ABSTRACT

Title of Dissertation: Reminding Me of the Future: Episodic Future Thinking as A Strategy for Mobile Health Interventions

Yan Qin, Doctor of Philosophy, 2021

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The use of mobile and wireless technologies has been rapidly increasing worldwide and sparked a growth in the use of these technologies to support the achievement of health objectives (i.e., mHealth). This dissertation aims to test the effect of an mHealth intervention using mobile apps for promoting healthy lifestyle behavior change among college students. It takes an "active ingredient" perspective that examines the utility of a single strategy in mHealth interventions. The strategy is called episodic future thinking (EFT), the ability to project oneself into the future to pre-experience future events. Drawing on future thinking, intertemporal choice, and construal level theory, this dissertation proposes that engaging in EFT (vs. episodic recent thinking, ERT) could help individuals make better health-related choices in their everyday lives in terms of taking sufficient sleep or physical activity. Through a two-week mHealth intervention using the health apps *SleepCycle* and *NikeTrainingClub,* this dissertation examines the effect of EFT on two lifestyle-related behaviors, i.e., sleep and physical activity participation, and explores the psychological mechanism underlying EFT's effect. The findings suggest that EFT could be a useful strategy incorporated into mHealth interventions to increase intentions for health behavior change and to promote actual behavior change among college students. However, it might have contradictory effects when applied to different types of behavior. Specific to the current study, EFT was effective in promoting physical activity as recorded through the health app *NikeTrainingClub*. However, EFT had negative effect when applied to the sleep behavior. The reasons why this was the case are explained and theoretical and practical implications for EFT research and mHealth interventions are discussed. In general, the findings complement and extend previous research on EFT and mHealth interventions and emphasize the importance of context (including the context of mobile technologies) in mHealth intervention research.

Reminding Me of the Future: Episodic Future Thinking as A Strategy for Mobile Health Interventions

by

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Dissertation submitted to the Faculty of the Graduate School of the
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Dedication

This dissertation is dedicated to my husband who encouraged me to pursue my dreams and finish my dissertation.

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course on academic writing helped improve my English writing and shape my academic writing style, which enabled me to be more confident when submitting papers to journals.

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Chapter 1: Introduction

1.1 Background and Overview

The use of mobile and wireless technologies has been rapidly increasing worldwide. Mobile coverage reached 98.8% for developed countries and 96% for developing countries (ITU, 2019). In the US, for example, 95% of the population own at least one mobile phone (PEW Research Center, 2017) and 84% have home access to the Internet (ITU, 2017). Globally, almost the entire world population (97%) could be reached through a mobile cellular signal (ITU, 2019). The high penetration rate of mobile phone, together with its mobility, instantaneous access, and direct communication, allows this technology to transfer health information in a fast and personalized way, which in turn supports medical and public health practices. These characteristics have sparked a growth in the use of mobile and wireless technologies to support the achievement of health objectives (i.e., mHealth). *mHealth* broadly refers to any use of mobile computing and communication technologies to address health care and public health challenges (Fiordelli et al., 2013, p. 2). mHealth for health promotion can include diverse mobile tools, ranging from text messages (e.g., Fortmann et al., 2017; Nelson et al., 2016) to apps for health promotion and self-management (e.g., Chavez et al., 2017; Holtz et al., 2017). Health promotion apps are designed to support daily health self-management. For example, sleep apps help monitor sleep quality and provide information on sleep hygiene knowledge; physical activity apps integrate various functions ranging from self-monitoring of daily steps/running miles to instruction videos on exercises such as yoga and functional training.

This dissertation aims to test the effect of an mHealth intervention using mobile apps to promote healthy lifestyle behavior change among college students. It takes an “active ingredient” perspective that examines the utility of a single strategy in mHealth interventions. The strategy is called *episodic future thinking* (EFT), the ability to project oneself into the future to pre-experience future events (Szpunar, 2010). Accordingly, this dissertation addresses the question: whether and how EFT helps individuals make better health-related choices in their everyday lives? Drawing on literature about future thinking, intertemporal choice, and construal level theory, this dissertation proposes that engaging in EFT helps individuals make better health-related choices in their everyday lives in terms of taking sufficient sleep or physical activity. Through a two-week mHealth intervention using the health apps *SleepCycle* and *NikeTrainingClub*, this dissertation examines the effect of EFT on two lifestyle-related behaviors, i.e., sleep and physical activity participation, and explores the psychological mechanism underlying EFT’s effect.

Chapter 2 gives a narrative review on mHealth interventions. Research shows that mHealth has the potential to efficiently deliver high-quality health interventions, but the evidence supporting its current effectiveness is still mixed. The reasons for the mixed results are manifold. But the key issue revolves around theory use in interventions. Specifically, there has been a lack of theory-based design in mHealth interventions, and it was often those unsuccessful interventions that lacked a theoretical framework grounded in behavior science. Even when theories are in use, efforts are still needed on devising theoretical techniques that are suitable for the technologies used in the intervention. Technology advances, on the other hand, should be better utilized to fulfill potential theoretical propositions.

mHealth stands at the crossing of mobile technologies, communication media, and health behavior change. The design of mHealth interventions thus needs to consider all these aspects. Specifically, we need to consider the use of behavioral change strategies in relation to the modes of intervention delivery, technology components, and different health domains and targeted populations.

Based on this understanding, Chapter 3 introduces the theoretical framework for this dissertation. This chapter provides "thinking about the future" as a general framework and discusses why and how this framework fit into the interventions developed in this dissertation. The choice of the strategy EFT is based on considerations of its suitability with the target behaviors under investigation and the mobile technologies employed. Chapter 3 elaborates on these relationships from a theoretical perspective.

Chapter 4 proposes the research questions and hypotheses of this dissertation based on previous theoretical discussion and empirical evidence. Chapter 5 introduces the intervention study that examines the effect of EFT on two behaviors (i.e., sleep and physical activity) among college students. In this chapter, study design, procedures, and measurements are presented. Chapter 6 provides results of the intervention study and chapter 7 elaborates on the implications of those results.

1.2 Theoretical Importance

A large body of literature has shown that EFT interventions reduce delay discounting (DD), individuals' preference for smaller, immediate rewards over larger, delayed rewards (Rung & Madden, 2018). EFT interventions usually involve an EFT cue generation task and a subsequent DD task during which the cues generated are presented auditorily or visually to the participants. In the EFT cue generation task, participants are usually asked to imagine vividly possible, positive future events.

Steep DD rate is associated with many unhealthy behaviors, such as cigarette smoking (Chiou et al., 2017; Stein et al., 2018), problematic drinking (Bulley & Gullo, 2017; Snider et al., 2016), drug use (Johnson et al., 2007; Sofis et al., 2020), and obesity (Epstein et al., 2010; Sze et al., 2017). It has also been associated with risky behaviors that are believed to pose a threat to public health, such as neglecting sunscreen and using seatbelt (Reimers et al., 2009). As such, EFT could be a promising strategy for reducing maladaptive impulsive behaviors and promoting public health.

This dissertation adds to the literature of EFT first by applying it to behavior types that have not been addressed before. A large amount of the EFT studies focused on addictive behaviors, e.g., smoking, alcohol use, and drug use. Recent studies have started to explore EFT's utility for other behavior types, such as weight loss maintenance (Leahey et al., 2020), prosocial (Gaesser et al., 2020), and pro-environmental behavior (Lee et al., 2020). Examining behavior types that have not been studied in previous research could help increase the generalizability of EFT as well as testing the boundary conditions of its applicability.

Moreover, this dissertation extends the literature of EFT by exploring the effect of repeatedly engaging in EFT on behavior change over time and examining its effect in natural settings.

Traditional EFT studies are mostly conducted in laboratory settings with one set of DD task and/or hypothetical behavior task following one session of the EFT task. Not many studies have examined the effect of repeatedly engaging in EFT over a period of time on DD or health behaviors. For those that examined the repeated effect of engaging in EFT, the results have been inconsistent. Two studies showed some promises of this approach (Mellis et al., 2019; Sze et al., 2015). For example, Mellis et al.'s (2019) study showed that for current and recent problem drinkers, the presence of future cues decreased their DD rates over six sessions, compared to those with no cue or shown with scarcity cues. However, another study examined the effects of repeated engagement of EFT (i.e., one week of time) showed no effect of such repeated engagement of EFT on DD, nor on the ad lib energy intake and the relative reinforcing value of snack food, compared to one engagement in EFT (Mansouri et al., 2020). Similarly, not many studies on EFT were conducted in natural settings, limiting its external validity and practical applicability (but see the following for some exceptions: Hollis-Hansen, 2020; Hollis-Hansen et al., 2020a, 2020b; O'Neill et al., 2016).

Lastly, this dissertation seeks to integrate EFT with mobile technologies to test the plausibility of such combination on health behavior change for different types of behavior. Previous research has proposed some ways for combining EFT with different media formats or technologies. For example, Kakoschke et al.'s (2018) and Sze et al.'s (2015, 2017) studies employed smartphone apps and text messages or emails to deliver EFT cues. Kaplan et al. (2016) asked participants to view age-progressed computer-generated images of themselves as a modified procedure for

EFT. Bays et al. (2018) examined the effects of photographs on the quality of future thinking. Recently, Wang et al. (2019) proposed a theoretical framework that integrated EFT into virtual reality (VR) to mitigate substance use disorders. In a word, exploring different possibilities of integrating EFT with new technologies or media formats has received increasing research attention. It could be a promising way to make this strategy more powerful (Wang et al., 2019).

1.3 Methodological Importance

This dissertation employs several ways to increase both the internal and external validity of its results. Specifically, 1) it employs a field experiment with longitudinal design; 2) it assesses two behavior types – physical activity and sleep – by means of objective data; 3) it uses ecological momentary intervention and assessment (EMI and EMA); 4) the use of thinking task (i.e., EFT), compared to reading health messages, facilitates participants' engagement with the information being communicated.

This dissertation involves a field experiment with longitudinal design (i.e., 2 weeks). Experiment has been a gold standard for probing causal relationships. However, one drawback of it is a lack of external validity due to the often controlled and artificial laboratory setting. Mobile technologies have increasingly become an integral part of people's everyday life to the extent of becoming our "extended self." (Belk, 2013) Addressing mHealth from an everyday use perspective become more practical and can increase the external validity of a study. Moreover, most choices about health are made during everyday activities. Approaching mHealth interventions from an everyday use perspective may thus provide researchers great opportunity to improve the efficacy of mHealth interventions as "influencing these choices constitutes the single greatest opportunity to improve health and reduce premature deaths" (Schroeder 2007, p. 1222).

This dissertation also employs EMI and EMA to increase its internal and external validity. EMI enables delivery of interventions to individuals as they go about their daily lives, that is, during their everyday lives (i.e., in real time) and in natural settings (i.e., real-world; Heron & Smyth, 2010), whereas EMA assesses individuals' experiences, behaviors, and moods as they occur in real time and in their real-world settings (Burke et al., 2017). Both the EMI and the EMA take advantages of the ubiquitous availability of mobile technologies and have increased in popularity in recent years (e.g., Heron & Smyth, 2010; Hollis-Hansen et al., 2020).

EMIs are ecologically valid because they occur in the natural environment. They could also provide real-time support in the real world because they are usually provided at specifically identified moments when they are most needed in people's everyday life. EMA reduces retrospective recall and the associated biases to some extent as people report on current or recent states or events. As with EMI, EMA increases generalizability and ecological validity because the measurements are taken in natural settings. In addition, there are usually multiple assessments over time, allowing for the exploration of temporal relationships among variables.

Last but not least, this study is able to deliver intervention and collect behavior data using the same device (Direito et al., 2018) thanks to the various functions, sensors, and applications of mobile phones.

1.4 Practical Importance

Lifestyle-related behaviors have significant influence on people's health during different times. On the one hand, unhealthy lifestyle is among the main reasons for the prevalence of chronic diseases. Many of such illnesses can be prevented or treated by making changes to people's own behaviors. On the other hand, promoting preventive health behaviors could inform responses to infectious diseases, especially during a pandemic such as the COVID-19 pandemic. Lockdowns during the COVID-19 pandemic have been shown to influence a variety of lifestyle-related behaviors, such as sleep time and mealtime (Sinha et al., 2020), sleep duration, physical activity, and social encounters (Oved et al., 2021), sedentary activity and exposure to digital media (Dutta et al., 2020).

mHealth has been suggested as an effective and cost-efficient way to address lifestyle related health behavior change due to the adoption, pervasiveness, and ubiquity of mobile technologies in our daily lives (Marcolino et al., 2018). This dissertation integrates streams of research on intertemporal choice (e.g., Lempert & Phelps, 2016; Loewenstein & Thaler, 1989), future thinking (e.g., D'Argembeau et al., 2010; Schacter, 2012), and construal level theory (e.g., Katz & Byrne, 2013; Trope & Lieberman, 2010) to understand how to better design mHealth interventions to promote health behavior change.

Since it has been coined in the first years of the new century, mHealth has been the center of debate in the health context (Bashshur et al., 2011). It has grown in importance given two lines of development in the health arena. One is that the scope of health has been broadened considerably to integrate lifestyle related aspects, such as diet, fitness, and wellness. The other is that new technologies have altered how people perceive health, opening new opportunities for individuals to take an active part in their health care and management, which also has empowering effect on them (Koinig & Diehl, 2020, p.179). Together with these two lines of development is WHO's (2011) call for discovering "new horizons for health through mobile technologies." As such, mHealth is a promising area in health communication that warrants further research.

Chapter 2: Literature Review on mHealth Interventions

mHealth is defined by the WHO as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" (Kay, 2014). While mHealth demonstrates potential for improving the coverage, efficiency, and quality of health systems, with likely benefits for health service utilization, behavior change, and clinical outcomes, its effectiveness by now is still mixed (Marcolino et al., 2018). A number of factors could be underlying the mixed results. These include different types of technology or functionality used in the interventions, types of targeted health behavior, participants, study designs, outcome measures, and theory use. The following sections review these aspects one by one.

2.1 Technologies and Functionalities Used in mHealth Interventions

Mobile technologies used in mHealth involve patient monitoring devices, personal digital assistants (PDAs), mobile phones, and other wireless devices. Even for a single technology such as mobile phone, the term has evolved to include different functionalities over the years as the technological capabilities have advanced. The functions of mobile phones used in mHealth include voice and short messaging service (SMS) as well as more complex functionalities and applications, such as global positioning system (GPS), Bluetooth technology, third and fourth generation mobile telecommunications (3G and 4G systems), and others.

This review focuses on mHealth interventions using mobile phones, which refer to interventions delivered through or in combination with mobile phones via short messaging services (SMS), multimedia messaging services (MMS), applications, phone calls, email, web browsers, and social media. Specifically, this review focuses on SMS and health applications (apps) because these two functions relate most closely to this dissertation.

Short messaging service (SMS), also called text messaging (TM), is one of the most frequently utilized functions of mobile communication. It is also among the first to be used in mHealth interventions and has expanded rapidly since 2002 (Hall et al., 2015). Systematic reviews and meta-analyses have shown statistically significant positive effects of text-massaging interventions (TMI) on diverse health outcomes and health behaviors, such as physical activity, smoking, and chronical disease self-management. For example, Head et al., (2013)'s meta-analysis found an overall weighted mean effect size of d = .329 (95% CI = .274, .385; p < .001) for text messaging-based interventions for health promotion.

As mobile applications (apps) began to emerge after 2008, there have been an increasing number of interventions using mobile apps. There are a few general reviews on app-based interventions (e.g., Payne et al., 2015; Zhao et al., 2016). The majority of reviews focused on a single behavioral type such as diabetes self-management (Wu et al., 2017), with app-based interventions associated with a clinically significant reduction of HbA1c (MD 0.48%, 95% CI 0.19%-0.78%); a small-to-moderate positive effect on physical activity (standardized difference in means [SDM] = 0.350, 95% CI 0.236 to 0.465, I^2=69%, T^2=0.051; Laranjo et al., 2021); and for improving nutrition behaviors (g = 0.19; CI, 0.06-0.32, P = .004) and nutrition-related health outcomes (g = 0.23; CI, 0.11-0.36, P < .001; Villinger et al., 2019).

Some of the research attention on app-based interventions has been directed to examining commercially available health apps and related issues, such as people's motivation to download certain apps or their attitudes and perception toward using those apps. In such studies, researchers usually relied on behavioral change theories as standard for the quality of app design. For example, Middelweerd et al., (2014) examined commercially available physical activity apps and found that the reviewed apps included an average of 5 behavioral change techniques ranging from 2-8. The most often used techniques included self-monitoring, providing feedback on performance, and goal setting. However, there has not been conclusive evidence on whether the number or type of behavioral change techniques used in a health app is associated with larger or small effect (Middelweerd et al., 2014).

Despite an emerging interest in using apps for improving health behaviors and the fact that thousands of health apps are now available for download, very few of these commercially available apps have been utilized and tested in interventions (Payne et al., 2015). It is shown that smartphone owners have an average of 41 apps installed with 52% using their phones for health purposes (Payne et al., 2015). Health apps have the potential to empower individuals, but evidence-based research is needed (Wiederhold, 2015).

2.2 Health Domains and Participants in mHealth Interventions

mHealth interventions have been applied to a variety of health domains. Free et al. (2010) proposed a framework of intervention classification (see Figure1). According to a systematic review on the systematic reviews of mHealth interventions (Marcolino et al., 2018), text messaging for chronic disease management was by far the most widely used and successful mHealth intervention. Evidence is still cumulating for the effectiveness of using mobile technologies for lifestyle-related behavior change. One meta-analysis reported that no article in their review examined the effectiveness of mobile-based technology in monitoring health behaviors and behavioral change (McMillan et al., 2017). A recent review found a moderate positive effect on lifestyle behavior outcomes (standardized difference in means [SDM] 0.663, 95% *CI* 0.228-1.10; Tong et al., 2021).

Closely related to health domain examined in mHealth interventions, participants in mHealth research were most often people with certain conditions such as people with diabetes and those who needed cardiac rehabilitation, etc. This is understandable because priority should be given to those who could benefit the most from the interventions. However, as mobile phones and apps become increasingly integrated into people's daily life and as "the old entitlement mindset of 'I'm broken, fix me' is giving way to 'I want to stay out of trouble' (Wiederhold, 2015)," it is also important to address how people use mobile devices to guide them toward a healthier lifestyle.

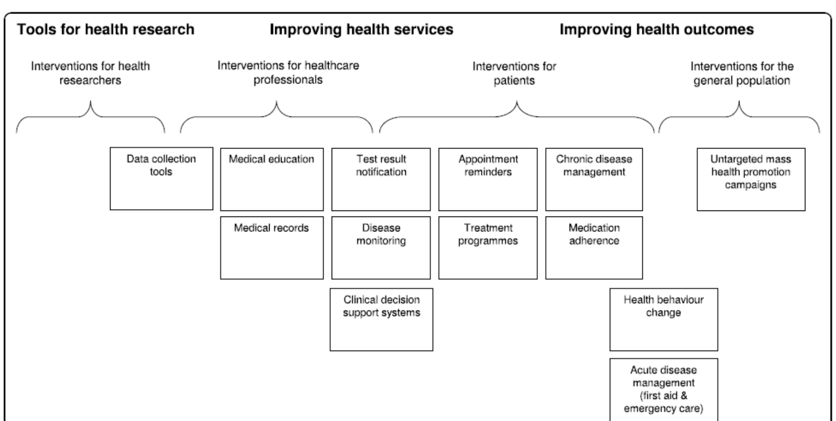

Figure 1 Conceptual framework for mobile electronic device intervention classification.

Figure 1 mHealth intervention by health domains (Free et al., 2010)

2.3 Study Designs and Outcome Measures in mHealth Interventions

Randomized controlled trials (RCTs) have long been considered the research gold standard for determining the efficacy of health interventions and have been well accepted in mHealth interventions as well. Most review articles and meta-analyses based their discussion on studies using this method. Another method often used in mHealth interventions was pilot study, especially for app feasibility tests. But the small sample size associated with this method and a lack of control group in many studies were often criticized.

Although RCTs remain to be the gold standard to test efficacy, scholars have argued for the use of other study designs and evaluation methods in mHealth studies, such as sequential multiple assignment randomized trial (SMART), multiphase optimization strategy (MOST), ecological momentary intervention (EMI), and assessment (EMA).

Two forces might be driving this call for other methods. One concerns the need to evaluate the active ingredients in a program, and the other is about using methods that best suit the characteristics of newer communication technologies.

First, there is a need to evaluate the active ingredient(s) driving the effect of mHealth interventions to generate better design of these interventions. Although evidence so far support the use of mobile technologies in health interventions, less is known about what specific strategies are responsible for the effect, and through what mechanisms. For example, Klasnja et al. (2011) posited that the use of RCTs might not be suitable to evaluate interventions using newer technologies, especially at early stages of technology development. They argued, instead, for a narrower notion of efficacy, “one that tailors outcome measures to the particular intervention strategies a technology employs” (p. 3063). This is especially important for interventions using health apps because the narrower notion of efficacy would enable researchers to test whether their apps are doing what they are intended to do. As was mentioned before, researchers have examined the use of behavioral change techniques (BCTs) in health apps, but there has been a lack of evidence on whether the number and type of BCTs used in an app is associated with larger or smaller effect for behavior change due to the methods used to test such effect.

In line with this, some scholars (Collins et al., 2007) recommended sequential multiple assignment randomized trial (SMART) as an alternative method. Traditional RCTs evaluate the intervention as a whole and do not allow isolation of the effects of individual components. SMART design, on the other hand, considers behavioral change as involving a set of components and addresses these components separately. The SMART design incorporates RCTs, but before the RCT is undertaken, it includes methods for “identifying which components are active in an intervention, and which doses of each component lead to the best outcomes” (Collins et al., 2007, p.2).

Additionally, scholars have advocated for using methods that better leverage the characteristics of mobile technologies, such as their ubiquity and easy access. These methods include ecological momentary intervention (EMI) and assessment (EMA), and just-in-time adaptive interventions (Nahum-Shani et al., 2018). EMA and EMI were proposed by Shiffman and Stone (1998), which are characterized by delivering intervention and collecting data in real-time and in subjects’ real-world environment and are considered as complements to laboratory studies in health psychological research. These methods are particularly well-suited for the study of mHealth interventions and have increased in number and popularity in recent years (Heron & Smyth, 2010). The array and scope of behaviors being studied also expanded but the emphasis has mainly been on substance abuse, chronic pain, physical activity, eating behaviors, and lapses among dieters (e.g., Heron & Smyth, 2010; Minami et al., 2018; Sokolovsky et al., 2013).

Technology advances allow a more effective use of methods such as EMI/EMA and just-in-time adaptive design in mHealth interventions. These advances also make it possible to track actual behavior change and collect data on objective measures of behavior. Broadly speaking, two types of outcome measure have been used in mHealth interventions: objective measures (e.g., health behaviors such as physical activity and clinical outcomes such as chemotherapy-related toxicity symptoms) and subjective measures (i.e., self-report behavior-related measures). Other than these primary health-related outcomes, secondary outcomes that related to technology use (e.g., technology acceptability, usability, and retention rate) and other aspects (e.g., cost-effectiveness analyses) have been reported less often but could still be found in empirical works and review articles.

Mobile technologies have increasingly become an integral part of people's everyday life, especially in industrialized countries and with younger generations. Addressing mHealth from an everyday use perspective will inform researchers of the best practice to implement mHealth interventions and provide knowledge on what strategies should be used in combination of what functions of the technology to generate optimal results. Moreover, most choices about health are made during everyday activities. Approaching mHealth interventions from an everyday use perspective may also provide researchers great opportunity to improve the efficacy of health interventions as “influencing these choices constitutes the single greatest opportunity to improve health and reduce premature deaths in the USA” (Schroeder 2007, p. 1222). For example, in a smoking cessation intervention, researchers utilized mobile phone and EMA to examine the moment-to-moment changes that may influence a smoker’s likelihood of smoking lapse. With such tools, researchers were thus able to identify factors associated with smoking lapses (Hébert et al., 2018). In short, taking advantage of the role mobile phones play in people’s daily life, mHealth intervention could better assist people in their moment-of-decision concerning health.

2.4 Theory Use in mHealth Interventions

The prevalence of newer communication technologies suggests that most people are already connected to a potential intervention device throughout most of the day. The ubiquity of mobile phones, however, is just one part of the equation to promote health behavior change. The second part is the knowledge on behavior change and on how people use communication technology in their daily life. These issues have been examined less often in previous studies but have received increasing attention these days. The following sections address the issue with theory use in mHealth interventions.

2.4.1 Use of Behavior Change Theories in mHealth Interventions

There are three aspects to theory use in mHealth interventions: (1) adopting theory-based research design, (2) adopting theories that are suitable for the technologies used in the intervention, (3) adopting theories that have dynamic, regulatory system components.

The issue of theory use in intervention design has been a key word since the early days of mHealth studies. Earlier reviews found that there was a lack of behavioral theories in the design of mHealth interventions (e.g., Buhi et al., 2013; Kaplan & Stone, 2013), and it was often those unsuccessful interventions that lacked an empirical or theoretical framework grounded in behavior science. Some of these earlier reviews also showed that fields such as health education, communication, and behavior science were underrepresented in mHealth literature (Buhi et al., 2013; Fiordelli et al., 2013). This may explain the lack of use of behavior change theories in early development of mHealth interventions. Theory guides what researchers need to know before they develop mHealth interventions and could inform researchers the reasons why people do or do not engage in certain health behaviors (Rimer & Glanz, 2005). Thus, it is important that the design of mHealth interventions is theory-based.

According to more recent reviews targeting at specific health areas, there has been an increase in the use of behavioral change theories or techniques (BCTs) in mHealth interventions (Conroy et al., 2014; Direito et al., 2014; Lyons, et al., 2014). However, even if a theoretical framework is in place, researchers need to devise the program strategies so that the theories used are suitable for the technologies. Stephenson et al. (2017) conducted a literature review comparing interventions delivered through computer, mobile phone and wearable device. They found that people preferred different behavioral change techniques (BCTs) depending on different platforms of intervention delivery. They argued that these different choices suggested that some BCTs might lend themselves well to certain modes of deliver and technology components. This argument is consistent with affordance theory. Affordance theory argues that a single technology affords multiple action capabilities (possibilities) which constraint what people could do with them; what capability a technology will achieve, however, depends on how individuals use it (Schrock, 2015). In other words, what technology could do to people depends on its own functions as well as how people use it.

Adapting theories to suit technologies also indicates that researchers should take more advantage of technology advances. The advancement of mobile technologies makes it possible to capture rich data on time-varying factors, such as mood, attitudes, urge to smoke, fatigue levels, etc., which can change hour-by-hour or even moment-to-moment. The availability of time-intensive information (e.g., longitudinal data on mood obtained at intensive frequency) increases our ability to provide intra-individual tailoring of health interventions (Riley et al., 2011).

However, current behavior change models are predominately static and linear in nature, which are limited at informing just-in-time intervention adaptations and intra-individual dynamics of future mobile technology interventions (Dunton et al., 2009; Riley et al., 2011). Riley et al. (2011) found that when a theory was used in mHealth intervention, the theory usually relied on dispositional constructs (e.g., self-efficacy) as the potential sources for behavior change. They argued that mHealth interventions should adopt conceptual frameworks "that have dynamic, regulatory system components to guide rapid intervention adaptation based on the individual's current and past behavior and situational context" (Riley et al., 2011, p. 54). They suggested that control systems engineering, characterized by dynamical systems and feedback regulatory processes, could help enrich current behavior change theories to better fit the time-intensive, interactive, and adaptive health behavior interventions delivered via mobile technologies (Riley et al., 2011). For example, regulatory feedback for disease management has been applied to diabetes management where frequent adjustments to insulin dose and diet are determined based on blood glucose levels (i.e., the glucose–insulin closed-loop system; Bequette, 2009). This suggestion might not be practical in the past but could be achieved with the advances in technologies.

2.4.2 Identification of Active Ingredients in mHealth Interventions

In addition to theory use for effective intervention design, researchers have also started to pay attention to identifying active ingredients that drive the effectiveness of mHealth interventions. This shift of attention mirrors the trend in health behavior change research in general. Researchers from this field noted that many health interventions tended to adopt multiple behavioral change strategies or techniques, making it difficult to identify which aspects of the intervention were effective in changing behavior and how different components might interact with one another (Hagger et al., 2016). They suggested to isolate specific strategies or techniques.

mHealth interventions using apps are good examples of this issue. As noted in previous sections, researchers have examined the quality of health apps based on behavioral change theories/techniques, but there was a lack of evidence on whether the number or type of behavioral change techniques used in a health app was associated with larger or smaller effect (Middelweerd et al., 2014). This is because apps were often used as a whole, or as part of a multicomponent strategy in mHealth interventions, which made it difficult to pinpoint the active ingredient(s) for the effectiveness. The same applied to mHealth interventions in general. Empirical studies have demonstrated a small-to-moderate effect of mHealth interventions. However, less is known about what "active ingredients" are driving the successful interventions (Stephenson et al., 2017).

Research on this issue is warranted because it will help produce a refined evidence base upon which mHealth interventions can be developed. As was mentioned before, different behavioral change strategies may lend themselves to different modes of deliver and technology components; different delivery components, in turn, could be more or less suitable for different health domains. Isolating the effects of specific strategies or techniques, thus, could not only produce more refined evidence base for mHealth interventions, but also help refine the design of optimal use of behavioral change techniques.

2.5 Summary

This dissertation addresses or responds to the above issues to varying degrees. First, this dissertation takes the "active ingredient" perspective and proposes a strategy named episodic future thinking. The choice of this strategy is based on considerations of its suitability with the target behaviors under investigation and the mobile technologies employed. In the next chapter, I will introduce this strategy and explain why it could be a good candidate to be integrated into mHealth interventions using mobile phones to promote lifestyle-related behavior change. In addition, this dissertation adopts longitudinal design, EMI, and EMA to better suit the multivariate, time-varying, and often nonlinear processes of behavior change.

Secondly, this dissertation employs two commercially available smartphone health applications targeting sleep and physical activity. Several reasons underly the choice of these two behaviors. First, both are lifestyle-related behaviors vital to individual health and wellbeing. Insufficient physical activity and sleep have been associated with increased risk for myriad disease states (Glowacki et al., 2018), whereas sleep, physical activity, and fruit and vegetable intake have been associated with increased overall quality of life and subjective health (Tan et al., 2018). Second, these two behaviors relate closely to the targeted population of this dissertation, i.e., college students (Laska et al., 2009). In a survey conducted by Glowacki et al. (2018) for an mHealth intervention using text messaging, sleep and fitness are among the top four topics perceived most relevant to college students' health. Moreover, both behaviors are negatively impacted by technology use (e.g., Owens et al., 2017), which is another important element of this dissertation.

Sleep habits are shown to be closely tied with physical activity (Fanning et al., 2016). While closely related to each other, sleep and physical activity differ in some important ways with which it would be interesting to see whether EFT exerts similar or different effects. For example, in terms of ability, those who have difficulties falling asleep do not have too much to rely on except for resorting to medications. On the other hand, people with different physical conditions could find some sort of exercise that is suitable for them. In addition, the sleep behavior is more susceptible to unexpected situations, such as a break-up with a romantic partner, a party lasting till late evening; whereas exercise behavior might be less susceptible to unexpected situations – someone who wants to go for a run could still realize the goal of running in an indoor stadium even if it suddenly rains outside. More importantly, sleep among college students has been shown to be influenced by academic and social considerations (Robbins & Niederdeppe, 2015). As such, more self-control effort might be needed for them to put themselves in a position that actually fosters a good night's sleep (Nauts & Kroese, 2017).

Last but not least, sleeping among college students has received less attention from healthcare professionals and researchers compared to other health promoting behaviors and risk-taking behaviors such as alcohol/drug use and sexual activity (Nauts & Kroese, 2017; Owens et al., 2017).

The targeted population of this dissertation is college students. This is first because of the close relationship between college students and mobile phone use. Ninety four percent of young adults (aged 18-29) in the US owned a smartphone (Statista, 2018). Mobile technologies have become an integral part of college students' life. Interventions using mobile phones may fit better with their lifestyles than more traditional treatments (Heron & Smyth, 2010). In addition, technology literacy is high among this population group. College students are thus more familiar with and comfortable using mobile phones and apps.

Moreover, the strategy used in the intervention concern thinking about the future, a concept closely related to an individual's trait time perspective. Based on studies on time perspective and chronological age, these two concepts inherently associated with one another. For example, planning for future is not developed until

8-10 years of age (Nurmi, 2005); as people get older, they perceive their time as more limited (Gellert et al., 2011). Young adults, on the other hand, have their futures ahead of them, but are also faced with developmental transitions and competing goals, making their time perspective more dynamic. Adding one layer to this "dynamism" is the prevalent use of mobile phone among this population and the effect of mobile phone use on time perspective. Wilmer and Chein (2016) conducted a study on mobile technology use, intertemporal preference, and some other self-control variables. They found a significant relationship between technology engagement and intertemporal preference. Specifically, heavier engagement in mobile devices was correlated with a relatively weaker tendency to delay gratification and a greater inclination toward impulsive behavior. The latter two features relate closely to a present-focus time perspective. Given the integral role mobile phones play in the life of college students, it might be important to employ proper intervention strategies to guide the use of such devices toward more rational and pro-health directions.

Chapter 3: Episodic Future Thinking as A Strategy for Mobile Health Intervention

"*The future is not a result of choices among alternative paths offered by the present, but a place that is created – created first in the mind and will, created next in activity. The future is not some place we are going to, but one we are creating. The paths to it are not found but made, and the activity of making them changes both the maker and destination*."

John Schaar,
American writer, scholar,
and Professor Emeritus,
University of California

In Chapter 2, I reviewed past mHealth interventions and issues associated with those interventions. Key issues revolve around theory use and the compatibility between target behaviors, behavioral change strategies, and mobile technologies. In this chapter, I will address the theoretical framework used in this dissertation, i.e., thinking about the future, and discuss why and how this framework fit into the intervention developed in this dissertation.

The quote above shows how thinking about the future plays a role in people's life. It also points to the two steps of getting to the (usually desirable) future: through a creation in the mind and through the creation of activity. In the sections that follow, I will show that the combination of episodic future thinking (EFT) with mobile technologies is an instantiation of these two steps. Briefly, episodic future thinking asks people to vividly imagine possible future events, i.e., "*the future is not some place we are going to, but one we are creating*;" whereas mobile technologies provide numerous action possibilities through functions such as apps, reminders etc., i.e., “*the paths to it are not found but made*.” But before that, I will start with a discussion on lifestyle-related health behaviors.

3.1 Health Behavior as Intertemporal Choice: Why EFT is Suitable for Lifestyle-Related Behaviors

Lifestyle-related behaviors include physical activity (PA), sedentary behavior (SB, with screen time as one important indictor), sleeping time (predicted by total sleep duration, TSD), and fast food (FF) consumption (Qin et al., 2021). Unhealthy lifestyle is among the main reasons for the increasing incidence of non-communicable chronic diseases including heart disease, diabetes, and cancer (WHO, 2021). Many of such illnesses can be prevented or treated by making changes to people’s own behaviors. For example, research has suggested that more than half of mortality from the leading causes of death could be reduced if people exercised regularly, maintained a reasonable weight, ate a healthy diet, and refrained from smoking cigarettes and excessive alcohol (e.g., Knoops et al., 2004; van Dam et al., 2008). In addition, many other behaviors would help people achieve or maintain optimal health, such as attending regular health screenings, adhering to medications, getting sufficient sleep, and reducing stress. As such, lifestyle-related behaviors are often called preventive health behaviors.

Promoting preventive health behaviors could not only benefit non-communicable chronic diseases, but also inform responses to infectious diseases, especially during a pandemic such as the COVID-19 pandemic. During the COVID-19 pandemic, for example, lockdowns have been adopted by governments from many countries and regions to prevent the community transmission of the virus. However, lockdowns also confined people at home and imposed social restrictions, which have been shown to alter people's daily routine and habits to varying degrees (Aguiar et al., 2021). For example, research has shown that lockdown has led to significant delay in sleep onset-wakeup times and meals' time (Sinha et al., 2020), significant changes in mood, sleep duration, physical activity, and social encounters (Oved et al., 2021), and drastic increases in sedentary activity and the use of digital media (Dutta et al., 2020).

Lifestyle-related behaviors have significant influence on people's health during different times. As such, it is important to gain more knowledge on how to promote lifestyle related, preventive health behaviors, be it in normal times or in this "new normal" brought about by the COVID-19 pandemic (Pietrobelli et al., 2020).

One important characteristic of lifestyle-related behavior is that the desirable outcomes are often temporarily distant, whereas the benefits of not adopting ot maintaining a healthy behavior, or engaging in unhealthy behaviors, are in the here and now (Klasnja et al., 2011). Decisions on lifestyle-related behaviors can be construed in this way - as decisions made between rewards available at different time points, especially between smaller, immediate rewards and larger, later rewards, which is called intertemporal choices (Lempert & Phelps, 2016). It is well documented in intertemporal choice literature that individuals have the tendency to over-value immediate rewards and undervalue larger, later rewards as the later reward becomes farther removed in time – a phenomenon known as "time discounting" or "delay discounting" (Loewenstein & Thaler, 1989).

Because decision-making for many health behaviors is intertemporal in nature (i.e., the benefits and costs carry different weights at the time of decision-making due to their association with either long-term or short-term outcomes), it is important to put time into the consideration of health behavior change. Researchers have proposed that effortful attempts to shift temporal focus toward the future could be a potent way of increasing healthy decision-making, that is, helping people understand how their actions today impact their lives in the future (Hall & Fong, 2007; Rutchick et al., 2018). EFT, the ability to project oneself into the future and pre-experience an event (Atance & O'Neill, 2001) is one such attempt. Research has shown that EFT can help extend an individual's temporal window and reduce impulsive choice by promoting consideration of the future, thereby reducing the valuation of immediately gratifying choices (e.g., Schacter et al., 2017). In the next two sections, I will introduce EFT, its related concepts, and why it works to bridge the present and the future, thus serves to help individuals make better intertemporal choices concerning health.

3.2 EFT and Related Concepts

Episodic future thinking (EFT) was proposed by Atance and O'Neill based on Tulving's *episodic memory*, the latter concept is defined as "the ability to remember one-time events from the personal past" (Szpunar, 2010, p. 143). For example, one could mentally reexperience the events happened during one's college graduation. A common mechanism underlying EFT and episodic memory is *autonoetic consciousness*, "the kind of consciousness that mediates an individual's awareness of his or her existence and identity in subjective time extending from the personal past through the present to the personal future" (Tulving, 1985, p. 1). The combination of episodic memory and autonoetic consciousness allows an individual to engage in mental time travel. One other type of consciousness, *noetic consciousness*, has been defined as being aware when people “retrieve general information in the absence of a feeling of reexperiencing the past” (Szpunar, 2010, p. 144), and is associated with one other type of memory, semantic memory. *Semantic memory* is thus defined as “a type of memory that is devoid of a feeling of personally experiencing the past” (Szpunar, 2010, p. 143). An example for semantic memory would be that someone knows that he/she attended the college graduation without any specificity of any event happening during the graduation. Thus, one characteristic of EFT is to *vividly* pre-experience future events.

EFT is different from nondirected *imagery* (Szpunar, 2010). First, mental imagery could be general or specific, but EFT is characterized by generating *specific scenarios* in one’s future events. Second, mental imagery could be anything from more realistic future scenarios to fantastic events that are highly unlikely to happen in one’s future. EFT, on the hand, has to have some *personal relevancy* to the individual who engages in the thinking. In other words, EFT involves thinking about specific events that are relevant to the individual and are possible to happen in one’s own future (Szpunar, 2010).

All characteristics mentioned above have been observed in empirical research on EFT. The descriptions produced by participants for future thinking tasks were often coded as personal (personal relevance), contextual (vividness), and emotional (valence). Among these, emotional intensity has been shown to enhance the effect of EFT based on neuroimaging results (Benoit et al., 2011). These characteristics were thus often used as criteria based on which participants rated their future thinking events.

The ability to think about the future has also been considered as a personal trait and this line of research is usually under the umbrella term *time perspective*. In fact, thinking about the future is a broad concept that has been approached from a variety of traditions and scientific fields. Two research traditions are dominant among those fields (Andre et al., 2018). One tradition originates from social cognition and neuroscience and considers thinking about the future as individuals' *capacity*. Research from this tradition investigates future-oriented cognitions, which could be experimentally manipulated, and their underlying mechanisms. Episodic future thinking research is from this tradition. The other is based on the framework of "*time perspective*," proposed by Lewin (1942) to refer to the overall importance people attach to the future. This tradition considers time perspective (or "time orientation" in some other conceptualizations) as an *individual difference*. Research from this tradition focuses on the relationship between different time perspectives and people's decision-making and behavior (Andre et al., 2018). Specifically, future time perspective (FTP) has received a lot of research attention because its relationship with motivation and its predictive role to attitudes and behaviors in important life domains, such as education, work, and health.

This dissertation entertains the possibility of treating future thinking as individuals' capacity, or a state that could be temporarily activated by self-generated thoughts, i.e., EFT. Indeed, studies have demonstrated the surprising effects of self-generated thoughts and situational cues on activating mental processes associated with seemingly stable, dispositional characteristics (e.g., Aaker & Lee, 2001; Shevorykin et al., 2019; Zhao & Pechmann, 2007).

In summary, EFT seeks to temporally extend an individual's temporal window by asking them to imagine positive, vivid, and personally relevant future events, thereby reducing the valuation of immediately gratifying choice. The next section discusses the various ways EFT works to extend an individual's temporal window. Specifically, it emphasizes EFT's ability to bridge the present and the future through enhancement in people's sense of temporal continuity and personal identity and through its connection with goals and self-control.

3.3 EFT – Bridging the Present and the Future

3.3.1 Thinking about the Future Enhances Our Sense of Temporal Continuity and Personal Identity

An emerging body of research has suggested that individuals vary in how they perceive their future selves – usually as a different person, from one who feels close to their current self to total strangers (Hershfield, 2018). The extent to which one feels emotionally connected to one's future self is called *future-self continuity* (Hershfield, 2011). Here, the continuity refers to continuity in one's identity, whereas many other aspects of our selves can change over time, e.g., people can alter their names, goals, and reputations. It is with this feeling of continuity that the present and future selves are tied together (Hershfield, 2011). Future-self continuity has been shown to influence a range of consequential outcomes, including decision-making, saving behavior, health, and well-being (e.g., Adelman et al., 2017; Blouin-Hudon et al., 2015; Ersner-Hershfield et al., 2009a, 2009b; Hershfield et al., 2012; Sadeh &

Karniol, 2012). For example, Rutchick et al.'s study (2018) showed that people with higher present-future continuity reported having better subjective health or exercised more in the days following a writing task that aimed to enhance future-self continuity. In a word, evidence has suggested that increases in future-self continuity help people make decisions with the future self in mind and has been proposed as one explanation for the success of temporal perspective interventions (Rutchick et al., 2018).

Episodic future thinking (EFT) works to make the future "me" feel close, connected to, and overlapping with the current me, i.e., increasing future-self continuity.

First, imagining future events shared many neural and cognitive similarities with remembering past events, which ground our sense of temporal continuity and personal identity (La Corte & Piolino, 2016; Klein, 2013). Research on *mental time travel (MTT)*, the ability to mentally project oneself backward or forward in time in order to remember an event from one's personal past or to imagine an event from one's potential personal future (Suddendorf & Busby, 2005), has shown that a common *core network* of brain regions underlies both future thinking and memory (Schacter & Addis, 2007). Numerous studies have compared EFT with the ability to remember past personal events and found that re-experiencing past events and pre-experiencing future events shared the same neural mechanism (e.g., Addis et al., 2007; Szpunar & McDermott, 2008; Spreng & Grady, 2010; Szpunar et al., 2007). Experimental studies also demonstrated striking similarities in cognitive structures (for a review see Schacter et al., 2012) and how people respond to a range of behavioral manipulations (e.g., D'Argembeau & Van der Linden, 2004; Schacter et al., 2013; see Szpunar, 2010 for a review) when they are imaging future experiences and remembering past experiences.

In addition to a shared neural mechanism between future thinking and remembering, the various features of EFT also facilitate future-self continuity by pulling the future-self closer to the current-self. Specifically, EFT tasks usually ask individuals to imagine future events that are positive, vivid, and autobiographical.

First, *autobiographical* means that the content of EFT is about the self. Thinking about the future requires people to draw information from their past, such as episodic memories and personal history, to construct and simulate possible future events (Addis et al., 2007; Schacter et al., 2012). Through this integral process, individuals collect and recombine elements of self-referential information that reflect the most salient issues and goals in their lives (Bang, 2018). As such, future thinking is usually self-referential and personally important. In addition, research has shown that the self is an organizing feature in imagining future events, as in remembering past events (Grysman et al., 2013), and it serves the foundation for the other aspects of EFT to work.

The positive and vivid features of EFT tasks help make the future "me" feel close and connected to the current "me". For *positivity*, Salgado & Berntsen (2019) found that, compared to negative future events, individuals forecasted positive events to occur closer to their present than negative events. This pattern, however, was found only in future events for the self but not for an acquaintance. Waugh and Fredrickson (2006) found that people feel a greater sense of overlap with another person who elicits positive (vs. negative) emotions when forming a new relationship. *Vividness*, on the other hand, serves as a distance cue in that closer objects can be seen in greater detail and more vividly, which in turn, imply closeness in time (Nurra & Oyserman, 2018). Things that are close in time and space are likely related (e.g., Ebert & Wegner, 2010). As such, vividness implies relevance. Vividness has been shown to make the future-self more salient and future events more emotionally evocative (Hershfield, 2018) and has downstream influence on financial (Ellen et al., 2012; Hershfield et al., 2011), ethical (Van Gelder et al., 2013; Van Gelder et al., 2015), and health (Kaplan et al., 2016; Kuo et al., 2016) behaviors.

3.3.2 Thinking about the Future Relates to Personal Goals and Increases Self-Control

Personal Goals

Although past and future thinking share many similarities in neural network and cognitive structures, they also differ in some important respects. Specifically, compared to past thinking, future thinking relates more closely to goal pursuit (Cole & Berntsen, 2016; D'Argembeau & Van, der, 2012) and is more emotionally positive and idyllic (e.g., Berntsen & Bohn, 2010; D'Argembeau & Van der Linden, 2004; Rasmussen & Berntsen, 2013; Salgado & Berntsen, 2019).

First, thinking about the future is essentially goal-directed and important for goal-directed cognition and behavior (Cole & Berntsen, 2016; D'Argembeau et al., 2010). When constructing a potential future event, either voluntary or involuntary, people use their most remarkable memories, driven by their personal goals, meaningful themes, and dominant schemata (D'Argembeau et al., 2010; Demblon & D'Argembeau, 2017). An EFT task usually consists of envisioning future events in relation to personal goals and self-schema, for example, picturing future states of the self that one aspires to attain (which is similar to goal setting), or conceiving ways to achieve those states (which is similar to goal striving). Evidence from fMRI studies shows that the default network in the brain region, which underpins future event simulation, supports cognitive activities that are associated with goal-directed processing (D'Argembeau et al., 2010; Schacter, 2012). In addition, behavioral evidence also links future simulations with planning, problem-solving, and related forms of goal-directed processing (Schacter, 2012).

On the other hand, goal related thoughts also involve and facilitate future thinking. Being one type of future thinking, personal goals offer a means of traveling through time. One conceptualization of goals is "people's desired future state or the outcomes to which they aspire." In a study conducted by D'Argembeau and Mathy (2011), participants who were cued with personal goals generated more episodic details when they were instructed to think about the future. The authors concluded that: "knowledge about personal goals plays an important role in the construction of episodic future thoughts" (p. 258).

Second, thinking about the future is self-referential, positive biased, and serves self-enhancement motivation (Grysman et al., 2013; Rasmussen & Berntsen, 2013; Salgado & Berntsen, 2019). Self-referential processing – imagining oneself versus another person – enhances attention to and memory for information. This, in turn, helps people better able to construct a variety of different versions of themselves that reflect their potentials and personal aspirations and use as incentives (Markus & Nurius, 1986; Markus & Ruvolo, 1989). These possible future selves, as Markus and

Nurius (1986) noted, “are not just any set of imagined roles or states of being. Instead, they represent specific, individually significant hopes, fears, and fantasies” (p.954). This constructive nature of future thinking increases motivation and guides its course toward goal pursuit (Bartels & Rips, 2010; D’Argembeau et al., 2010).

In addition, a positive image of oneself in the future can motivate action by also helping people articulate their goals clearly, organize, and improve the adoption of behaviors over time that allow them to fulfill those goals (Vasquez & Buehler, 2007). In addition to the positive representations of future selves, people’s mental simulation of discrete actions and events may also affect motivation by increasing their emotional involvement, prompting concrete plans and problem-solving activities, and increasing people’s expectations of success (Taylor et al., 1998).

Self-control

Given that future thinking creates desirable images of possible future selves and reflects the potential for growth and change, that is, incentives placed in the future, such mental simulation can be effective especially when people face internal conflicts between instant gratification and future consequences (Bang, 2018). EFT is said to give people the ability to counteract their natural disposition to short-term decision making by directing people’s attention to long-term benefits and enables them to make better intertemporal choice.

A standard intertemporal choice task is called delay discounting task. *Delay discounting* (DD) refers to the process of devaluing future outcomes as the time of its actualization goes further from the present time (Frederick et al., 2002). DD relate closely to *self-control*, individual’s ability to exert control over the self (Tangney et al., 2004). Theoretically, self-control is defined as voluntary actions aligned with personally valued longer-term goals in the face of conflicting impulses to seek immediate gratification (Duckworth & Steinberg 2015; Fujita, 2011). This conceptualization of self-control fits well with the concept of DD and serves the basis for research in delay-of-gratification and temporal (and delay) discounting. In fact, DD has often been used as a measure of self-control (e.g., Bickel et al., 2019).

Research on future-self also sheds light on the effect of future thinking on self-control (e.g., Kaplan et al., 201; Kuo et al., 2016; Hershfield et al., 2011; Van Gelder et al., 2013, 2015). Findings from multiple studies showed that exposure to vivid, age-progressed images of participants (so that they were looking at their future self) prompt more patient long-term intentions and behaviors in financial (Hershfield et al., 2011), ethical (Van Gelder et al., 2013; Van Gelder et al., 2015), and health (Kuo et al., 2016) domains.

3.4 Bridging Specific Actions and High-level Goals: Why EFT is Suitable to be Integrated into mHealth Interventions using Mobile Phones

EFT helps bridge the future and the present and highlights future benefits and long-term goals. However, even though the future goal is highlighted and wanted, the process to achieve it is in the present. Failures occur when individuals do not know how best to achieve their future goals (Taylor & Wilson, 2016). In other words, how could a shift in temporal focus influence decision on a given day or at a particular moment?

This dissertation proposes that mobile technologies, specifically, mobile phones, could serve to bridge the gap between high level goals and specific actions.

EFT makes higher level goals (i.e., health-related goals) salient and wanted. Mobile health apps provide action possibilities related to the target health behavior, whereas reminders sent through mobile phones connects higher level goals highlighted by the EFT task with specific actions offered by the health apps.

Action possibilities relate closely to a concept called affordance. The concept of affordance was proposed by Gibson (1977) to describe action possibilities that an environment or artifact offer a living being. Affordances are driven by material design of the artifact but are not fully determined by it. On the one hand, the materiality of the artifact creates possibilities for and constraints on the functionality that the technology offers to its users. On the other hand, technological affordances are not solely determined by the materiality of technology, people's perceptions of a technology are equally important in determining how they are used. As such, this perspective seeks to find a middle ground between technological and social determinism. In other words, it encompasses the relationship between technology with potentialities and actors with motivations and abilities. It is thus a useful way to explain why people interact with (media) technology the way they do.

Specifically, mobile phones provide various action possibilities to its users. For example, the feature of physical activity app on the phone provides action possibilities for doing and recording a variety of workouts, whereas the sleep app feature provides action possibilities for monitoring and recording sleep time and quality, among other action possibilities, like gaming and communicating provided by all sorts of features of the device. Although technologies and their features may be the same across users, affordances are social constructs experienced in unique ways. In other words, whether a mobile phone is perceived as a physical activity device, a sleep alarm device, or a gaming device depends on a user's situation and context-specific interpretation of that technology (Vaast & Kaganer, 2013).

Our everyday decisions are strongly context dependent (Kahneman & Tversky, 1979; Louie & De Martino, 2014). A choice between two alternatives could be influenced by context effects, such as framing, incidental affective states, prospection, and cues in the media environment (Kahneman & Tversky, 1979; Louie & De Martino, 2014). Research has suggested that interventions targeting behavior change need to compete with many activities in individuals' daily routines that could distract them from their action plans (Schwerdtfeger et al., 2012). Weinstein (1988) once used the term "messy desk" to illustrate the obstacles that may emerge when people aim to transform intentions into action. To counter this, Weinstein suggested using reminders to keep intentions active (e.g., Prestwich et al., 2010), which could be realized through mobile technologies.

Reminders sent through mobile phones bring people's attention to the connection between abstract health-related goals (high construal level) and specific actions (low construal level), a process called cognitive bridging. Cognitive bridging refers to the situation when abstract higher level goals (i.e., be healthy) are mentally connected to the specific means to achieve them (i.e., using a physical activity app). As such, delivering EFT task through mobile phone reminders might enhance its effect by connecting goals and motivations highlighted by EFT with specific actions offered by the health apps.

High vs. low construal levels are concepts from the construal level theory (CLT, Liberman & Trope, 2003). Mental construal refers to how objects, events, and constructs are represented in mind and is often categorized into high-level mental construal (e.g., why one might take a certain action) and low-level mental construal (e.g., how one might do so). Another important concept in the CLT is psychological distance, which refers to "the subjective experience that something is close or far away from self, here and now" (Trope & Liberman, 2010, p. 440). Psychological distance has been established along four dimensions – temporal, spatial, social, and hypotheticality. Mental construal could influence psychological distance, and vice versa. As an example, the CLT would predict that an individual who is asked to describe the attributes of a vacation next year (i.e., temporally distant) would mention abstract qualities of the vacation (i.e., high-level construal), such as relaxing and tropical. However, when asked to describe a vacation tomorrow (i.e., temporally closer than next year), one might mention concrete considerations of the vacation (i.e., low-level construal), such as packing a bathing suit and confirming a flight (Clark & Semin, 2008).

Accordingly, mobile phone could influence people's construal level of an event through perceived psychological distance. Mobile phones are anchored with the self and in the here and now, i.e., they are of proximal psychological distance to the users (Katz & Byrne, 2013). This means that mobile phones could sense the environment from the same perspective as their users. As such, mobile devices serve as low abstraction cues (Katz & Byrne, 2013).

As it was mentioned above, cognitive bridging features two or more logically related abstraction cues. At least one of these cues should be at a high level of abstraction, such as the goal of being healthy, whereas one at a low level of abstraction, such as using mobile phone apps to do workouts (mobile phones serve as low abstraction cues). When these cues are processed, the cognitive bridging is induced in the mind.

Chapter 4: Research Questions and Hypotheses

In its broadest sense, this dissertation seeks to examine the joint effect of mobile technologies and communication in promoting positive outcomes such as healthy lifestyle. More specific, this dissertation addresses the question: whether and how EFT, a communication intervention, delivered through mobile technology, helps individuals make better health-related choices in their everyday lives?

4.1 EFT, Delay Discounting, and Health Behavior

The strategy examined in this dissertation is called episodic future thinking (EFT). As it was mentioned in Chapter 3, EFT directs people's attention to long-term benefits and enables them to make better intertemporal choice. Intertemporal choice is usually measured through a delay discounting task. Delay discounting (DD) refers to an individual's preference for smaller, sooner over larger, later rewards. In a DD task, participants are usually asked to choose between an immediate, smaller reward and a later, larger one. Numerous studies have shown the effect of EFT on reducing DD compared to various control conditions (e.g., Daniel et al., 2013; O'Neill et al., 2016; Snider et al., 2016). Meta-analysis studies showed that EFT reduced DD with medium effect size (Rösch et al., 2021; Rung & Madden, 2018; Ye et al., unpublished). The most often used control condition in EFT studies is episodic recent thinking (ERT). Participants in the ERT group vividly describe events in their recent past in the same way as those in the EFT group. ERT helps control for episodic thought and the procedures used to construct episodic cues. As such, this comparison highlights the temporal differences between EFT and ERT (Hollis-Hansen et al., 2019).

H1: EFT (vs. ERT) will lead to decreased delay discounting.

The effects of EFT in reducing DD have also extended towards improving health behaviors (e.g., Bromberg et al., 2017; Daniel et al., 2013; Dassen et al., 2016; O'Neill et al., 2016; Snider et al., 2016; Stein et al., 2016). For example, Stein et al. (2016) tested the effect of EFT on discounting rates and cigarette self-administration among smokers. Smokers in the EFT group showed significantly reduced DD rates and the number of cigarette puffs earned in a cigarette self-administration task compared to smokers in the ERT group. Stein et al.'s (2018) later study showed that the effects of EFT on DD rates and the intensity of demand for cigarettes in a hypothetical purchase task were significant even when controlling for measures of demand characteristics including participants' perceptions about the experiment.

For alcohol related decision-making and behavior, Snider et al. (2016) demonstrated that participants showed reduced DD rates and reduced number of drinks purchased at various price points in an alcohol purchase task in the presence of future-cues compared to being exposed to the control cues. Bulley and Gullo (2017) showed that EFT reduced DD rates and alcohol demand intensity during hypothetical alcohol purchase tasks among college students.

For eating behavior, Dassen et al. (2016) found that EFT led to reduced DD rates and healthier eating (less caloric intake), whereas Sze et al. (2017) found that EFT reduced DD rates and the demand for fast foods, even when challenged by negative income shock. These latter authors employed online-administered EFT and suggested that this could be a reliable way to conduct EFT related studies. They also noted that "EFT is a scalable intervention that has implications for improving public health by reducing discounting of the future and demand for high energy dense food" (p. 683).

All these studies offer evidence for the impact of EFT on actual health behavior change. Although previous studies on EFT and health behavior mainly focused on addictive behaviors, e.g., smoking and alcohol use, recent studies have started to explore EFT's utility on other behavior types, such as weight loss maintenance (Leahey et al., 2020), prosocial (Gaesser et al., 2020), and pro-environmental behavior (Lee et al., 2020). Examining behavior types that have not been examined in previous studies could help increase the generalizability of EFT as well as testing the boundary conditions of its applicability.

In this dissertation, I examine two types of behavior that have not been examined in previous EFT studies. The two targeted health behaviors are sleep and physical activity. Given the close relationship between intention and behavior (Ajzen, 1991; Sheeran 2002), this dissertation proposes the following hypotheses:

H2: EFT (vs. ERT) will increase (a) intention to get enough sleep and (b) intention to engage in physical activity.

H3: EFT (vs. ERT) will increase (a) sleep time and (b) physical activity.

H4: Behavioral intentions will be positively related to actual behaviors.

In addition, this dissertation examines the effect of repeatedly engaging in EFT on behavior change. Not many studies have examined the repeated effect of engaging in EFT on DD or health behavior. For those that examined the repeated effect of engaging in EFT, the results are inconsistent. Two recent studies have showed some promises of this approach (Mellis et al., 2019; Sze et al., 2015).

Specifically, Mellis et al.'s (2019) study showed that for current and recent problem drinkers, the presence of future cues decreased their DD rates over six sessions, compared to those with no cue or shown with scarcity cues. Sze et al.'s (2015) study showed that prompting individuals to engage in EFT with personalized future cues over a four-week engendered weight loss among adults. However, another study (Mansouri et al., 2020) examined the effects of repeated engagement of EFT (i.e., one week of time) showed no effect of such repeated engagement of EFT on DD, nor on the ad lib energy intake and the relative reinforcing value of snack food compared to one engagement in EFT.

Based on the above discussion, I propose a research question concerning the effect of engaging in EFT (vs. ERT) repeatedly over a two-week period:

RQ1: Does increasing the dose of EFT (vs. ERT) lead to more behavior change?

4.2 Psychological Mechanism Underlying the Effect of EFT

As evidence on the role of EFT in reducing DD and improving health behaviors being cumulated, it is important to examine the psychological processes underlying these influences.

However, less is known in terms of the psychological mechanisms underlying the effect of EFT. Being developed from the field of neuroscience, research on EFT has focused more on the neural correlates of this strategy. Specifically, research has explored the role of individual differences such as working memory, inhibitory control, medial rostral prefrontal cortex, prefrontal-mediotemporal interactions, and dopamine genetics on the effect of EFT on DD (e.g., Benoit et al., 2011; Lin &

Epsterin, 2014). Among these constructs, working memory has been found to moderate the effect of EFT on DD (Lin & Epsterin, 2014). Neural correlates and physiological features are important mechanisms to learn about but are less relevant to the current study.

In terms of psychological variables, previous discussion has hinted to two aspects – positive affect and self-control – as potential underlying mechanisms. For example, Lin and Epstein (2014) suggested that "the time perspective and emotional valence of episodic thinking may dynamically shape intertemporal choice" (p. 12). Ye et al. (2020) proposed that anticipated affect and self-control are among the potential mechanisms underlying EFT's effect on delay discounting after systematically reviewing literature on EFT and meta-analyzed thirty-seven studies. These two mechanisms are also hinted in the discussion on the adaptive functions of EFT, which include far-sighted decision-making, emotional regulation, improved prospective memory, and greater spatial navigation (Schacter et al., 2012, 2017).

Accordingly, positive affect and self-control are proposed as two potential psychological mediating variables in the current dissertation. On the one hand, imagining events with positive emotion is one of the characteristics of EFT task, and EFT effect was shown to be more pronounced for episodes that were imagined with a higher emotional intensity (Benoit et al., 2011). Thus, positive affect might be one candidate mediating the effect of EFT on behavioral intentions and subsequent behavior change (Lin & Epsterin, 2014). On the other hand, self-control relates closely to delay discounting and has been an important construct in self-regulation research (De Ridder et al., 2012). Thus, I propose self-control as the other mediating variable.

4.2.1 EFT, Self-Control, and Health Behavior Change

As it is mentioned above, the relationship between EFT and self-control first comes from study results showing the relationship between EFT and delay discounting (DD). Previous research has generally supported that EFT interventions modify DD such that engaging in EFT helps reduce DD (e.g., Rung & Madden, 2018; Ye et al., 2020), i.e., increase self-control. Based on a meta-analysis (Rung & Madden, 2018), EFT produces sizeable ($B = 0.38$, $SE = .09$), significant reductions in DD ($z = 4.02$, $p < .0001$) with little study variability ($I^2 = 3\%$) based on the ten studies in this review. Another two unpublished meta-analysis studies also showed similar results.

Low DD (i.e., high self-control), in turn, is associated with a variety of health outcomes and behaviors, including positive drug treatment outcomes (MacKillop & Kahler, 2009; Sheffer et al., 2012), lower rates of smoking initiation (Audrain-McGovern et al., 2009), and alcohol consumption (Moore & Cusens,2010). Whereas an excessively high DD has been hypothesized to be a trans-disease process that behaviorally contributes to the development of countless diseases (Bickel et al., 2012). Direct evidence has also suggested that self-control is beneficial for a large range of behaviors (De Ridder et al., 2012), including health-related behaviors, e.g., dieting, physical activity, and condom use (Kuijer et al., 2008; Wills et al., 2007).

The relationship between EFT and self-control also comes from research on future time perspective (or future time orientation) and self-control. In theory, self-control requires individuals to act in accordance with long-term, rather than short-term, outcomes (Trope & Fishbach, 2000), which is one of the characteristics of future time perspective. There is growing evidence that time perspective is linked to self-control (Joireman et al., 2008; Wills et al., 2001). For example, Price et al. (2017) found that higher future time perspective scores were associated with higher self-control, which in turn, related to lower body mass index. In another study, Kim et al. (2017) showed that a future time perspective was associated with greater self-control and Internet use and procrastination indirectly. Self-control also predicted less procrastination and Internet addiction.

EFT works to broaden individuals' temporal window and activate a future (vs. present) time orientation (Rung & Madden, 2018). For example, Cheng et al.'s (2012) study showed that participants engaging in prospective imagery tended to focus on delayed utility over immediate utility when making financial decisions. This relationship was mediated by a future-oriented mindset induced by the prospective imagery. As such, EFT will likely improve individuals' ability to engage in self-control.

Based on the above discussion, one could argue that EFT (vs. ERT) will lead to improved self-control, which is then expected to increase intentions to change health behaviors and actual behavior change. However, evidence is not enough to suggest whether EFT (vs. ERT) would cause a change in self-control overtime. Accordingly, the following hypotheses and research question are proposed:

H5: EFT (vs. ERT) will increase self-control.

H6: Self-control will be positively related to a) behavioral intentions and b) actual behaviors, such that the effects of EFT (vs. ERT) on c) behavioral intentions and d) actual behaviors are mediated by self-control.

Q2. Whether EFT (vs. ERT) will increase self-control over time?

4.2.2 EFT, Positive Affect, and Health Behavior Change

The relationship between EFT and positive affect comes from the characteristics of future thinking. First, the majority of imagined future events are emotionally charged (D'Argembeau et al., 2011; Wilson & Gilbert, 2005). This emotion is usually positive biased and serves self-enhancement motivations (Rasmussen & Berntsen, 2013; Salgado & Berntsen, 2019). On the contrary, individuals suffering psychiatric disorders such as major depressive disorder, dysphoria, anxiety, and bipolar disorder usually have pessimism biased future-oriented thinking profiles (Miloyan et al., 2014; Moustafa et al., 2018). Empirical research has shown that future imagination produced strong affective response (e.g., Caruso et al., 2008; D'Argembeau & van der Linden, 2006; Rasmussen & Berntsen, 2013).

The emotional experience embedded in EFT can render decisions more farsighted and maximizes future benefits through making the later, larger reward bring more good feelings to the decision-maker (Benoit et al., 2018). As it was mentioned in Chapter 3, future thinking and remembering share similar neural network, labelled autonoetic consciousness. Autonoetic consciousness is human's capacity to "mentally represent and to become aware of one's protracted existence across a subjective time and to focus directly on one's own subjective experience"

(Wheeler et al.,1997, p. 335). It allows for the experience of “what it felt like” when remembering past events and “what it would feel like” when simulating future events (Tulving, 2002; Klein, 2013). One reason for temporal discounting is that people do not experience the anticipated emotional impact of a future reward when making an intertemporal decision (Benoit et al., 2018). By simulating the future moment of consuming the reward, one can mentally create this experience. This simulated experience, in turn, has been hypothesized to increase the valuation of the delayed reward and, consequently, to attenuate discounting (Benoit et al. 2011; Boyer 2008). Researchers thus argued that autonoetic consciousness conveys prospective emotions that can render decisions more farsighted and maximizes future benefits through making the later, larger reward bring more good feelings to the decision-maker (Benoit et al., 2018). As a result, the following hypothesis is proposed:

H7: EFT (vs. ERT) will increase positive affect.

Again, there is not enough evidence to suggest whether EFT (vs. ERT) would cause a change in positive affect overtime. Thus, a research question is proposed:

Q3. Whether EFT (vs. ERT) will increase positive affect over time?

The relationships between positive affect and intention and that with subsequent behavior change are less straightforward. Ferrer et al. (2016) reviewed research on various emotions and four categories of judgments and thought processes that relate closely to health decisions: risk perception, valuation and reward-seeking, interpersonal attribution, and depth of information processing. They found that the influence of emotions on health decisions varied depending on a variety of factors. For example, the emotions fear, anger, and happiness can systematically influence risk perceptions, with fear triggering more pessimistic risk judgments and risk-averse choices than happiness and anger. However, when it comes to valuation and reward-seeking, most research focuses on emotions sadness, disgust, and happiness. And happy individuals have been shown to be less willing than individuals in a neutral emotional state to forgo greater future monetary rewards in exchange for receiving smaller, immediate rewards (Ferrer et al., 2016). Peters et al. (2006) suggested that "affect's role in health communication is likely to be nuanced; … Affect sometimes may help and other times hurt decision processes" (p. S156). As such, this dissertation proposes two research questions concerning the relationships between positive affect and intentions and between positive affect and behavior:

RQ4: Is positive affect associated with (a) behavioral intentions and (b) actual behaviors?

RQ5: Does positive affect mediate the effect of EFT (vs. ERT) on (a) behavioral intentions or (b) actual behaviors?

To conclude this chapter, a table summarizing all the research hypotheses and questions and a figure showing the theoretical model are shown below:

Table 1
Summary of research hypotheses and questions

Research Hypotheses	**Research Questions**
H1: EFT (vs. ERT) will lead to decreased delay discounting.	RQ1: Does increasing the dose of EFT (vs. ERT) lead to more behavior change?
H2: EFT (vs. ERT) will increase (a) intention to get enough sleep and (b) intention to engage in physical activity.	RQ2: Whether EFT (vs. ERT) will increase self-control over time?
H3: EFT (vs. ERT) will increase (a) sleep time and (b) physical activity.	RQ3: Whether EFT (vs. ERT) will increase positive affect over time?
H4: Behavioral intentions will be positively related to actual behavior.	RQ4: Is positive affect associated with (a) behavioral intentions and (b) actual behaviors?
H5: EFT (vs. ERT) will increase self-control.	RQ5: Does positive affect mediate the effect of EFT (vs. ERT) on (a) behavioral intentions or (b) actual behaviors?
H6: Self-control will be positively related to a) behavioral intentions and b) actual behaviors, such that the effects of EFT (vs. ERT) on c) behavioral intentions and d) actual behaviors are mediated by self-control.	
H7: EFT (vs. ERT) will increase positive affect.	

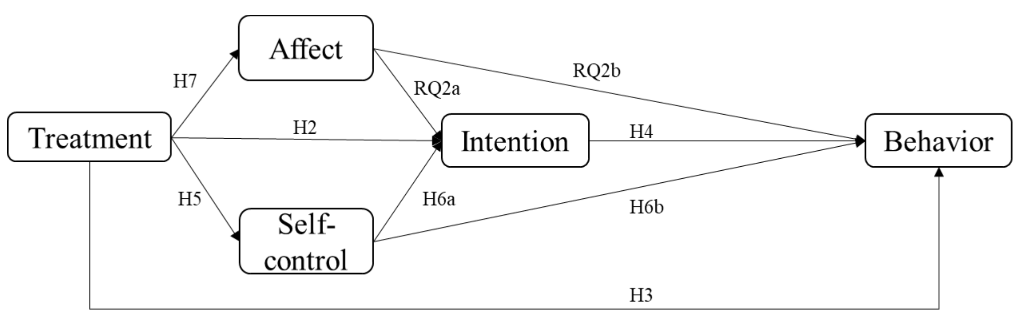

Figure 2 Theoretical model

Note: H1 is about the effect of EFT (vs. ERT) on delay discounting, which was measured in the baseline session. H6c and H6d are about the mediation relationship from treatment to behavioral intentions through self-control (H6c) and that from treatment to actual behavior through self-control (H6d). RQ3a & RQ3b are also about mediation relationships. RQ3a concerns the effect of EFT (vs. ERT) on behavioral intentions through positive affect and RQ3b concerns the effect of EFT (vs. ERT) on actual behaviors through positive affect.

Chapter 5: Methods

5.1 Design & Procedures

5.1.1 Recruitment and Baseline Session

The purposes of the baseline session were to 1) randomly assign participants to one of the four experimental groups (EFT * Sleep, EFT * PA, ERT * Sleep, ERT * PA), 2) gain baseline information of participants, and 3) familiarize participants with the EFT/ERT task that would be used in the intervention session.

Participants were recruited from the UMD SONA communication participation pool. SONA is an online participant pool management system. It allows researchers to manage their research easily and allows participants to sign up and take part in online or offline studies. It could integrate outside online survey systems, such as Qualtrics, and help researchers assign course credit to participants easily. As such, it is well suited for the current dissertation. After signing up for this study on SONA, participants were directed to a Qualtrics survey (baseline session) and were randomly assigned to one of the four groups mentioned above. In this online survey, participants needed to answer questions on basic information such as demographics, baseline sleep time or physical activity time (depending on their group assignment) and provided their contact information. Participants also needed to engage in one of the two thinking tasks (i.e., EFT vs. ERT), again, depending on their group assignment.

For those who had provided their contact information, an invitation email was sent with detailed information on how to participate in the intervention session. Thus, participants were fully informed of the demands of the intervention. They were also asked to download two apps – *SleepCycle* and *LifeCycle* for the sleep groups and *NikeTrainingClub* and *LifeCycle* for the physical activity groups – and send screenshots of those apps with their reply email.

SleepcCycle and *NikeTrainingClub* were the two focal apps that were related closely to the targeted behaviors under investigation. Participants needed to actively engage in using these apps to generate data. The *LifeCycle* app, on the other hand, could operate in the background and did not require active input from the participants. The purpose of adding this app was to make sure that the researcher had some behavior data even when participants did not use the two focal apps on certain days. These health apps (*SleepCycle* and *NikeTrainingClub*) are also used to record actual behavior change data (i.e., length of sleep time and physical activity time).

5.1.2 Intervention Session

After receiving reply emails from participants, the researcher first checked their eligibility for participation, which was decided based on participants' responses to self-reported sleep time and physical activity time. Eligibilities are: (1) For physical activity: MVPA (moderate-to-vigorous physical activity) and BRISK walking ≤ 300 min/week; (2) For sleep: Sleep time ≤ 7.99 h/night.

For those who were eligible, the researcher would set a schedule with them for their participation in the intervention session. This was a two-week intervention in which email prompts were sent to participants everyday/every third day depending on their frequency group assignment.

Specifically, participants were randomly assigned to one of the two frequency groups – high-dose (i.e., everyday) vs. low-dose (i.e., every third day) groups. The high-dose group received a reminder email everyday (13 times + one last email) throughout the two-week timeframe, whereas the low-dose group received such email every third day (5 times + one last email). In other words, participants in the high-dose group needed to engage in EFT (or ERT) everyday whenever they received the reminder email (13 times in total), whereas those in the low-dose group needed to engage in EFT (or ERT) every third day (5 times in total). The purpose of the frequency assignment was to test dose effect, i.e., whether engaging in EFT everyday (vs. every third day) was more effective. In all, there were eight experimental groups in the intervention session.

Researchers have suggested the need to assess the relative effectiveness of specific intervention characteristics, such as frequency of intervention delivery, timing of delivery, and duration of interventions, as it is difficult to draw strong conclusions on what characteristics worked better than others. (Hall et al., 2015). Because there has been a lack of guidelines on best practice and that the intervention characteristics could be quite idiosyncratic, this dissertation refers to previous studies to decide the frequency and timing of intervention delivery.

However, previous studies on EFT usually involved cross-sectional experiment conducted in laboratory settings. Less is known about the effect of repeated engagement of EFT over a period of time on delay discounting or other behavioral variables. As such, there is not enough evidence to help decide the frequency and timing of email reminders from the EFT studies. Mansouri et al.'s (2020) study is among the few EFT studies that examines the repeated engagement of EFT, which lasted for one week. During this one-week period, participants needed to engage in EFT daily prior to three eating occasions and visit the lab 4 times where they needed to engage in EFT and complete a delay discounting task.

Procedures from previous health intervention studies on physical activity and sleep could be informative but, in these studies, the timing of intervention delivery could be rather flexible because it does not necessarily require content to be delivered before a specific decision-making scenario, e.g., like the EFT study mentioned above, participants needed to engage in EFT prior to three eating occasions. For example, for sleep interventions, the majority of the studies employed individual sessions with a face-to-face design (Friedrich & Schlarb, 2018). As such, the timing of sending emails with intervention content was not applicable. For physical activity interventions, the reminders were usually sent multiple times during the day, e.g., morning, mid-day, evening (Martin et al., 2015), during nonschool waking hours (3-9 pm on weekdays and 7 am-9 pm on weekend days) (Dunton et al., 2016).

I also referred to ecological momentary assessment and intervention studies. Similarly, intervention content or EMI/EMA was usually delivered multiple times during the intervention period. In addition, Mead and Irish's (2021) study provided a timeframe from which participants could select a fixed time that worked best for them. Several EMI/EMA studies adopted the duration of one week or two on topics such as alcohol consumption, physical activity, eating behavior and negative affect (Ehlers et al, 2017; Heron et al., 2014; Riordan et al., 2015). As such, two-week was chosen as the study duration.

As for the frequency and timing of intention delivery, it might be better to send intervention content multiple times during the day or provide a timeframe for participants based on the above discussion. That said, given considerations on intervention implementation by a single researcher and on reducing response burden to facilitate compliance, the current dissertation assigned participants to engage in one EFT every day as high does (13 times in total + one exit survey) and every third day as low dose (5 times in total + one exit survey). Emails were sent at 8 pm for the sleep behavior and 10 am for the physical activity behavior based on the rationale that participants would have engaged in EFT/ERT before their decision-making for implementing the behavior (i.e., go to sleep and participate in physical activity). It will not be perfect timing for every participant because it is not an adaptive intervention wherein messages are sent based on individuals' moment-to-moment responses. Still, the timing was set as such so that the thinking task was implemented before a decision-making point for sleep or physical activity for as many participants as possible.

This study collected data in the fall semester of 2018 and again the spring and fall semesters of 2019. Students could start their participation in the intervention at any time point throughout the semester as long as there was a two-week time window left before the semester ended. As a result, the influence of seasonal trend and fluctuation during a single semester should be minimal.

This dissertation uses emails to deliver intervention content. This is because this dissertation uses Qualtrics to deliver surveys to participants. Within the Qualtrics platform, it is more convenient to manage and deliver surveys through email, whereas delivering surveys through SMS is an add-on feature not included in the standard Qualtrics license. Also, research and market statistics have shown that about 80% of users use smartphones to access email. Smartphones are the most common device for checking emails especially for younger individuals less than 35 years old (ITU, 2019; van Rijn, 2021). As a result, this dissertation uses email as means of survey delivery for the intervention

A reminder email contained a short message reminding participants to use the focal app and a link to a Qualtrics survey in which participants needed to complete either one EFT or one ERT task (similar to those that they had already done in the baseline session). Participants also needed to take a short survey 5 times throughout the intervention session (specified below, under *Measures*). To keep the measurements equivalent across the two frequency groups, measures were included in the 5 reminder emails for low-dose groups and in reminder emails on the 1^{st}, 4^{th}, 7^{th}, 10^{th}, 13^{th} days for high-dose groups.

For the sleep groups, the reminder emails were sent at 8pm to participants whereas for physical activity groups, emails were sent at 10am. Participants were given a two-hour time window to complete the thinking task and fill out the survey after the first reminder email was sent. If a participant were unable to respond within this time window, a second email would be sent to remind participants to complete the thinking task and fill out the survey. A nonresponse was recorded if participants did not complete the task by the end of the day (for the sleep groups) or if they did not complete the task 4h later after the first prompt was sent (for the physical activity groups).

By the end of the two-week period, participants would receive another email with instructions on how to share their app use data with the researcher. Participants were asked to send their sleep and physical activity data to an email account that was created to be used only for this study. Data, together with identification information, were downloaded to the researcher's computer and were deleted from the email account and Qualtrics website to ensure data safety. Figure 3 shows the flow of this study.

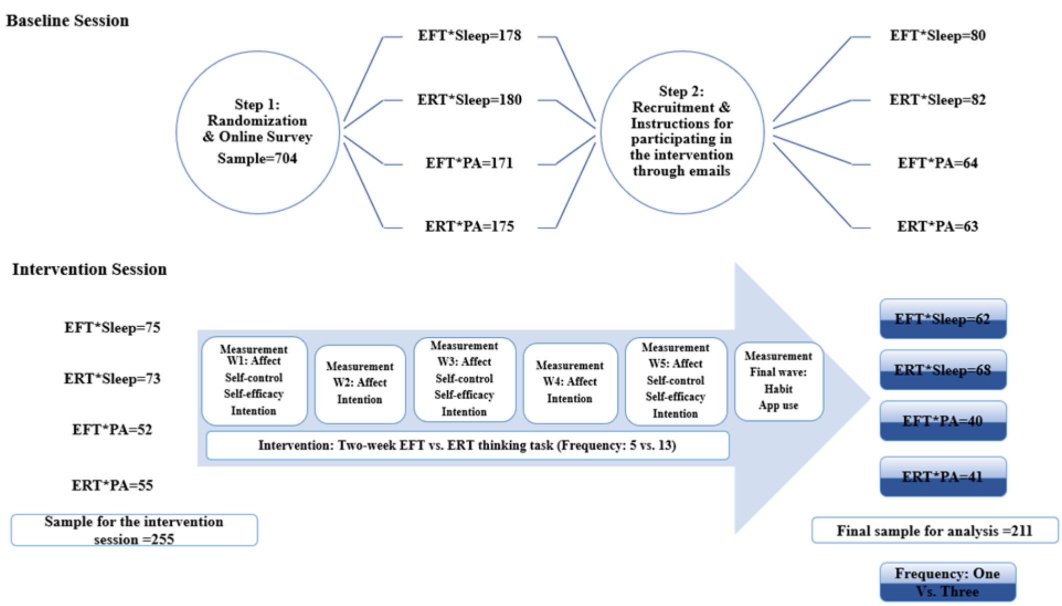

Figure 3 Flowchart for study design

5.2 Participants

After replying to the researcher, eligible participants were enrolled in the intervention session and a schedule for participation was set with each participant. For the sleep groups, there were 148 participants (41 men, 105 women; mean age= 19, *SD*= 2.23). Eleven participants dropped out at various points of the intervention session. There were no significant differences between those who dropped out (i.e., dropout) and who completed (i.e., completer) the study in terms of their baseline self-reported sleep time, sex, race, age, health status, CFC, intention to get enough/more sleep, and interest in (downloading) a sleep related health app.

For the physical activity groups, there were 107 participants (18 men, 89 women; mean age= 19, *SD*= 1.62). Twenty-three participants dropped out at various points of the intervention session. There were no significant differences between dropouts and completers in terms of their baseline self-reported physical activity time, race, age, health status, and interest in (downloading) a physical activity related health app. However, there were statistically significant differences in terms of their sex (χ^2= 5.925, *p*= .015), with all dropouts being female students; CFC (*t*= 2.556, *p*= .012, $M_{Completer}$= 4.79, $M_{Dropout}$= 4.25), with dropouts having lower CFC; and intention to participate more in physical activity/keep participating in regular physical activity (*t*= 2.541, *p*= .017, $M_{Completer}$= 6.21, $M_{Dropout}$= 5.43), again, with dropouts having lower intention scores. The majority of participants in the intervention session were female students, this might in part explain why dropouts in the physical activity groups were all females. On the other hand, the relative low intention for physical activity participation might explain why some participants dropped out, as intention is strongly related to behavior change. This could potentially bias the results of the current study. However, there was no statistically significant difference in treatment assignment between dropouts and completers (11 were in the EFT group, 12 were in the ERT group). In other words, the differential drop-out rate was minimal. As a result, the difference between dropouts and completers should not affect the results associated with the relative effect of EFT. However, those differences indicate that cautions should be taken when interpret the results because the results might only be applied to those who are high in motivation to adopt a healthy lifestyle. Figure 4 shows the flowchart for participants.

Participants received 0.75 SONA credit for completion of the baseline survey. They would receive an additional 2.00 credits after they completed the intervention. Although there were no monetary incentives for participation, the drop-out rate for the main study was 13.33%, which is a reasonable rate for longitudinal study (Cramer et al., 2016; Torous et al., 2020). In order to encourage retention and compliance, participants were told that they needed to complete 70% of the survey to receive the full 2 credits but could still receive partial credits depending on their survey completion rate. Recent meta-analysis study has suggested that strategies to reduce participant burden (e.g., flexibility in data collection methods) might be the most effective in maximizing retention (Teague et al., 2018). In line with this, the current dissertation employed health apps that are easy to export behavior data and kept the survey short and easy to fill out.

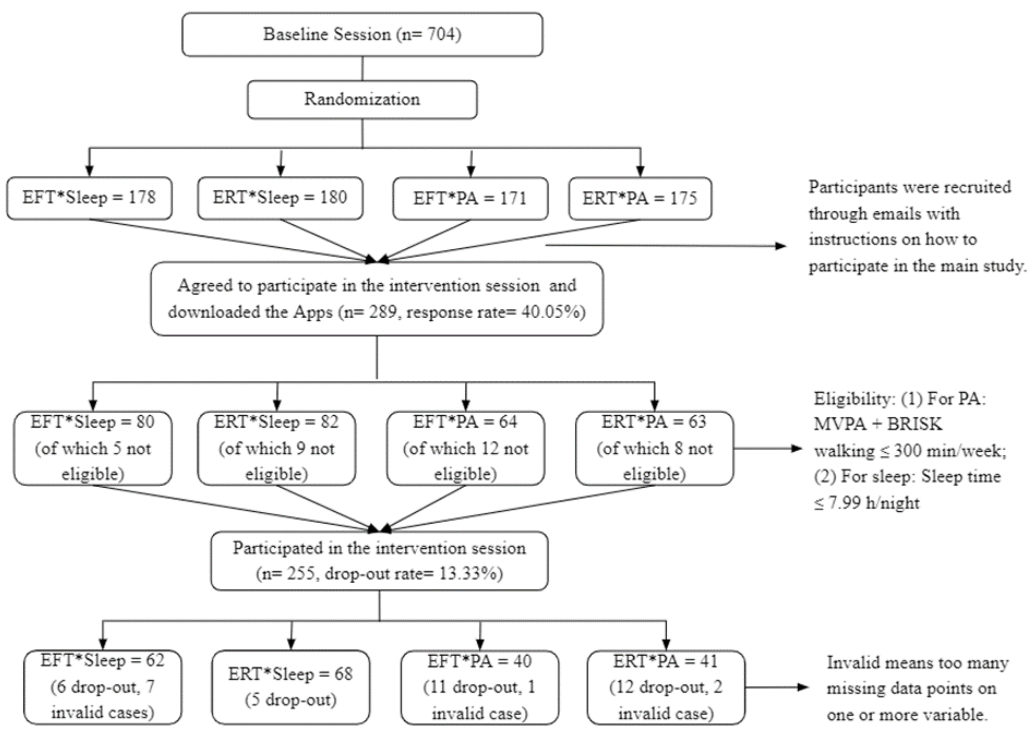

Figure 4 Flowchart for participants

5.3 Stimulus: Episodic Future Thinking (EFT)

In the baseline session, EFT groups were asked to generate six positive, autobiographical events that could realistically occur following some delays of time (i.e., 1w, 2w, 1m, 2m, 4m and 6m). The events could be related or not related to sleep/physical activity. The instructions are as follows and are also shown in Appendix A (alternative statements for ERT control participants are shown in the second paragraph):

> "In the following task, we want to invite you to imagine ***positive*** events that realistically could happen or that you have already planned ***in the future*** (e.g., in a week, a month, six months). This could be anything that comes to your mind (e.g., a getaway or something study-related). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible (what do you do, where are you, who are with you, accompanying feelings, etc.). These images will be used in the next exercise. Please describe these events according to the time frames provided."
>
> "In the following task, we want to ask you to ***recall positive*** events that have taken place recently (e.g., 1 hour ago, 4 h ago, 1 day ago, and 3 days ago). This may for example be a getaway or something study related. Think of something that applies to you. Re-experience this event in mind. Consider as many details of this event as possible (what did you do, where were you, who were with you, accompanying feelings). These images will be used in the next exercise. Please describe these events according to the time frames provided."

In the intervention session, participants needed to generate only one event on a given day after they received the reminder email, but this event should be somewhat related to sleep/physical activity (e.g., "I will go to bed and have a nice sleep," "I will go jogging in a sunny spring Saturday with me friends."). The instructions are as follows and are also shown in Appendix B (statements for ERT control participants are shown in the second paragraph):

> "Please describe a future event that realistically could happen and ***relates, even remotely, to your physical activity participation*** (e.g., something good resulted from your exercising behavior, something fun happens during your workout). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. If you cannot think of anything new, please write down a future event that you've imagined before. (There is a minimum 20-character requirement for this task)"
>
> "Please describe a positive recent event that happened in the past week. Think of something that applies to you. Re-experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)"

There was a textbox below this instruction in which participants would write down the content of their future or recent thinking. After documenting the events, participants in the EFT groups rated each event on a 7-point Likert scale (1= not at all; 7= very much) on vividness, positive valence, and how future-oriented the event was. Whereas participants in the ERT groups rated each event on vividness, positive valence, and difficulty to recall. These measures were used as manipulation checks.

These measures were used as manipulation checks as per the norm in studies of EFT. These measures assess participants' experience of thinking about the future, which are called phenomenological measures (Miloyan & McFarlane, 2019). They are recommended as manipulation checks because it is believed that participants may have better access to their own mental processes than observers (Bø & Wolff, 2019). Specifically, ERT was employed to ensure that episodic content in both groups engages memory and is matched for vividness and positive valence, and only time perspective is shifted during EFT (Hollis-Hansen et al., 2019).

5.4 Measures

(All measures were answered on a 1-7 Likert scale unless specified otherwise)

Key Measures in the Intervention Session:

Behavior. Sleep and physical activity were measured mainly through records in the two focal apps i.e., *SleepCycle* and *NikeTrainingClub*, both of which use time as metric. For those who did not interact with the two focal apps and thus did not have data points on certain days, data from the *LifeCycle* app were used. If there was no data on neither *SleepCycle/NikeTrainingClub* nor *LifeCycle* for a given day, it would be treated as a missing data point.

Affect was measured 5 times through the following question and items on a scale ranging from 0-100 with 5 Likert-scale style indicators to aid response (e.g., 0=None at all and 100=A great deal). Q: How do you feel right now? (Renner & Schwarzer, 2005, p. 28). Scores of the three negative emotions were recoded as negative numbers. A composite score summing across all the emotions was used for further analyses with higher score indicating higher positive affect.

- Furious
- Stressed out
- Good
- Happy
- Elated
- Depressed
- Other

For the *Other* category, participants needed to fill out the specific emotion they were feeling, and the researcher decided whether it was a positive or negative emotion.

Self-control was assessed 3 times with the 13-item brief self-control scale (Tangney et al., 2004) with answers from 1 (not at all like me) to 5 (just like me). For sleep data, Cronbach's Alpha was 0.842 for the first measurement wave (M=3.24, SD=0.36), 0.858 for the second measurement wave (M=3.29, SD=0.33), and 0.848 for the last measurement wave (M=3.30, SD=0.34). For physical activity data, Cronbach's Alpha was 0.821 for the first measurement wave (M=3.32, SD=0.35), 0.861 for the second measurement wave (M=3.37, SD=0.35), and 0.867 for the last measurement wave (M=3.31, SD=0.33).

1. I am good at resisting temptation.
2. I have a hard time breaking bad habits. (R)
3. I am lazy. (R)
4. I say inappropriate things. (R)
5. I do certain things that are bad for me, if they are fun. (R)

6. I refuse things that are bad for me.
7. I wish I had more self-discipline. (R)
8. People would say that I have iron self- discipline.
9. Pleasure and fun sometimes keep me from getting work done. (R)
10. I have trouble concentrating. (R)
11. I am able to work effectively toward long-term goals.
12. Sometimes I can't stop myself from doing something, even if I know it is wrong. (R)
13. I often act without thinking through all the alternatives. (R)

Intention *to get enough sleep* was measured 5 times through the following two items: 1) I intend to go to bed early and get enough sleep today, 2) I intend to use the sleep app to help me get more sleep today. ***Intention*** *to do more physical activity* was measured 5 times through the following two items: 1) I intend to do some physical activity today, and 2) I intend to use the physical activity app when I'm exercising today.

Other Measures Used in the Study:

Sleep time *(self-reported)*: On average, how many hours a night do you sleep during weekdays," which was answered on a 7-point scale ranging from "less than 5h" with increments of 1h (5–5.99h, 6–6.99h, ...) to "more than10h" (Kroese et al., 2014).

Physical activity *(self-reported)*: Self-report physical activity were measured using a 7-day recall measure, derived from the Stanford 7-Day Recall (Blair et al., 1995) measure. Participants were asked to estimate the number of hours they engaged in vigorous and moderate intensity physical activity and brisk walking over the course of the past 7 days, to the nearest half hour by responding to the following question: “During the last 7 days, how much total time did you spend doing VIGOROUS physical activity, MODERATE physical activity, and/or BRISK WALKING? Record only time that you actually engaged in the activity (ignore breaks, rest periods, etc.).”

Delay discounting (DD). DD was measured in the baseline session after the stimuli through a computerized version of the Monetary Choice Questionnaire (MCQ, Kirby et al., 1999). The measure consisted 21 out of the 27 original questions, asking participants to choose either a smaller, immediate monetary reward or a larger, delayed monetary reward. An example of a question is “Would you prefer $14 today, or $25 in 19 days?” The timeframes of the future events participants had imaged in previous task approximated the time delays specified on the MCQ.

Trait time perspective in terms of health behavior: This was a domain-specific, shorter version adapted from the Consideration of Future Consequences scale (CFC, Strathman et al., 1994). Cronbach’s Alpha was .703 for the sleep data and .694 for the physical activity data (M_{Sleep}= 4.02, SD_{Sleep}= 1.44; M_{PA} = 4.45, SD_{PA}= 1.49). Both results showed that items 5 and 6 were problematic. Cronbach’s Alpha increased to 0.745 for the sleep data and .737 for the PA data after these two items were deleted (M_{Sleep}= 4.13, SD_{Sleep}=1.46; M_{PA}= 4.77, SD_{PA}=1.48). These two items seemed to focus less on the behaviors themselves but more on feelings such as feelings of convenience and happiness. As a result, these two items were deleted and composite scores of CFC_{Sleep} and CFC_{PA} were calculated for further analyses.

1. I consider how my health might be in the future and try to influence my health with my day to day sleep behavior (physical activity).
2. Often I engaging in health behaviors such as getting sufficient sleep (participating in physical activity) in order to achieve outcomes that may not result for many years.
3. I get to bed at night (participate in physical activity) whenever I feel like to in order to satisfy immediate needs, figuring the future will take care of itself.
4. My sleeping behavior (exercise behavior) is only influenced by the immediate (i.e., a matter of days or weeks) consequences of my actions.
5. *My convenience is a big factor in the sleep time I choose or my sleeping behavior (the physical activity I choose or my exercise behavior) in general. (deleted in final analysis)*
6. *I am willing to sacrifice the immediate happiness or gain I derive from going to bed late at night (not doing physical activity) in order to achieve future health outcomes. (deleted in final analysis)*
7. I think it is important to take warnings about negative consequences of not getting enough sleep (physical activity) seriously even if the negative consequence will not occur for many years.
8. I generally ignore warnings about possible future consequences of my sleeping behavior (exercise behavior) because I think they will be resolved before they reach crisis level.

9. I choose when to sleep at night (participate in physical activity) to satisfy immediate needs, figuring that I will take care of future health problems that may occur at a later date.

Socio-demographics: Age, sex, race/ethnicity, education level, and health status.

Chapter 6: Results

6.1 Randomization Check

For randomization of the four experimental groups, a series of independent *t* tests and chi square tests were conducted to examine whether random assignment was achieved. For both the physical activity and sleep data, there were no statistically significant differences between the two groups (i.e., EFT vs. ERT) in terms of baseline self-reported physical activity/sleep time, sex, race, age, health status, and CFC (Table 2). It is thus concluded that randomization for group assignment was realized.

In addition, during the intervention session, survey completion rate ranged from 14.3% to 100% with a mean of 85.7% (*N*=211). There was no statistically significant difference among the four experimental groups on completion rate (i.e., EFT_S, EFT_PA, ERT_S, ERT_PA), $F\ (3, 207)$= 0.751, p= .523; $\widehat{M}_{EFT\_S}$= 84.71%, SD= .228; $\widehat{M}_{EFT\_PA}$= 89.34%, SD= .166; $\widehat{M}_{ERT\_S}$= 88.99%, SD= 0.176; $\widehat{M}_{ERT\_PA}$= 86.52%, SD= .162.

Table 2
Key statistics for randomization check (experimental group assignment)

		N	*Mean*	*SD*	*t*	*p*	*95% CI*
Baseline self-reported PA	ERT_PA	175	4.05	2.91	0.239	0.811	-0.51715, 0.66024
	EFT_PA	171	3.98	2.64			
Age	ERT_PA	175	19.27	1.76	-0.897	0.370	-0.599, 0.224
	EFT_PA	171	19.46	2.11			
Health status	ERT_PA	175	5.97	0.67	0.515	0.607	-0.117, 0.200
	EFT_PA	171	5.93	0.82			
CFC	ERT_PA	175	4.67	0.92	0.514	0.607	-0.14192, 0.24237
	EFT_PA	171	4.62	0.89			

Baseline self-reported sleep	ERT_S	180	3.37	1.12	1.441	0.150	-0.060, 0.389
	EFT_ S	178	3.20	1.03			
Age	ERT_ S	180	19.64	2.44	0.648	0.517	-0.351, 0.696
	EFT_ S	178	19.47	2.59			
Health status	ERT_ S	180	3.94	0.79	1.774	0.077	-0.017, 0.321
	EFT_ S	178	3.79	0.84			
CFC	ERT_ S	180	4.0516	0.85	0.642	0.522	-0.11983, 0.23584
	EFT_ S	178	3.99	0.86			
Chi Square	**PA-Sex**	2.071	*p*= .355	**PA-Race**	11.406	*p*= .494	
	Sleep-Sex	2.039	*p*= .361	**Sleep-Race**	14.196	*p*= .584	

For randomization of the two frequency groups (i.e., high- vs. low-dose groups), similar analyses were run with frequency as the between-group variable. For both physical activity and sleep data, there were no statistically significant differences between the two groups (i.e., high- vs. low-dose) in terms of baseline self-reported physical activity/sleep time, sex, race, age, health status, and CFC (Table 3).

Table 3

Key statistics for randomization check (frequency assignment)

		N	*Mean*	*SD*	*t*	*p*	*95% CI*
Baseline self-reported PA	High	38	2.95	1.71	-1.010	0.316	[-1.122, 0.366]
	Low	43	2.57	1.64			
Baseline self-reported sleep	High	68	3.29	0.92	-0.662	0.509	[-0.401, 0.200]
	Low	62	3.19	0.81			
Age	High	106	19.13	1.23	0.911	0.363	[-0.234, 0.637]
	Low	105	19.33	1.90			
Health status	High	106	4.64	1.33	-0.073	0.942	[-0.365, 0.339]
	Low	105	4.63	1.26			
CFC	High	106	4.42	0.10	-0.774	0.440	[-0.367, 0.160]
	Low	105	4.32	0.94			
Sex-Frequency	Chi-square= 5.279			*p*= .071			
Race-Frequency	Chi-square= 4.930			*p*= .295			

6.2 Manipulation Check

Some of the phenomenological measures for the thinking tasks are used for manipulation check purposes (Miloyan & McFarlane, 2019). As a reminder, the use of ERT controls for episodic thought (i.e., vivid measure) and valence (i.e., positive measure), highlighting the temporal differences between EFT and ERT. As such, scores on vivid and positive measures were compared between EFT and ERT.

For the thinking tasks in the baseline session, each participant engaged in EFT/ERT on a single occasion, i.e., during the online survey. However, during this one time point, they thought about 6 different events for 6 different time points in the future/past. After thinking about each event, they were asked the phenomenological measure questions. As a result, the scores for the phenomenological measures were averaged across the 6 time points for each participant. The phenomenological measures for manipulation check and mean scores of the answers are shown in Table 4. The differences on vividness and positive valence between participants in the EFT and ERT groups were not significant: for physical activity data, $t_{vivid}= 0.316$, $p= 0.80$; $t_{positive}= 0.0004$, $p= 0.99$; for sleep data, $t_{vivid}= 0.076$, $p= 0.95$; $t_{positive}= 0.0003$, $p= 0.99$.

For the thinking tasks in the intervention session, each participant needed to think about only 1 event on one occasion. However, there were multiple occasions on which they needed to engage in EFT/ERT. As a result, the phenomenological scores were averaged across different occasions for a single participant. Answers were combined for physical activity and sleep data. The differences on vividness and positive valence between EFT and ERT groups were not significant, $t_{vivid}= -0.129$, $p=$

0.198, M_{EFT}= 5.69, SD = 1.10, M_{ERT}= 5.88, SD = 1.10; $t_{positive}$= -1.067, p= 0.287, M_{EFT}= 5.83, SD = 1.17, M_{ERT}= 5.98, SD = 0.84.

In addition, for the baseline session, the mean scores for future-oriented and difficulty to recall measures were shown as a function of time (Figure 5), which helped illustrate the time direction – as time in the future increases, the event felt more future oriented (for EFT groups) and as time in the past increases, it is more difficult to recall an event (for ERT groups).

Based on the above information, it is thus concluded that the manipulation of future thinking was successful. The episodic content in both EFT and ERT groups was equivalent in vividness and positive valence and only time perspective was shifted (Hollis-Hansen et al., 2019).

Table 4
Mean scores of the answers for manipulation check questions in the baseline session

Question for EFT	Mean_PA	Mean_S
How vivid is the event?	5.40	5.59
How positive is the event?	6.11	6.17
Questions for ERT	**Mean_PA**	**Mean_S**
How vivid was the event?	5.22	5.17
How positive was the event?	5.72	5.67

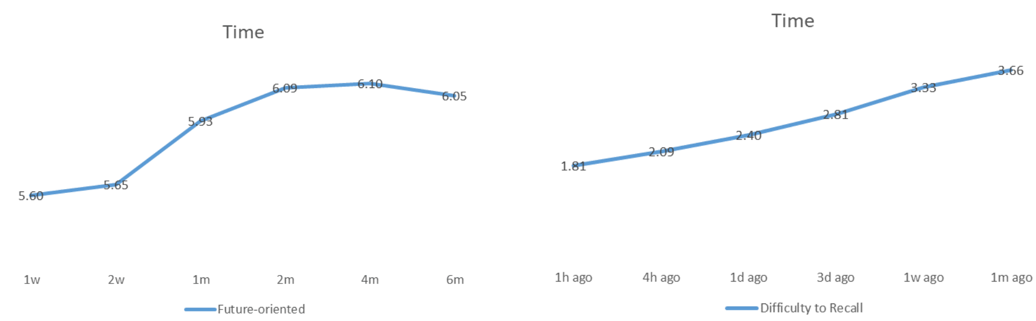

Figure 5 Change in mean scores on future-oriented (left) and difficulty to recall (right) measures as a function of time – baseline data

6.3 Main Analysis – Baseline Session

First, for the baseline session, the outcome variable was delay discounting (DD), which has been used in many studies on EFT as an important outcome variable (e.g., Bulley & Gullo, 2017; Leahey et al., 2020). Compared to participants in the ERT group, participants engaged in EFT were shown to have lower DD (Rösch et al., 2021; Rung & Madden, 2018; Ye et al., 2020). The results in the current dissertation showed that participants in the EFT group did have lower DD compared to those in the ERT group (M_{EFT}= 0.017, M_{ERT}= 0.021). However, this difference was not statistically significant with a one-tail *t* test at 0.05 level (*t*= 1.348, *p*= 0.089). Hypothesis 1 was not supported. This might be because no cues were shown to participants during the DD task, as it was the case in many of the previous EFT studies. Still, the direction is consistent with previous study results.

6.4 Main Analysis - Sleep Data

For the intervention session, for both sleep and physical activity data, three different types of analyses were conducted to test the hypotheses and answer the research questions proposed in Chapter 4. Specifically, one-way MANCOVA and SEM were conducted to examine hypotheses 2-7, research questions 4 and 5, whereas longitudinal analyses were conducted to answer research questions 1-3 but could also aid in examining hypothesis 3. The analyses were done separately for sleep and physical activity data. However, the two frequency groups (high- vs. low- dose) were combined for most analyses except for the analysis on dose effect.

6.4.1 One-Way MANCOVA

One-Way MANCOVA was conducted to compare the effect of EFT (vs. ERT) on the combined dependent variables (DV) of affect, self-control, intention, and behavior while controlling for CFC, health status, frequency assignment, survey completion rate, and demographics. The behavior variable was a difference between baseline (self-reported) sleep time and an average sleep time over the 14 waves of the intervention session. For the other outcome variables (i.e., affect, self-control, and intention), average scores across different measurement waves were used. There was a statistically significant difference between EFT and ERT groups on the combined DVs after controlling for the aforementioned covariates, $F(4, 115) = 4.352$, $p = .003$, Wilks' $\Lambda = .869$, partial $\eta^2 = .131$. Univariate analysis showed that the treatment was effective for the outcome variable self-control ($F = 2.901$, $df\,(1,118)$, $p = .004$, partial $\eta^2 = .068$) and behavior ($F = 4.628$, $df\,(1,118)$, $p = .053$, partial $\eta^2 = .031$). Means and standard deviations on the four DVs for EFT and ERT groups are shown in Table 5.

Table 5
Descriptive results for the sleep data

DV	Group	Mean	Std. Deviation	N
Affect	ERT	10.5987	9.9618	68
	EFT	6.7581	11.0916	62
Self-control	ERT	3.1137	0.6628	68
	EFT	3.3261	0.6031	62
Intention	ERT	4.8565	1.0463	68
	EFT	4.8836	1.0309	62
Sleep time difference	ERT	0.4963	1.1294	68
	EFT	-0.0108	1.0444	62

6.4.2 Longitudinal Data Analysis on Behavior Variable

Descriptive Results

The outcome variable for longitudinal analysis was sleep time recorded by *SleepCycle* and *LifeCycle* (when needed). Linear mixed-effects models were used to analyze longitudinal sleep data using the R package lme4 (Bates et al., 2014). There were 62 participants (with 930 observations including the baseline self-reported data) in the EFT group and 68 participants (with 1020 observations including the baseline self-reported data) in the ERT group. There was a total of 14 waves in the intervention session. Descriptive statistics of the sleep data for these 14 waves are shown in Tables 6-8, whereas individual trend lines are shown in Figure 6.

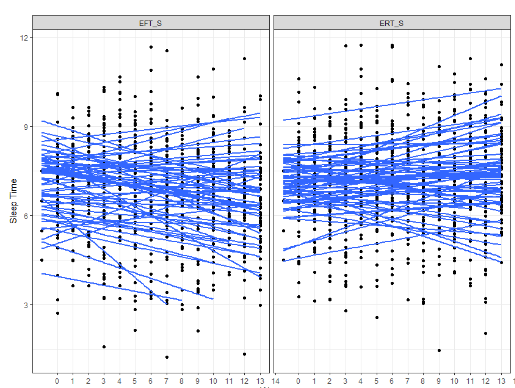

Figure 6 Descriptive individual trend lines for EFT vs. ERT groups

Table 6
Descriptive statistics by wave for the sleep data

Wave	***Mean***	***Median***	***Minimum***	***Maximum***	***SD***	***Missing***	***n***
1	7.05	7.2	2.72	10.6	1.41	5	130
2	7.17	7.29	3.12	10.3	1.3	8	130
3	6.97	7.22	3.18	9.65	1.57	10	130
4	7.11	7.4	1.6	11.7	1.82	6	130
5	7.4	7.5	3.22	11.7	1.64	8	130
6	6.97	7.07	2.15	10.3	1.66	3	130
7	7.24	7.31	3.21	11.7	1.71	6	130
8	6.98	7.03	1.23	11.6	1.6	5	130
9	6.82	7.11	2.84	10.1	1.66	12	130
10	6.86	6.92	1.46	11	1.8	12	130
11	7.17	7.16	3.5	10.9	1.64	11	130
12	7.12	7.21	3.65	11.3	1.48	13	130
13	6.75	6.75	1.35	11.3	1.83	12	130
14	7.01	6.93	2.98	11.1	1.53	13	130

Note: These descriptive statistics were for the outcome variable *sleep time* in minutes.

Table 7
Percentages of missing data for each wave for the sleep data

Wave	***W_1***	***W_2***	***W_3***	***W_4***	***W_5***	***W_6***	***W_7***
Missing data	3.85%	6.15%	7.69%	4.62%	6.15%	2.31%	4.62%
Wave	***W_8***	***W_9***	***W_10***	***W_11***	***W_12***	***W_13***	***W_14***
Missing data	3.85%	9.23%	9.23%	8.46%	10.00%	9.23%	10.00%

Table 8
Correlation matrix between different waves for the sleep data

	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	0.399	0.289	0.297	0.239	0.381	0.257	0.285	0.281	0.301	0.155	0.255	0.379	0.329
2		0.176	0.376	0.333	0.388	0.421	0.238	0.384	0.287	0.328	0.211	0.431	0.348
3			0.194	0.201	0.21	0.31	0.182	0.268	0.314	0.126	0.286	0.128	0.274
4				0.45	0.255	0.343	0.267	0.408	0.25	0.244	0.238	0.33	0.247
5					0.404	0.461	0.416	0.317	0.174	0.252	0.499	0.356	0.292

6	7	8	9	10	11	12	13
0.347							
0.256	0.236						
0.229	0.352	0.348					
0.118	0.314	0.321	0.331				
0.413	0.479	0.321	0.335	0.5			
0.344	0.36	0.283	0.207	0.239	0.386		
0.422	0.295	0.193	0.355	0.311	0.281	0.423	
0.245	0.439	0.273	0.484	0.382	0.377	0.33	0.359

Main Results

Group mean trendline with a linear and a polynomial function are shown in Figure 7. It seemed that both functions could fit the data. As a result, a linear model with random intercept (Model 1), a linear model with random intercept and random slope (Model 2), and a linear model with random intercept and a quadratic term (Model 3) were fitted to data from the 14 waves + baseline self-reported sleep time.

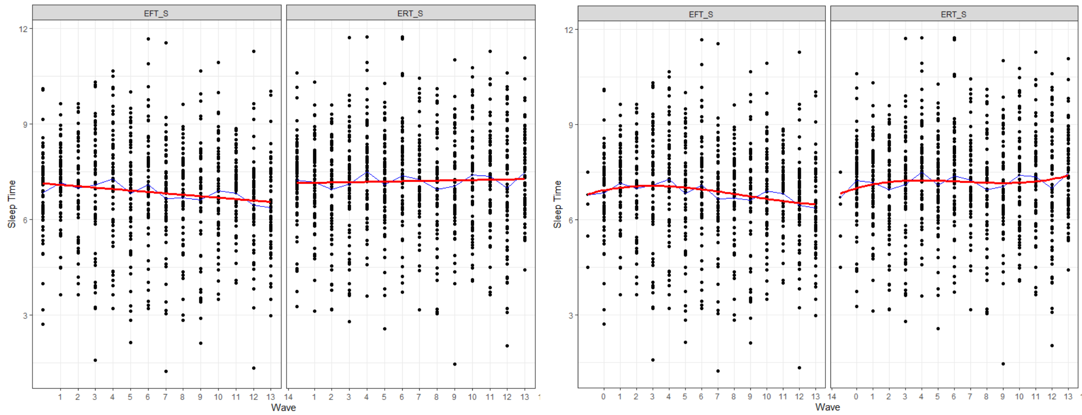

Figure 7 Descriptive mean trendlines fitted with a linear (left) and a polynomial (right) function for EFT vs. ERT groups

Model 1: Linear model with random intercept: $y_{ij} = (\beta_0 + b_{i0}) + \beta_1 Wave_j + \varepsilon_{ij}$

Model 2: Linear model with random intercept and slope: $y_{ij} = (\beta_0 + b_{i0}) + (\beta_1 + b_{i1})Wave_j + \varepsilon_{ij}$

Model 3: Linear model with random intercept and a quadratic term: $y_{ij} = (\beta_0 + b_{i0}) + \beta_1 Wave_j + \beta_2 {Wave^2}_j + \varepsilon_{ij}$

The time trend in Model 3 was not statistically significant. Whereas for both Models 1 and 2, there were statistically significant time effects: (Model 1) $\hat{\beta}_1$= -0.019, *p*= 0.017; (Model 2) $\hat{\beta}_1$= -0.021, *p*= 0.021. In general, participants slept an average of 7.14h at the first wave of the intervention session, compared to 6.92h at baseline. Their sleep time then decreased over the course of the intervention. Model comparison using AIC and BIC was conducted on Models 1 and 2. The results are shown in Table 9. Although AIC and significance result showed that Model 2 was slightly better, BIC indicated that Model 1 was better. Model 1 was chosen because it was a simpler model.

Table 9
Model comparison results

	Df	AIC	BIC	logLik	deviance	Chisq	Chi	Df	Pr(>Chisq)
Model 1	4	6077.1	6098.9	-3034.6	6069.1				
Model 2	6	6072.9	6105.5	-3030.4	6060.9	8.2501	2	0.01616	*

In the next steps, covariates were added to the model to test the effect of treatment (i.e., EFT) and the effect of treatment controlling for demographics and CFC scores. First, a model with treatment as the covariate was examined (Model 4). Then, interaction term between time and treatment was added to the model (Model 5). Lastly, other covariates mentioned above were added to the model (Model 6).

Model 4: Linear mixed-effects model with treatment as covariate: $y_{ij} = (\beta_0 + b_{i0}) + \beta_1 Wave_j + \beta_2 Group + \varepsilon_{ij}$

Model 5: Linear mixed-effects model with treatment and interaction between wave and treatment: $y_{ij} = (\beta_0 + b_{i0}) + \beta_1 Wave_j + \beta_2 Group + \beta_3 Group * Wave + \varepsilon_{ij}$

Model 6: Linear mixed-effects model with treatment, interaction, and other covariates: $y_{ij} = (\beta_0 + b_{i0}) + \beta_1 Wave_j + \beta_2 Group + \beta_3 Group * Wave + \beta_4 CFC + \beta_5 (Age - 18) + \beta_6 Gender + \beta_7 Race + \varepsilon_{ij}$

For Model 4, the treatment effect was statistically significant ($\hat{\beta}_2$= 0.41, *p*= 0.024, with EFT as the reference group), indicating that participants in the ERT group slept about 25mins more on average than those in the EFT group at wave 1, which was contrary to what was hypothesized.

For Model 5, the interaction between time and treatment was statistically significant ($\hat{\beta}_3$= 0.06, *p*< 0.001). This interaction effect was significant after controlling for participants' demographics and their CFC (Model 6: $\hat{\beta}_3$= 0.06, *p*< 0.001). In other words, the time trends were different between the two groups. As time went by, sleep time decrease for participants in the EFT group compared to those in the ERT group.

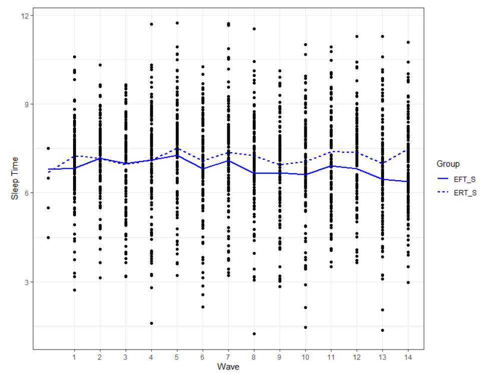

Figure 8 Mean trendlines from baseline to the last wave for EFT and ERT groups for the sleep data

6.4.3 Longitudinal Data Analysis on Psychological Variables

Mixed ANOVA was conducted on the three psychological variables (affect, self-control, and intention) for sleep and physical activity datasets separately, with treatment as the fixed (between-subject) factor and different time points of measurements as the random (within-subjects) factor.

For the sleep data, after controlling for demographics, CFC, health status, survey completion rate, intervention frequency, there was a statistically significant within-subjects main effect for time, in other words, the mean affect scores differed statistically significantly between time points (F_{time} (4,288) = 2.345, p = 0.055; M_{T1}= 11.61, M_{T2}= 11.29, M_{T3}= 11.32, M_{T4}= 8.41, M_{T5}=7.37). There was a close to significant within-between subjects interaction effect between time points and treatment ($F_{interaction}$ (4,288) = 2.214, p = 0.068). The between-subjects main effect for treatment was not significant ($F_{EFT}(1,72) = 2.385$, $p = 0.127$). For self-control and intention, none of the effects (including two main effects and an interaction effect) was significant.

6.4.4 SEM Analysis

SEM was used to fit the proposed model to the sleep data using the R package lavaan (Revelle, 2019). All variables were treated as observed variables. The treatment was used as the exogenous variable. A difference between baseline (self-reported) sleep time and an average sleep time over the 14 waves of the intervention session was used as the behavior variable. Other endogenous variables included: affect, self-control, and intention. Because none of the between-within interactions is statistically significant, average scores across different measurement waves were used. Correlations between key variables are shown in Table 10. Maximum likelihood estimation with robust standard errors and a Satorra-Bentler scaled test statistic (Revelle, 2019) was used to address nonnormality for some variables. Indirect effects were estimated using bootstrapping procedures. Multiple fit indices were employed. The cutoff criteria were based on Hu and Bentler (1999) recommendations: *CFI* close to .95, *SRMR* close to .08; *RMSEA* close to .06.

Table 10

Correlation matrix of the endogenous variables with means and sd for the sleep data[1]

	Affect	**Self-control**	**Intention**	**Sleep (Diff)**	**Treatment**
Affect	1	0.047	0.143	0.133	-0.181*
Self-control		1	0.196*	0.181*	0.166
Intention			1	0.267**	0.013
Sleep (Diff)				1	-0.228**
Treatment					1
Mean (*SD*)	8.77 (10.65)	3.21 (0.64)	4.87 (1.04)	0.25 (1.11)	NA

Note: *. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).

The model fit the data well, χ^2 = 0.750 (*df*=1, *p*= 0.387), *CFI*= 1.000, *RMSEA*= 0.000 (90% *CI* [0.000, 0.231]), *SRMR*= 0.021. According to the path coefficients (Figure 9), the effect of EFT (vs. ERT) on intention was not significant, *hypothesis 2a* was not supported); but that of behavior was statistically significant ($\hat{\beta}_{EFT-S}$= -0.252, *p*< .01). However, the direction was contrary to what was hypothesized, *hypothesis 3a* was not supported. That is, engaging in EFT (vs. ERT) significantly decreased sleep time. Intention related to behavior in a positive and significant way ($\hat{\beta}_{INT-S}$= 0.229, *p*< .01), *hypothesis 4* was supported. EFT (vs. ERT) significantly predicted increases in self-control ($\hat{\beta}_{EFT-SC}$= 0.176, *p*= .054), *hypothesis 5* was supported. Self-control, in turn, related significantly to intention ($\hat{\beta}_{SC-INT}$= 0.189, *p*= .028) and behavior ($\hat{\beta}_{SC-SLEEP}$= 0.176, *p*= .023) in a positive way, *hypotheses 6a and 6b* were supported. Lastly, EFT (vs. ERT) had a statistically significant negative effect on affect ($\hat{\beta}_{EFT-A}$= -0.181, *p*= .037), *hypothesis 7* was not supported. In other words, participants in the EFT (vs. ERT) group had lower positive

[1] The significance score for correlation between treatment and self-control is 0.059 and that between treatment and affect is 0.04. The MANOVA results with no covariates produced similar results as shown in the correlation matrix table. However, the MANCOVA results with covariates are as a bit different, as shown in the text on page 74. Results from all three types of analyses were used to help make decision on whether a hypothesis was supported or not. This applies to the physical activity data as well.

affect (or higher negative affect). The effects of affect on intention and behavior were not significant ($\hat{\beta}_{A-INT}$= 0.135, *p*= .176; $\hat{\beta}_{A-S}$= 0.047, *p*= .589).

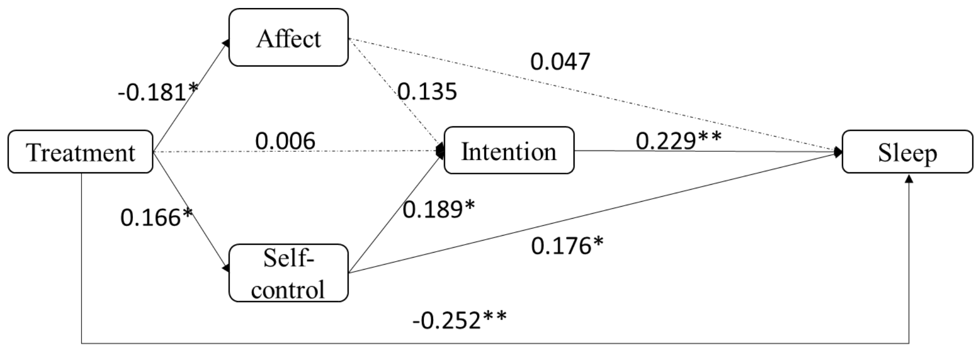

Figure 9 Path model with standardized path coefficients for sleep data
Note: *. Coefficient is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).

Mediation analyses were performed to examine whether affect and self-control mediated the effect of EFT on intention and actual behavior change. The indirect effects showed that none of the mediation was significant ($\hat{\gamma}_{EFT-A-INT}$= -0.05, *p* = .224, 95% *CI* [-0.132, 0.031]; $\hat{\gamma}_{EFT-SC-INT}$= 0.064, *p* = .145, 95% *CI* [-0.022, 0.151]; $\hat{\gamma}_{EFT-A-S}$= -0.031, *p* = .463, 95% *CI* [-0.115, 0.052]; $\hat{\gamma}_{EFT-SC-S}$= 0.081, *p* = .143, 95% *CI* [-0.027, 0.189]), hypotheses 6c and 6d were not supported.

6.5 Main Analysis - Physical Activity Data

6.5.1 One-Way MANCOVA

One-Way MANCOVA was conducted to compare the effect of EFT (vs. ERT) on the combined dependent variables (DV) of affect, self-control, intention, and behavior while controlling for baseline (self-reported) exercise time, CFC, health status, frequency assignment, survey completion rate, and demographics. Data for physical activity behavior was drawn from *NikeTrainingClub* measured as time in minutes. A log transformation was applied to the data to correct its skewness. For the other outcome variables (i.e., affect, self-control, and intention), average scores across different measurement waves were used. There was a statistically significant difference between EFT and ERT groups on the combined DVs (i.e., affect, self-control, intention, and behavior) after controlling for the aforementioned covariates, $F(4, 66)= 3.039$, $p= .023$, Wilks' $\Lambda = .844$, partial $\eta^2 = .156$. Univariate analysis showed that the treatment was effective for the outcome variable intention ($F= 9.426$, $df\,(1,69)$, $p= .003$, partial $\eta^2 = .120$). Means and standard deviations on the four DVs for EFT and ERT groups are shown in Table 11, participants in the EFT group had higher scores on all four DVs.

Table 11
Descriptive results for the physical activity data

DV	Group	Mean	Std. Deviation	N
Affect	ERT	7.9053	11.64524	41
	EFT	12.6617	10.82561	40
Self-control	ERT	3.1667	0.62502	41
	EFT	3.4260	0.60154	40
Intention	ERT	4.6848	0.93246	41
	EFT	5.3298	0.92306	40
PA (log)	ERT	2.4990	0.48504	41
	EFT	2.7380	0.56100	40

6.5.2 Longitudinal Analysis on Behavior Variable

Descriptive Results

For the physical activity data, there were 40 participants (with 574 observations) in the EFT group and 41 participants (with 560 observations) in the ERT group. The observations were computed as composite scores based on intensity and time in minutes from records in both *NikeTrainingClub* and *LifeCycle*. Specifically, the observations were mostly from the *LifeCycle* app where participants' daily walk time was recorded and multiplied by 3 (i.e., the intensity index) to form a composite score. Most participants in the physical activity groups did not use *NikeTrainingClub* every day, so there were a lot of “missing” data points. This missingness is understandable because 1) even the recommendation of physical activity is an average time per week (i.e., 150 minutes MVPA per week, American Heart Association, 2018). It is highly likely that people exercise on some days of a week but take a break on other days. 2) Participants might not record every type of physical activity they did with *NikeTrainingClub*, or the exercise in which they participated could not be recorded by this app. Descriptive statistics of the physical activity data for these 14 waves are shown in Tables 12-14, whereas individual trend lines are shown in Figure 10.

Table 12

Descriptive statistics by wave for physical activity data

Wave	***Mean***	***Median***	***Minimum***	***Maximum***	***SD***	***Missing***	***n***
1	148	103	6.05	888	158	15	81
2	145	131	7.65	540	113	21	81
3	170	83.8	6.95	1390	222	17	81
4	154	108	7	743	149	21	81
5	157	106	12.6	929	175	19	81
6	153	107	10.1	776	153	17	81
7	138	93	6	540	120	18	81
8	153	79	6.1	1324	204	20	81
9	146	98.8	10	900	155	20	81
10	123	82.5	10.8	917	147	27	81
11	132	67.8	6.65	1239	205	20	81
12	137	74	7.2	835	179	27	81
13	152	89.2	9	625	151	22	81
14	174	120	14.2	938	184	17	81

Note: These descriptive statistics were for the outcome variable *physical activity* in composite scores computed based on intensity and time in minutes.

Table 13

Percentages of missing data for each wave for physical activity data

Wave	***W_1***	***W_2***	***W_3***	***W_4***	***W_5***	***W_6***	***W_7***
Missing data	19%	26%	21%	26%	23%	21%	22%
Wave	***W_8***	***W_9***	***W_10***	***W_11***	***W_12***	***W_13***	***W_14***
Missing data	25%	25%	33%	25%	33%	27%	21%

Table 14

Correlation matrix between different waves for physical activity data

	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	0.206	0.241	0.263	0.193	0.51	0.45	0.272	0.435	0.273	0.019	0.662	0.203	0.385
2		0.112	0.171	0.152	0.223	0.235	0.257	0.632	0.594	0.399	0.231	0.108	0.463
3			0.314	0.472	0.182	-0.024	0.204	-0.022	0.136	0.038	0.589	0.065	0.083
4				0.44	0.107	0.187	0.405	0.261	0.257	0.168	-0.021	0.082	0.434
5					0.112	0.069	0.424	-0.014	0.127	-0.114	0.401	0.144	0.156
6						0.628	0.282	0.48	0.388	0.105	0.58	0.389	0.356
7							0.157	0.509	0.308	0.348	0.394	0.435	0.431
8								0.252	0.008	-0.108	0.165	0.502	0.271
9									0.686	0.424	0.388	0.071	0.381
10										0.483	0.262	0.04	0.631
11											0.016	-0.035	0.328
12												0.252	0.243
13													0.394

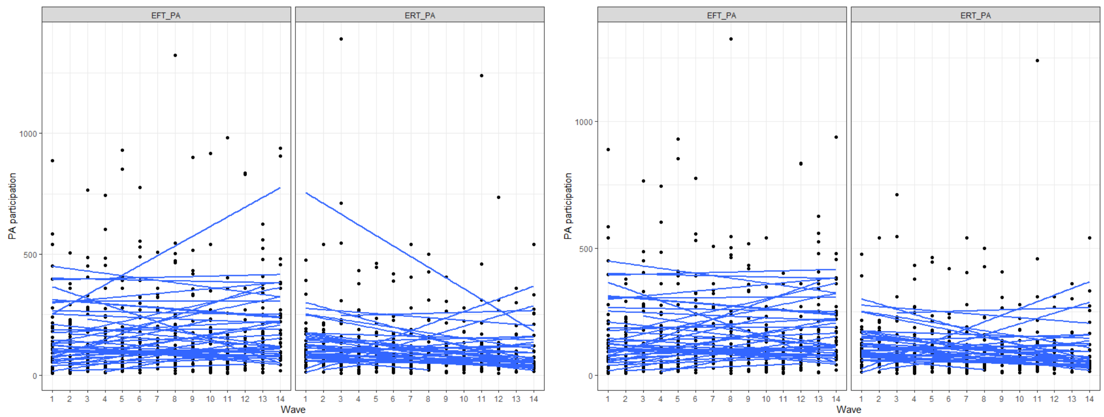

Figure 10 Descriptive individual trend lines for EFT vs. ERT groups with (left) and without (right) problematic data points.

Main Results

Exploratory results indicated that there were two cases, one in each group, that were problematic (Figure 10). These two cases were excluded for following analyses. Because the sample size was small, only a linear model with random intercept was fitted.

Model 1: Linear model with a random intercept: $y_{ij} = (\beta_0 + b_{i0}) + \beta_1 Wave_j + \varepsilon_{ij}$

Model 1 showed that the time trend was not significant. Explorative analysis showed that there might be some treatment effect. As a result, group was added to Model 1 and was examined (see Model 2).

Model 2: Linear mixed-effects model with treatment as covariate: $y_{ij} = (\beta_0 + b_{i0}) + \beta_1 Wave_j + \beta_2 Group + \varepsilon_{ij}$

The results showed that there was a statistically significant effect of treatment ($\hat{\beta}_2$= -59.45, *p*= 0.002, with EFT as the reference group). The effect of the treatment was statistically significant after controlling for baseline self-reported exercise time, CFC, and demographics (Model 3, $\hat{\beta}_2$= -55.16, *p*= 0.008). This result indicated that the treatment (i.e., EFT) might be effective in promoting physical activity behavior change in terms of a variety of workouts recorded by *NikeTrainingClub* and walking recorded by *LifeCycle,* which indicated that *hypothesis 3b* could be supported.

Model 3: Linear mixed-effects model with treatment and other covariates: $y_{ij} = (\beta_0 + b_{i0}) + \beta_1 Wave_j + \beta_2 Group + \beta_3 * Base + \beta_4 CFC + \beta_5 (Age - 18) + \beta_6 Gender + \beta_7 Race + \varepsilon_{ij}$

6.5.3 Longitudinal Analysis on Psychological Variables

For the physical activity data, after controlling for demographics, CFC, health status, survey completion rate, intervention frequency, and baseline self-reported physical activity time, for affect, the between-subjects main effect for treatment was significant ($F_{EFT}(1,42) = 4.773$, $p = 0.035$; M_{EFT}= 14.303 M_{ERT}=7.524), participants in the EFT (vs. ERT) group had higher positive affect. The within-subjects time effect was not significant ($F_{time}(4,168) = .797$, $p = 0.529$). The within-between subjects interaction effect between time points and treatment was not significant ($F_{interaction}(4,168) = 0.619$, $p = 0.649$). For intention, the between-subjects main effect for treatment was significant ($F_{EFT}(1,42) = 5.648$, $p = 0.022$; M_{EFT}= 5.377 M_{ERT}= 4.687), participants in the EFT (vs. ERT) group had higher intention to do more physical activity. The within-subjects time effect was not significant ($F_{time}(4,168) = 1.628$, $p = 0.170$). The within-between subjects interaction effect between time points and treatment was not significant ($F_{interaction}(4,168) = 0.619$, $p = 0.649$). For self-control, none of the effects (including two main effects and an interaction effect) was significant.

6.5.4 SEM Analysis

Again, all variables were treated as observed variables. The treatment was used as the exogenous variable. Total time of workouts (in minutes) recorded in the *NikeTrainingClub* app was used as the behavior variable with a log transformation to correct for skewness. Other endogenous variables included: affect, self-control, and intention. Again, because none of the between-within subjects interactions is statistically significant, average scores across different measurement waves were used. Correlation matrix of the five variables with their means and standard deviations are shown in Table 15.

Because the sample size was small, SEM results were presented but not interpreted. The model fit indices were as follows: χ^2 = 6.649 (*df*=1, *p*= 0.01), *CFI*= 0.828, *RMSEA*= 0.321 (90% *CI* [0.126, 0.570]), *SRMR*= 0.089. Path coefficients are showed in Figure 11.

Table 15
Correlation matrix of variables with means and standard deviations for physical activity data

	Affect	**SC**	**Intention**	**PA (Log)**	**Treatment**
Affect	1	0.367**	0.266*	0.332**	0.209
SC		1	0.097	0.254*	0.209
Intention			1	0.482**	0.332**
PA (Log)				1	0.225*
Treatment					1
Mean (*SD*)	10.25 (11.43)	3.29 (0.62)	5.00 (0.98)	2.62 (0.53)	NA

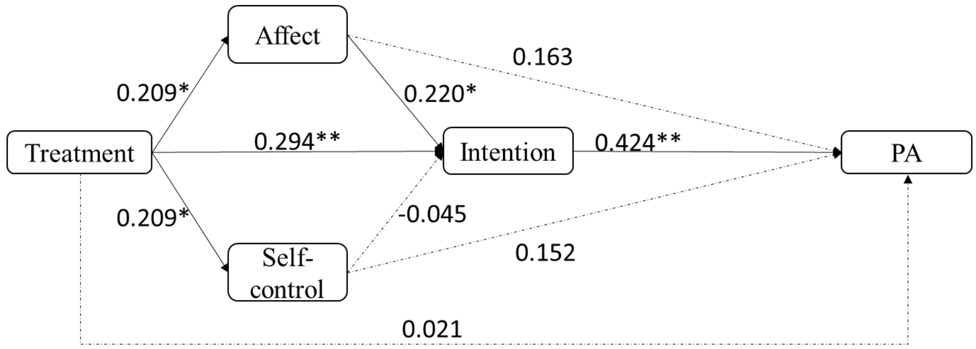

Figure 11 Path model with standardized path coefficients for the physical activity data

6.5.5 Additional Analyses

Mediation analysis on physical activity data

Although the SEM results are not reliable due to the small sample size, they suggested that there might be 1) an indirect effect of EFT on behavior change through intention, and 2) an indirect effect of EFT on intention through affect. Accordingly, two mediation analyses were conducted: one with intention as the mediating variable between treatment and physical activity results; the other with affect as the mediating variable between treatment and intention. These analyses were conducted using the r package mediation (Tingley et al., 2014).

The effect of EFT on physical activity was fully mediated via intention to do more physical activity. As Figure 12 illustrates, the regression coefficient between treatment and intention and the regression coefficient between intention and PA were significant. The indirect effect was 0.16. The significance of this indirect effect was tested using bootstrapping procedures. Unstandardized indirect effects were computed for each of 1000 bootstrapped samples. The 95% confidence interval ranged from .05 to .30. The indirect effect was statistically significant (p <.001). The indirect effect remained significant ($\hat{\gamma}_{EFT-INT-PA}$= 0.15, p < .01, 95% *CI* [0.04, 0.28]) after controlling for covariates (i.e., baseline self-reported PA, CFC, health status, and demographics), which suggested that *hypothesis 3b* could be supported. The indirect effect of EFT on intention through affect was not significant.

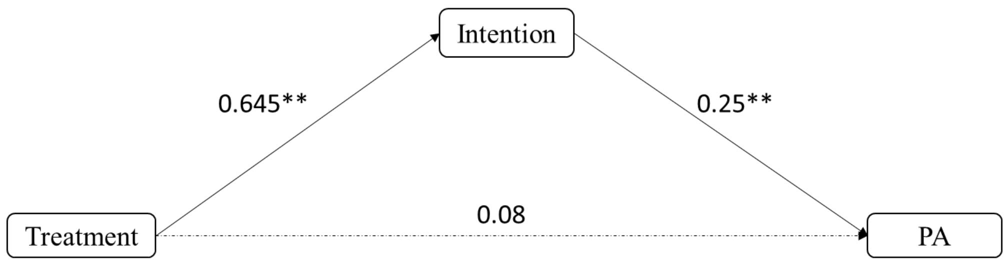

Figure 12 Indirect effect of EFT on physical activity through intention

Dose effect

In the intervention session, participants were randomly assigned to low- vs. high-dose groups to test the dose effect of sending reminders on behavior change. Specifically, participants in the high-dose group needed to engage in EFT (or ERT) everyday whenever they received the reminder email (13 times in total) whereas those in the low-dose group needed to engage in EFT (or ERT) every third day (5 times in total). The behavior variable for sleep groups was a difference between baseline sleep time and an average sleep time over the 14 waves of the intervention. Whereas that for physical activity groups was the total time of workouts (in minutes) recorded in the *NikeTrainingClub* app with a log transformation. Data on sleep and physical activity behaviors were combined to conduct the analysis. The results showed that the does effect was not significant, *F*= 1.636, *df*= 1, *p*= 0.202, $\widehat{M}_{high}$= 1.287, *SD*= 1.51; $\widehat{M}_{low}$= 1.037, *SD*= 1.45.

Based on the above analyses, a summary of the results in terms of hypotheses and research questions across the two data sets are shown in Table 16.

Table 16
Summary of results across two data sets

Hypotheses	**Sleep data**	**Physical activity data**
H1: EFT (vs. ERT) will lead to decreased delay discounting.	Not significant	
H2: EFT (vs. ERT) will increase (a) intention to get enough sleep and (b) intention to engage in physical activity.	Not significant	Supported
H3: EFT (vs. ERT) will increase (a) sleep time and (b) physical activity.	Not supported	Supported
H4: Behavioral intentions will be positively related to actual behaviors.	Supported	
H5: EFT (vs. ERT) will increase self-control.	Supported	Not enough evidence
H6a: Self-control will be positively related to behavioral intentions.	Supported	Not enough evidence
H6b: Self-control will be positively related to actual behaviors.	Supported	Not enough evidence
H6c: The effect of EFT (vs. ERT) on behavioral intentions will be mediated by self-control.	Not supported	
H6d: The effect of EFT (vs. ERT) on actual behaviors will be mediated by self-control.	Not supported	
H7: EFT (vs. ERT) will increase positive affect.	Not supported	Not significant
Research Questions	**Sleep data**	**Physical activity data**
RQ1: Does increasing the dose of EFT (vs. ERT) lead to more behavior change?	Engaging in EFT (vs. ERT) repeatedly led to a decrease in sleep time.	No
RQ2a: Is positive affect associated with behavioral intentions?	No	No
RQ2b: Is positive affect associated with actual behaviors?	Not significant	Not enough evidence
RQ3a: Does positive affect mediate the effect of EFT (vs. ERT) on behavioral intentions?	No	No
RQ3b: Does positive affect mediate the effect of EFT (vs. ERT) on actual behaviors?	No	No

Chapter 7: Discussion

This dissertation takes an “active ingredient” perspective towards examining the effect of mHealth interventions and proposes and examines one strategy called episodic future thinking (EFT) in mHealth lifestyle intervention to promote healthy behavior change. The choice of this strategy is based on considerations of its suitability with the targeted behaviors under investigation and the mobile technologies employed.

Specifically, many decisions about lifestyle-related behavior change are intertemporal in nature. That is, the desirable outcomes of health behavior change are often temporarily distant, whereas the temptations, or benefits for not engaging in the behavior, are at the here and now. The value of the distant outcomes is usually discounted sharply by people, a tendency called delay discounting (Frederick et al., 2002; Kang & Ikeda, 2016). The subjective value of more immediate rewards, on the other hand, are valued more at the moment of choice, for example, an immediate gratification of eating high calorie food or binge-watching TV shows without moving all day. Researchers have proposed that effortful attempts to shift temporal focus toward the future could be a potent way of increasing healthy decision-making (Hall & Fong, 2007).

Episodic future thinking (EFT) is one such strategy. It broadens one’s temporal horizon and bridges the future and the present through enhancing one’s sense of temporal continuity and personal identity and through its close relationships with personal goals and self-control.

However, even if the future benefits or health goals are highlighted and wanted, the means and process to gain those benefits or achieve the goals are in the here and now. Failures occur when individuals do not know how best to achieve their goals (Taylor & Wilson, 2016). Specific to health behaviors, research has shown that a substantial number of individuals are motivated to engage in health behavior and form goal intentions to do so but fail to carry out those intentions (Gollwitzer et al., 2010; Rhodes & Dickau, 2012).

New technologies, such as smart mobile devices, can serve as tools that connect present actions with future goals. Based on the construal level theory, mobile phones serve as low abstraction cues because they are anchored with the self and in the here and now (Katz & Byrne, 2013). This characteristic enables mobile phones to bridge high level goals with specific actions, which are also supplied by the various APPs embedded in mobile devices. Due to these characteristics, it is thus argued that combining EFT with mobile technologies helps connect present actions with future health goals and might enhance the effect of EFT.

Participants who met the inclusion criteria and who showed an initial interest in changing their behavior through using health apps were invited to participate in a two-week intervention study. During the two-week, they received reminder to engage in EFT (vs. ERT) and use two health apps. Their self-control, affective state, behavioral intentions, actual behavior were measured through self-reported instruments and mobile apps.

In general, the results suggested that EFT could be a useful strategy incorporated into mHealth interventions to promote health behavior change.

However, it might have contradictory effects when applied to different types of behavior. Specific to the current study, EFT was effective in promoting physical activity as recorded through the health app *NikeTrainingClub* among college students. However, EFT had negative effect when applied to the sleep behavior. The reasons why this was the case are explained and theoretical and practical implications for EFT study and mHealth interventions are discussed in the following sections.

7.1 EFT and Psychological Outcomes (i.e., affect, self-control, and intention)

EFT predicts change in psychological outcomes to varying degrees for the sleep and physical activity behaviors. Specifically, EFT (vs. ERT) increases self-control for the sleep behavior, which in turn, is associated with an increase in intention, and increases positive affect and intention for the physical activity behavior. Across two datasets, the results seem to suggest that EFT (vs. ERT) has the potential to increase intentions for health behavior change, which is consistent with previous evidence showing the relation between future thinking and personal goals and the motivating effect of EFT (D'Argembeau et al., 2010; Demblon & D'Argembeau, 2017). Specifically, one of the adaptive functions of EFT is to boost prospective memory, i.e., the ability to remember carrying out a designated intention at a future time (Schacter et al., 2017).

7.2 EFT and Behavioral Outcomes (i.e., sleep and physical activity)

In theory, EFT should also promote actual behavior change because simulating performing an upcoming intention should make it more likely that this intention be carried out. Previous studies have also provided empirical support for the effect of EFT on actual behavior change. For example, EFT has been associated with changes in one's demand for cigarettes (Stein et al., 2016), alcohol (Snider et al., 2016) and food (Sze et al., 2017). It has also been shown to improve clinical outcomes, including reduced eating in the laboratory (Daniel et al, 2013; Dassen et al., 2016) and in a food court (O'Neill et al., 2016).

However, in the current intervention, EFT (vs. ERT) was shown to promote physical activity participation but decrease sleep time compared to baseline among college students. I argue that the relation between EFT (and repeatedly engaging in EFT) and actual behavior change is more complex than its relations with psychological outcomes, such as self-control and intention.

Specific to the current dissertation, the two behaviors under investigation differ in their controllability (Sheeran, 2002), which is an important aspect for intentions to be translated into action. In other words, individuals must have control over performing a behavior to be able to turn their intention into the realization of that behavior (Sheeran, 2002).

Several control factors have been proposed to determine the amount of control a person actually possesses over performing a behavior and thus whether an intention is translated into action. These factors include knowledge, ability, resources, opportunity, availability, cooperation, and unexpected situations (Sheeran, 2002, p.10).

One key difference between the sleep and physical activity behaviors is their controllability – individuals have less control over their sleep behavior than over physical activity behavior as measured in the current dissertation. For example, in terms of ability, those who have difficulties falling asleep do not have too much to rely on except for resorting to medications. On the other hand, people with different physical conditions could find some sort of exercise that is suitable for them. In terms of unexpected situations, the sleeping behavior is more susceptible to unexpected situations, such as a break-up with romantic partner, a party lasting till late evening; whereas exercise behavior might be less susceptible to unexpected situations – someone who wants to go for a run could still realize the goal of running in an indoor stadium even if it suddenly rains outside. For opportunity, in the current study, sleep was measured once when participants went to bed at the end of a day, whereas physical activity was measured whenever participants felt like doing it.

All these factors contribute to the low controllability of the sleep behavior, which might influence one's confidence in his/her ability to perform the behavior, i.e., their self-efficacy. This dissertation did measure self-efficacy and found that self-efficacy beliefs were associated positively with affect. Previous research has pointed to the close relationship between self-efficacy and emotions, suggesting that self-efficacy relate positively to positive emotions, probably through the perception of being capable to manage the challenging situations; whereas low self-efficacy may lead an individual to perceive goals as less attainable, which may increase negative emotions (e.g., Buric et al., 2018; Buric & Frenzel, 2019; Lohbeck et al., 2018). The repeated measures ANOVA results showed that there was a main effect of time on positive affect in the sleep data, with mean affect scores decreasing over the course of the two-week.

As it was mentioned in Chapters 3 & 4, there is an enhanced positivity bias for future thinking relative to remembering the past among health adults (Rasmussen &

Berntsen, 2013). While this positivity bias serves self-enhancement motivations, it could also trigger feelings of shame and guilt when there is failure to meet personal health goals (Sirois, 2015), e.g., getting more sleep in the case of the current dissertation. Future thinking is closely related to personal goals and the EFT tasks in the current dissertation specifically asked participants to imagine health goal related events. As such, engaging in EFT repeatedly might thus heighten goal failure (if there is any) and the associated negative feelings. In other words, when used as an intervention strategy to influence repeated decisions and behaviors in life, EFT might interact with the realization of the behavior (or a lack thereof). This interaction might in turn impact affect and subsequent behavior change.

The interaction between future thinking and real-life situation are hinted in previous studies on future thinking as well. For example, Quoidbach et al.'s (2009) study on future mental time travel (MTT) examined the effect of positive, negative, and neutral future MTT on happiness and anxiety. They found that participants in the negative MTT group showed a significant increase in happiness, whereas those in the neutral MTT group showed a significant reduction in anxiety. Their explanations were, for the negative MTT group, that the negative events imagined did not actually happen, which could have led participants to evaluate themselves as relatively lucky people and increased their happiness; for the neutral MTT group, they found that the content of the projections were mainly related to daily routines and to planning, which prepared participants for organizing the upcoming day and reduced stress. They thus speculated that MTT might interact with affective forecasting (Wilson & Gilbert, 2005) to influence outcomes such as wellbeing.

Future studies could investigate how EFT interact with the realization of goal-directed behavior and how this interaction might affect subsequent behavior change, individuals' affective forecasting, and their overall wellbeing. For example, is the mere simulation of positive events enough to increase positive affect? Do imagined positive events still lead to motivation when one is disappointed by the actual result at one point of time? Such intricate relationships might require researchers to conduct studies in more natural settings and with longitudinal design.

7.3 Technological Functions in mHealth Interventions

In addition to behavior type, the difference in the two health apps (i.e., technological functions) might also contribute to the contradictory effect of EFT on behavior change for sleep and physical activity.

Fogg (2009) proposed a model called the Fogg behavior model (FBM) to address the issue of using technology to persuade, which was referred to as "attempts to influence people's behaviors, not attitude" (p.1). Behavior is proposed as a product of three factors that constitute the FBM: motivation, ability, and triggers. The FBM asserts that for a person to perform a target behavior, he or she must (1) be sufficiently motivated, (2) have the ability to perform the behavior, and (3) be triggered to perform the behavior. These three factors must occur at the same moment.

On the basis of this framework, EFT works to address the motivation factor, whereas mobile phone reminders work as triggers. Health apps, due to their powerful computing power and various functionalities, aid their users in performing the behavior. For example, with *NikeTrainingClub*, users can do various workouts at a place of their choice. They do not need to worry about the weather or not having an instructor. As such, using *NikeTrainingClub* might increase one's confidence in their ability to perform the behavior. When they finish a workout, there will be a record of it, which could serve as an indicator of the user's success that further boosts their confidence or self-efficacy. However, not all APPs are equal in this ability to boost confidence or self-efficacy. The *SleepCycle* app, for example, only has the record function and provides analysis on sleep quality. These functions do not seem to help offer more opportunities to facilitate behavior, nor do they provide alternatives for when the users encounter obstacles. These two apps, while being able to work similarly as triggers and provide action opportunities for the users, differ significantly in their ability to aid performance of the behavior. This difference might interact with the behavior change strategy accompanying their usage to influence the actual behavior change.

Taken together, the above discussion provides some explanation on why EFT had distinct effects on sleep and physical activity in the current study. It emphasizes the importance of examining the "active ingredient" before applying one or even more strategies to influence behavior. Various situations could arise and influence the end results. For example, a strategy could be effective for changing the target behavior but not suitable to be combined with a target technology or another strategy. Or a strategy might be effective for changing one target behavior but could backfire when being applied to another behavior.

More broadly, the results also dovetail a long-lasting emphasis on the vital importance of context in intervention research (Moore & Evans, 2017). As Pawson and Tilley (1997) cogently articulated that the mechanisms of change are always contingent on context; what "works" in one time and place may be ineffective, or even harmful, elsewhere (Moore & Evans, 2017, p. 134).

In addition, the results of the current study also hinted the possibility that EFT may not always be adaptive, which is consistent with suggestions from a meta-analysis that it is not always beneficial to nudge decisions via EFT (Rösch et al., 2021). Future thinking is inherently uncertain (Bulley et al., 2017; Wilson & Gilbert, 2005). As a result, highlighting the positive reward-related emotions for delayed choice option may, at times, impair efforts to obtain future goals or even backfire.

7.4 Practical Implications

Previous studies on EFT were usually conducted in laboratory settings with DD tasks and one time behavior choice as outcomes. These studies suggested that EFT provided motivational incentives for choices that can immediately be acted upon (Rösch et al., 2021). That is, individuals could make the decision to forego an immediate but smaller reward right away, such as in a DD task. However, for long lasting behavior change, merely foregoing an immediate reward may not be enough. An additional identification of possible obstacles may also be required (Oettingen & Gollwitzer, 2018; Oettingen & Reininger, 2016). Under such circumstances, other self-regulation strategies may be needed to company EFT in order to generate optimal results. However, less is known about the effect of EFT outside of the laboratory setting and that of repeatedly engaging in EFT on long lasting behavior change over an extended period of time. The results of the current dissertation suggest that it is important to test the effect of EFT in real-world settings so that the power of this strategy could be better leveraged by people in daily life. Future studies could keep testing the effect of EFT on other types of behavior in natural settings or test the combined effects of EFT and other self-regulation strategies.

The results of the current study showed that EFT sent through mobile phones could increase self-control, which in turn, influence intention and behavior (at least for the sleeping behavior). Though an increase in self-control did not seem to mediate the effect of EFT on intention and behavior. Researchers have proposed that using EFT to enhance self-control would be one approach to incorporating EFT into standard behavioral interventions. They also suggested that interventions could use EFT to increase self-control by cueing EFT when individuals detect a situation in which they may favor an immediate reward over a future outcome (O'Donnell et al., 2019). This could be realized through mobile technologies, for example, when a health app on the mobile device detects that the user has entered a bakery, it can translate this spatial measurement into an estimation of psychological distance and determine that the user is likely to be close to a health decision-making moment. This could trigger the app to send EFT cues to the user and help reduce responding for immediate gratification (Katz & Byrne, 2013; O'Donnell et al., 2019). The results of this dissertation could be seen as one initial step toward this synergistic work by mobile technologies and behavioral change strategies. Future studies could explore other possibilities of integrating EFT (or other behavioral change strategies) with different types of mobile technologies/functionalities.

7.5 Limitations

The current dissertation study is limited in several ways. First, the attrition rate was quite high and, even though there were no group differences in the exclusion/dropout rate for each experimental group, a possible selection effect cannot be excluded. Related to this, the final sample size of the study, especially for physical activity, is rather small. The small sample size means that the study may lack adequate statistical power to detect an effect size of practical importance and lead to incorrect conclusions about the efficacy of the intervention (Pan et al., 2018). Small sample size in longitudinal studies might be a regular instead of an anomaly. As a result, researchers have also suggested other methods to increase statistical power, such as blocking, including additional predictors, obtaining more reliable measures or modeling measurement error, and sampling participants with more variability on the outcome variables (Fritz et al., 2015). This study measured key variables multiple times and used the average scores of these measures to reduce measurement error and adopted analysis method that modeled measurement error. Still, the results should be interpreted with caution.

Second, treatment compliance might be an issue since the experiment was conducted in the natural setting with very limited experimenter control. Various ways were used to enhance compliance. For example, participants were informed about what the study was trying to achieve, and the important roles they played in the study. Research has shown that it is important to develop a partnership with participants at baseline and throughout the study and to let participants know the purpose of the study and their important role in it in order to enhance adherence and compliance to

EMI/EMA (Burke et al., 2017). Another method is to use follow up such as an email or phone call if a person does not fill out the survey within a specific time frame. This study used reminder email to follow up when participants did not respond within the predefined time window. Participants were also told that they needed to complete 70% of the prompt surveys in order to receive participation credits. However, these might introduce measurement reactivity and demand characteristics to the study.

Related to the compliance issue is that the whole study was conducted "online." That is, both the EFT tasks and DD tasks and all the survey measures were completed online. Although there has been an increase in studies on EFT and DD to be conducted online, this is not a standard procedure of EFT studies. Accordingly, the traditional procedures and measures in EFT studies might not fit well with an online setting. This study thus employed some untraditional procedures and measures. Future studies aiming at comparing results should keep this in mind. As more and more studies on EFT chose online platforms, new standard might develop quickly.

The third limitation concerns the health apps used to collect behavior data. Although actual behavior data should be more accurate than self-reported data, several issues could impact the accuracy of data collection through mobile apps. For example, most participants in the physical activity groups did not use the focal app *NikeTrainingClub* every day, so there were a lot of "missing" data points. This missingness is understandable because 1) even the recommendation of physical activity is an average time per week. It is highly likely that people exercise on some days of a week but take a break on other days. 2) Participants might not record every type of physical activity they did with *NikeTrainingClub*, or the exercise in which they participated could not be recorded by this app. If this is the case, using *NikeTrainingClub* might actually interfere with participants exercise routine. For the sleep app *SleepCycle*, the data collection could be inaccurate if participants wake up during the night and use the phone, which could mess up with the record or may generate many short sleep time records. As such, the results should be interpreted with these constraining conditions in mind. In addition, although this dissertation adopted ecological momentary evaluation to measure key cognitive and behavioral variables, the data collection process could still feel unnatural to the participants, or pose inconvenience to their daily life, both of which might influence the accuracy of data collection.

Last but not least, some intervention characteristics, such as the duration of the intervention, and frequency and timing of intervention delivery, were decided rather subjectively. While not enough evidence in the previous EFT intervention to suggest a best practice, based on health interventions for physical activity and sleep, it might be better to send intervention content multiple times during the day or provide a timeframe for participants given that it does not impose too much response burden.

7.6 Conclusion

mHealth has grown in its importance since this term was coined in the first years of the new century, thanks to two lines of development in the health arena. One development is that the scope of health has been broadened considerably to integrate lifestyle related aspects of diet, fitness, and wellness, among others. The second is that new technologies have altered how people perceive health, opening new opportunities for individuals to take an active part in their health care and management, which also has an empowering effect on them (Koinig & Diehl, 2020, p.179). This development also poses challenges to researchers and practitioners, for example, lifestyle-related behavior change usually requires more self-regulatory resources from the individuals and takes longer time to realize, whereas the additional layer of mobile technologies bring with it more complexity in terms of how to integrate them with behavioral change strategies. Following the WHO's (2011) call to discover "new horizons for health through mobile technologies," we should take advantage of the development in mHealth and leverage mHealth to promote better health.

Appendices

Appendix A Instructions for the EFT Task Used in the Baseline Survey

In the following task, we want to invite you to imagine positive events that realistically could happen or that you have already planned in the future (e.g., in a week, a month, six months). This could be anything that comes to your mind (e.g., a getaway or something study-related). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible (what do you do, where are you, who are with you, accompanying feelings, etc.). These images will be used in the next exercise. Please describe these events according to the time frames provided.

1.1 Please describe a positive future event that realistically could happen or that you have already planned in the future in 1 weeks (7 days). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)

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1.2 Please rate the event you just described on the following 7-point scale (1 = not at all; 7 = very much)
How vivid is the event?
How positive is the event?
How future-oriented is the event?

2.1 Please describe a positive future event that realistically could happen or that you have already planned in the future in 2 weeks (14 days). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)

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2.2 Please rate the event you just described on the following 7-point scale (1 = not at all; 7 = very much)
How vivid is the event?
How positive is the event?
How future-oriented is the event?

3.1 Please describe a future event that realistically could happen or that you have already planned in the future in 1 month (about 30 days). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)

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3.2 Please rate the event you just described on the following 7-point scale (1 = not at all; 7 = very much)
How vivid is the event?
How positive is the event?
How future-oriented is the event?

4.1 Please describe a positive future event that realistically could happen or that you have already planned in the future in 2 months (about 62 days). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)

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4.2 Please rate the event you just described on the following 7-point scale (1 = not at all; 7 = very much)
How vivid is the event?
How positive is the event?
How future-oriented is the event?

5.1 Please describe a positive future event that realistically could happen or that you have already planned in the future in 4 months (about 120 days). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)

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5.2 Please rate the event you just described on the following 7-point scale (1 = not at all; 7 = very much)
How vivid is the event?
How positive is the event?
How future-oriented is the event?

6.1 Please describe a positive future event that realistically could happen or that you have already planned in the future in 6 months (about 186 days). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)

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6.2 Please rate the event you just described on the following 7-point scale (1 = not at all; 7 = very much)
How vivid is the event?
How positive is the event?
How future-oriented is the event?

Appendix B Instructions for the EFT Task Used in the Intervention

Sleep:

Please describe a future event that realistically could happen and relates, even remotely, to your sleeping behavior (e.g., something good resulted from your good sleeping habit, something relaxing before your bedtime). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)

Please rate the event you just described on the following 7-point scale (1 = not at all; 7 = very much)
How vivid is the event?
How positive is the event?
How future-oriented is the event?

Physical activity

Please describe a future event that realistically could happen and relates, even remotely, to your physical activity participation (e.g., something good resulted from your exercising behavior, something fun happens during your workout). Think of something that applies to you. Experience this event in mind. Consider as many details of this event as possible. (There is a minimum 20-character requirement for this task)

Please rate the event you just described on the following 7-point scale (1 = not at all; 7 = very much)
How vivid is the event?
How positive is the event?
How future-oriented is the event?

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