, one part of the puzzle is finding models of bodily action and interaction which operate both on an algorithmic level as well as on a folk-knowledge level. Making it possible for interaction designers to present change, and the possible outcomes of potential changes, in ways that are explorable, actionable, and make obvious that the control over the change lies with the end user and not with the system. It is here that we believe that the three interconnected types of rhythmic interaction we have presented in this paper can have impact on how people achieve meaningful change through tracking.

6.2 Democratisation through Interaction with Medical Models

The expanding practice of self-tracking has been, by some, praised as a move towards the democratisation of health care. This era in healthcare is defined by patient empowerment, user autonomy, and improved health literacy [53]. Through consumer-grade tracking technology, people can take control of their own life and health care, even on days when they are not in touch with healthcare providers: "*the rest of the year*" you are your own doctor [50].

There are challenges to the view that agency and knowledge increase the more users collect their own data, as we have discussed. However, even though data can be difficult to act upon [77], the ability to take those actions means that some will go to extraordinary lengths to wrestle control of their health technology from institutions. For example, Brown et al. [9] present case studies of end-users hacking their sleep apnea and artificial pancreas machines in order to better fit their lives and the lives of their loved ones when their goals diverged from the mandated behaviours of the devices programmed by the medical device manufacturers.

These groups of users were forced to rely on a small number of group members with the technical skills to reverse engineer and update parts of the algorithms, but a wider community was involved in understanding the translation between these algorithms and the medical outcomes of the interventions the devices performed.

In Awari, the user can interact directly with the three process model of alertness. This model is foremost not intended to be used by end users but instead provides rigorous structure in the recommending and testing schedules in aviation [29], in the maritime industry [67], and in automated long haul trucking [4]. Although people can find and read the theory and work out the model being used, as the community did for the artificial pancreas machines [9], the outputs of such models alone do not provide agency over, and understanding of, one's own bodily processes.

Instead, we propose that wellbeing-related technology be built to allow the end user to practically understand the model, by providing the ability to 'hands-on' explore the results in the context of one's own data – a way of addressing the *data valences* of self-tracking [19]. In the context of Awari, we have shown that there are many who live outside the safety net of structured scheduling. While we have explicitly tried to widen the contexts and conditions in which the system can be used, we are under no illusions that this could ever be a universal model. What the ability to explore and understand the model in the context of one's own data allows, is for those for whom the model may not perfectly fit to understand *how* and *why* it deviates from their bodies and experiences. In doing so it removes the implicit and harmful dichotomy that exists in a myriad of medical-adjacent technology in which users are either 'normal' and embraced by the algorithm or 'deviant' and excluded from use unless they can change. As Ruckenstein noted, "*people do not always use tracking tools or engage with data in the ways that technology designers, website developers, or medical institutions imagine or intend*" [52]. This work encourages bringing forth more models where users can, in their own context, understand the recommendations and predict outcomes from an understanding of what the system expects, how it may or may not fit them, and what that means in relation to the choices they make regarding any change they may desire.

7 CONCLUSION

Through our design process, we describe the underlying rhythms that shape our relationship between everyday life and sleep. We present these as three categories of rhythmic influence, *Slow & Cyclical, Pressure & Release* and *Anchored*, each with their own material properties for designers and developers to better understand and integrate them into systems for interacting with the body. This work contributes through the description and deconstruction of the complex assemblage that is technologically enhanced sleeping practice, pointing to where these different rhythmic influences can be interacted with in other bodily and social processes.

Starting from the goal of undertaking a participatory design process to redesign tracking technology for people who sleep differently, in the shaping of the initial prototype this work was reframed around the challenge of how to design sleep-tracking technology to aid in the planning of future alertness. We argue that this focus, alongside the orientation towards users who slept outside of the norm – during the daytime, on shifting schedules or with extensive use of naps – guides the design of the system away from the passive use of sleep tracking, to placing the user in a more active role.

We show that there is an opportunity to develop new interactive tools to explore the continuous rhythmic and flexible nature of body processes. With a better understanding of how they interact, their inertia, and their material properties for the interaction we expose an opportunity in interaction design, supported by body tracking, that gives the user the opportunity to take action to change their complex bodily processes and shape the pacing of their life to fit their bodies, preferences and socio-economic constraints.

For future work, we intend to report user experiences, both short-term and long-term use of the system and report a deeper dive into the space of reinforcement learning algorithms in the context of multi-objective alertness planning.

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