A MICRO-RANDOMIZED TRIAL TO IMPROVE COLLEGE STUDENTS' WAKE TIME REGULARITY

by

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DISSERTATION ABSTRACT

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Many college students experience irregular sleep patterns due to their unique schedule. These patterns confer risk for other sleep problems as well as mental health difficulties including mood disorders, physical aggression, and suicidal ideation. Current interventions to improve college students' sleep are often created using Cognitive Behavioral Therapy for Insomnia components, although the components used are often not consistent. These interventions are also plagued by drop out, often by those that need the intervention the most.

The current study takes a step toward creating an intervention with fewer, simpler components that is more agreeable to college students due to its ease and delivery through a phone-based application. In order to achieve this, I use a micro-randomized trial design to assess the most effective timing and content for an intervention that reminds students of techniques to help increase the regularity of their wake up times. The aims of the study were 1) to determine the feasibility and acceptability of the intervention; 2) to determine the effect of the reminders on immediate use of sleep hygiene strategies and on subsequent wake time regularity; and 3) to determine whether proximal outcomes were related to variability in wake times at the end of the intervention. Participants completed a baseline week of sleep diaries, an online psychoeducation

module about sleep regularity, and then entered the intervention phase, where they were randomized each day to receive a reminder. If they were randomized to receive one, the timing and content of that reminder were also randomized.

The results of this study indicate that participants were invested in completing our intervention and found it somewhat helpful. However, there was no effect of the reminders nor their timing or content on proximal outcomes. Lastly, there was no relationship between sleep hygiene use and wake time variability during the final week of the study. Although our results indicate that the intervention components were not effective, future iterations of the study are being planned to address several important limitations. The goal of the next iteration will be to assess the effect of these reminders without a number of unintended, confounding factors.

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TABLE OF CONTENTS

Chapter Page

LIST OF FIGURES

LIST OF TABLES

Table Page

Table Page

CHAPTER I

INTRODUCTION

The college experience is promoted as one full of opportunity and growth. Brochures for universities paint a rosy picture full of classes students will love, groups and clubs they will join, and, above all, differences they can make. For many, the reality of college is much bleaker. Students find themselves plagued with uncertainty about the present and the future. Attending school for the purpose of learning is often usurped by other, more thrilling or enjoyable activities, creating further confusion for students who came to college to "discover themselves." More concerning, however, is the toll college life can take on students' mental health. Rates of depression, anxiety, substance use, and risky decision-making are all elevated during the college years (Arnett, Žukauskienė, & Sugimura, 2014; Bradley & Wildman, 2002; Auerbach et al., 2016). The difficulties these disturbances create during those formative years coupled with their potential to persist beyond college indicates that mental health among college students is an area that is not being adequately addressed.

The sleep difficulties that are unique to college students' experience may contribute to their mental health difficulties. Often, their sleep is disturbed in part due to the circumstances of university life such as variable class schedules and frequent nighttime socializing. This chapter will detail difficulties with sleep regularity, a problem specific to college students, as well as causes and consequences of those difficulties.

Current sleep treatments that have been used in this population will be reviewed along with their limitations for treating college students' sleep problems. Lastly, the case will be made for the need to optimize these interventions, and provide an overview of a protocol and accompanying methods that could assist the field in that endeavor.

Importantly, college students fall into an unusual developmental category. Adolescence, a developmental period often studied especially in the context of mental health, is most often defined using age ranges from middle to high school. However, one commonly understood *end* to the adolescent period is the "attainment of adult roles and responsibilities" (Sawyer, Azzopardi, Wickremarathne, & Patton, 2018). As society has progressed, more young adults have attended college or engaged in other self-exploration before settling down, and it has become common to avoid the attainment of many of those traditional roles until one reaches their late twenties (Nelson & Barry, 2005). Given this predicament, a new developmental phase has been explored and labeled "emerging adulthood" (Nelson & Barry, 2005). This is meant to encompass the group that has attained traditional adult age but has not yet settled into their adult roles and identities. College students can be considered a subgroup of emerging adults. Although they fit this particular description, students often experience problems and circumstances that are unique to the college experience. One such problem is a specific lack of regularity in their sleep/wake patterns.

The State of College Students' Sleep

Regularity of bed times and rise times is a topic that is particularly relevant to college students' sleep, partially because it is one of few sleep parameters that actually worsens during the transition from high school to college. Studies demonstrate that while

sleep duration and quality improve across the transition from high school to college, regularity of bed and wake times, as well as their timing, decline (Doane et al., 2015). College students display irregularity between their weekday and weekend timing (Lund et al., 2010) that is similar to common patterns seen in high school students (Gradisar et al., 2013). Restricted sleep on weekdays gives way to extended sleep time on weekends to "make up" for lost sleep during the week. One study reported a two- to four-hour delay in bedtime from weekdays to weekends (Singleton & Wolfson, 2009). Doane and colleagues' (2015) longitudinal study indicated that variability in bed times and rise times increased in college. This indicates that college students experience further variability within the week as well. Indeed, Eliasson and colleagues (2010) found that on days they did not have class, students went to bed an average of an hour later, awoke two and a half hours later, and slept an hour and twenty minutes longer than on days when they had class. College courses often occur every other weekday (e.g., on Monday and Wednesday or on Tuesday and Thursday). In addition, there are more likely to be nighttime social activities during college than in earlier years. Given these factors, it is likely that many college students experience irregular sleep patterns on an almost daily basis.

In addition, college students' sleep timing tends to move later during this transition. The timing of college students' sleep is largely related to their developmental biology (described in more depth below), but also seems to relate to having more personal control over their schedule than in high school. However, as noted above, that control is largely available on non-class days. One study on college students' sleep patterns indicated that average bedtimes for students were around 11:40pm on weekdays, but much later on weekends at 1:17am. The same pattern was seen with wake times

(7:42am on weekdays, 9:45am on weekends; Buboltz Jr. et al., 2001). More recent studies of college students indicate slightly later school-night bedtimes that are closer to midnight for this group, while non-school bedtimes are consistently reported at just past 1:00am (Gradisar et al., 2013; Elliason et al., 2010; Singleton & Wolfson, 2009). Wake times have also remained consistent, with the exception of Gradisar and colleagues' (2013) finding that young adults woke up around 7:20am on non-school/work days. All of these reported bedtimes and wake times are close to an hour later than reports of high school students' sleep patterns (Gradisar et al., 2013), indicating that a shift occurs in the timing of sleep over the transition from high school to college. Zimmermann (2011) found that students who were characterized as "evening" types (later to bed, later to rise) were more likely to experience a greater degree of delay in sleep times from high school to college. Thus, that group may be the driving force of this difference.

Difficulties in regularity and timing may contribute to more commonly discussed sleep difficulties. For instance, keeping a regular sleep/wake schedule acts as a zeitgeber that informs the body when it is close to bedtime (Monk, 2010). For individuals who are not on such a schedule, it is harder to fall asleep because their bodies do not get sleepy at a regular time, leading to longer sleep onset latencies. Indeed, reports of latency in college students range from an average of 24 minutes (Lund et al., 2010) to 39.2 minutes (Mairs & Mullan, 2015), which is slightly longer than ideal (Ohayon et al., 2004).

In addition, irregular sleep/wake patterns may contribute to shorter sleep duration when the combination of a late bedtime (e.g., due to a late rise time that day) and early rise time (e.g., due to class schedules) occurs. Sources differ on whether college students' sleep duration meets recommendations. Estimates range from 6.9 hours during the last

year of college (Galambos, Vargas Lascano, Howard, & Maggs, 2013) to 8.5 hours by age 22 (the typical age during the last year of college; Maslowsky & Ozer, 2014). However, a study by Adams and Kisler (2013) found that 37% of college students reported getting less than 6.5 hours of sleep per night. While there are likely multiple contributors to this difficulty, it is clear that improving sleep/wake regularity would at the very least improve sleep duration. Daytime alertness is also a difficulty for college students. The quantified reports we have indicate that approximately two-thirds of college students believe they do not get enough sleep (Gradisar et al., 2013) and that about half report being "mostly tired" during the day (Buboltz Jr., Brown, and Soper, 2001).

All of these sleep deficits have been targeted in intervention programs; however, as we will see, sleep interventions for college students have considerable room for improvement. Although any improvement in sleep parameters may contribute to better mental health, it seems likely that improving the regularity of sleep/wake patterns would have downstream effects for other sleep parameters, which may have additive benefits for mental health. Before discussing interventions, however, I will present several correlates of disturbed sleep, specifically of lack of sleep regularity.

Variables Related to Inconsistent Sleep Patterns

Sleep disturbance is usually concerning because of the negative consequences it produces. Unfortunately, there is much evidence demonstrating that there are plenty of negative outcomes related to sleep disturbance regardless of age or stage of life (Knutson, Spiegel, Penev, & Van Cauter, 2007; Shochat, Cohen-zion, & Tzischinsky, 2014; Meerlo, Mistlberger, Jacobs, Heller, & McGinty, 2009; Okun, 2011). Difficulties keeping regular sleep/wake patterns are related to a wide range of biological, social, and psychological

phenomena. The college experience includes a unique blend of delayed circadian rhythms, novel academic and social environments, and increased risk for both internalizing and externalizing disorders. In turn, this blend of factors paints a complex picture when considering causes and consequences of sleep difficulties. Given the prevalence of cross-sectional, correlational studies within this field, variables related to sleep are presented here correlationally, along with any proposed hypotheses of causality. Longitudinal and experimental data are presented and used to strengthen these hypotheses when available.

Biological. The chronobiology of individuals of typical college student age has a significant influence on their sleep difficulties. Emerging adults straddle the adolescent and adult developmental periods. During the adolescent years, circadian rhythms tend to delay, so that teenagers feel ready for bed later. This delay peaks around age 20, and gradually returns to pre-adolescent levels (Roenneberg et al., 2004). This tendency to fall asleep late at night and wake up during late morning (or later) is termed "eveningness" (its counter being referred to as "morningness"). This developmental trend is seen across individuals, but those that tend more toward eveningness than their age-matched peers often keep that rank order throughout development. Those who experience the greatest shift toward eveningness tend to be at greater risk for difficulties. Research suggests that evening-types across age groups experience poorer sleep (Roeser et al., 2012), school performance (Tzischinsky & Shochat, 2011), and mental health (Gau et al., 2007; Lyall et al., 2018) than morning- or intermediate-types. Evening types are less likely than morning types to sleep for as long as they feel is necessary (Zimmermann, 2011), more likely to report fatigue (Taylor, Clay, Bramoweth, Sethi, & Roane, 2011), and have worse scores on scales designed to detect sleep disorders (Digdon, 2008). The irregularity

between weekday and weekend sleep is more extreme for evening types, and in one study, this group experienced more drastic changes to their sleep patterns during the transition from high school to college (Zimmermann, 2011). Digdon's (2008) sample of college students included so few morning-type participants that they were not included in analyses. This is not surprising given the developmental trajectory of circadian rhythms. In fact, one would expect that individuals exhibit more eveningness tendencies at college age than at any other. Thus, the sleep difficulties detailed above can be expected to plague a large number of college students due to their biological development alone. Given the existence of this phenomenon across species (Hagenauer & Lee, 2013), developmental circadian phase is thought to be largely biological and a contributor to sleep difficulties such as short duration and irregularity.

Social Processes. The college experience is dissimilar to just about every other phase of life. In high school, the timing of almost all obligations is set and the majority of new social connections are made within structured formats such as class or sports teams. Entrance into college offers a much different set of opportunities that are characterized by choice. Students can now choose which classes to take, when to take them, and when to work, which impacts sleep by giving them more control over when to schedule obligations. They also choose their social connections in more fluid ways, as the typical college classroom is not set up to form connections with peers, and joining student groups can be a task that is difficult to navigate. Twenty-five percent of a college-student sample reported that emotional stress was the greatest difficulty interfering with their sleep (Lund et al., 2010). Some of that stress likely stems from the novelty of the college environment, as well as the general prevalence of mental health difficulties (Arnett et al.,

2014). The social structure mentioned above can also contribute to difficulty sleeping, especially when living in college dorms. Galambos and colleagues (2013) found that students living on campus, as opposed to off-campus or with parents, had later bed times and wake times. Dorms offer a chance for more structured social connections than other aspects of college, making it likely that students will socialize for longer in order to solidify connections they may have trouble making elsewhere. However, few studies have explicitly examined the relationship between dormitory living and sleep at this point.

The phenomenon of sleeping later on weekends due to social activities, such as work or socializing and subsequently waking up early on weekdays, is known as social jetlag (Wittmann, Dinich, Merrow, & Roenneberg, 2006). The term is used because the subsequent days of early awakenings that follow these late nights can feel similar to switching time zones during travel. As mentioned above, this lack of regularity can result in shorter, to the point of inadequate, sleep duration.

Psychological Factors – Internalizing Symptoms. Sleep disturbances have long been associated with mental health disorders, especially internalizing disorders like depression and anxiety. Disturbed sleep is even a symptom of depression (American Psychiatric Association, 2013), suggesting an intrinsic connection. Associations between symptoms of mental health disorders and sleep difficulties are commonly present in college students (Owens, 2014; Friedrich & Schlarb, 2017). In a large, cross-sectional survey of these difficulties, students who endorsed more sleep difficulties on the PSQI also endorsed higher levels of negative mood and daily stress than those who had fewer sleep difficulties. In addition, students could write-in "other" reasons for sleep difficulty

on the PSQI, and the largest proportion of those write-ins related to stress and worry (Lund et al., 2010).

There are also several longitudinal studies that have examined this relationship. A study conducted over the transition to college measured sleep and mental health symptoms during students' senior year of high school, fall semester of freshman year of college, and spring semester (Doane et al., 2015). A cyclical relationship between subjective sleep problems and anxiety revealed that sleep problems at time 1 predicted anxiety at time 2, in turn predicting sleep problems at time 3. An inverse relationship was found for bedtime variability, which was predicted at time 2 by anxiety at time 1, but predicted time 3 anxiety levels. Thus, anxiety symptoms demonstrated a bidirectional relationship over time with multiple sleep variables across this longitudinal study. However, this study did not find that sleep variables predicted depressive symptoms at any time point (Doane et al., 2015).

Psychological Factors – Externalizing Symptoms. Being in college, like adolescence in general, is associated with an increase in risk-taking behaviors (Bradley & Wildman, 2002). There is an abundance of research on the relationship between sleep and risk-taking behaviors (O'Brien & Mindell, 2005; Catrett & Gaultney, 2009) and suicidal behaviors (Liu, 2004; Liu & Buysse, 2005; Fitzgerald, Messias, & Buysse, 2011) among high school students. However, very few studies have examined these relationships specifically in college samples. As has been mentioned previously, the unique sleep difficulties inherent to college student life make this a compelling area for research. Vail-Smith and colleagues (2009) examined several risky behaviors and found a cross-sectional association between sleep quality and both getting into a fight and considering

suicide in the past 12 months. Randler and Vollmer (2013) found a specific correlation between social jetlag and increased physical aggression. Moreover, Bernert and colleagues (2017) assessed college students at three time points over a 21-day period. Sleep variability, measured via actigraphy watches (devices that record movement, enabling them to detect sleep periods), predicted suicidal ideation at both 7- and 21-day follow ups, controlling for depressive symptoms. The small amount of research conducted on this topic indicates that sleep disturbance may predict suicidal ideation and aggression.

It is difficult to tease apart the causes and consequences of, as well as the bidirectional relationship between, irregular sleep and other difficulties in college students. Disturbed sleep is related to many aspects of functioning for college students. Students' social atmospheres and developmental stages likely contribute to late timing of sleep periods. Sleep demonstrates a possible bidirectional relationship with variables commonly thought of as consequences of sleep disturbance, such as mental health difficulties. However, longitudinal research makes clear that some of the most harmful correlates of sleep are likely to result from poor sleep quality, sleepiness, and short sleep duration, all of which may be affected by sleep/wake irregularity. These include depression, anxiety, getting into fights, and suicidal thinking. The evidence above paints a clear picture of students who are in need of intervention on some level in order to improve the quality of their lives and decrease their risk for distress, injury, and even death. Many researchers have attempted to tackle this problem by creating interventions to improve sleep for college students.

Sleep Treatment Available for College Students

Studying college students as a population of interest because of their specific developmental stage and context is a relatively new endeavor. College students have often been used as the "guinea pigs" of psychology research because they are a sample of convenience. Most universities conducting psychology research have built-in mechanisms to receive data from students for college credit. This makes students easily accessible and low-cost participants who often provide the first set of data to test any given hypothesis. Unfortunately, research questions have often ultimately focused on a different population, so our use of college students as an analog population rarely translates back into help for their specific needs or improvement of their circumstances. Instead, the next steps of research are rolled out for the population of interest.

However, a number of sleep treatments directed at college students specifically have emerged in the last decade (e.g., Baroni et al., 2017; Levenson et al., 2016; Quan et al., 2013). Although validated sleep interventions exist for younger adolescents (Blake, Sheeber, Youssef, Raniti, & Allen, 2017) as well as adults (Morgenthaler et al., 2006; Zachariae, Lyby, Ritterband, & Toole, 2016), colleges provide a unique opportunity to reach a large number of participants through interventions that are integrated into those academic or social structures. Friedrich & Schlarb's recent (2017) systematic review illuminates the main intervention components and delivery methods of sleep treatments for college students. Here, I will briefly summarize the state of these interventions and, importantly, their current limitations.

The majority of sleep interventions for college students have utilized components of Cognitive-Behavioral Therapy for Insomnia (CBT-I; Morin et al., 2006; Schutte-Rodin, Broch, Buysse, Dorsey, & Sateia, 2008). The principles and key interventions utilized in

CBT-I aim to consolidate sleep into efficient time periods, rather than the broken, inefficient sleep that people with insomnia tend to experience. The hallmark components of CBT-I include restricting the amount of time one spends in bed (sleep restriction, which is followed by sleep extension after sleep efficiency has increased), exclusively using one's bed for sleep (stimulus control), and challenging negative cognitions and worries about sleep (cognitive restructuring; Perlis, Jungquist, Smith, & Posner, 2005). An additional component of CBT-I is self-monitoring sleep diaries. This often includes calculating clients' own sleep efficiencies, based on the amount of time spent asleep divided by the amount of time spent in bed.

Other components of CBT-I are used more widely in interventions without the behavior change skills described above. These include relaxation techniques, such as progressive muscle relaxation, guided imagery, and diaphragmatic breathing, that are intended to decrease arousal and facilitate sleep onset. Sleep hygiene tips are also made available in CBT-I. These can include how the timing of eating, drinking caffeine, and exercising can affect sleep, as well as how to optimize one's sleeping environment. In addition, there are interventions that use simple education to intervene on sleep difficulties by providing participants with information about sleep and better sleep hygiene. Delivery of these methods occurs through traditional therapy methods, both individual and group, as well as through college courses and email- and other technology-based interventions.

Examination of the studies reviewed by Friedrich & Schlarb (2017) indicates that use of the components listed above is very study dependent. While many used sleep diaries, for example, very few used the sleep restriction technique, a hallmark CBT-I

component. Often many components were presented in email or other online formats and thus were not well integrated into a larger, in-person intervention.

As with all forms of treatment, sleep interventions for college students include a certain amount of participant dropout. Dropout percentages in college students range from 8.6 (Petrov et al., 2014) to 31 percent (Farias, 2012). The average dropout percentage across studies cited by Friedrich & Schlarb (2017), not correcting for sample size, was 18.9 percent. Thus, the average study lost one participant for every four to five who consented to the study. Although many factors can contribute to drop out in intervention studies, I believe the various and non-uniform components mentioned above may create specific risk for drop-out. Given the busy schedules of college students, it is likely that interventions with multiple visits and a variety of intervention targets provide too many barriers to treatment, leading to more students opting out.

The Burden of Sleep Treatments for College Students

The contrast between the burden college students face as a result of poor sleep and the fact that almost one in five students drop out of sleep interventions signals a need for change. While many of the interventions cited above demonstrate effective reductions in sleep disturbance, there are many students who these interventions do not reach, even after they have been recruited and consented. There is evidence from college counseling centers that students with the largest number of presenting problems are the most likely to drop out of treatment (Castonguay et al., 2017), indicating that those who these interventions do not reach may be in the most need. In order to reduce the incidence of difficulties with mental health, physical aggression, and suicide risk, as well as other

sleep-related difficulties, a greater effort must be made to create interventions that are feasible and digestible for college students.

There are many possible avenues to tackling this particular task. An effort to create workshops and courses more congruent with college life was one such attempt (Baroni et al., 2018; Tsai & Li, 2004). Disseminating interventions in dormitories rather than classrooms may be another. However, to accomplish any of these tasks and still create a feasible intervention, it seems that we need a better understanding of which components of interventions are truly effective. By using feedback from college students themselves, we can determine which components and delivery systems are most effective and parsimonious. Shorter and more specific interventions may also be more easily integrated into dormitories, etc. than more traditional therapeutic modalities. For example, an intervention focused only on improving sleep/wake regularity may be effective by creating downstream effects on other difficulties such as short sleep duration and long sleep onset latency. Even then, however, the effective intervention components would have to be determined. Strategies to determine these effective components are discussed below.

Addressing Intervention Burden through Component Analysis

Dismantling Studies

Questioning the effectiveness of certain components over others is not a new concept to those who study psychotherapy. Although they are still not conducted often, dismantling and add-on studies have been used to examine the utility of treatment components across treatment types. Dismantling studies compare the full model of a certain treatment to that model without one or more of its hypothesized "main ingredients"

(Papa & Follette, 2015). The theory underlying this method is that a component's necessity will be determined by the differences in treatment outcome between conditions. Thus, if the full condition and the pared down condition yield similar results, the absent component is not a necessary component of the treatment. Add-on studies operate out of the same theory, but instead of removing components, conditions include additional components to the full treatment model (Papa & Follette, 2015).

Although these types of studies exist in psychotherapy more generally (Jacobson et al., 1996; Resick, Galovski, Uhlmansiek, Scher, & Clum, 2008), there are very few that examine the effectiveness of components of sleep treatment. Epstein, Sidani, Bootzin, & Belyea (2012) conducted a dismantling study of behavioral treatment for insomnia in a sample of older veterans. They included conditions using only stimulus control or sleep restriction, as well as the combination of the two, and found no difference across conditions in sleep outcomes. However, remission rates were better for those in the full treatment condition (Epstein et al., 2012). This type of study within the realm of sleep interventions has been rare. To our knowledge, there is no component analysis research on sleep interventions for college students. This seems a large oversight in the field considering the numerous types of interventions that have been created for this population and the varied forms those interventions have taken.

Dismantling studies would begin to address the question of which components of sleep interventions are effective. However, these studies come with some limitations. Doss (2004) points out that breaking down treatment into components only examines change processes without addressing change mechanisms outside of the therapy room. Papa & Follette (2015) specifically point to limitations of the comparisons that are made

in these studies. When components are removed, but treatment implementation is still matched on the basis of number of sessions or homework, participants, and later clients, are actually receiving a larger dose of Component A than they would in the full treatment when Components A and B are both utilized within the same time span. It is nearly impossible to truly isolate the component in question without compromising other elements of the intervention, including timing and the interaction between and order effects of multiple components in the full treatment model (Papa & Follette, 2015). In addition to these critiques, Ahn and Wampold (2001) conducted a meta-analysis on component analysis studies of psychotherapy during the 1990s. Their results demonstrated that the average effect size was not different from zero. This finding has been interpreted multiple ways. The authors posited that specific treatment components are no more important than general characteristics of therapy (Ahn & Wampold, 2001), whereas others have speculated that this finding was due to the lack of specificity in identifying the mechanisms of change (Doss, 2004).

Emerging Methods

New methods of component analysis have recently emerged, both in response to limitations of current component analysis methods and to accommodate interventions utilizing various forms of technology for dissemination. Such methods are comprehensively included in the Multiphase Optimization Strategy (MOST; Collins, Murphy, & Strecher, 2007). MOST was designed as a method for creating interventions that include the most effective treatment components disseminated within the optimal context and timing. Studies that would contribute to the design and components of the final intervention occur in phases. Phase 1 examines potential components to be included

in the study by evaluating their effectiveness on their own as well as their interactions with other components. Components are then selected based on their effectiveness. Phase 2 refines the use of selected components by determining their optimal level and timing. Phase 3 combines these components used at their optimal levels and tests the whole intervention against a control treatment, just as is done in a randomized clinical trial (Collins, Murphy, & Strecher, 2007). Methods used to complete Phases 1 and 2 are discussed below.

Factorial design and analysis are major contributors to Phase 1 of MOST. Utilizing factorial designs over trials that compare one program or delivery component to another provides several analytic advantages. First, both main effects of and interactions between components can be assessed. When designing a presumably multi-component intervention, it is important to know not just what "works," but also how components work in the context of each other (Collins, Dziak, Kugler, & Trail, 2014). Second and relatedly, the main effect of each component is analyzed while controlling for other components, because each subject has received some level of each component (Baker et al., 2017). This is an inherently different analysis than a trial that compares components to each other without controlling for their presence or absence. Factorial designs allow the investigator to understand how each component behaves controlling for and in the context of other components. Determining which components will work together to create the most effective treatment package marks the end of Phase 1 (Collins, Murphy, & Strecher, 2007).

An important method during Phase 2 is known as a micro-randomized trial (MRT). In a MRT, one participant can receive multiple levels of a treatment component

by randomizing what they receive at each "decision point." Decision points occur every time a participant has the opportunity to receive an intervention component. Decision points are at the discretion of the intervention creators, but an example would be randomizing participants into types of booster sessions (i.e., in-person, phone-based, or none) at each possible booster session time point. If the intervention offered potential booster sessions on a monthly basis for six months, a new decision point would occur each month, and participants could be randomized into a different condition at each of those six time points. Two goals of MRTs are to evaluate an intervention component both between- and within-subjects and to have the opportunity to evaluate different dimensions of the component in one intervention (Dempsey, Liao, Klasnja, Nahum-shani, & Murphy, 2015). In the example given, the delivery component of the intervention is being evaluated, in addition to the effect of its absence versus presence. Intervention components could also randomize content, such as randomizing different types of psychoeducation or behavioral prompts a person receives at each decision point. In this way, MRTs examine several dimensions of a component at once, taking both within- and between-subject effects into account (Dempsey, Liao, Klasnja, Nahum-shani, & Murphy, 2015). This type of design makes MRTs especially suitable for Phase 2 of MOST. By examining both the content and delivery of each intervention component, questions of timing, frequency, and effective content can be answered. In addition, when decision points and data collection are relatively frequent, researchers can examine the proximal effect of any one intervention, as well as the lagged outcomes that could occur days or weeks following the intervention.

One example of such a trial comes from Klasnja and colleagues' (2015) study of a program called HeartSteps. The goal of this trial is to increase sedentary participants' step count to 10,000 steps per day. The main intervention components are behavioral suggestions that are meant to encourage a gradual increase in activity. The researchers varied features of the components to determine most effective intervention delivery. This included offering five decision points each day at which time a participant could receive one of two types of suggestions (either going for a walk or standing up and stretching). The researchers also used randomization to ensure that participants received, on average, two suggestions per day out of the five possible time points (Klasnja et al., 2015). The goal of such an endeavor is to create a "just-in-time" adaptive intervention (JITAI; Spruijt-metz & Nilsen, 2014). Such an intervention would be informed by enough data to deliver optimally helpful interventions at times that are most effective.

The MOST protocol and its accompanying innovative paradigms allow researchers to create optimized and, often personalized, interventions. So far, most of this work has been done to create interventions for health outcomes such as increased physical activity to prevent cardiovascular disease (Klasnja et al., 2015) and obesity (Pellegrini, Hoffman, Collins, & Spring, 2014), as well as smoking (Piper et al., 2017). Sleep, however, is not an outcome that has been examined this way to our knowledge. However, it is not difficult to conceptualize a JITAI for sleep outcomes that could be designed using the MOST protocol. Sleep difficulties faced by college students can be addressed in a number of ways, as we have seen above. The interventions above could be optimized by separately examining the effectiveness of components, their optimal timing and content, and subsequently the treatment as a whole. Using the college students to

conduct studies in Phase 1 and 2 would offer specifically relevant information about which components and their combinations are effective specifically for that population. In addition, at least some sleep difficulties would also lend themselves to the type of interventions used by Klasnja and colleagues (2015) and others, namely, interventions that are "pushed" to participants in a randomized fashion. The majority of interventions used for sleep difficulties fall under specific types of behavior change and psychoeducation. Developing an intervention to deliver those two categories of interventions to participants could follow a MOST protocol pattern and ultimately resemble the HeartSteps intervention (Klasnja et al., 2015).

The Current Study

Theory of Change

One area of interventions for which the MOST protocol excels is just-in-time adaptive interventions (JITAIs). The concept behind JITAIs is that the decision to change behavior is, at least partially, a time-dependent one. The given context that a person can find themselves in affects whether or not they will make a helpful, neutral, or harmful decision. For example, someone is prompted to make sure to eat a healthy lunch, the behavior is more likely to occur if healthy food is available where they are. In addition, few people will get up in the middle of a work meeting to get in their needed daily steps. Instead, prompts must be tailored to an individual's current context in order to have the best chance of having the desired effect (Spruijt-metz & Nilsen, 2014).

One way of creating interventions that can be delivered at specific times is to prompt participants when a detected "optimal" time has occurred. Given the prevalence of smart phones in our lives, such prompts can easily be delivered in a way that will get

our attention "just-in-time." The question, then, is what to send. In the current study, we opted for very basic reminders such as something one would receive from an app such as Fitbit. In effect, we have altered the environment to make the desired behavior more salient without taking away participant options (Thaler & Sunstein, 2008).

Goals of Current Study

Given the burdensome consequences of poor sleep, including poor mental health, substance use, and risky behavior, this is not an area where we can afford to be satisfied by trials with poor retention and unstandardized methods for choosing intervention components. Thus, in the current study, I used the micro-randomized trial design to deliver reminders to college students related to their sleep/wake regularity. One of the preeminent sleep hygiene techniques in CBT-I is regulation of wake times. Because people are often unable to control when they become sleepy, a set wake time allows for control of the sleep period by fixing the beginning of the waking period and allowing sleep pressure to become greater over the course of the day, helping one become sleepy at a similar time each day. Sleep hygiene tends to emphasize the regularity of wake times regardless of bedtimes because of the tendency to become sleepy the longer one is awake (Perlis, Jungquist, Smith, & Posner, D., 2005). Thus, our reminders focused on students' use of techniques to wake up at or around the same time each day. I tested the effectiveness of differing levels of timing and content within the reminders to determine whether there are optimal levels.

This study was meant to be a first step toward creating a JITAI for sleep in this population. Many variables were not considered in order to focus on creating a minimally

viable product (MVP). Only the presence of these reminders, their timing (addressing the JITAI concept that the specific time is key), and different content were manipulated.

Specific Aims

The goals of the current study are two-fold. First, I hoped to test the use of a micro-randomized trial for a sleep intervention, which has not previously been done to our knowledge, and to assess the acceptability and feasibility of this study for our participants. Second, I assessed the effectiveness of the reminders themselves, as well as the different levels of timing and content, on wake time regularity both throughout the study and during the final week. Consequently, there are three specific aims.

Aim 1. The first aim is to determine the feasibility and acceptability of this micro-randomized trial. This will be measured using the time participants take to complete study components, how often participants indicate following the instructions of a "nudge" (reminder), the objective level of retention, and participants' responses to a study satisfaction questionnaire.

Aim 2. The second aim is to determine whether the micro-randomized "nudges" have an effect on the two *proximal outcomes*: use of wake up techniques and daily wake time regularity. I hypothesize that the intervention will increase the use of wake up techniques as well as regularity of participants' wake times. There are no set hypotheses as to whether the proximal outcomes will be affected by the timing or content of the delivery of the nudge.

Aim 3. The third aim of the study will be to determine whether the *proximal outcomes* affect variability in wake times during the final week of the intervention. I

hypothesize that an interaction between the presence of nudges and participants' successful response to them will predict the final outcome.

CHAPTER II

METHOD[1]

Participants

Participants were college students at a university in Oregon. Thirty-seven participants consented to participate in the study, 34 of whom completed the study (see Participant Recruitment section for more details). Participant ages ranged from 18-24. Twenty-one (57%) of the participants identified as cis-gender women and twelve identified as cis-gender men. Two participants identified as gender queer/gender non-conforming, and one other identified as a transgender woman. Twenty-two (59%) participants identified as Caucasian, five Asian, three Latin or Mexican-American, three Black/African-American, three biracial, and one Ethiopian.

Procedure

Overview of Intervention. The goal of the project was to intervene on the regularity of college students' wake times using "nudges" sent to their phones that would encourage them to plan ahead and use specific techniques to help them wake up at a similar time each morning. The intervention consisted of a week of baseline sleep diary data collection followed by an online psychoeducation module and subsequent, micro-randomized nudges over 4 weeks.

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[1] All procedures were reviewed and approved by the University of Oregon IRB.

Participant Recruitment. For this study, I recruited college students from a public higher education institution in Oregon using the psychology research participant pool, classroom announcements, emails to undergraduate coordinators for specific departments on campus, and printed flyers to post in public places on campus (department list and recruitment materials can be found in Appendix C). Eligible participants were 18-24 years old, owned an Android phone that they used as their primary phone, reported no prior diagnosis of a sleep disorder, and reported greater than two hours of variability between their earliest and latest wake up times during the past week. Sixty-nine students responded to the recruitment invitation. Thirty-seven (53.6%) of those participants attended the consent session, consented to participate, and completed the consent session (see Table 1 for additional information on ineligibility/non-consent). Subsequently, two participants' phones were deemed incompatible with the software application, and one student contacted the research assistant to withdraw from participation. That participant did not provide a reason for withdrawing. Thirty-four participants completed the study. Two participants' sleep diary and nudge data were removed prior to analysis because the nudge data indicated that the application had not created a nudge opportunity on multiple occasions. This error was likely due to the phone closing the application when it was not in use.

Consent Session. Participants who attended the consent session were consented and completed a baseline questionnaire battery (see Materials section for the full battery list). Next, the researcher installed the study software application on their phone, for the purpose of sending reminders to their phone about wake-up techniques and completing daily questionnaires. See Appendix D for the consent form.

Baseline Week. During the first week of the study, participants received daily sleep questionnaires approximately half an hour after their reported average wake up time.

Psychoeducation Session. After participants completed their baseline week, they received a link to a website where they received psychoeducation about their sleep regularity. The focus of the psychoeducation was on the benefits of keeping a regular sleep schedule and techniques for achieving this goal. Participants interacted with the website by reading the psychoeducation materials, responding to questions about their current sleep regularity, and creating a plan to help them achieve a more regular schedule. Participants were asked to review the website within 48 hours of receiving the link (days 5-7 of the study). See Appendix E for the content of the psychoeducation website. Due to a bug in the application, the majority of participants received a notification to complete the psychoeducation session more than once. Twenty six (76%) participants did complete the module more than once, with one participant completing it 12 times.

Intervention Weeks. For four weeks following the psychoeducation session, participants continued to receive daily sleep questionnaires approximately half an hour after their reported average wake up time. They also received prompts ("nudges") according to a micro-randomized pattern (see Table 2) that encouraged them to increase the regularity of their wake times. One decision point occurred per day. At each decision point, participants had a seventy-five percent chance of receiving a nudge. Given that they were randomized to receive a nudge, participants had a fifty percent chance of receiving each of two possible prompts: a) "Make sure to set your alarm for your normal wakeup time" or b) "Remember to use your wake up routine tomorrow morning."

Participants could also receive a nudge either one hour or four hours before their reported average bedtime on nights they were randomized to receive one. Once again, they had a 50 percent chance of receiving either timing option.

Study Check-ins. All participants received a call approximately one week after their psychoeducation session to make sure their experience was going well and to evaluate whether they had experienced any specific difficulties related to the software application or surveys. Efforts were made throughout the study to address difficulties that arose in the beta version of the application.

Debriefing Session. During their final session, participants completed the same battery of questionnaires as at the consent session (aside from the demographic questions), with the addition of a satisfaction survey (Appendix F), in which participants were briefly interviewed about their experience in the study, including what they did and did not enjoy and what they thought could have gone better. Third, participants were debriefed regarding the purpose of and format of the study. Lastly, the application was uninstalled from their phone. See Appendix G for debriefing form.

Compensation. Participants had the option to receive compensation in the form of money or course credit. The majority of participants received 20 dollars for completing the consent session, 35 dollars for completing the online sleep education module, and 45 dollars for attending the debriefing session. The final two payments were provided at the debriefing session. Seven (21%) participants chose to receive research credit that was part of their course requirement. These participants received one credit for completing the consent session, one credit for completing the online sleep education module, one credit

for attending the debriefing session and one credit if they opened 75 percent of the sleep diary surveys that they received during the study.

Materials & Measures

Demographics. I asked participants for the following information at the consent session: date of birth, age, biological sex, gender identity, race & ethnicity, parental highest education (for socio-economic status), and whether they have ever been diagnosed with a sleep disorder other than insomnia, such as narcolepsy or sleep apnea. I also asked for their mailing address and phone number to keep in contact with the participants over the course of the study (Appendix H includes all Demographic questions).

Pittsburgh Sleep Quality Index. The PSQI (Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989; Appendix I) is a validated self-rated questionnaire used to assess subjective sleep quality and disturbances and the impact of poor sleep on functioning over a one-month interval. The questionnaire contains 19 individual items that are used to create seven component scores. Each component score indicates a different aspect of sleep difficulty: subjective sleep quality, sleep onset latency, total sleep time, sleep efficiency, sleep disturbance, taking sleep medicine, and daytime dysfunction. These scores are summed to create one overall score indicating sleep quality, where higher scores indicate poorer sleep quality. A cutoff of five was established as a reliable indicator of poor or disordered sleep (Buysse et al., 1989). Research has demonstrated that the scale has good internal consistency at the level of individual items ($\alpha = 0.83$) and at the level of components ($\alpha = 0.83$). Paired t-tests

conducted 18-months apart indicated that the scale also has good test-retest reliability (Buysse et al., 1989).

In this sample, participants had an average score of 7.46 (sd = 2.94) at their consent session, and an average score of 9.76 (sd = 3.59) at their debriefing session. PSQI scores ranged from 0 to 13 at baseline and 0 to 17 at the debriefing session. In this sample, the PSQI lacked adequate internal consistency, specifically at baseline ($\alpha = 0.66$). At the debriefing session, internal consistency was right below the "adequate" cutoff ($\alpha = 0.69$; Tavakol & Dennick, 2011).

DASS-21. The DASS-21 is a short-form version of the original Depression Anxiety Stress Scales (Lovibond & Lovibond, 1995; Appendix J). The original scale was developed to make a clear distinction between self-reported anxiety and depression, and resulted in a third factor being discovered that was labeled "stress." The questionnaire has largely been used with and was normed in non-clinical samples. The original questionnaire consisted of 42 items; however, the short version of the form that does not contain several of the weaker items from the original was used for this study (Henry & Crawford, 2005). An analysis of the DASS-21 indicates that it has good reliability as an entire scale ($\alpha = 0.88$) as well as within the depression ($\alpha = .82$), anxiety ($\alpha = 0.90$), and stress ($\alpha = 0.93$) subscales.

In this sample, the average depression score was 11.78 (sd = 9.86) at baseline, which is considered mild on the DASS scale. The average depression score at the debriefing session was 9.19 (sd = 8.35), indicating "normal" levels of depression. At baseline, the average anxiety score was 8.54 (sd = 6.59) which represents mild levels of

anxiety, while the average score at debriefing was 6.54 (sd = 5.84), which indicates "normal" levels of anxiety. Lastly, the average stress score at baseline was 13.51 (sd = 9.12). At the debriefing session, the average score was 11.68 (sd = 9.12). Both scores indicated "normal" levels of stress.

The internal consistency for the DASS scale was good at baseline (α = 0.91), but just below adequate at the debriefing session (α = 0.69). The depression subscales had good internal consistency at both time points (baseline α = 0.89; debrief α = 0.87). The anxiety subscales had adequate internal consistency at baseline (α = 0.70) but were below adequate at the debriefing session (α = 0.62). Finally, the stress subscales had good internal consistency at both time points (baseline α = 0.83; debrief α = 0.81).

MEQ. The MEQ is a questionnaire designed to assess participants' levels of morningness versus eveningness, in other words, when they feel they function best during the day (Horne & Östberg, 1976; Appendix K). The scale contains 19 items that question when participants feel best or more able to do specific activities during the day, as well as questions about when participants would normally go to bed or wake up if they were not adhering to any external schedule. A review of chronotype literature indicated that the MEQ shows good reliability (0.76-0.86) in multiple studies (Adan et al., 2012).

Participants' average score on the MEQ at baseline was 43.84 (sd = 8.22), which indicates the "Neither" category. Scores ranged from 29 to 68, indicating that none of our participants were categorized as "Definitely Morning" at baseline. The average score at the debriefing session was 48.17 (sd = 6.96) and scores ranged from 36 to 67. Thus, at the debriefing session, none of our participants were categorized as "Definitely Morning" or

"Definitely Evening." The scale demonstrated adequate internal consistency at baseline ($\alpha = 0.80$) and debriefing ($\alpha = 0.72$).

Daily Sleep Diary. Participants received a smart phone delivered notification to complete the daily sleep diary each morning, approximately half an hour after their reported typical wake up time. The daily sleep diary asked participants what time they got into bed, fell asleep, woke up, and got out of bed during their most recent sleep period. They were also asked to record any naps they had taken in the past 24 hours and how many minutes they believed they had spent napping (see Appendix L for full sleep diary). The daily sleep diary was designed by the PI for this study, but asks questions similar to other published daily sleep diaries (such as the Pittsburgh Consensus Sleep Diary; Carney, Buysse, Ancoli-Israel, Edinger, Krystal, Lichstein, & Morin, 2012). Following the first week of the study, the diary also asked whether they received a prompt and whether they adhered to the prompt's suggestion.

Phone Application. The application was developed explicitly by the ADAPT Lab at University of Oregon for this project and was installed on participants' phones to passively collect data that allowed the researchers to approximate the time participants went to sleep and woke up. The application specifically collected when the participant's phone was charging, when the phone was moving (using phone accelerometer and gyroscope data), and light exposure in lumens, with a +/- 3 lux filter. Movement sensor data were collected using the following parameters: Accelerometer: 10Hz, with a 0.05 ms-2 filter (i.e., any changes less than 0.05 meters per second per second are ignored) Gyroscope: 10Hz, with a 0.01 radians per second filter. These data were encrypted and pushed to a cloud-based service once per day for storage. In addition, the phone

application pushed a link for the sleep diary to participants once per day, a half hour after their reported typical wake up time. It also delivered the "nudges" to participants during the intervention phase.

Participants reported their typical bedtime and wake up time on weekdays and weekends in order to inform individualized timing of application-delivered nudges. They reported this information as part of the application installation process.

Of note, the application went through several iterations during the course of the study. Changes were minor but important, and mostly consisted of removing bugs. For instance, the ability to dismiss nudges was removed so that participants had to open the application in order to dismiss them, rather than swiping them away. Five participants redownloaded the application in order to fix a bug that allowed repeat sleep diary notifications.

Data analysis

Power Analysis. An a priori power analysis was conducted using the MRTSampleSize R package, a tool used to determine the needed sample size for a given micro-randomized trial (Huang, Seewald, Liao, and Sun, 2017). I entered the following parameters: 28 decision points occurring once per day, a predicted quadratic effect, and a predicted effect size of 0.3. For 80% power and an alpha level of 0.025, 33 participants were needed.

The number of decision points is further explained above. The quadratic effect was included because I hypothesized that the effect of the intervention would weaken over the course of the study. The predicted effect size was difficult to estimate, since this

is the first micro-randomized trial to be conducted in relation to sleep. We used the smallest sample size found in studies examining sleep hygiene education (Tsai & Li, 2004).

Analyses Addressing Aims. I used for R (R Core Team, 2018) for all of the analyses.

Aim 1: Acceptability and Feasibility of the Intervention. Descriptive statistics were calculated for three main variable categories: demonstrated participant investment, reported participant opinion, and demonstrated and reported helpfulness of the intervention. Means and standard deviations are reported in relation to the range of each scale. In addition, a paired samples t-test was conducted to assess the difference between participant reports of their wake time variability during the first and last seven days of the intervention.

Aim 2: Effect of the Intervention on the Proximal Outcomes. Two proximal dependent variables were computed to assess the effect of the intervention on proximal outcomes. The first variable indicates whether a participant acted on the nudge they received on any given day. Participants responded about whether they followed the nudge's instructions or not, and responses could be 'yes,' 'no,' or 'partially.' Participants wrote in what they meant by partially. The variable used is dichotomous: true if participants indicated following the nudge's instructions and false if they did not. There is also a value for no nudge received. Thus, responses that indicated that participants 'partially' responded to the nudge were hand coded to determine whether participants enacted the change behavior encouraged by the nudge or not. Participants who received

the “alarm” nudge were considered to have followed instructions if they reported setting an alarm that was within one hour of their normal wakeup time. Thus a ‘partial’ response coded as ‘yes’ could have been “I set my alarm for half an hour later than normal.” Similarly, participants who received the “wake up routine” nudge were considered to have followed instructions if they reported engaging in some component of a wake up routine other than setting their alarm. If these conditions were not met, the variable was coded as false.

The second proximal dependent variable is the rolling standard deviation for each 5-day window of wake up times. Each wake-up time was converted to number of seconds after midnight. The zoo package from R (Zeileis & Grothendieck, 2005) was used to calculate the average wake up time and standard deviation for each 5-day window (e.g. days 1-5, days 2-6, days 3-7, etc.). Values were then converted back to time format. Thus, the dependent variable represents the variance in wake up times for five days following any given nudge (or non-nudge) event.

The original wake time variable was winsorized to address wake times that were likely mis-entries (e.g., 12:00am or 8:40pm). I chose to decide on a specific cut off after examining the data in order to keep as much data as possible that seemed within a reasonable scope of college student wake times. The options I examined were winsorizing values outside of 2 or 3 standard deviations or winsorizing a percentage of values (not to exceed 5%). Analyses were conducted with winsorized and original values for both aim 2 and aim 3.

Modified generalized estimating equations were used to analyze the effect of the intervention on these proximal outcomes. Generalized estimating equations allow evaluation of linear models within clustered data. In order to analyze the effect of each intervention point on subsequent behavior, an independent working correlation matrix was used. Other methods use all of the existing data to estimate an effect, while this method allows only variance from the data following the intervention point to be included in estimation. This specific method allows the researcher to make a clearer causal inference regarding the effect of the intervention point on the proximal outcome. Although this type of correlation matrix ignores correlations that certainly exist in within-subjects data, it allows causal inference to be preserved because of the way it estimates. In addition, robust standard errors were specified due to the presence of within-subjects covariance.

Our original plan was to conduct hierarchical models followed by model selection using the quasi-likelihood information criterion (QIC). This fit index is appropriate for generalized estimating equations because both QIC and GEE are non-likelihood based, whereas more commonly used fit statistics such as the Akaike information criterion (AIC) are based on maximum likelihood estimation (Pan, 2001). The relevant hierarchical models would have included the following independent variables, added one-by-one in this respective order: intervention condition, day in study, the interaction of the first two, quadratic of day in study, interaction between quadratic and intervention condition, baseline dependent variable, and gender. Three intervention conditions were assessed: the presence or absence of a nudge, the timing of the nudge, and the nudge's content. Thus, for the model assessing the effect of the nudge's presence on variability in

wake up times over the following 5 days, the following variables would be added one-by-one to the equations: nudge presence/absence, day of study, the interaction of these two, variability in wake up times during the 5 days before the nudge, and gender. An unforeseen obstacle prohibited us from following through with this analytic method. In order to obtain the QIC for a given model in R, a GEE model object must be supplied. Due to the necessity of multiple imputation, one GEE summary does not exist for each model, and the steps taken to summarize the coefficients into one model do not yield the same object class. Thus, using existing R packages, it does not seem possible to obtain the QIC of models that result from multiple imputation. It was determined by this author and members of the committee that attempting to move analyses to another software at this stage would be too costly. Thus, it was instead decided that one model with solid theoretical grounding and parsimony would be used for each sub aim within aim 2.

The following models were decided upon as a result. To test the effect of nudge timing (1 hour versus 4 hours before bed) on nudge response, I included a) nudge timing, b) the participant's current day in the study, c) the interaction of a) and b), d) the quadratic form of current day in study, e) the interaction of a) and d), and f) whether the day was a weekday or weekend. To test the effect of nudge content (setting an alarm versus using a wake up routine) on nudge response, I included a) nudge content, b) the participant's current day in the study, c) the interaction of a) and b), d) the quadratic form of current day in study, e) the interaction of a) and d), and f) whether the day was a weekday or weekend. It was hypothesized that engagement with nudges would increase over time in the study, but that there may be an acclimation that occurred before the study was over. This is the reason for both the linear and quadratic variables. There is also

reason to believe that students would be less likely to engage with nudges that encourage them to wake up "on time" on weekend days. To test the effect of nudge presence on rolling wake time variability, I included a) nudge presence/absence, b) day in study, c) the interaction of a) and b), d) quadratic of day in study, e) the interaction of a) and d), and e) the variability in wake up times during the 5 days before the nudge. To test the effect of nudge timing on rolling wake time variability, I included a) nudge timing, b) day in study, c) the interaction of a) and b), d) quadratic of day in study, e) interaction of a) and d), and e) variability in wake up times during the 5 days before the nudge. To test the effect of nudge content on rolling wake time variability, I included a) nudge content, b) day of study, c) the interaction of a) and b), d) quadratic of day in study, e) interaction of a) and d), and e) variability in wake up times during the 5 days before the nudge. Variability in wake up times during the 5 days before the nudge acts as a baseline measure in these models. I chose to omit gender from all models because there was no theoretical reason for keeping it; rather, I had intended to include it in a possible model to assess whether its presence contributed significantly to model fit. Each model was run on each imputed dataset; thus, parameter estimates were pooled using Rubin's rules (Rubin, 1987) to obtain one set of results for each model.

Aim 3: Relationship between Proximal and Final Outcomes. The ultimate goal of a micro-randomized trial is to affect longer term outcomes – in this case, to improve long-term wake time regularity. One of the inclusion criteria for the study was that participants must have wake times of more than two hours difference within one week. Thus, our final outcome measure examined the variability in wake up times during the participant's last week of the intervention. I measured variability using the standard

deviation of these seven days. Although many sources emphasize the importance of assessing distal outcomes with micro-randomized trials (Dempsey et al., 2015; Klasnja et al., 2015), the studies that have come out of the Pennsylvania State University Methodology Center, which is the preeminent center for the development and dissemination of micro-randomized trail methods, thus far have only demonstrated the effect of their interventions on proximal outcomes. In theory, the proximal outcome should be either a more immediate version of the ultimate outcome (e.g., the regularity of wake up times over five days following a nudge) or a behavior or outcome that is hypothesized to mediate the relationship between the intervention and the distal outcome (e.g., the frequency of sleep hygiene techniques used during wake up times; Dempsey et al., 2015). Given that techniques to test these particular statistical questions within a micro-randomized trial have not yet debuted, the goal of the third aim for this study was to examine whether a proximal outcome of the study is related to the final outcome. In order to test this relationship, I conducted a linear model examining participant-level variables. Namely, the model tested the effect of the proportion of successful nudges (proximal outcome 1) on the standard deviation of wake up times during the final seven days of the study. To test the effect of successful nudges on final wake time variability, I included a) proportion of nudges that were successful and b) standard deviation for first seven days in study. In a second model, I added c) the number of nudges a participant received in their final seven days and d) the number of sleep diaries they completed in their final seven days. Both models were conducted four times - on original values and winsorized values using both raw data and imputed data. Participants who completed

fewer than half of their sleep diaries in the final seven days of the study were excluded from this analysis.

Missing Data. The patterns of missing data were assessed and arguments for and against not-missing-at-random cases were made. Specifically, the nudge response dependent variable could have been missing not at random (MNAR) if the likelihood of a participant completing their sleep diary was dependent on whether or not they had successfully responded to the nudge. This could potentially come about due to a desirability effect where participants would not want to complete a survey if they would have to say "no" to that question. Missingness as a function of whether one successfully responded to the nudge is not able to be assessed; however, I assessed whether there was more missingness on days that nudges occurred than on days when they did not. If more missingness occurred on nudge days, it could potentially be explained by this desirability argument if participants had not responded to the nudge on those days. Additionally, the wake up time dependent variable could have been MNAR if the likelihood of a participant completing their sleep diary was dependent on the time that the participant woke up. In order to examine this variable, I looked at the distribution of wake times across the study, with the goal of identifying any possible truncation of wake times due to missing data. Lastly, our dependent variable for aim 3, variability in wake up time during the final week of the intervention, could have been MNAR if variability in wake up times made a participant less likely to fill out those final surveys. Fewer surveys would result in lower variability; thus, this was not able to be assessed. However, I did assess the variability in baseline wake times for participants who completed more versus less than half of their final week of sleep diaries. A Little's MCAR test (Little, 1988) was

conducted to assess whether the missingness was at random (MAR) or completely at random (MCAR). I calculated the missingness in the variables that would be used to compute the proximal dependent variables (See Appendix M for list of variables). Unless arguments for MNAR seemed likely, I planned to conduct multiple imputation, since it is relatively robust to patterns in MAR data. In addition, our second aim uses generalized estimating equations analyses, which necessitates a full dataset that can only be achieved using imputation. I planned to create as many multiple imputation data sets as there were percent of missing data in the most missing dependent variable (Bodner, 2008).

CHAPTER III

RESULTS

Descriptives

The average wake time for college students in this sample was approximately 8:36 am (sd = 2 hours and 3 minutes). During the first 7 days of the study, that average was approximately 8:43 am (sd = 2 hours and 15 minutes), and during the last 7 days it was approximately 8:28 am (sd = 1 hour and 41 minutes).

On average, participants received a nudge on 79% of possible nudge days. Due to the random generation of nudges, that percent varied by participant, with participants ranging from 53% to 93%.

Days when participants reported following the instructions of a nudge were considered to be days with "successful" nudges. On average, participants were successful in following nudge instructions on 52% of days. This varied by participant, ranging from one participant who never indicated following a nudge's instructions to a participant with 69% successful nudges. Participants failed to report whether they followed a nudge on 26% of days that nudges were received.

Missing Data

Missing responses were examined for the first dependent variable: nudge response. There were 80 missing responses on days that participants did not receive a nudge (after nudges had begun) versus 110 missing responses on days participants had received a nudge. While 110 is greater than 80, the proportions of nudges mentioned

above must be taken into account. Nudges were delivered on 79% of days following the start of the intervention, while missing responses following nudges only accounted for 58% of missing nudge responses. Thus, I did not find evidence for MNAR for this variable.

Missing responses were examined for the second dependent variable: reported wake times. Figure 1 shows the histogram of wake times during the study, indicating a large range. Figure 2 shows this same histogram with the most extreme 1% of the data removed in order to examine the typical range of wake times more clearly. Both figures indicate a relatively normal distribution with wake times ranging from 4am to 6pm are represented. The histogram is slightly positively skewed, with an average of 8.61. This seems like a plausible average wake time for college students, but could potentially indicate that later wake up times are not as well represented in the data. However, given the representation of a range of wake times, I concluded that it is unlikely that this variable is MNAR.

Possible arguments for MNAR in our final variable included if variability in wake up times made a participant less likely to fill out those final surveys. Fewer surveys would result in lower variability; thus, this was not able to be assessed. However, I did assess the variability in baseline wake times for participants who completed more versus less than half of their final week of sleep diaries. Participants who completed fewer sleep diaries at the end of the study were slightly more variable than their counterparts at baseline ($t = 1.83$, $p = 0.08$). However, this did not reach statistical significance. Thus, I did not conclude that this variable was MNAR.

A subset of the data with relevant dependent and independent variables was assessed for missingness and used for imputation. Due to multicollinearity, not all of the "nudge" variables could be included in this subset. Thus, I chose to include the content variable because it had the largest number of missing data points. Little's MCAR test was conducted on the dataset to assess whether the missing data was missing completely at random (MCAR) or missing at random (MAR). The test indicated that the data are MAR ($X^2(52) = 332.7655$, $p < .001$). Thus, I conducted multiple imputation, which is robust to patterns within MAR data (Pedersen et al., 2017). Multiple imputation was necessary because of our main analysis technique for Aim 2 (generalized estimating equations), which requires a full dataset. Analysis of the missing patterns indicated approximately 16% missing data in the dependent variables. However, the necessary modifications to impute the nudge response variable resulted in approximately 50% missing data for that variable. For this reason, I created 50 separate multiple imputation data sets, creating enough imputed datasets to correspond to the percentage of missing data in the dependent variables.

Aim 1

Participant Investment in the Intervention. Investment in the intervention was measured in multiple ways. Participants were asked during the phone call or email check-in how likely they were to complete the remaining three weeks of the study. Thirteen indicated that they would definitely be completing the study, while 21 indicated that their completion was "likely". One participant did not respond. All 34 participants attended their debriefing session, thus completing the study in its entirety.

Participants' time spent on the information portion of the online education module was used as a measure of investment in that specific portion of the intervention. Participants spent an average of 3 minutes and 16 seconds (sd: 2 minutes and 34 seconds) reading the education materials, which amounted to 32.71 seconds per page.

Three recent college graduates who were naive to the study completed the online education module as a comparison group. This group spent an average of 2 minutes and 28 seconds (sd: 52 minutes) reading the education materials, which amounted to 24.64 seconds per page. Thus, it seems the participants spent equal or perhaps even more time on the psychoeducation materials than the comparison group.

Throughout the intervention, participants were asked to complete daily sleep diaries. Participants completed an average of 86% of their sleep diaries. Completion ranged from one participant who completed 38% to the most compliant participant who completed 98% of completed sleep diaries.

As can be seen in the Method section, retention following consent was high. Two participants' sleep diary and nudge data were removed prior to analysis because the nudge data indicated that the application had not created a nudge opportunity on multiple occasions. This error was likely due to the phone closing the application when it was not in use.

Participants' Opinion of the Intervention. Participants reported their opinions of the study during the debriefing session. On a 5-point Likert scale ranging from 1 (very interesting) to 5 (very boring), the average participant response was 2.71, indicating that the study was "interesting" (15 participants) to "neutral" (11 participants; see Figure 3).

When rating intervention quality, participants reported an average rating of 2.74, indicating that the quality was "very good" (8) to "good" (14; see Figure 4).

Participants were asked several opinion questions during the phone/email check-in. First, they were asked whether it took them "too long" to fill out the daily sleep diaries. All participants (34) indicated that the sleep diaries did not take too long to complete. Second, they were asked whether the nudge instructions were easy to follow. The majority of participants (25) indicated that they were easy to follow, while 4 indicated that they were somewhat easy to follow. Five participants told the research assistant that the nudges were not easy to follow.

Helpfulness of the Intervention. Participants were asked during the phone/email check-in whether they believed the nudges were helping their wake up regularity. Participants were more split on this question, with 12 indicating that the nudges were helping and 13 indicating that the nudges did not help. Among those who did not fall into these categories, seven felt that the nudges were somewhat helpful, while two remarked that they were unsure whether they were receiving benefit.

During the psychoeducation module (beginning of the intervention) and the debriefing survey (end of the intervention), participants reported the number of days out of seven that they woke up within two hours of their average wake time. At the beginning of the intervention, participants reported an average of 3 on a 0-4 Likert scale (0 indicating "0 days" and 4 indicating "All 7 days"). At the end, participants reported an average of 3.20. A paired Wilcoxon Signed Rank test indicated that this difference was

not significant (t = -1.31, CI: -0.51 - 0.11)). Participant reports for this variable are displayed in Figure 5.

During the debriefing survey, participants answered questions about the value and importance of the intervention, its usefulness, and how helpful they found each intervention component. Twenty-three participants found the study to have lasting value and importance. Usefulness was measured on a 5-point Likert scale from 1 ("very useful") to 5 ("not at all useful"). Participants' average response rating was 2.60, with the majority of participants rating the study either "useful" (17) or "neutral" (11).

Participants rated the helpfulness of five intervention components: the sleep diary, the online education, the creation of the sleep plan, the "nudge" to set their alarm, and the "nudge" to use their wake up routine. Each was rated on a 5-point Likert scale from 1 ("very helpful") to 5 ("not at all helpful"). The nudges were rated as the least helpful components of the study, the mean helpfulness of the alarm nudge rated as 2.83 and of the wake up routine nudge as 3. Thus, both nudges were rated as "neutral" on our helpfulness scale. The rest of the components were rated as "helpful" to "neutral", with the sleep plan (2.31) rated as the most helpful, followed by the sleep diaries (2.43) and then the online education (2.57). See Figure 6 for frequency of ratings for each component.

Aim 2

The goal of aim 2 was to determine the effect of the intervention on two designated proximal outcomes: taking action to improve sleep hygiene and wake time variability. Generalized estimating equations indicated that the intervention did not

significantly affect either proximal outcome. The effect of the presence of the nudge on sleep hygiene technique use could not be estimated due to limitations mentioned above. However, Table 3 shows that the coefficient for content is 0.314, which indicates that the probability of following a nudge after receiving the "wake up routine" nudge is 0.58 compared to the "alarm" nudge. Table 4 shows that the coefficient for timing is -0.889, which indicates that the probability of following a nudge after receiving the nudge 4 hours before bed time is 0.29. Based on the absence of other micro-randomized trials focused on wake time regularity (and sleep in general), we lack a benchmark to which we can compare these probabilities. Future studies will need to be conducted in order to determine what an "average" probability of following this type of nudge would be.

In addition, there were no variables related to the nudges that were significantly related to 5-day wake time variability after the nudge (or non-nudge) event. The presence of a nudge decreased the average 5-day standard deviation of wake up times by 1,238 seconds, or about 21 minutes, compared to the absence of a nudge. Compared to the nudge occurring one hour before bedtime, the four-hour nudge decreased the average 5-day standard deviation of wake up times by 434 seconds, or about 7 minutes. Lastly, the wake up nudge content decreased the average standard deviation by 209 seconds, or 3.5 minutes. Again, none of these effects were significant due to large standard errors that indicate marked variation in these estimates. Given that these statistics are unstandardized betas, and that there is no validated way (that the author has found) to estimate effect sizes for GEEs, we cannot determine how large these effects are. However, decreasing the standard deviation of wake times by approximately 20 minutes does seem to be clinically significant based on conventional wisdom.

The only significant predictor of improvement in sleep hygiene techniques was whether the current day was a weekday or weekend (see Tables 3 & 4). The only significant predictor of wake time variability for the five days following the nudge was baseline variability in wake time (the variability in the five days preceding the nudge; see Tables 5, 6, & 7).

Aim 3

The goal of aim 3 was to determine the effect of a proximal outcome of the intervention on the final outcome: standard deviation of the final week of the intervention. Linear models indicated that the neither the proportion of successful nudges nor the standard deviation of wake times during the first week of the intervention significantly predicted the final outcome. In addition, the final outcome was not predicted by the proportion of nudges or the proportion of sleep diaries completed during the final week. These results were true for models conducted with the raw (Tables 8 & 9) as well as winsorized values (Tables 10 & 11). Standardized betas indicate that in the simplest model, one standard deviation increase of proportion of successful nudges co-occurred with a decrease by 0.1 standard deviations in final week standard deviation of wake times, which amounted to approximately 18 minutes. Although this is not statistically significant, this change in standard deviation of wake times does seem to be clinically significant, depending on how variable a participant was before the intervention.

Eight participants were removed from this analysis due to too few completed sleep diaries. I compared their baseline standard deviation to those participants included in the analysis. They demonstrated a 4,203.53 second difference in standard deviation, which resulted in a trend level difference ($t = 1.83$, $p = 0.08$).

CHAPTER IV

DISCUSSION

The purpose of the present study was to assess the feasibility, acceptability, and efficacy of a method for delivering pre-arranged reminders through a phone application with the goal of helping to regulate college students' wake up times. Although participants demonstrated high investment in the intervention, they seemed to have only slightly better than neutral opinions about the study's quality and its helpfulness. In addition, I found that the main components of the intervention did not affect wake time regularity during the study, nor in the final week of data collection.

Aim 1

The goal of aim 1 was to determine the acceptability and feasibility of this intervention for its intended audience. To accomplish this aim, I examined data related to participants' levels of investment, their reported opinion of the intervention itself, and measurements, both subjective and objective, of the intervention's helpfulness. The goal of testing these intervention components was to create a lower burden intervention that would be more acceptable to participants than other, larger scale interventions. Thus, I was hoping to see that participants were sufficiently invested in completing the intervention and that they had a high opinion of the intervention. In addition, I hoped the intervention components would be perceived as helpful.

Participant Investment

Overall, participants' investment in the study seemed to be high. For instance, I compared the amount of time they spent on the psychoeducation module to three invested control participants (i.e., the author's college-aged sisters) and found that participants

spent slightly more time than those controls. We can take this to mean that they took the necessary time to attend to the presented stimuli and consider the creation of their personalized sleep plan. With all self-led intervention components, such as this website that I asked participants to navigate through themselves, there is risk that participants will click through the information without reviewing it in order to get through their tasks more quickly. The comparison above indicates that this is not a problem that our intervention faced on average.

Other measurements, such as high completion of sleep diaries and high retention, also indicated high investment. However, the participant with the lowest compliance to this component only completed 38% of their sleep diaries (corresponding to only 13 completed sleep diaries). Although this low level of investment was not common, it will be important to further examine the qualitative data from participants like this in order to improve the intervention for future iterations.

Within the first week of the study, two (5.4%) participants' phones were found to be incompatible with our phone application, leading to our termination of their participation. In addition, two other sets of data were excluded due to the phone closing the application when it was not in use, and thus preventing nudge opportunities and completion of sleep diaries. Thus, although investment in the study was high, including a procedure to check the compatibility of one's phone to our application will be an important part of future consent sessions.

Participant Opinions

Opinions of the intervention were assessed in the satisfaction survey administered at the debriefing session as well as during the mid-study phone check-in. Participants

were asked to report how interesting they found the study and its quality. They also reported their opinion of specific intervention components, namely, how agreeable they found sleep diaries to complete and how easy they believed the nudges were to follow. Overall, participants' opinions of the study were somewhat neutral, but positive leaning.

Participants reported that the quality of the study was "Good" on average, where the scale markers were Excellent, Very Good, Good, Fair, and Poor. Their numeric average was 2.74, which landed them just above the middle of the scale. This indicates that while participants seemed satisfied with the intervention, they saw places where it could have been improved. Based on the issues presented in our method section, it is possible some of the difficulties participants faced with receiving repetitive or unnecessary notifications could have contributed to this rating. Participants rated the study as "Interesting" on average, where the mid point of the scale was "Neutral." This mirrors many conversations had during debriefing sessions during which participants mentioned that they found the study very interesting. A handful of participants asked to be sent the results of the study when they became available. It seemed from these responses as well as more informal conversations that participants were overall interested in the goal of the study, but felt underwhelmed by the delivery of the intervention.

Helpfulness of the Intervention

The helpfulness of the intervention per participant report was assessed in different forms at the check-in and the debriefing session. Participants were asked at the check-in whether they believed the nudges had been helpful to improving their wake time regularity thus far. At the debriefing session, they were asked whether they believed the study had importance or value, how useful it was, and to rate each intervention

component for how helpful they believed it was. In addition, participants estimated how many days they had woken up within 2 hours of their normal wake up time at the psychoeducation survey (5-7 days after their entry into the study and, thus, before they had received the intervention) and at the debriefing session. Overall, participants offered mixed reports as to whether the intervention was helpful.

Several check-ins resulted in changes made to the application to fix bugs that sent the nudges at incorrect times or that sent reminders to complete sleep diaries more than once per day. A small handful of participants found the bugs to be understandably frustrating, and many participants reported being confused about what they should be receiving via the app. It is therefore not surprising that participants may have found the intended notifications to be unhelpful, as they may have had to identify them within a sea of unhelpful notifications. Either way, the bugs truly confound our understanding of why many participants found the nudges unhelpful.

I also assessed self-reported data on participants' wake time regularity during the first and final weeks of the study. Visual inspection of Figure 3 did show that more people indicated a full week of regularity while fewer reported 0-4 days of regularity and, given how little power I had to detect group differences in this sample, it is possible that there is a true difference that could not be detected due to the nature of the ordinal responses and resulting analysis.

Finally, participants rated each intervention component on a 5-point scale from Very Helpful to Not at all Helpful. Disappointingly, the two nudges were rated as the least helpful components of the study, with the average of each indicating a neutral stance

on their helpfulness. The sleep plan, psychoeducation, and sleep diaries were all rated as more helpful than the nudges.

The contrast between participants' high investment, neutral opinion, and split beliefs about helpfulness points to a few key features of this intervention. This intervention includes elements of psychoeducation, behavioral tracking, and generalized change behaviors in the participants' own environments. It is clear that participants considered the education and tracking components to be more helpful than the behavior change components, but it is likely that those opinions partially stem from how often the education and tracking were utilized compared to how often the reminders were heeded. Interventions are rarely designed to be helpful if they are not utilized at the appropriate frequency or dose, and we saw that participants only followed half of the delivered nudges but completed more than 80% of the sleep diaries.

When these intervention components are compared to their counterparts in individual therapy, the pattern we see makes sense. The field of Motivational Interviewing grew out of the recognition that clients may have the "right" beliefs or attitudes, but without intention to change, behavior does not often shift (Miller & Rose, 2009). This is often because behavior change comes with costs that do not accompany easier skills like learning and tracking. In the example of our intervention, keeping a regular wake time impedes participants' ability to get more sleep on the weekends, a time when they believe they can make up for their sleep debt. Planning for the next morning's wake up time also may impede either the fun or relaxing nature of the prior night. Thus, the pattern seen in participant reports of this intervention mirrors health behaviors more generally, with participants prioritizing short-term gains over those in the long-term.

Of note, our intervention did maintain retention and investment in a way that many prior interventions have not achieved. The phone-based method and minimally invasive intervention were likely key components in participants' willingness to continue to engage in the study. This provides sound reasoning for using future, similar interventions to impact college students. Future use of MRTs is also warranted given their ability to further refine which intervention components will be the most useful for this population.

Aim 2

The goal of aim 2 was to determine the effect of nudges, as well as specific levels of nudge timing and content, on proximal outcomes related to wake time regularity. Those proximal variables were reported use of sleep hygiene techniques the morning after a nudge and the five-day rolling average of wake time variability. To accomplish this aim, I asked participants to report their wake time each morning and, on days they received a nudge, whether they followed the nudge's instructions. I hypothesized that the presence of a nudge would predict use of sleep hygiene techniques, as well as less variability in wake times. I did not have specific predictions about whether specific timing or content levels would have unique effects.

Wake Time Variability

The presence of a nudge did not have a significant effect on the variability of the five subsequent wake times. The only significant predictor of wake time variability was the variability of the five baseline days, which were the five days before the nudge. This indicates that a participant's variability may be relatively stable over time. This would mean that participants who wake up around the same time each day continue to do so,

while participants with variable wake times maintain that variability. Our intervention was not robust enough to have an effect above and beyond that stability. Given the inconsistencies in some of the earlier versions of the application, it is unclear whether this was a problem with the intervention itself or due to the bugs that were eventually removed.

Use of Sleep Hygiene Techniques

An oversight in the data collection methods did not allow me to test the hypothesis that the presence of a nudge the night before would make participants more likely to use sleep hygiene techniques the next morning. Use of these techniques was only assessed on days participants received a nudge; thus, there is no reported data for days when nudges were not received. I was therefore, unable to test this hypothesis.

Timing and Content

Neither the differing levels of timing nor content had a significant effect on the proximal outcomes. The only significant predictor of wake time variability continued to be baseline variability. In addition, the only significant predictor of use of sleep hygiene techniques was whether the current day was a weekday or weekend. Given that the goal was to wake up at the same time as the day before, it is not surprising that participants were specifically reluctant to take steps to do so on a weekend. Once again, it seems the intervention was not robust enough to have an effect above and beyond these contextual ones.

Aim 3

The goal of aim 3 was to determine the effect of the first proximal outcome of the intervention on the final outcome: standard deviation of the final week of the intervention.

To accomplish this aim, I used the proportion of nudges that participants followed, as well as the variability of wake time during the baseline week of the study, to predict variability during the final week. I hypothesized that a higher proportion of successful nudges would predict lower variability during the final week.

There were no significant predictors of final week variability in the tested models. This is an interesting contrast to our models in aim 2, where baseline variability predicted later variability. It seems that variability from four weeks prior is not similar enough to be predictive. Having data on use of sleep hygiene techniques on non-nudge days would have allowed examination of the frequency of use of these techniques and how that may have affected final sleep variability.

The Strength of Context

Although our study achieved a level of interest, adherence, and retention that was very acceptable, it failed to change behavior. Instead, we saw both individual differences (in the form of baseline variability) and context (in the form of day of the week) influence behavior. While our data shows evidence of the influence of both individual differences and social context on behavior (straddling a very classic debate in the fields of personality and social psychology; Benjamin & Simpson, 2009), it did not demonstrate an added effect of intervention on that same behavior. Thus, it seems we should be moving toward an intervention that has a greater effect on either individual differences, context, or both.

The goal of this study was to create a minimally viable product (MVP) that could be used in future interventions to help college students regulate their wake times and, thus, their sleep cycles. Due to its minimal nature, we were not able to address many of

the relevant contextual components that would be perfect for a true Just-In-Time intervention. Contextual barriers to a regular sleep schedule mentioned above included social activities and school work, both of which often take place outside of the home for college students. Future iterations of this study could include a GPS tracking component in order to send a nudge regarding wake times only when the student is home, while sending a nudge that is about staying up and out late if the student is elsewhere. It is clear that this is the way we should move in developing this intervention in order to better address the contextual difficulties that we faced.

The Intervention

Despite the null results that this trial yielded, we can learn quite a bit from the data. In this intervention, I included elements of both psychoeducation and behavior change, but have focused more heavily on the behavior change component in evaluating the acceptability, feasibility, and efficacy of the study. As was mentioned previously, changing behavior is often much more difficult than changing knowledge or attitude. I speculate that this discrepancy may contribute directly to participants' perceived lack of helpfulness of the reminders compared to the education and tracking intervention components.

In addition to the difficulties inherent in behavior change, we found evidence of consistent contextual influences on behavior that create additional barriers to making change. Both pre-reminder variability and whether it was currently a weekend had significant effects on participants' variability and use of sleep hygiene techniques, respectively. Our reminders did not create change that counteracted these contextual influences. This points not only to the difficulty of behavior change, but also to the reality

that there is often external motivation for resisting change and/or staying the same. It is possible that beginning with motivational interviewing techniques would improve the next iteration of this intervention by helping participants identify why these changes could be important.

Despite the great difficulty that these results highlight, it is important that we do not abandon this work. Although behavior change is hard, it is the only way that health behaviors can truly improve. We know that the "homework" component of treatment significantly contributes to overall improvement (Kazantzis, Deane, & Ronan, 2000). Knowledge about the effects of sleep irregularity and even being aware of one's own sleep irregularity do not change those effects; only an increase in sleep regularity can have a true effect on health.

This focus on behavior change as at least as important as changes in knowledge and attitude is one of the main innovations of this study. It seems that the next step is to determine how to make that goal attainable. Motivational interviewing as a new study component may be one option. The future directions section also focuses on changes that will be made in the next iteration of this intervention.

Limitations and Strengths

Several limitations have already been mentioned, which I will summarize again here. Following that summary, I will present other limitations of the study and then lay out the future directions that are indicated by these limitations.

As was mentioned previously, there were several difficulties with the phone application due to this being the first study in which it was tested. Two participants who were consented had phone models that were not compatible with our application.

Although I did not know this ahead of time, there was no timely remedy, and both participants were dismissed from the study. In addition, I excluded two additional sets of data because of difficulties with the app during participation; specifically, the phone would default to closing the application if it was "idle," preventing the app from sending the next nudge opportunity or the sleep diary notification. Thus, for these participants, I did not get enough data over the course of five weeks to include them in the sample. In addition, there were several bugs that were remedied throughout the study, the most problematic of which sent nudge opportunities multiple times during the day and prompted participants to complete the psychoeducation module more than once.

The above limitations could have been largely remedied with more extensive pilot testing of the phone application. While a week or two of testing was conducted, it clearly was not enough to catch these problems. The majority of these bugs have now been remedied and that the current version of the application (the final version administered in the study) is appropriate; however, pilot testing before a second iteration of this study would be prudent.

I speculate that the limitations of this application contributed to participants' close to neutral opinions about the quality of the study and the helpfulness of the nudges. In the next iteration of the study, which will include pilot testing, we will test this theory.

An additional limitation of our method is that the nudges were sent at the same time each weekday (and each weekend) and sent regardless of the participant's location or larger context. It is possible that personalizing the nudges based on participants' location (whether or not they are home) or other factors would have increased compliance to the nudges.

Additional limitations have to do with our statistical methodology. First, the study did not achieve the desired level of statistical power with our final sample. Although 34 participants completed the protocol, only 32 had usable data. Thus, the study was underpowered by two participants. Due to oversights in survey logic, one of our main hypotheses about proximal outcomes was not able to be tested. We also could have benefitted from this data when examining the effect of proximal outcomes on the final outcomes. A last point on methodological limitations is that our final outcome was not truly distal, as it was measured while the intervention was still occurring. Thus, the outcomes cannot be used to demonstrate outcomes after the intervention has ended.

In addition, although the original sample size was powered to detect proximal effects for the MRT, it was a small sample on which to detect participant-level trends, such as using one final variable for each participant as an outcome. This may be a difficulty for all MRTs that have additional aims and needs to be taken into account when conducting such trials. It seems unlikely that we could enroll hundreds of participants in a six-week study; however, something of at least this magnitude would be needed to test the proximal to distal relationship.

This current study was an innovative project with the potential to impact lives on a large scale with minimal effort. It is the first intervention in the sleep field to test the effects of specific components using a micro-randomized trial. The field of sleep interventions is plagued with an unstandardized use of multiple intervention components; use of this design technique could spark a more standardized way of testing treatments in the future. In addition, college students are a group faced with a myriad of mental health concerns and an unconventional lifestyle compared to the rest of society. If a future

iteration of this intervention is successful, it could allow sleep and mental health professionals a way to intervene on a basic function in order to improve the lives of college students. Thus, it is important to consider how to take what has been learned from the limitations mentioned above and use them to improve the intervention.

Future Directions

Our team plans to conduct a second version of this intervention after making certain changes to the methodology. First, we plan to extensively pilot the application in order to remove any additional bugs and to check the application's utility for a wider selection of Android phones. We will also increase our sample size with the main goal of being adequately powered for the micro-randomized trial. While we did account for a 10% drop out rate, we ended up with 16% of participants that had dropped out or were excluded. Thus, we plan to recruit at least 50 participants for the next iteration of the intervention. We will include a final, post-intervention week in the protocol. Thus, participants will be in the study for one baseline week, four weeks that include the nudge intervention, and a final week without intervention in order to quantify gains post-intervention. Lastly, we will send participants a copy of the sleep plan they create in the psychoeducation module. This idea will serve two purposes: first, it will confirm for the participant that they have completed this module and, second, it will allow them to review the information they self-generated if they would like to be reminded of their sleep plan and goals.

There are additional changes that would make this intervention even more appealing and likely more successful, but which may necessitate more financial resources and thus, may not go into the MVP (minimally viable product) version of this

intervention. Thus, the following ideas will be kept in mind for future implementation. First, we could implement "trial" participation periods in order to test the application on each participant's phone, given the several participants whose data was excluded due to phone incompatibility. Second, we could create more automation in order to better personalize the intervention. We could do so, first, by asking participants when they create their sleep plan to choose which techniques they would like to be reminded of in the intervention phase. Second, we could use geolocation data to prevent nudges from being sent if participants are not home. Third, we could create a motivational interviewing aspect to take place before the beginning of the intervention, perhaps during the psychoeducation module. This approach may also encourage dissemination of the psychoeducation in in-person groups rather than an online module.

Conclusion

The current study was an important step toward using micro-randomized trials and the MOST protocol more generally to improve the quality of sleep interventions, specifically for the college student population. These methods, which have significant potential to speed optimization of treatments have not yet been systematically applied to sleep improvement interventions, despite their high potential for advancing this area (Blake, Latham, Blake, & Allen, 2019). Despite major limitations in this current iteration, this method has the potential to identify the most important intervention components for a sleep intervention tailored to this population. In addition, participants demonstrated sustained investment in the study, which may indicate that they would be sufficiently engaged in a true phone-based application intervention. A new version of this study will be conducted to test our hypotheses without the current confounds and determine whether

the current intervention would have the potential to assist students in regulating their wake times and, thus, their sleep schedule.

APPENDIX A

FIGURES

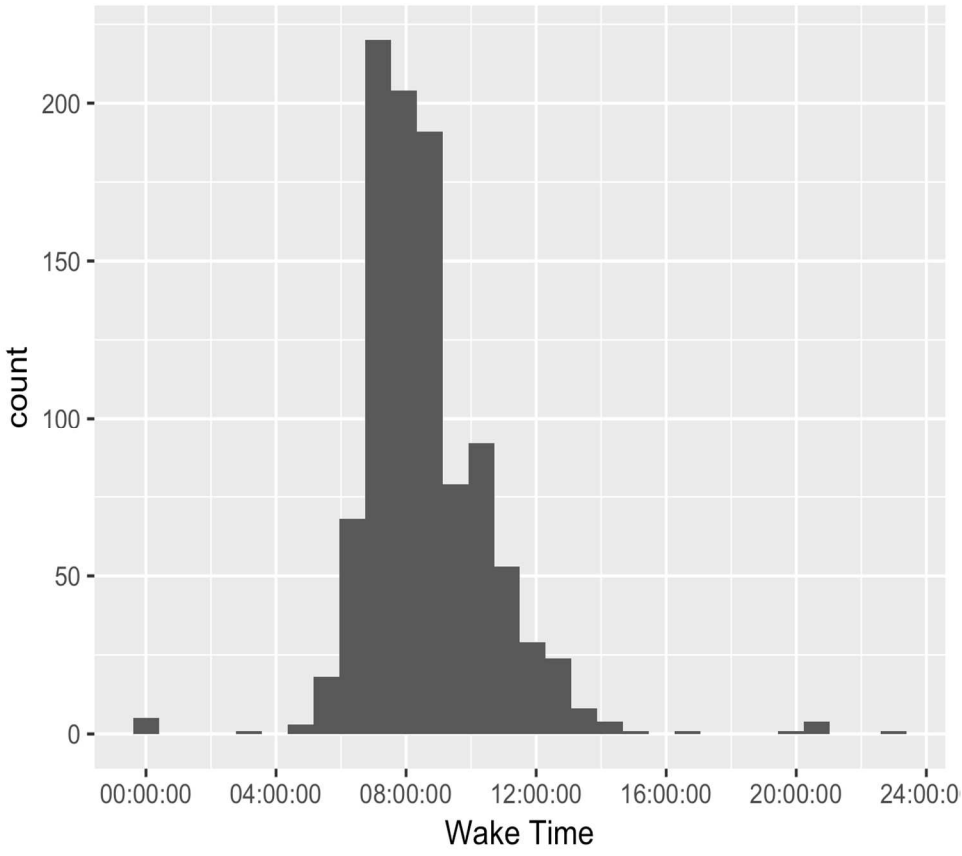

Figure 1. Histogram of Raw Wake Times.

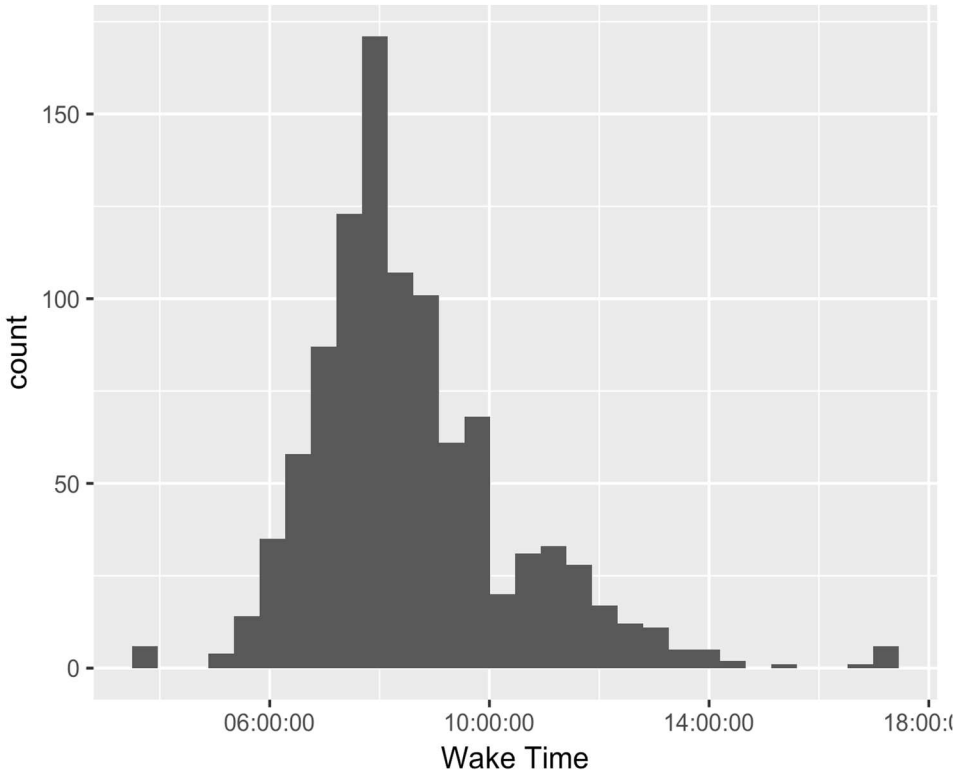

Figure 2. Histogram of Winsorized Wake Times.

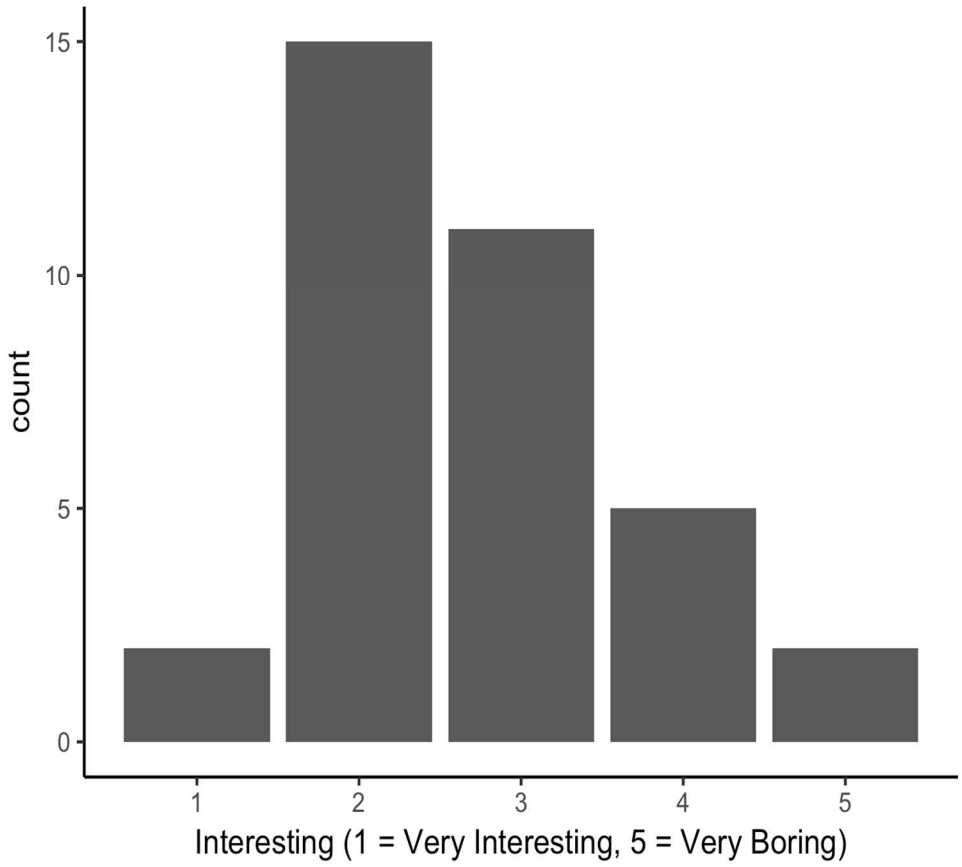

Figure 3. Bar Chart of 'Interesting' Ratings of Study.

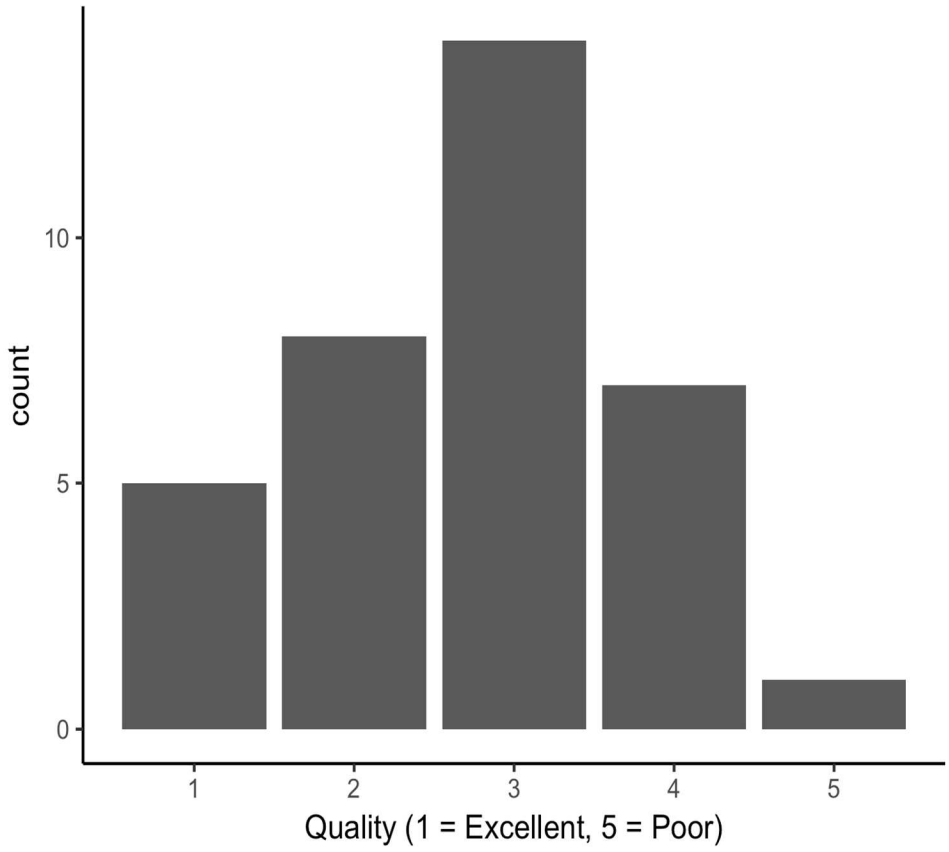

Figure 4. Bar Chart of 'Quality' Ratings of Study.

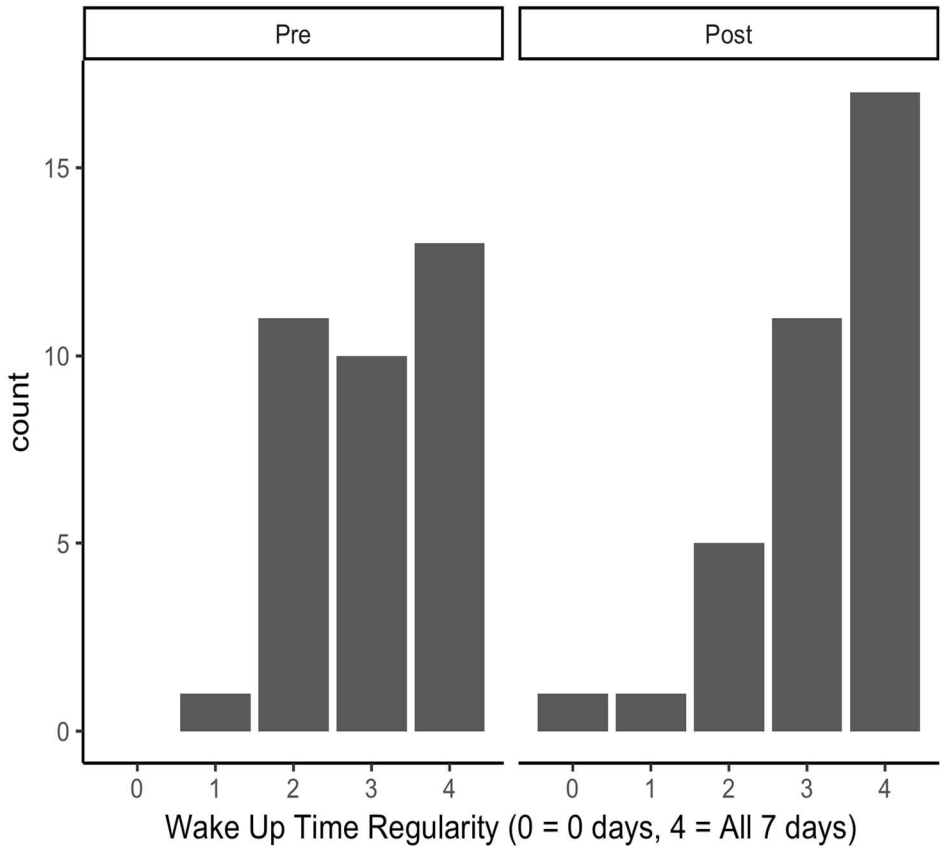

Figure 5. Bar Chart of Wake Up Time Regularity by Timepoint (Baseline and Debrief).

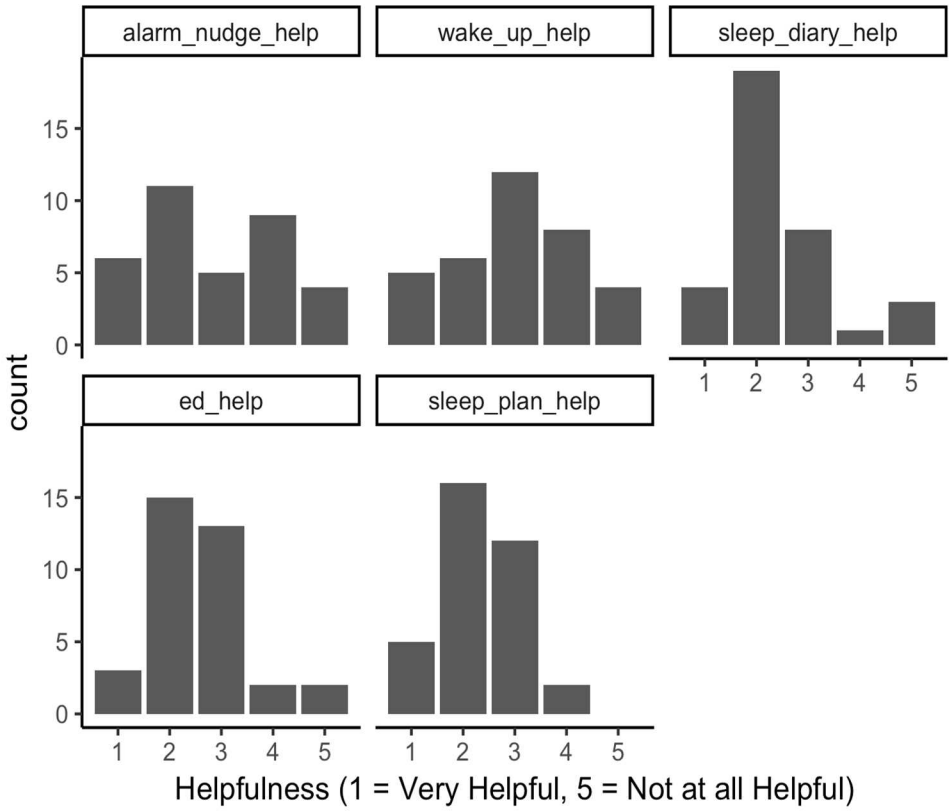

Figure 6. Bar Chart of Helpfulness Ratings by Intervention Component.

APPENDIX B

TABLES

Table 1.

Participant flow from contact to consent.

Phase	Specifier	*N*
Responded to recruitment		69
Ineligible before consent session		12
	Non-Android phone	*9*
	Outside age range	*2*
	Consistent sleep times	*1*
No response		5
Did not attend consent session		10
Attended consent session		42
Ineligible at consent session		5
	Non-Android phone	*3*
	Consistent sleep times	*1*
	Phone blocked install	*1*
Consented to participate		37
Non-completers		3
	App incompatible with phone	*2*
	Declined further participation	*1*
Completers		34

Table 2.

Nudge Randomization Scheme

<table>
<tr><td>Step 1</td><td colspan="4">75%
Prompt</td><td>25%
No Prompt</td></tr>
<tr><td>Step 2</td><td colspan="2">50%
“Make sure to set your alarm for your normal wakeup time.”</td><td colspan="2">50%
“Remember to use your wake up routine tomorrow morning.”</td><td rowspan="2"></td></tr>
<tr><td>Step 3</td><td>50%
One hour before bedtime</td><td>50%
Four hours before bedtime</td><td>50%
One hour before bedtime</td><td>50%
Four hours before bedtime</td></tr>
</table>

Table 3.

Coefficients for Model of Nudge Timing predicting Nudge Response.

term	estimate	std.error	statistic	p.value
intercept	0.830	0.849	0.978	0.328
content - wake up	0.373	1.087	0.343	0.732
day in study	0.018	0.089	0.204	0.839
quadratic day in study	0.000	0.002	-0.121	0.904
weekend	-0.761	0.210	-3.622	0.000
content:day	-0.048	0.102	-0.474	0.636
content:quad day	0.001	0.002	0.446	0.656

Abbr: quad = quadratic

Table 4.

Coefficients for Model of Nudge Content predicting Nudge Response.

term	estimate	std.error	statistic	p.value
intercept	1.426	0.758	1.881	0.060
timing – 4 hour	-0.959	1.055	-0.909	0.364
day in study	-0.023	0.078	-0.293	0.770
quadratic day in study	0.001	0.002	0.292	0.770
weekend	-0.798	0.210	-3.792	0.000
timing:day	0.045	0.102	0.438	0.661
timing:quad day	-0.001	0.002	-0.322	0.748

Abbr: quad = quadratic

Table 5.

Coefficients for Model of Nudge Presence predicting Wake Time Variability.

term	estimate	std.error	statistic	p.value
intercept	4403.137	938.542	4.691	0.000
nudge presence	-1135.452	2084.078	-0.545	0.586
day in study	-149.924	103.984	-1.442	0.150
quadratic day in study	3.553	2.605	1.364	0.173
bl var of wake time	0.346	0.065	5.302	0.000
nudge presence:day	154.037	208.868	0.737	0.461
nudge presence:quad day	-3.787	4.508	-0.840	0.401

Abbr: bl var = baseline variability; quad = quadratic

Table 6.

Coefficients for Model of Nudge Timing predicting Wake Time Variability.

term	estimate	std.error	statistic	p.value
intercept	3383.329	2348.654	1.441	0.150
timing - 4 hrs	-391.879	1683.059	-0.233	0.816
timing - no nudge	1017.863	2605.395	0.391	0.696
day in study	12.756	212.917	0.060	0.952
quadratic day in study	-0.737	4.655	-0.158	0.874
bl var of wake time	0.347	0.065	5.324	0.000
timing - 4 hrs:day	1.054	154.896	0.007	0.995
timing - no nudge:day	-162.719	255.011	-0.638	0.524
timing - 4 hrs:quad day	0.551	3.408	0.162	0.872
timing - no nudge:quad day	4.291	5.461	0.786	0.432

Abbr: bl var = baseline variability; quad = quadratic

Table 7.

Coefficients for Model of Nudge Content predicting Wake Time Variability.

term	estimate	std.error	statistic	p.value
intercept	3299.821	2717.242	1.214	0.225
content - wake up	-341.138	2968.323	-0.115	0.909
content - no nudge	1102.051	2947.115	0.374	0.709
day in study	31.439	231.834	0.136	0.892
quadratic day in study	-1.116	4.813	-0.232	0.817
bl var of wake time	0.346	0.065	5.337	0.000
content - wake up:day	-33.841	239.220	-0.141	0.888
content - no nudge:day	-181.387	275.123	-0.659	0.510
content - wake up:quad day	1.384	4.668	0.296	0.767
content - no nudge:quad day	4.670	5.706	0.818	0.413

Abbr: bl var = baseline variability; quad = quadratic

Table 8.

Coefficients for Model of Proportion of Successful Nudges predicting Final Variability in Wake Time.

	Estimate	Standardized	Std. Error	t value
(Intercept)	3165.452	0.000	996.071	3.178
bl_sd_waketime	0.101	0.244	0.087	1.161
prop_success_nudge	-1077.077	-0.108	2101.647	-0.512

	Pr(>|t|)
(Intercept)	0.005
bl_sd_waketime	0.259
prop_success_nudge	0.614

Abbr: bl_sd = baseline standard deviation; prop_success_nudge = proportion of nudges followed

Table 9.

Coefficients for Model of Proportion of Successful Nudges predicting Final Variability in Wake Time with Control Variables.

	Estimate	Standardized	Std. Error	t value
(Intercept)	580.644	0.000	2656.796	0.219
bl_sd_waketime	0.064	0.155	0.089	0.726
prop_success_nudge	-3742.385	-0.375	2955.490	-1.266
days_complete	5364.722	0.452	3325.265	1.613
prop_nudge_final	-554.957	-0.050	2532.568	-0.219

	Pr(>|t|)
(Intercept)	0.829
bl_sd_waketime	0.477
prop_success_nudge	0.221
days_complete	0.123
prop_nudge_final	0.829

Abbr: bl_sd = baseline standard deviation; prop_success_nudge = proportion of nudges followed; days_complete = number of days with completed sleep diaries; prop_nudge_final = proportion of days with nudges in final week

Table 10.

Coefficients for Model of Proportion of Successful Nudges predicting Winsorized Final Variability in Wake Time.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2711.25	1103.307	2.457	0.023
bl_sd_waketime_wins	0.17	0.118	1.447	0.163
prop_success_nudge	-720.49	2076.446	-0.347	0.732

Abbr: bl_sd = baseline standard deviation; prop_success_nudge = proportion of nudges followed

Table 11.

Coefficients for Model of Proportion of Successful Nudges predicting Winsorized Final Variability in Wake Time with Control Variables.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	386.578	2637.719	0.147	0.885
bl_sd_waketime_wins	0.115	0.122	0.943	0.358
prop_success_nudge	-3371.021	2985.241	-1.129	0.273
days_complete	5075.428	3327.701	1.525	0.144
prop_nudge_final	-494.580	2510.002	-0.197	0.846

Abbr: bl_sd = baseline standard deviation; prop_success_nudge = proportion of nudges followed; days_complete = number of days with completed sleep diaries; prop_nudge_final = proportion of days with nudges in final week

Supplemental Table 1.

Coefficients for Model predicting Final Variability in Wake Time in Imputed Dataset.

term	estimate	std.error	statistic	p.value
intercept	6705.942	1589.52	4.219	0.000
bl var of wake time	0.056	0.09	0.626	0.538
prop successful nudges	-5329.157	2952.90	-1.805	0.085

Abbr: bl var = baseline standard deviation; prop successful nudges = proportion of nudges followed

Supplemental Table 2.

Coefficients for Model predicting Final Variability in Wake Time with Control Variables in Imputed Dataset.

term	estimate	std.error	statistic	p.value
intercept	7994.055	3191.369	2.505	0.022
bl var of wake time	0.075	0.096	0.777	0.446
prop successful nudges	-4145.443	3330.504	-1.245	0.228
final week nudges	-93.681	3016.082	-0.031	0.976
completed diaries	-2378.153	3927.681	-0.605	0.552

Abbr: bl var = baseline standard deviation; prop successful nudges = proportion of nudges followed; completed diaries = number of days with completed sleep diaries; final week nudges = proportion of days with nudges in final week

Supplemental Table 3.

Coefficients for Model predicting Winsorized Final Variability in Wake Time in Imputed Dataset.

term	estimate	std.error	statistic	p.value
intercept	6064.992	1575.655	3.849	0.001
bl var of wake time	0.106	0.118	0.898	0.379
prop successful nudges	-4816.599	2754.401	-1.749	0.095

Abbr: bl var = baseline standard deviation; prop successful nudges = proportion of nudges followed

Supplemental Table 4.

Coefficients for Model predicting Winsorized Final Variability in Wake Time with Control Variables in Imputed Dataset.

term	estimate	std.error	statistic	p.value
intercept	6952.405	2970.561	2.340	0.030
bl var of wake time	0.125	0.128	0.978	0.340
prop successful nudges	-3913.655	3185.918	-1.228	0.234
final week nudges	-75.759	2807.990	-0.027	0.979
completed diaries	-1714.829	3708.099	-0.462	0.649

Abbr: bl var = baseline standard deviation; prop successful nudges = proportion of nudges followed; completed diaries = number of days with completed sleep diaries; final week nudges = proportion of days with nudges in final week

APPENDIX C

RECRUITMENT FLYER TEXT

Having trouble getting good, consistent sleep?
Are you a college student with too many demands on your schedule?
Are you looking for a way to make some extra money?
If so, you may be interested in participating in a study designed to improve sleep for college students! Researchers from the Psychology Department at the University of Oregon have created an online sleep intervention that is currently being tested. Participants will be asked to complete brief daily sleep diaries and online psychoeducation about improving their sleep. Two in-person visits will be required. The total time spent participating will be **4 hours** over 5 weeks. Participants have the opportunity to be reimbursed up to **$100**. If you are interested, please call XXX-XXX-XXXX or email us at XXX@gmail.com.

DEPARTMENTS CONTACTED

1. Psychology
2. Biology
3. Human Physiology
4. Computer and Information Science
5. Family and Human Services
6. General Sciences
7. Linguistics
8. Art

APPENDIX D

CONSENT FORM

Consent for Research Participation

Title: Micro-Randomized Trial for College Sleep Difficulties
Researcher: Melissa D. Latham, University of Oregon
Researcher Contact Info: 541-525-0877, mlatham@uoregon.edu

You are being asked to participate in a research study. The box below highlights key information about this research for you to consider when making a decision whether or not to participate. Carefully consider this information and the more detailed information provided below the box. Please ask questions about any of the information you do not understand before you decide whether to participate.

Key Information for You to Consider

- **Voluntary Consent**. You are being asked to volunteer for a research study. It is up to you whether you choose to participate or not. There will be no penalty or loss of benefits to which you are otherwise entitled if you choose not to participate or discontinue participation.
- **Purpose**. The purpose of this research is to test whether a specific type of sleep intervention is acceptable and effective for a group of college students. This is the first time that this type of intervention will be used to improve sleep.
- **Duration.** It is expected that your participation will last for 5 weeks, and that you will spend approximately 4 hours participating over those 5 weeks.
- **Procedures and Activities.** You will be asked to complete a questionnaire battery during two sessions; complete daily, brief questionnaires; read and interact with education about sleep; and receive suggestions during the weeks about your sleep habits.
- **Risks.** Some of the foreseeable risks or discomforts of your participation include boredom or irritation in response to the questionnaires or the sleep suggestions. Some of the questionnaire items may also make you uncomfortable.
- **Benefits**. Some of the benefits that may be expected include improvement of your sleep habits, yielding better sleep overall.
- **Alternatives.** Participation is voluntary and the only alternative is to not participate.

Who is conducting this research?
The researcher Melissa Latham from the Psychology Department at University of Oregon is asking for your consent to this research.
Why is this research being done?
The purpose of the research is to determine whether a specific type of intervention can help improve sleep for college students. The intervention consists of online, personalized

education about sleep and subsequent messages that are sent to participants reminding them of that education. So far, no one has used this type of intervention to improve sleep. If this type of intervention could improve sleep, it would be an easier way to help participants with sleep problems than the current interventions that are available. You are being asked to participate because you are a college student who is 18 years of age or older at the University of Oregon. About 30 people will take part in this research.

How long will I be in this research?

We expect that your participation will last for 5 weeks. During those weeks, you will attend two in-person sessions, both of which will take an hour to complete. You will also participate online, reading about sleep and using that information to create a personalized sleep plan, which will take an additional hour. Lastly, you will complete daily questionnaires about your sleep, which will take approximately one hour over the course of the study. Thus, you can plan to spend 4 hours participating in this study over the next 5 weeks.

What happens if I agree to participate in this research?

If you agree to be in this research, your participation will include three main components.

Phone application. We will install an application onto your phone that will be used for two purposes: to track your sleep and to send you messages. The application will approximate your sleep by tracking when your phone's screen is off, when it is plugged in, and when the phone moves. The application will also send you two types of messages. The first will be a reminder to complete a daily sleep diary. You will receive the reminder half an hour after your typical wake up time, and completing the sleep diary should take approximately 1-2 minutes each day. After the first week of the study, you will also receive short suggestions about your sleep hygiene from the app. These are set to occur in a randomized pattern; however, you will likely receive them 3 out of every 4 nights, between 1 and 4 hours before your typical bed time.

Online sleep education. After one week of participation, you will receive a notification to access a webpage that provides education about sleep. You will be asked to read through all of the text, answer a couple of questions, and create an interactive sleep plan. Completing this will take half an hour to an hour of your time.

In-person sessions. You will participate in two in-person sessions in the ADAPT Lab, located in Straub Hall at the University of Oregon. Each session will take approximately one hour. During the first, if you consent to participate, you will complete a set of questionnaires and the researchers will install an app on your phone (described below). The second in-person session will take place five weeks later. During that session, you will complete a set of questionnaires and the researchers will uninstall the app from your phone. The researchers will also ask you some questions about your experience in the study, and you will have the opportunity to ask questions and give feedback.

Overall, we expect that you will spend 4 hours participating in this study over the next 5 weeks, broken down as follows:

- First in-person session – 1 hour
- Sleep education session – 1 hour
- Sleep diaries – 12 minutes per week (1 hour total)
- Second in-person session – 1 hour

What happens to the information collected for this research?

Information collected for this research will be used to inform future research on sleep interventions, specifically for college students. We plan to publish and present the results of this research. However, your name and any other identifying information will not be used in any published reports, conference presentations, or other presentations about the data from this study. All data from participants will be presented in an aggregated fashion.
How will my privacy and data confidentiality be protected?
We will take measures to protect your privacy including conducting sessions in private rooms and not discussing your participation outside of the research team. Despite taking steps to protect your privacy, we can never fully guarantee your privacy will be protected. We will take measures to protect the security of all your personal information including keeping your identifiable information in a password-protected database that is only accessible by the researchers for the study. All other data you provide will be kept in separate databases and your data will only be linked to a unique ID code that only you and the researchers will know. All data that the phone application collects will be encrypted on the phone and kept in a secure, encrypted cloud-based storage. Researchers will have to decrypt data after accessing it from this cloud service. At that point, it will be deidentified and stored in a password-protected database to which only the researchers have access. Despite these precautions to protect the confidentiality of your information, we can never fully guarantee confidentiality of all study information.
Individuals and organization that conduct or monitor this research may be permitted access to and inspect the research records. This may include access to your private information. These individuals and organizations include The Institutional Review Board (IRB) that reviewed this research.

We protect your information from disclosure to others to the extent required by law. We cannot promise complete secrecy. You should understand that the researcher is not prevented from taking steps, including reporting to authorities, to prevent serious harm of yourself or others.
What are the risks if I participate in this research?
There may be risks of stress, emotional distress, inconvenience, boredom, and possible loss of privacy and confidentiality associated with participating in this research study. We anticipate these risks to be minimal.
What are the benefits of participating in this research?
You may or may not benefit from participating in this research. We cannot promise any benefits to you or others from your participation in this research. However, possible benefits to you include improvements in your sleep hygiene and sleep quality, both during the study and after the study has ended. Possible benefits to others include improvements in the way sleep interventions are designed and implemented for college students as well as the general public.

What if I want to stop participating in this research?
Taking part in this research study is your decision. Your participation in this study is voluntary. You do not have to take part in this study, but if you do, you can stop at any time. You have the right to choose not to participate in any study activity or completely withdraw from continued participation at any point in this study without penalty or loss of benefits to which you are otherwise entitled. Your decision whether or not to

participate will not affect your relationship with the researchers or the University of Oregon.
Your participation is voluntary. Your decision whether or not to participate will not affect your relationship with the UO Psychology Department or the UO Linguistics Department. If you decide to participate, you are free to withdraw your consent and discontinue participating at any time without penalty. The Psychology and Linguistics Departments have established alternative assignments for students who do not wish to participate as research subjects. Please see your instructor if you would rather complete an alternative assignment.
If you withdraw from the study, you are free to request that your data not be used for this research. If you decide to leave this research, contact the research team so that the investigator can remove all of your data from the databases detailed above and set up a time for you to visit the lab so that we can remove the application from your phone.
The investigators may stop you from taking part in this study. Reasons for withdrawal might include failure to attend in-person sessions or failure to complete the online sleep education module.
Will I be paid for participating in this research?
This study will take 4 hours over the course of 5 weeks to complete. You will be paid $100 or will be awarded 4 credit(s) for your participation. If you discontinue participation in the middle of the study, you will receive ¼ credit for each 15 minutes of participation, rounded up to the next 15 minutes. For example, if you complete 1-15 minutes you will receive ¼ credit, if you complete 16-30 minutes you will receive ½ credit, and so on. If you keep your scheduled study appointment but choose not to participate in the study at all, you will still receive ¼ credit.
For taking part in this research, you have the option to be paid up to a total of $100 cash. Your compensation will be broken down as follows: You will receive $20 for completing the first in-person session, provided to you at the end of that session. You will receive $35 for completing the online sleep education module, including the personalized sleep plan. You will receive $45 for attending the second in-person session at the end of the five weeks. The final two payments will be provided to you at that final session. If you do not attend the final session, but did complete the online sleep education module, we will send the $35 cash to your mailing address after the scheduled date of your final session.
If you are a student in a psychology course that requires research credit, for taking part in this research, you have the option to instead receive up to a total of 4 course credits. Your compensation will be broken down as follows: You will receive 1 credit for completing the first in-person session, added to your account up to one week after the end of that session. You will receive 1 credit for completing the online sleep education module, including the personalized sleep plan, added to your account up to one week after the end of that session. You will receive 1 credit for attending the second in-person session at the end of the five weeks, added to your account up to one week after the end of that session. In addition, as long as you have opened 75% of your sleep diary surveys, you will receive 1 credit, also after the end of the final session.
If you are a student in a psychology course that requires research credit, you may choose between these two compensation options during your first in-person session. Your decision will be recorded, and you will not be able to change your decision later. If you

are not a student in a psychology course that requires research credit, you will receive the monetary compensation.
Please be aware, compensation for participation in research studies may be considered taxable income.
Who can answer my questions about this research?
If you have questions, concerns, or have experienced a research related injury, contact the research team at

Melissa Latham
541-525-0877
mlatham@uoregon.edu

An Institutional Review Board ("IRB") is overseeing this research. An IRB is a group of people who perform independent review of research studies to ensure the rights and welfare of participants are protected. UO Research Compliance Services is the office that supports the IRB. If you have questions about your rights or wish to speak with someone other than the research team, you may contact:

Research Compliance Services
5237 University of Oregon
Eugene, OR 97403-5237
(541) 346-2510

Authorization to Use or Disclose (Release) Health Information that Identifies You for a Research Study

If you sign this document, you give permission to the study researchers from the Psychology Department in the University of Oregon to use or disclose (release) your health information that identifies you for the research study.
The health information that we may use or disclose (release) for this research includes whether or not you have been diagnosed with a sleep disorder. We are asking for this information to better assess the benefits you may or may not receive from the intervention. This is the only way this data will be used.
The health information listed above may be used by and/or disclosed (released) only to the researchers of the study.
The "covered components" of the University of Oregon are required by law to protect your health information. By signing this document, you authorize the covered components of the University of Oregon to use and/or disclose (release) your health information for this research. Those persons who receive your health information may not be required by Federal privacy laws (such as the Privacy Rule) to protect it and may share your information with others without your permission, if permitted by laws governing them.
Please note that you do not have to sign this document, but if you do not, you may not receive research-related treatment.
Please note that you may change your mind and revoke (take back) this Authorization at any time. Even if you revoke this Authorization, the researchers may still use or disclose health information they already have obtained about you as necessary to maintain the integrity or reliability of the current research. To revoke this Authorization, you must write to Melissa Latham at mlatham@uoregon.edu.
This Authorization does not have an expiration date.

STATEMENT OF CONSENT

I have had the opportunity to read and consider the information in this form. I have asked any questions necessary to make a decision about my participation. I understand that I can ask additional questions throughout my participation.
I understand that by signing below, I volunteer to participate in this research. I understand that I am not waiving any legal rights. I have been provided with a copy of this consent form. I understand that if my ability to consent or assent for myself changes, either I or my legal representative may be asked to re-consent prior to my continued participation in this study.
You may also be asked to wear an actigraphy watch during the first week of participation in this study. This data will be collected as an additional measurement of sleep. We ask that you wear the actigraphy watch as often as possible during that week. We will provide you with the actigraphy watch today and ask you to return it to the lab in one week. Initial the space below if you consent to the use of wearing the actigraphy watch as described.

____ I agree to wear the actigraphy watch for the first week of the study.

I consent to participate in this study.

_____ _____
Name of Adult Participant Signature of Adult Participant

_____
Date

Researcher Signature (to be completed at time of informed consent)
I have explained the research to the participant and answered all of his/her questions. I believe that he/she understands the information described in this consent form and freely consents to participate.

_____ _____
Name of Research Team Member Signature of Research Team Member

_____
Date

APPENDIX E

PSYCHOEDUCATION WEBSITE CONTENT

Page 1

Circadian Rhythms

- There are rhythms everywhere around us: night follows day, spring follows winter, some flowers close at night and open during the day, some birds migrate annually, the sea has high and low tides.
- Our bodies have similar rhythms: have you noticed that you usually get hungry just around lunchtime?
- Our body rhythms, or internal biological clocks, are known as circadian rhythms. Our circadian rhythms regulate a number of bodily functions throughout a 24-hour period.
- The word 'circadian' comes from the Latin c*irca* (around) and *diem* (day) → around the day!
- Regular signals help to maintain your body's circadian rhythms.
- Eating at regular times lets your body know when it's time to eat.
- **Sleeping and waking at the same time helps our bodies know when it's time to sleep.**

Page 2

Circadian rhythms and sleep

- Daylight is the most important signal for our circadian rhythms.
- Sleepiness, body temperature and a hormone called melatonin all have circadian rhythms that are regulated by daylight. At night, we are the most sleepy, our body temperature drops, and melatonin levels are high. When these three rhythms are working together, we have the best chance of a good night's sleep.
- When our sleep/wake cycles get out of sync with the day/night cycle, sleeping difficulties can arise:
- When we travel across time-zones (jet lag)
- When shift workers have to work the night shift
- **When we stay up all night doing school work or at a party**

Page 3

"Larks" & "Owls" have different circadian rhythms

- ***Larks*** have "early" circadian rhythms. They wake up early and go to bed early, and usually operate best in the mornings.
- ***Owls*** are the opposite. They operate best in the afternoon and evenings, and often find that they have a hard time going to bed or waking up early.

    - ***Many college students find that they are owls, and that their sleep preferences don't match up with college life.***
- These differences are biological, but there are ways to tailor your lifestyle that allow you to respect your biology but still respond to the demands of life.
- Keep a few things in mind:
    - In college, you have a lot of choice about when you take classes, eat, and sleep. How much of your schedule can you adapt to your preferred rhythm?
    - Over time, we all become a little bit more like larks. So don't worry too much if being an owl is difficult now – chances are it will get easier.

Page 4

Maintaining your circadian rhythms

1. Keeping a regular sleep/wake routine

While some of the biology controlling your circadian rhythms is beyond your control, there are some things you can do to help maintain regular circadian rhythms and increase your chances of getting a good night's sleep.

- **The best way to maintain regular circadian rhythms is to keep a regular sleep/wake routine.**
- **This means:**
    - **Wake up at about the same time every morning.**
    - **Go to bed at about the same time every night.**
- **Try to keep to your regular sleep/wake routine on weekends.** This means going to bed and waking up **within 2 hours** of when you normally would on a week day.
    - With all of the social activity associated with college life, it might not always be possible for you to go to bed within 2 hours of your normal bedtime.
    - **If so, make sure you wake up within 2 hours of your normal wake-up time the morning after.** You may feel tired during the day, but this will help you get back into your normal sleeping patterns more quickly.
    - **The following night, make sure you go to bed at your normal bedtime.** Don't go to bed earlier than usual because you feel tired – this will disrupt your circadian rhythms.
    - **Avoid staying up later than usual for two nights in a row.** Your body will recover quickly from one night of staying up late, but two nights makes it much more difficult, and might cause you to have difficulty sleeping for several nights after that.

2. A quick wake-up routine

Having a quick-wake-up routine is one of the simplest and most beneficial things you can do to regulate your circadian rhythms and improve your sleep. This means:

- Get up as soon as your alarm goes off.
- Keep your alarm on the other side of the room so you have to get up to turn it off.
- Don't press the snooze button!
- Open the curtains or turn on the lights – light will help you wake up.

- Do some exercises, take a shower or make your breakfast to help your body wake up.

3. Design a personal sleep plan for how you will go to bed at night and wake up in the morning.
   - Keep it realistic. This might mean making gradual changes, e.g., if you usually go to bed at 2:00am on a Saturday night, try bringing it back to 1:00am, and then midnight, etc.
   - Include the following things in your plan:
     - A set time to finish your work/activities and all media to be switched off (include a goal time to leave parties/social gatherings)
     - A wind-down routine at the end of the day
     - A set time for lights out
     - A set time for waking up
     - A quick wake-up routine.

Page 5

In the past 7 days:

1. I have gone to bed within 2 hours of my normal bed time:
   a. 0 days
   b. 1-2 days
   c. 3-4 days
   d. 5-6 days
   e. All 7 days
2. I have woken up within 2 hours of my normal wake up time:
   a. 0 days
   b. 1-2 days
   c. 3-4 days
   d. 5-6 days
   e. All 7 days
3. I have made a habit of doing the following things to wake up quickly:
   a. Set an alarm the night before.
   b. Gotten up as soon as my alarm went off.
   c. Kept my alarm on the other side of the room so I have to get up to turn it off.
   d. Did not press the snooze button!
   e. Opened the curtains or turned on the lights.
   f. Did some exercises, took a shower, made my breakfast, or some other activity to help my body wake up.
   g. Other

Page 6

My Personal Sleep Plan

- I am more like a **Lark** / **Owl**.
- I will finish doing school work/other activities and switch off all media at the following time:_____

- My leave parties/gatherings time is:_____
- My lights out time is:_____
- My waking up time is:_____
- My quick-wake-up routine is:_____

  _____

  _____

  _____

  _____

APPENDIX F

SATISFACTION SURVEY

1. Do you feel you got something of lasting value or importance from the intervention?
2. Please rate how useful the intervention has been for you.
3. Please rate how interesting you found the intervention.
4. Please rate the overall quality of the intervention.
5. What were the main things you got out of the intervention?
6. Please rate how helpful each of the following components has been for you.
    a. Completing sleep diaries
    b. Online education content
    c. Making your own sleep plan
    d. Receiving the "set your alarm" nudge/reminder
    e. Receiving the "wake up routine" nudge/reminder
7. In the past 7 days, I have gone to bed within 2 hours of my average bed time:
8. In the past 7 days, I have woken up within 2 hours of my average wake up time:
9. What did you like about this intervention?
10. What didn't you like about this intervention?
11. Was there anything that was difficult to implement or understand?
12. How do you think the intervention could be improved? Any suggestions would be greatly appreciated!

APPENDIX G

DEBRIEFING FORM

University of Oregon
Department of Psychology

Debriefing Form

Study Title: "Micro-Randomized Trial for College Sleep Difficulties**"**
Principal Investigator: Melissa Latham, M.S.

Introduction:
Thank you for participating in this study. Now that the study has concluded, we will answer any questions you may have about your participation in this study.

Purpose of the Study:
The purpose of this study was to evaluate whether a sleep intervention consisting of education and messages about sleep hygiene was acceptable and effective.

Risks/Benefits of Your Participation:
There are no known or foreseeable risks associated with the study in which you just participated. However, some of the questions in the surveys asked about sensitive information and you may want to talk to someone about these. Please inform the research personnel if you would like us to connect you to someone that you can talk to.

It is possible that you benefited from this study by improving your sleep regularity or quality. If so, that's great! It is also possible that you did not receive any specific benefits, which would be a normal outcome. Since the intervention is still being researched, we do not yet know if it will benefit those who use it.

Questions & Contact Information:
Please inform the research personnel if you have any questions about your participation in this study. Should you be interested in the results of this study, please feel free to contact the Principal Investigator (Melissa Latham, mlatham@uoregon.edu).

If you have any questions concerning your rights as a research participant, please contact the University of Oregon Office of Research Compliance Services or the Human Subjects Coordinator in for the Departments of Psychology and Linguistics:

Office of Research Compliance Services

5237 University of Oregon Eugene, OR 97403
541-346-2510; researchcompliance@uoregon.edu

Marcus Mayorga, M.S.
Human Subjects Coordinator, Departments of Psychology and Linguistics
hscoord@uoregon.edu

Copy of Debriefing Form:
You will be given a copy of this form to keep for your records and future reference.

Statement of Debriefing:
I have read (or have had read to me) the contents of this debriefing form and have been encouraged to ask questions. I have received answers to my questions, and I have received (or will receive) a copy of this form. My signature below indicates that I have been debriefed.

Signatures/Dates

_____
Study Participant (Print Name)

_____
Participant or Legal Representative Signature **Date**

APPENDIX H

DEMOGRAPHICS QUESTIONS at CONSENT SESSION

1. What is your date of birth?
2. How old are you?
3. What is your biological sex?
4. What is your gender identity?
5. With what race do you identify?
6. With what ethnicity do you identify?
7. What is your mother's highest level of education?
8. What is your father's highest level of education?

APPENDIX I

PITTSBURGH SLEEP QUALITY INDEX (Buysse et al., 1989)

Instructions: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

During the past month,

1. When have you usually gone to bed? _____
2. How long (in minutes) has it taken you to fall asleep each night? _____
3. When have you usually gotten up in the morning? _____
4. How many hours of actual sleep do you get at night? (This may be different than the number of hours you spend in bed) _____
5. During the past month, how often have you had trouble sleeping because you…
    a. Cannot get to sleep within 30 minutes
    b. Wake up in the middle of the night or early morning
    c. Have to get up to use the bathroom
    d. Cannot breathe comfortably
    e. Cough or snore loudly
    f. Feel too cold
    g. Feel too hot
    h. Have bad dreams
    i. Have pain
    j. Other reason(s), please describe, including how often you have had trouble sleeping because of this reason(s):
6. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?
8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?
9. During the past month, how would you rate your sleep quality overall?

APPENDIX J

DEPRESSION, ANXIETY, and STRESS SCALES – 21 (Lovibond & Lovibond, 1995)

1 I found it hard to wind down
2 I was aware of dryness of my mouth
3 I couldn't seem to experience any positive feeling at all
4 I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)
5 I found it difficult to work up the initiative to do things
6 I tended to over-react to situations
7 I experienced trembling (eg, in the hands)
8 I felt that I was using a lot of nervous energy
9 I was worried about situations in which I might panic and make a fool of myself
10 I felt that I had nothing to look forward to
11 I found myself getting agitated
12 I found it difficult to relax
13 I felt down-hearted and blue
14 I was intolerant of anything that kept me from getting on with what I was doing
15 I felt I was close to panic
16 I was unable to become enthusiastic about anything
17 I felt I wasn't worth much as a person
18 I felt that I was rather touchy
19 I was aware of the action of my heart in the absence of physical exertion (eg, sense of heart rate increase, heart missing a beat)
20 I felt scared without any good reason
21 I felt that life was meaningless

APPENDIX K

MORNINGNESS-EVENINGNESS QUESTIONNAIRE (Horne & Östberg, 1976)

1. What time would you get up if you were entirely free to plan your day?
2. What time would you go to bed if you were entirely free to plan your evening?
3. If there is a specific time at which you have to get up in the morning, to what extent do you depend on being woken up by an alarm clock?
4. How easy do you find it to get up in the morning (when you are not woken up unexpectedly)?
5. How alert do you feel during the first half hour after you wake up in the morning?
6. How hungry do you feel during the first half hour after you wake up in the morning?
7. During the first half hour after you wake up in the morning, how tired do you feel?
8. If you have no commitments the next day, what time would you go to bed compared to your usual bedtime?
9. You have decided to engage in some physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 7:00 - 8:00am. Bearing in mind nothing but your own internal "clock," how do you think you would perform?
10. At what time of day do you feel you become tired as a result of a need for sleep?
11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last for two hours. You are entirely free to plan your day. Considering only your own internal "clock," which ONE of the four testing times would you choose.
12. If you got into bed at 11:00pm, how tired would you be?
13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following are you most likely to do?
14. One night you have to remain awake between 4:00 - 6:00 am in order to carry out a night watch. You have no commitments the next day. Which ONE of the alternatives will suite you best?
15. You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your own internal "clock" which ONE of the following times would you choose?
16. You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10:00 - 11:00pm. Bearing in mind nothing else but your own internal "clock" how well do you think you would perform?
17. Suppose that you can choose your own work hours. Assume that you worked a FIVE hour day (including breaks) and that your job was interesting and paid by results. Which FIVE CONSECUTIVE HOURS would you select?
18. At what time of the day do you think that you reach your "feeling best" peak?

19. One hears about "morning" and "evening" types of people. Which ONE of these types do you consider yourself to be?

APPENDIX L

SLEEP DIARY

1. What time did you get into bed last night?
2. What time did you fall asleep last night?
3. Did you wake up in the middle of the night?
    a. How many times did you wake up?
    b. How long do you think you were awake, in minutes, across all of your awakenings?
4. What time was your final awakening this morning?
5. What time did you get out of bed this morning?
6. Have you taken any naps since you completed yesterday's sleep diary?
    a. How many naps have you taken since then?
    b. How long do you think you spent napping, in minutes, across all of your naps?

AFTER FIRST WEEK OF INTERVENTION

7. Did you receive a "nudge" or reminder last night?
    a. At approximately what time did you receive the "nudge"/reminder?
    b. Did you follow its instructions?
    c. Where were you when you received the "nudge"/reminder?

APPENDIX M

LIST OF VARIABLES USED FOR MULTIPLE IMPUTATION

Participant ID
Date
Response to nudge
Bed time
Wake time
Weekday or weekend
Gender
Content of nudge
Winsorized wake time

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