Personalization in Circadian Rhythm-Based Event Scheduling

Prachi Sadekar, Jackson Baitinger, Sean Conway, Matthew Clark, and Afsaneh Doryab

***Abstract*— The human body follows a natural circadian rhythm, influencing sleep timing, cognitive abilities, and physical energy. Many people live contrary to this biological rhythm, leading to reduced cognitive performance and sleep loss, with college students especially vulnerable to these effects. Currently, there are limited technologies that assist with circadian rhythm alignment, despite the potential for health and productivity benefits. This paper investigates the feasibility of circadian-based activity scheduling for college students. We develop three circadian-based activity schedules that are increasingly personalized: (1) common activity timing according to circadian rhythms research, (2) timing curation according to sociodemographic context, and (3) timing adjustment based on individuals' specific constraints and context. In a three-week study, we explore users' responses to each scheduling approach and the potential impact on subjective wellbeing and overall performance. Our results show that participants could follow more activity recommendations as the level of personalization increased. Participants who followed the circadian schedules reported significantly improved well-being than others. However, reported wellbeing was not significantly correlated with increased personalization of timings. These observations provide useful insights into design requirements for circadian-aware recommendation systems.**

I. INTRODUCTION

It is established in the scientific literature that organisms operate on a biological clock– internal systems which react accordingly to time-based changes in environment [1], [2]. Dubbed circadian rhythms, these 24-hour cycles result in physical, mental, and behavioral changes in response to light/darkness stimuli. Research into this biological mechanism grants scientists insight into mental health, sleeping disorders, genetic factors, and other health-related issues [3].

Misalignment between social and biological clocks, referred to as "social jetlag" [4] impacts physical, emotional, and cognitive performance and has prolonged health effects [5]. With surging research on biological clocks and health-tracking technology, optimally timed cognitive activities, physical activities, and sleep according to circadian rhythms could lead to significant health results. Since circadian rhythms influence an individual's disposition, productivity, and daily schedule, it may be worth exploring how scheduling one's day around their biological clock can affect social obligations and overall performance.

This paper first investigates the physical, social, and cognitive factors influencing circadian rhythms. These factors include exercise timing and frequency, wake and sleep timing, morning/night preference-specific scheduling, cognitive workload timing, and implementation of social-specific timing blocks. We then explore the feasibility of scheduling daily activities according to circadian clocks for college students. Using data from 116 survey participants and 15 experiment subjects over 3 weeks, we show that unique chronotypes appreciate event timings optimal to their needs and preferences. We also show participants who follow circadian schedules more closely report significantly higher subjective well-being than others. However, pivoting to overfit towards one's existing routines shows no statistically significant effect on wellbeing. While the latter could be due to the short duration of our study, we believe our results provide valuable design considerations for personalizing future circadian-aware schedules.

II. RELATED WORK

Recommendation systems utilize algorithms and context to help users find desirable products or ideal solutions. These systems are often developed with one of three approaches: knowledge-based, content-based, or collaborative-based filters [6] or combinations of the approaches. Knowledge-based filters make recommendations using literature [7], not weighing personal preferences as highly as content and collaborative filters. Content and collaborative-based filters make recommendations by comparing the user's preferences to similar users or items to personalize the recommendations [6]. For real-world applications, these systems must heavily consider literature and user preferences to make recommendations. For example, when used in wellness settings, such as diet, the recommender must identify healthy and enjoyable meals for the user [8]. Our recommended activity timings build upon these systems, creating and determining how personalization in activity timing recommendations improves effectiveness.

There is limited research and testing of a circadian rhythm-aligned recommendation mechanism or the benefits such a system provides. These studies primarily investigate how sleep [9], [10] and physical activity [11] interventions can

*This work was supported by the National Science Foundation (NSF-IIS-1816687)

Prachi Sadekar is an undergraduate student at the University of Virginia, Charlottesville, VA 22904 USA ps6nf@virginia.edu

Jackson Baitinger is an undergraduate student at the University of Virginia, Charlottesville, VA 22904 USA jtb4yd@virginia.edu

Sean Conway is an undergraduate student at the University of Virginia, Charlottesville, VA 22904 USA syc3sm@virginia.edu

Matthew Clark is a computer science PhD student at the University of Virginia, Charlottesville, VA 22904 USA wdd6ts@virginia.edu

Afsaneh Doryab is with the Department of Engineering Systems and the Environment, University of Virginia, Charlottesville, VA 22904 USA ad4ks@virginia.edu

improve user wellness. Investigations into both personalized [9] and generalized [10] approaches found positive effects on participants. However, no study seeks to identify the proper balance between knowledge and user context. Our study builds off prior work by testing multiple levels of context awareness for activity scheduling and expanding beyond sleep and physical activity suggestions to include cognitive and social activity scheduling.

III. System Design

We investigate the feasibility of a circadian-based daily activity schedule through three increasingly personalized schedules using data from different sources: literature, the studied population, and each individual. For the first activity schedule, we extract appropriate circadian timings for different types of activities from a literature review. These timings are generic for the two chronotypes and the entire population without considering constraints and demographics. We adjust the literature-based recommendations for the second activity schedule to align with our study population, college students, and their routines, preferences, and constraints.We assume this population shares routines and practices evoked by cultural, environmental, and sociodemographic factors. We personalize the literature-based, population-curated recommendations for the final activity schedule by considering each individual's current schedule commitments, preferences, and chronotype. In the following sections, we describe each approach followed by our study design and procedure.

A. *Knowledge-Based Activity Scheduling*

We reviewed relevant literature on circadian timing to develop a baseline circadian-based activity schedule. We chose sleep, cognitive tasks, exercise, and social activity as our primary factors as there is significant research on interactions between these factors and overall wellness, health, and functional normalcy.

Humans may have different sleep/wake preferences, referred to as a chronotype, influencing timing of wakefulness, sleep quality, and overall wellness [12]. The two major chronotypes are "morning" and "evening". Morning chronotypes prefer to wake up and go to bed earlier and experience optimal energy levels in the morning, while evening chronotypes both sleep and experience optimal energy levels at later times. To account for these biological differences, our knowledge-based schedule uses chronotype to recommend the four activity types.

Regarding optimal sleep patterns, prior research found morning chronotypes went to bed at approximately 10:30PM. In contrast, evening chronotypes went to bed at approximately 11:30PM [13], times that are reflected in our knowledge-based activity schedule. Our schedule recommends morning chronotypes wake up at 8AM and evening chronotypes wake up at 8:45AM to account for a winding down, falling asleep and receiving 8 hours each night [14]. Morning chronotypes require a longer sleep duration than evening chronotypes, so the schedule incorporates a 15-minute surplus in sleep duration for morning chronotypes [13].

Cognitive functioning is a reflection of variations in subjective sleepiness or alertness, also known as circadian arousal [15]. For cognitive activity recommendations, the knowledge-based schedule places cognitive tasks between 9:30-11:30AM for morning chronotypes, 8-10PM for evening chronotype, and 1-3PM for both chronotypes, each aligning with their peak cognitive energy [16]. This schedule also recommends a 15 minute break for every 45 minutes of cognitive activity to reduce mental fatigue [17].

For physical activity recommendations, the knowledge-based schedule recommends the same physical activity window of 4-5PM to both chronotypes because muscle power, body temperature, and muscle contractility (flexibility) are at their peak at this time regardless of chronotype [18]. Because adults should get at least 30 minutes of physical activity per day [19], this schedule recommends the 4-5PM window all seven days of the week.

The schedule recommends social activity from 7-9:30PM and 7:30-10PM for morning and evening chronotypes, respectively, because both chronotypes have the propensity to socialize and make new social connections in the evening [20]. The specific activity time blocks were determined concerning the sleep timing recommendations for each chronotype. Additionally, this event is only recommended on Friday and Saturday nights because these are common nights for college students to engage in social activities.

Overall, the knowledge-based activity schedule provides circadian rhythm-aware activity timings for a general population with respect to chronotype. This schedule includes no context for a given user. The next two proposed schedules increase personalization to the knowledge-based schedule by considering more of the user's preferences and demographic context.

B. *Population-based Activity Scheduling*

1) Gathering Population Routines and Preferences: Our population-based activity schedule explores how the general preferences and routines of a specific population align for circadian scheduling improvements. To collect population preferences, we administered a survey to 116 college students at an American university. We collected timings for social, cognitive, and physical activities, wake-up and sleep times, variations in their existing routines, and self-reported wellness levels. This information allowed us to model the behavior of both chronotypes and create circadian-aware schedules.

Within the 116 responses, the average age was 20.97 (SD = 1.59). 61 respondents self-identified as female, 52 as male, and 3 as non-binary/other. In terms of preference towards chronotypes, 41 identified themselves as morning type, 54 considered themselves evening type, and 18 reported having no preference. Our data analysis provided the following

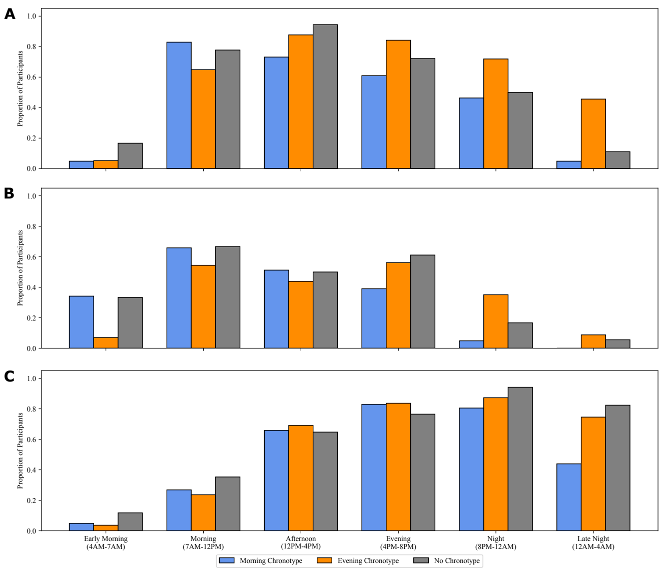

Fig. 1. The proportion of chronotype event timing preferences for A) cognitive tasks, B) physical tasks, and C) social tasks.

insights and implications for designing population-based schedules for college students.

2) Chronotype Preferences (Day/Night and Timing) and Timing of Physical, Social, and Cognitive Activity Events: Figure 1 displays the distribution of timings for cognitive, physical, and social tasks among the survey participants. Chi-squared tests found a significant difference between when the three chronotypes preferred to complete cognitive tasks ($p = 0.017$), and physical tasks ($p = 0.003$), but not social tasks ($p = 0.838$). As expected, participants with a morning chronotype preferred completing tasks earlier than evening chronotypes. Participants with no chronotype preference showed similarities with both the morning and evening chronotypes. Spearman R tests showed preferences of "no chronotype" participants correlated with both chronotypes. However, the correlation with morning chronotype was stronger than evening types for cognitive ($\rho_M = 0.928$ vs. $\rho_E = 0.771$) and physical ($\rho_M = 0.943$ vs. $\rho_E = 0.771$) tasks, but the correlation with the evening chronotype was stronger for social events ($\rho_M = 0.714$ vs. $\rho_E = 0.943$).

When analyzing specific timings, those who considered themselves morning people preferred 7AM to 4PM for cognitive tasks, while evening chronotypes tended to complete cognitive tasks between 12Pm and 8PM. Both morning and evening chronotypes preferred the times between 12PM and 12AM for social tasks, and evening chronotypes also tended to be social between 12PM and 4AM. Participants with morning chronotypes were more likely to complete physical tasks between 4AM and 4PM, while evening chronotypes were more likely to exercise between 7AM and 12AM.

3) Wake Up / Sleep Times between Chronotypes: In our sample, the most frequent wake-up time for morning chronotypes was 8AM, whereas evening chronotypes preferred to wake up around 10AM. Similarly, the most frequent sleep time for morning chronotypes was between 10PM and 12AM, whereas the range was 12AM to 2AM for evening chronotypes. Kruskal-Wallis tests indicated a significant difference between the chronotypes for both sleep time ($p = 2.156 * 10^{-5}$) and wake-up times ($p = 2.953 * 10^{-8}$).

4) Exercise timing and frequency: The most frequent exercise time was between 7AM and 12PM for morning chronotypes, and between 4PM and 8PM for evening chronotypes. Morning chronotypes often worked out either once or twice a day, whereas evening chronotypes exercised less frequently, typically less than once a day. A chi-squared test indicated a significant difference between how frequently the chronotypes prefered to exercise ($p = 0.012$).

5) Schedule Design: Using the survey results, the population-based schedule adjusts the activity timings in the knowledge-based schedule. For sleep timings, the evening chronotype wake-up time is adjusted from 8:45AM-9AM, and sleep time was updated to 12-1AM. For both chronotypes, the wake-up time duration on weekends is increased from 30 minutes to one hour due to students sleeping in on weekends. We reduced the frequency of physical activity from every day to three times each week based on students' preferences of exercise frequency , and adjusted the timing from 4-5PM to 3:30-4:30PM. For social activities, we added a third social activity block on Thursdays from 6:30-8PM for both morning and evening chronotypes because students indicated they enjoy participating in social activities on Thursday evenings. We also adjusted the social activity timings for evening chronotypes from 7:30-10PM to 9-11PM based on evening chronotypes engaging in social activities later at night on the weekends.

This population-based recommended activity schedule adds an element of personalization to the knowledge-based schedule by adjusting for demographic preferences. However, this recommendation schedule still lacks the ability to schedule timings around a student's obligations. This level of personalization is addressed in the following schedule.

C. *Personalized Activity Scheduling*

The personalized activity schedule balances activity timings with regard to a student's class schedule and obligations. Unlike the previous two approaches, this schedule considers user input about their usual weekly commitments and personal preferences for: wake and sleep times, cognitive and social activity, and meal times. This personalized recommendation schedule was built upon the population-based schedule by increasing the awareness of the individual's context in the following ways. Cognitive activity recommendations must be before 6:30pm for morning chronotypes and after 12pm for evening chronotypes. As individual schedules permitted, two blocks (3-5 hours total) of cognitive activity were assigned for each day Sunday-Thursday and one on Friday (2-3 hours). Cognitive activities were only recommended on Saturdays if a student preferred completing homework on Saturdays. The frequency of physical activity recommendations was based on a student's preference for physical activity frequency but included at least 3 sessions a week. As much as possible, physical activities were scheduled during the afternoon unless a student has classes throughout the afternoon or indicates they participate in a required physical commitment such as a club sport, in which case the physical activity was scheduled to match that commitment. Social activities were recommended on Friday and Saturday evenings, and follow timings based on the bedtime of their chronotype and wake up times were scheduled by averaging their preferred wake-up time and the wake-up time provided by the population-based schedule.

The personalized activity schedule provided a unique set of activity timings for each individual, unlike the previous two schedules which had one set of recommendations for each chronotype. This level of personal context awareness would allow users to incorporate a circadian rhythm-based schedule into their daily life easily.

IV. EVALUATION STUDY

We conducted a user study to gain insight into how an adjusted, rhythm-aware schedule could work in daily life and how personalization influence wellbeing and likelihood of following a recommendation. Every participant received all three schedules for a week in the order of increasing personalization. The baseline, knowledge-based schedule was first, so the more context-aware recommendations did not influence participants. The personalized schedule was last since it incorporated feedback from the previous two weeks. The recommended activity timings were provided to participants on their Google Calendars as events (Figure 2).

A. Study Design and Procedure

15 participants were recruited through word of mouth, social media posts, and email lists at an American university. The participants were students at the university, at least eighteen years of age, and routinely used Google Calendar.

To begin the study, each participant completed a background survey which collected data about their health and behavioral routines. This survey allowed the research team to assign the proper chronotype-based schedule and gain the required information to implement the personalized recommendation schedule in Week 3. If participants identified as a "No chronotype," they were assigned the morning chronotype schedule because of their strong correlation for cognitive and physical activities. Participants then received the first week of recommended events. The subsequent weeks were added to the participants' calendars as the study progressed. Each calendar event represented an activity, and the three recommendation approaches decided the time at which each event was placed.

We administered weekly feedback surveys to collect information about participants' sleep quality, physical, social, and cognitive energies, the perceived usefulness of the schedule, and the days affected by extraneous factors. These surveys helped identify differences among the three schedule-calculation strategies and the success of each strategy individually. This study and its procedures were approved by the Institutional Review Board at the target university.

The activity timings in Week 1 were shared using the knowledge-based schedule. Participants were assigned one of two calendars based on their chronotype. Week 2 used activity timings based on the population-based schedule, and Week 3 assigned activity timings based on the personalized recommendation schedule and information inputs from the weekly surveys.

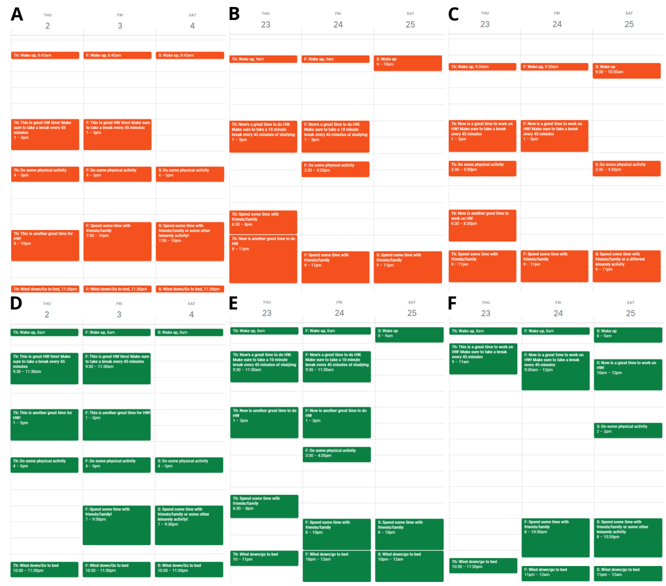

Fig. 2. Sample evening (A-C) and morning (D-F) chronotype calendars for Week 1 (A, D), Week 2 (B, E), and Week 3 (C, F).

B. Analysis and Results

Our analysis investigated participants' responses to circadian-based scheduling and its potential impact on their sense of health and wellness. We focused on three main observations from our user study: participant-reported wellness, participation rates in the four activity types, and the impact of personalizing the activity calendar.

We recorded how many of the scheduled calendar events were followed for each type of activity (cognitive, social, physical, and sleep) by comparing the participant's assigned calendar events at the beginning of the week to their adjusted schedule at the end of each week. An activity was considered *followed* if the participant did not modify the calendar event or just shortened it within the originally recommended time block. If a participant did not participate in the activity, they *deleted* it from their calendar. We define *activity participation rate* as the proportion of events followed on the assigned day and time for each activity type over each week.

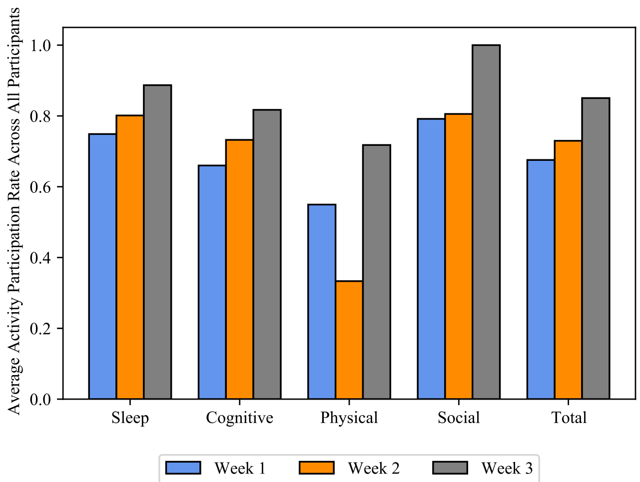

Fig. 3. The average activity participation rate for each activity over each week.

Of our 15 participants, 12 provided data through the calendar for all 3 weeks. 2 participants altered the calendar in at least 1 week (but not all 3), while 1 participant failed to move any calendar events. Since we cannot identify whether participants did not edit the calendar due to perfect compliance or lack of participation, participants' calendar and survey data were excluded from analysis during these weeks.

We analyzed the following questions:

1) RQ1. What impacted participants' participation in the recommended activity timings: We investigated relationships between the participation rate and activity type, demographics, chronotype, and personalization level to answer this question.

Using a Kruskal-Wallis test, we explored how activity participation rates (figure 3) differed between **activity types**. We found that participants were most likely to follow social activity recommendations ($p = 5.2 * 10^{-5}$) and least likely to follow physical activity recommendations ($p = 3.2 * 10^{-5}$). The difference in participation rates between the four activity types was significant ($p = 9.077 * 10^{-6}$). We then looked at the relationship between activity participation rate and **personal factors** such as a participant's chronotype, gender, and age. Participation in total activities ($p = 0.401$), sleep timing activities ($p = 0.493$), physical activities ($p = 0.796$), and social activities ($p = 0.578$) did not differ between genders. However, male participants followed significantly more cognitive activity timing recommendations than female participants ($p = 0.031$). We did not observe a significant relationship between the two chronotypes ($p = 0.987$) or age ($p = 0.061$) for the total activity participation rate.

Next, we analyzed how **personalizing the activity timings** impacted activity participation rates. Through a series of Mann-Whitney U tests, we found that participation was not significantly different between Week 1 and Week 2 ($p = 0.375$). However, participants followed Week 3 recommendations significantly more than Week 1 ($p = 0.005$) and Week 2 ($p = 0.008$).Specifically, participants followed more of Week 3's events than Week 1's for each activity type except physical activities ($p = 0.133$). None of the Week 3 activity participation rates were significantly higher than the Week 2 rates for the specific activity types.

TABLE I
THE NUMBER OF PARTICIPANTS REPORTING A CHANGE IN WELLBEING AFTER EACH WEEK OF RECOMMENDATIONS.

	Worsened	No Change	Improved
Week 1	0	6	7
Week 2	0	4	10
Week 3	0	7	6

2) RQ2. How did the recommended activities affect participants' sense of health and wellness: We investigated this question by analyzing relationships between the reported wellbeing factors and the activity participation rate, activity type, personalization level, and chronotype.

Using ordinal regressions, we analyzed how participants **activity participation rate** for each activity type impacted their weekly energy levels, sleep quality, and overall wellbeing. Participants who followed a greater proportion of sleep events reported significantly higher levels of sleep quality across all three weeks of the study ($p = 0.006$). Following physical activity, cognitive activity, and social events had no impact on a participant's reported physical energy ($p = 0.814$), cognitive energy ($p = 0.863$), and emotional energy ($p = 0.732$), respectively. However, participants with higher activity participation rates reported improved wellbeing ($p = 0.021$). When considering each type of event, participation in cognitive tasks resulted in improved wellbeing ($p = 0.024$), while physical ($p = 0.671$), social ($p = 0.108$), and sleep ($p = 0.076$) had no significant changes. It is worth noting that no participants reported a decrease in wellbeing due to the schedules (table I).

Our results indicate that increasingly **personalized activity scheduling** does not significantly impact participant wellbeing ($p = 0.206$). Week 2 had the highest proportion of participants reporting improved wellbeing over Week 1, while Week 3 showed no improvement. This may indicate personalization is beneficial over a knowledge-based schedule, but over-personalization of events minimizes their impact.

There was no significant difference in reported wellbeing between morning and evening **chronotypes** ($p = 0.324$).

V. DISCUSSION

Our initial hypothesis was that both event participation and wellness would increase as events become more personalized to a user. We discovered that event compliance increased with personalization and following circadian-based events correlated with reported wellbeing. However, our population-based events showed the most improvement in participants' wellness than personalized events. This may be due to an "overfitting" of events to the participant's schedule in the personalized activity schedule, resulting in recommendations that are too similar to the user's normal routine. However, this overfitting may be necessary for physical activity recommendations, where Week 3's recommendations were followed twice as frequently as Week 2's. Thus, future circadian-based schedules may consider utilizing a population-based schedule for sleep, cognitive, and social events and a personalized activity schedule for physical activity.

An interesting observation and possible future study area is understanding how recommending activity times can increase participants' general awareness of how they spend their time. Despite not being explicitly instructed to, multiple participants added their own activities to the calendar outside of our recommendations, indicating that they began tracking what they do throughout the day.

Though our results show that following a schedule in sync with natural circadian rhythms can improve wellbeing, some limitations still exist. Only all 3 weeks of data from 12 of the 15 participants could be used in the analysis because some failed to adjust their participation in the Google Calendar. Also, for some participants, the university spring break occurred during the study. While data was not collected this week, it may have influenced participants' wellbeing perceptions of the weeks around it. Lastly, many participants were recruited through the university's engineering school, so generalizing the results to other student groups and universities may be limited.

Future researchers can use these insights to create a more robust activity timing recommendation. While we observed that overfitting the activity timings has a neutral effect on wellbeing, it could be worth exploring in future studies whether a schedule developed from daily rather than weekly can provide more useful activity timings.

VI. CONCLUSION

We investigated the benefits of following a circadian-based schedule, and how different levels of activity timing personalization improve an individual's wellbeing and ability to follow the recommended events. We analyzed literatureon biological rhythms concerning social, cognitive, physical, and sleep patterns and conducted a population survey of 116 college students to understand their daily habits and schedule. Using this information, we tested three increasingly personalized activity schedules, knowledge-based, population-based, and personalized, on 15 college students. Our results showed that activity timings from the population-based schedule yielded the highest improvement in wellbeing despite not being the most personalized. However, providing increasingly personalized activity recommendations made it easier for participants to follow them. Our results demonstrate how following a circadian cycle can impact one's wellbeing, and how some level of personalization will allow more activity recommendations to be followed.

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