Treating Depression Behaviorally Using Rhythm-Aware Recommendation Systems

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Many aspects of health are affected by the timing of our daily activities. Our biological clock, called circadian rhythm, affects our nerve conduction, body temperature, and muscular blood flow (Hayes et al., 2010). In addition, depressive disorder is a health crisis affecting 15% of people, less than 40% of which seek medical treatment (Kessler et al., 1994). This STS research paper seeks to determine how technology can be used to help regulate one's circadian rhythm to mitigate depression symptoms. The key technologies to be discussed are rhythm-aware recommendation (RAR) systems. This technology includes any systems that can produce and recommend a schedule of circadian-synced daily activities to a user. This paper investigates the application of RAR systems to the lifestyle-related aspects of depression treatment. There are existing RAR systems being used for this purpose, often building upon an existing therapeutic strategy called pleasant activity scheduling (PAS). Combining RAR systems with PAS to correctly time a depression patient's daily schedule can result in enhanced depression relief. To analyze the feasibility of RAR systems in this context, two main frameworks were used. First, I used a framework for analyzing "technological fixes" to guide an assessment of RAR systems' solution potential. Second, I used a descriptive framework for understanding technology's influence on society, technological determinism, in a breakdown of RAR system design features that aim to change human behavior. The investigation of this topic can be summarized into the research question: "How can human rhythm-aware recommendation systems be used to behaviorally treat depression?" It was found that RAR systems for behavioral depression treatment did not fully qualify as successful technological fixes, but have a high ability to change patient behavior when design features embrace technological determinism's idea that technology can indeed drive human behavior.

Background and Significance

Pleasant activity scheduling (PAS) has been growing in popularity in depression mitigation, and is now seen as effective enough to be a stand-alone treatment (Morin, 2022). However, when depression patients are simply told to schedule enjoyable activities, the timing, commitment level, and frequency all contain uncertainty. Cognitive behavior therapy (CBT) principles, including behavior change and sleep regulation, are being integrated into mobile health (mHealth) apps (Denecke et al., 2022). 70% of the population lives contrary to their biological clocks (Roenneberg et al., 2012), which can often lead to depression symptoms, so the realignment of depression patient activities is paramount. I am identifying "rhythm-aware recommendation" (RAR) systems as a specific type of application that takes sleep and habit data from the user, either from manual logging or wearable technology, and assists in finding the optimal timing for impactful daily activities including sleep, exercise, meditation, social time, or cognitive work. RAR systems also must present this timing to the user in the form of recommended activities (wake up, exercise, meditate, etc.) or a schedule as a whole. Most systems allow users to choose which types of activities they would like to engage in and turn into habits, while some recommend specific activities automatically. Symptoms of "social jetlag", or circadian rhythm misalignment, include impaired alertness, poor performance, and poor sleep quality in the short-term. Long-term effects include a higher risk of obesity, cancer, cardiovascular diseases, and depression (Caliandro et al., 2021). If a depression patient follows RAR system recommendations enough to fix their sleep schedule, they could avoid these symptoms. Additionally, the systems help the user find their best time to socialize or engage in pleasant activities according to their existing schedule and peak energy hours, which could provide a more calculated form of PAS therapy. Even if users do not follow all of the system's

recommendations, simply being aware of one's fluctuating cognitive and physical capabilities can provide comfort.

Many RAR systems focus mainly on sleep tracking and recommending optimal sleep and wake times. This type of RAR system can more specifically be called a context-aware sleep health recommender (CASHR) (Liang, 2022). Examples of existing CASHR systems include mobile applications such as FitBit sleep tracking, Sleepio, Sleep Cycle, and Headspace. Other RAR systems are more focused on activity scheduling, including apps such as Fabulous, Happify and Remente. One specific RAR system, MUBS, is at the forefront of this technology as it provides activity planning, mood tracking, reflection, daily routines, feedback and reward, activity inspiration, and activity recommendation (Rohani et al., 2020). As I am investigating the future feasibility of fully developed RAR systems, I will consider the capabilities of the MUBS system as standard specifications of RAR systems in my analysis and for the remainder of this paper. While activity recommendation technology has been proven successful (Rohani et al., 2021) in self-management of depression for specific RAR systems, this paper will observe the technology's potential in a broader socio-technical sense, using two STS frameworks.

Research Methods:

The analysis of this technology's application is broken down into two parts: The "three rules for technological fixes" framework and technological determinism. The first part is a framework set forth by Daniel Sarewitz and Richard Nelson that contains a process to assess how technology may or may not fix a problem (Sarewitz & Nelson, 2008). Their first rule is that "technology must largely embody the cause-effect relationship connecting problem to solution," or that the fix must be "broadly effective" in the current landscape of the problem (Sarewitz &

Nelson, 2008, p. 871). The second rule is "the effects of the technological fix must be assessable using relatively unambiguous or uncontroversial criteria." Lastly, a technological fix is "most likely to contribute decisively… when it focuses on improving a standardized technical core that already exists" (Sarewitz & Nelson, 2008, p. 872). Each rule will be examined for rhythm-aware recommendation systems in the task of "fixing" pleasant activity scheduling.

The second part of the analysis pertains to technological determinism, which states that technological change is directly active in creating social change. More specifically, justificatory determinism involves using technology and its progress to justify changes in human's lives and society (Wyatt, 2008). In the context of this research, justificatory determinism will be employed to analyze how users justify changes in their behavior and daily schedules with recommendations from rhythm-aware systems. The main materials for technological determinism analysis were common design features of fully-capable RAR systems. These features were analyzed from the perspective of justificatory determinism to understand how this technology can influence human behavior and society. This paper previously proposed to additionally analyze survey data from users of wearable lifestyle technology, however I found this method to be unnecessary.

Results

Framework 1: RAR Systems as a Technological Fix for Depression

Rule 1

First, I evaluated the ability of rhythm-aware recommendation systems to act as a feasible "technological fix" in a socio-technical context using Sarewitz and Nelson's "Three Rules for Technological Fixes." The first rule of this framework has two parts: 1) "the technology must largely embody the cause-effect relationship connecting problem to solution," 2) it must be

"successful within the context of a complex socio-technical system" with "clear advantage[s] over other approaches" (Sarewitz & Nelson, 2008, p. 871). In other words, the fix must be aimed at the cause of the problem rather than any symptoms of the problem, and it should be a clear favorite approach even when considering social aspects. With depression as the identified problem, the main causes were found to vary drastically. While behavior alone is not always the cause of depression, this paper is solely focused on application of RAR systems in the behavioral treatment field. The behavioral causes being examined with this framework that are proven to worsen depression are social jetlag, passivity, and a lack of enjoyable activity (Cognitive Behavioral Therapy Los Angeles, 2014). Behavioral activation (BA) and PAS are two-widely used techniques in CBT upon which RAR system design and algorithms are based. Both techniques are centered around changing behavior to include activities that are scientifically proven to decrease depression risk. These observations lead to the conclusion that BA and PAS are in fact solutions that are directly connected to the causes of the problem, and since RAR system design includes these techniques, part 1 of rule one is satisfied. The second part of the framework's first rule states that RAR systems must be "successful within the context of a complex socio-technical system." The primary socio-technical system would be the current landscape of behavioral depression treatment, which contains mobile health (mHealth) applications and behavior mandated by clinicians and therapists. RAR systems fit into the mHealth application category, which proves to also be a complex socio-technical system itself, as "more than 10,000" (Torous & Roberts, 2017, p. 437) mHealth applications can be downloaded from the mental health category alone. Treatment through mHealth applications can often be successful due to several advantages, such as the fact that "smartphones are within reach 90% of the time with access 'in-the-moment,'" (Rohani et al., 2021, p. 4) and the limited clinical

involvement caters toward treatment-seeking behavior (Rohani et al., 2021). However, fully-functional rhythm-aware recommendation systems are still being developed, so receiving policy and operational coordination to bring together the complex mHealth application system is a difficult next step. This system includes many actors such as doctors, clinical guidelines, smartphone manufacturers, and the APA. Additionally, within the thousands of mental health applications, "finding… valuable applications… is a challenge for both patients and clinicians," (Torous & Roberts, 2017, p. 437) indicating a lack of clear advantage over other approaches. All of these factors limit how RAR systems are viewed within the scope of behavioral treatments, and indicate that they are not yet successful within their socio-technical system.

Ultimately, rhythm-aware recommendation systems are confined to the current landscape of mental mHealth applications. Rhythm-aware recommendation systems harness the techniques of BA and PAS, which are valid solutions connected to the problem, with desired effects aimed at the cause. However, they are not yet successful within the context of the mental mHealth application system, which fails to satisfy part 2 of Sarewitz and Nelson's first rule.

Rule 2

The second rule for technological fixes is that "the effects of the technological fix must be assessable using relatively unambiguous or uncontroversial criteria" (Sarewitz & Nelson, 2008, p. 871). The desired effect of rhythm-aware recommendation systems within this topic is simply depression relief through behavioral treatment. There are a multitude of instruments that can measure and assess depression and one's progress. The APA has a list of nineteen scales or indices that measure depression (American Psychological Association, 2019). There are instruments for measuring depression across the lifespan, in children, in the general adult population, and in older adults. Additionally, an existing BA-based recommendation system for

depression relief used PHQ-9, one of the APA-approved instruments to measure success in their study. So, there is already usage of these unambiguous criteria, and RAR systems for depression relief satisfy the second rule of the framework due to the unambiguous and uncontroversial instruments approved by the APA.

Rule 3

Sarewitz and Nelson assert that "research and development is most likely to contribute decisively to solving a social problem when it focuses on improving a standardized technical core that already exists" (Sarewitz & Nelson, 2008, p. 872). This is the third rule of the framework, and rhythm-aware recommendation systems satisfy this rule. The necessary technical core of rhythm-aware recommendation systems comprises multiple parts: the mHealth app, the recommendation algorithm, the clinical knowledge, and BA/PAS therapeutic strategies. All four of these parts exist independently but also together within existing RAR systems. There are two cases by which it is evident that a standardized technical core exists for RAR systems: context-aware sleep health recommender systems (CASHRS) and the MUBS application. First, in a review by Zilu Liang, twelve CASHRS are observed. All twelve systems are fully automated, contain personalized recommendations, and are nonproprietary (Liang, 2022). "Contextual factors" such as physical activity, diet, and sleep quality of previous nights, were considered in each of these systems, qualifying the systems as "rhythm-aware." While Liang found CASHRS to be heading in a promising direction on a system level, "developing and validating new algorithms for recommendation generation, context filtering, and context life cycle management" (Liang, 2022, p. 20) is currently required. The third rule of the framework does include the phrase "improving upon," so RAR systems may take those next steps to advance the technical core of CASHRS and still satisfy the rule. The second example of the technical core already

being developed is in a study by Darius Rohani, where the research team designed MUBS, "a personalized recommender system for behavioral activation in mental health" (Rohani et al., 2020, p. 1). The study involved depression patients using the MUBS application which "supports the core" of BA's principles and therapeutic process. Patients within the study that started with mild to severe depression were the main beneficiaries, especially participants who personalized their use of the application and performed a diverse range of activities (Rohani et al., 2020). While MUBS is mainly being used to show that RAR systems satisfy the third rule of technological fixes, it also serves as one direct example of an existing RAR system being used to treat depression behaviorally. Its technical core contains all four necessary parts: it is an mHealth app, uses a recommendation algorithm, utilizes clinical knowledge, and was developed as a technological version of BA and PAS therapy. All in all, there is a standardized technical core available for RAR systems to treat depression on a larger scale in the future, and rule three is satisfied.

Framework Summary

When assessing RAR systems as a technological fix using all three rules, the only rule in which RAR systems fail is rule one. RAR systems are not currently seen to have a clear advantage over other depression treatments, as many mHealth applications are not successful and it is difficult for patients to find the right apps for their personal treatment. Policy creation within RAR systems' socio-technical network also is necessary. However, the first part of rule one, that the solution of the technological fix must be aimed at the problem, is in fact satisfied. The problem is simply depression itself, and RAR systems address the behavioral causes in the solution by building upon proven BA and PAS techniques. Next, rule two was clearly satisfied; APA-approved instruments easily assess depression progress. Lastly, rule three was satisfied as a

widespread use of RAR systems within the socio-technical network would be able to improve upon the technical core of CASHRS and the MUBS application. Using this framework, it is not possible to fully classify RAR systems as a successful fix in behavioral depression treatment. However, the technology has potential and simply needs to develop to have evident advantages over other behavioral treatments. The use of Sarewitz and Nelson's framework is summarized in Table 1 below:

Table 1

Summary of "Three Rules for Technological Fixes" Framework Analysis

Rule	Criteria	Result
1.1	"the technology must largely embody the cause-effect relationship connecting problem to solution"	Satisfied
1.2	"successful within the context of a complex socio-technical system" with "clear advantage[s] over other approaches."	Not satisfied
2	"the effects of the technological fix must be assessable using relatively unambiguous or uncontroversial criteria."	Satisfied
3	"focuse[d] on improving a standardized technical core that already exists."	Satisfied

The lack of clear advantages over alternate approaches is the main characteristic of a technological fix that RAR systems are currently lacking. Even though there is proven success in behavior change and depression reduction, why is this technology not widely viewed as a solution for depression? The failure of many mHealth applications can stem from concerns regarding the technology's ability to actually influence a patient's behavior for the better in the long run. This consideration brings me to the second part of my analysis– using the descriptive framework of technological determinism to analyze the ability of RAR system technology to create social advancement in depression treatment strategy and influence human behavior.

Framework 2: Technological Determinism in RAR Systems

Justificatory technological determinism is the notion that technology is a main driving force in social and human change, and that our progress over the past few centuries can be defined and justified by the evolution of technology (Wyatt, 2008). While this perspective is defensibly criticized for overlooking how political, social, and economic factors shape our development and use of technology, it is useful when examining how the design and functionality of RAR systems drive users to follow recommendations and change their behavior. From the deterministic perspective, the technology itself includes a set of affordances and limitations that influence how users interact with the system. In the case of recommendation systems, the nature of the affordances and limitations have an amplified effect, as users are being directed to take a certain action. This section of my analysis will examine design features that promote human action, "deterministic features", as well as features that do the opposite, "non-deterministic features". Each feature is common in existing recommendation systems, and this analysis will allow me to gauge the technology's overall ability to induce behavior change. These findings will help guide the future design of RAR systems for behavioral depression treatment.

Deterministic RAR System Features

The general nature of RAR systems elicits technological determinism. Recommendation systems are an extremely clear example of technology driving change in human behavior, as they give direct instructions to the user to perform an activity. Highly deterministic designs lead to higher recommendation compliance, which usually leads to increased user wellbeing as the recommended activities and their timings are proven to reduce symptoms.

The first feature of RAR system design that prompts technological determinism is the system's personalization. RAR technology is often developed to target the specific preferences, sleep schedule, and existing commitments of the user. In this thesis portfolio's technical paper, our team explored varying levels of personalization in one RAR system and found that a highly-personalized, user-specific recommended activity schedule yielded a higher user participation rate as opposed to more general schedules based on simply common circadian knowledge and demographic population. These findings suggest that highly-targeted RAR systems are more likely to drive behavior change and recommendation compliance.

The next deterministic design characteristic is the use of feedback loops. RAR systems can capitalize on activities that successfully increase wellbeing by accounting for user feedback. If a feedback-capable system receives user input that certain activities are making them feel better, the system can include more of these activities to drive the user into a self-reinforcing cycle of behavior change. If the system uses data from many users or even just one, its recommendation algorithm may be able to identify and implement successful activity patterns that the user would not have known otherwise. Users are more likely to perform a recommended activity if it has worked in the past, so user feedback loops improve behavior change.

The next successful features that drive behavior change are goal-setting and reward mechanisms. Incorporating these concepts into the design of a RAR system would help users see their progress and stay motivated. Similar to the use of feedback loops, users are more likely to continue changed behavior when they see successful results. Allowing for personalized rewards that the user chooses (e.g. vacation, fun purchase) may usefully steer the design away from hard technological determinism while still promoting behavior change through the technology.

Personalization, feedback loops, goal-setting functions, and reward mechanisms are all strong characteristics of recommendation systems that, when applied to RAR systems for depression, will increase user recommendation compliance, and therefore, behavioral treatment success.

Non-deterministic RAR System Features

There are additional characteristics of recommendation systems that lead to a lack of behavior change and would need to be addressed in the design of a successful RAR system. While I mentioned personalization as a characteristic that assists technological determinism and behavior change, one must consider the nature of such personalization. If a RAR system has extensive data about the user's current behavior, overfitting a recommendation algorithm to their current state may lead to no changes in their behavior and wellbeing. After all, if their recommended activities closely resemble their current schedule, it is unlikely to see an improvement in depression symptoms. Designers of RAR systems for depression treatment must be careful to make the recommended activities personally feasible for the user, while also keeping in mind that new activities must be added or the timing of their current activities must be adjusted.

Next, recommended activities must be perceived as relevant to the user. Sufficient user data must be considered in the recommendation algorithm to ensure the activities are in fact enjoyable and effective for the user. If recommendations that the user follows are consistently unsuccessful, they are unlikely to continue changed behavior. This point emphasizes the importance of personalization and feedback loops in RAR system design.

Furthermore, the user's capability of performing the recommended activities must be considered in the design. Users must feel like each recommendation is feasible with regard to

their budget and access to facilities. For example, a user without gym access that receives a recommendation to lift weights may lose confidence and trust in the RAR system and fail to change their behavior. Sufficient user input about their available resources must be collected to avoid this type of failure.

Lastly, recommendation systems with biased or limited data sources may lead to the prioritization of certain methods and a lack of a full range of activities or coping strategies. If a RAR system is based on only a small selection of medical results and sources, it may give users a narrow set of solutions that do not work for them. This phenomenon could again lead to a lack of trust and abandonment of the system.

Framework Summary

In this section, I have examined components of RAR system design while considering the perspective of technological determinism to identify what specific features drive successful behavior change for depression treatment. Overall, I found that the non-deterministic design features may all be mitigated through a careful design of a feedback-capable system with the right level of personalization and user data. This finding leads to the conclusion that we can factor in technological determinism to design RAR systems with deterministic features to give the technology high ability to change human behavior for depression treatment.

Conclusion

In this paper, I have used two main frameworks to determine how rhythm-aware recommendation systems can be used to treat depression with respect to socio-technical concepts. My first framework evaluated the technology as a “fix” for depression using three

rules, and I found that it is simply lacking in part of the first rule, and still requires advantages over other approaches and success within the complex socio-technical system of mental mHealth applications. RAR systems did, however, have unambiguous criteria and have an established technical core, so the second and third rules were satisfied. My second framework, technological determinism, describes our world as driven by technology and its capabilities. While hard determinism is not necessarily an accurate view of the world, its perspective was useful in the analysis of RAR system design features and considering how each of them drive changes in human behavior, the main goal of the BA and PAS techniques that provide the strategic basis for RAR systems. I found that the deterministic features of RAR system design outweigh the non-deterministic features as feedback capability and the right amount of user data and personalization will mitigate the non-deterministic features. Overall, I conclude that RAR systems for behavioral depression treatment did not fully qualify as successful technological fixes, but have a high ability to change patient behavior when design features embrace technological determinism's idea that technology can indeed drive human behavior.

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