Circadian computing: Towards a bodyclock friendly smartphone

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Abstract
Human biology is deeply rooted in the daily 24 hour temporal period. Our biochemistry varies significantly and idiosyncratically over the course of a day; and consequently our levels of alertness, productivity and physical activity are dependent on the time of day. Continued disruption of biological rhythms often has serious consequences for physical and mental well-being, causing cardiovascular disease, cancer, obesity, and mental health problems. In our recent work, we have shown that the patterns of mobile phone use can be indicative of biological disruption and the resulting effects including social jetlag and sleep inertia.

Given that digital technology often impacts our rhythms, there is the opportunity for a new class of circadian-based technologies that are not only dynamically aware of variations in our circadian rhythms but that can help stabilize them. In this work, we are exploring ways to provide feedback through smartphone and wearables about disruptions to individuals and and providing actionable suggestions and interventions that might help stabilize the internal clock.

Author Keywords
Biological Rhythms; Mobile Computation; mHealth;

ACM Classification Keywords

H.5.m. [Information Interfaces and Presentation (e.g. HCI)]: Miscellaneous

Introduction

Rhythms guide our lives. Within our bodies there are hundreds of biological clocks, synchronized by a "master clock" in our brain – the Suprachiasmatic Nucleus or SCN. These body clocks vary across individuals, from "early birds" (early types) to "night owls" (late types) and control our circadian rhythms: mental and physical processes that follow a roughly 24-hour cycle (*circa*): about + (*diem*: a day). These interindividual variations in temporal organization results in different as *chronotype*s.

Chronotype is a phenotype – a characteristic that results from genetic factors [13] interacting with environmental factors. In particular, light influences chronotypes — longer exposure to sunlight results in earlier chronotype [11]. Our chronotype is thus not a matter of choice and does not necessarily correspond to the social clock. As a result, a persistent cultural bias across the globe towards maintaining an "early to bed and early to rise" lifestyle can result in most of us living contrary to our biology. Indeed, approximately 80% of the population are having to operate during their biological night[9].

Roenneberg et al. [10], using survey data from over 55, 000 participants, have found that a significant discrepancy exists between sleep duration on workdays and on weekends. During weekdays, early birds get adequate sleep while night owls sleep consistently less. As a result, owls sleep more on weekends in order to compensate for "sleep debt" accumulated over workdays. On the other hand, the birds tend to sleep less on weekends, possibly due to social pressures to stay up later on non-work nights since the majority of the population have later body clocks. This sleep discrepancy resembles the situation of traveling westerly across several time zones on Friday evening and returning back Monday morning resulting in "social jetlag". Social jetlag indicates a misaligned circadian system and acts as an internal disruptive agent. The effects of crossing time zones can cause temporal lobe atrophy (amnesia) and spatial cognitive deficits [3]. It has been shown the larger the social jet lag, the greater the risk of using cigarettes, caffeinated drinks, and alcohol [15]. It has also been associated with obesity [9]. Sleep debt can also result in longer "sleep inertia", which is a transitional period from sleep to a fully awake state, characterized by disorientation of behavior as well as impaired cognitive and behavioral performance [6]. Prolonged sleep inertia has been shown to negatively affect attention, performance, and mood [5] as well as produce learning deficits [2].

Continued disruption of biological rhythms often has serious consequences for physical and mental well-being, resulting in higher likelihood for cardiovascular disease, cancer, obesity, and mental health problems [7]. Constant changes in daily rhythm due to shift work has been shown to increase risk factors for cancer, obesity, and type-2 diabetes [12]. The advent of technology and the resultant always-on ethos can cause rhythm disruption on personal and societal levels. Sleep pathologies, which can be indicative of disruption of internal biological rhythms, are reaching an epidemic level, with sleep disorders affecting around 70 million people in United States alone [1]. A growing area of research also relates sleep and circadian rhythm disturbance to affective illnesses, such as bipolar disorder and major depressive disorder.

[1]http://www.cdc.gov/sleep/aboutus.htm

HCI researchers have recently begun investigating solutions for addressing the challenges surrounding rhythms [14], sleep [1], and mental health [8]. A greater awareness of biological rhythms could significantly impact the design of technology to support increased well-being, productivity and higher quality of sleep. Improvements in the ease of measurement of many biological factors means there is also an opportunity for computers to play to our biological strengths. For example, Digdon et al. [4] have found that participants displayed varying levels of alertness throughout the day. Owls (late chronotypes) generally are less alert early in the morning and become more focused in the afternoon, reaching peak alertness in the early evening. This knowledge could impact systems that support concentration, for instance through a single-threaded application that recommends activity reduction or that pleasurably enhances distraction in order to help us enjoy (or at least feel less guilty about) procrastination. Or, a circadian rhythm-aware calendar applications that could more appropriately schedule events like meetings, workouts and relaxation. In this work, we are exploring ways to provide biologically attuned support in the areas of physical and cognitive performance, sleep, and well-being based on individual idiosyncratic circadian variation and sleep oscillation with following research questions:

- How to provide effective feedback about disruptions to individuals to increase awareness of their patterns of sleep debt, productivity cycle and overall dyssynchrony?
- How could we design actionable suggestions and interventions that might help stabilize the internal clock?

Living a rhythmic life in tune with your personal bodyclock is essential for sleeping well, being productive and living a healthy life. Maintaining stable daily routine and sleep-wake patterns are recommended for treating many illnesses such as mood disorders. Findings from this research hence may have broad applicability in both clinical and non-clinical settings.

Work in Progress

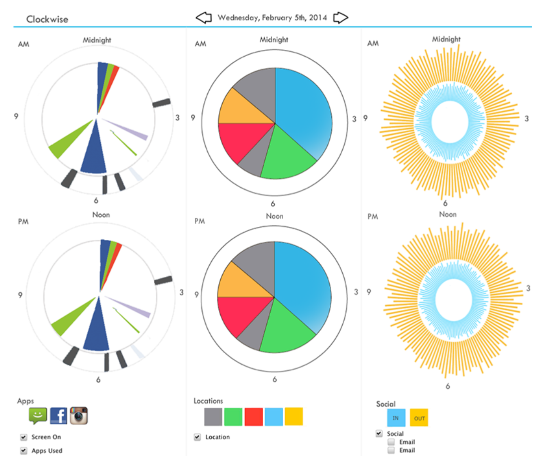

Figure 1: Feedback on phone usage pattern.

In our recent work, we capitalize on the high levels of ownership and use of smartphone devices among college students to find novel ways to cheaply, accurately, and continuously collect real-time data on behavioral factors associated with chronotype and daily rhythms. From the result of 97 days long study with 9 participants (*under review*), we have found that smartphone interaction patterns can be used to measure idiosyncratic sleep and circadian patterns as well as to detect symptoms of sleep deprivation, including the social jet lag that results from

Figure 2: A watch face showing showing best hours for specific tasks.

undersleeping on workdays and oversleeping to compensate on free days. We also show that duration of morning phone usage can be indicative of sleep inertia, a transitional period from sleep to a fully awake state.

We are currently exploring ways to provide feedback about the discrepancy between internal and external time in a meaningful, non-overwhelming way. For example, figure 1 shows patterns of communication, phone usage and location which, in combination with knowledge about individual chronotype, might be useful in providing insights about dyssynchrony as mediated through technology usage.

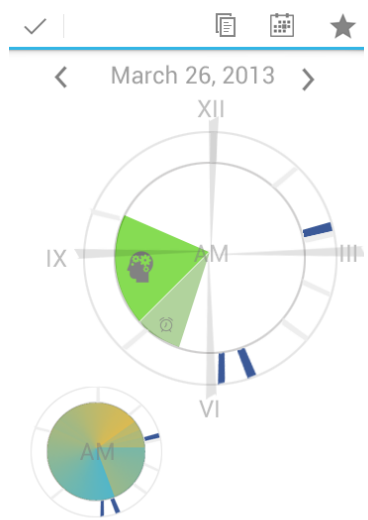

Figure 3: A paper based prototype for providing feedback about chronotype. The visualization relates personal ‘inner-time‘ with external clock time.

We are also interested in providing actionable suggestions and interventions through smartphone and wearables that might support stabilizing personal rhythms and capitalize on users' biochemical diurnal variations to maximize performance and well-being. Figure 3 shows a prototype of such system indicating hours of heightened cognitive alertness as inferred from internal clock.

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