Toward Future-Centric Personal Informatics: Expecting Stressful Events and Preparing Personalized Interventions in Stress Management

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ABSTRACT

Stress is caused by a variety of events in our daily lives. By anticipating stressful situations, we can prepare and better cope with stressors when they actually occur. However, many past-centric personal informatics (PI) tools focus on capturing events that already happened and analyzing the data. In this work, we examine how *anticipation*—a future-centric self-tracking practice—could be used to manage daily stress levels. To address this, we built MindForecaster, a calendar-mediated stress anticipation application that allows users to expect stressful events in advance, generates activities to mitigate stress, and evaluates actual stress levels compared to previously estimated stress levels. In a 30-day deployment with 47 users, the users who explicitly planned and executed coping interventions reported reduced stress more than those who only expected stressful events. We suggest design implications for stress management by incorporating the properties of anticipation into current PI models.

Author Keywords

Stress, anticipation, intervention, coping planning, self-experimentation, future-centric personal informatics.

CCS Concepts

•**Human-centered computing** → **Empirical studies in interaction design;** *Field studies;*

INTRODUCTION

Increasingly, people are focusing as much on their mental health as they are on their physical health. Stress is an enduring aspect of everyday life and one of the critical determinants of mental health. Thus, an accurate understanding of the daily behaviors associated with stress is central to mental health management. The advent of personal informatics (PI) systems has enabled users to capture and analyze data about their personal behaviors that might affect mental health (*e.g.,* stress [4, 9, 32, 36, 46], mood [20, 25, 54], depression [35, 51]). PI researchers have also strived to help individuals accurately assess daily stress from physiological signals, smartphone application usage patterns [14, 55], social media logs [34], and even from the users' self-reported data [1]. Due to the subjective nature of stress, which involves highly personal, social, and environmental factors, it is particularly important to engage individuals in the form of self-experimentation—an iterative PI procedure of personal data collection and reflection—to gain meaningful self-insight [8] and create personalized behavior-change plans to mitigate stress [27, 29].

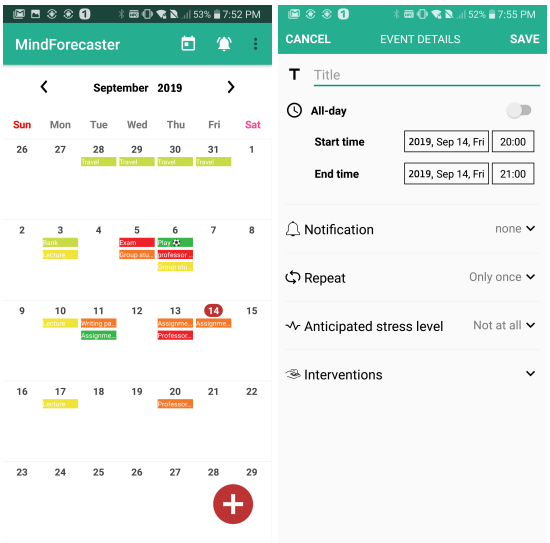

Figure 1. The MindForcaster Application. Schedule Overview (left) and Registering a New Event Page (right)

However, most prior PI systems have been past-centric in nature, addressing the retrospective aspects of data collection and analysis. Relatively few studies have examined methods for helping users engage in prospective and proactive approaches,

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such as anticipating events to help them generate actionable and remedial plans to improve mood or health conditions. Recent studies have found that presenting users with future forecasts based on their past data (*e.g.,* mood [20], weight [45]) positively influenced motivation for behavioral change. Thus, it is worth investigating how the aspect of future could be incorporated into the design of PI systems. In this work, we examine how anticipation, a future-centric self-tracking practice, affects users' daily stress in the near future.

Anticipation—an ability to imagine negative or positive future events—is associated with psychological well-being. Greve *et al.* present that the anticipation of emotional outcomes provides the opportunity to avoid risks, to recognize opportunities in time, and to adapt behavioral strategies accordingly [19]. Anticipation is comprised of two key elements—imagining concrete future scenarios (*i.e.* expectations) and preparing ways to navigate any challenges they present (*i.e.* preparations)—, both of which are significant factors in constructing *coping planning* [52], a psychological concept in the domain of health behavior change. Coping planning is also known as a self-regulatory strategy that involves the anticipation of barriers and ways to overcome them. Regarding this concept, having concrete anticipation criteria, instead of mere suppositions or fantasies, is the key to behavioral change [39].

To exploit the benefits of anticipation and thereby mitigate stress, we designed MindForecaster (see Figure 1), which allows users to anticipate stressful events in advance, prepare personalized intervention plans to deal with the stress, and evaluate actual stress levels compared to previously estimated stress levels. Incorporating the concept of coping planning [52], MindForecaster asks participants to predict the level of stress associated with a specific scheduled event and to create a remedy plan if negative experiences are expected, through the use of a smartphone's calendar.

We conducted a four-week field deployment with 47 participants comparing the complete version of MindForecaster (i.e., allowing full processes of anticipation), with a basic version of the system excluding the creation and execution of interventions, to address the following questions:

- *Stress and resilience*: Does MindForecaster actually reduce stress? If so, what is the underlying mechanism for achieving stress reduction?

- *Anticipation*: Which components of anticipation (expectation and/or preparation) affect stress reduction? In particular, does intervention reduce stress more than non-intervention?

Our results indicate that the experiencing the entire procedure of anticipation from stress prediction to intervention execution can lead to more effective stress reduction. Our statistical analysis shows that the effectiveness of anticipation alone or intervention planning without execution is limited. By employing MindForecaster's specific features (*e.g.,* scheduling interventions on a specific time and sharing interventions with fellow participants), participants were able to prepare for the anticipated stress by generating a variety of problem-focused and emotion-focused coping plans.

This paper concretely makes the following threefold contribution to the research in this area:

- We developed MindForecaster, a digital tool that helps users anticipate stress in their upcoming schedule and manage it by preparing personalized (*i.e.,* "Self" mode), system-recommended *i.e.,* "System" mode), and shared by fellows participants (*i.e.,* "Peers" mode) interventions based on theoretical frameworks;

- We validated the effectiveness and usefulness of MindForecaster on stress reductions and resilience, through usage logs, questionnaires, and interviews from a four-week field study with forty-seven participants; and

- proposed implications for designing future-centric PI systems that incorporate the properties of *anticipation*, which is the opposite to existing past-centric PIs to address mental-health-related challenges, especially daily stress management. This could guide future research on anticipation (*i.e.,* coping planning) in the course of health behaviour change system design.

RELATED WORK

We conceptualize future-centric personal informatics, an emergent tracking paradigm that helps people obtain insight into the future. To this end, we first describe the correlation between anticipation and coping planning as a motivation and framework for developing MindForecaster study. We then identify the limitations of current PI models in mental health and highlight the importance of a future-oriented approach.

Anticipation and Coping Planning

According to a conceptual analysis of stress and coping [26], stress could be comprised of three processes—(1) primary appraisal, the process of anticipating a threat to oneself, (2) secondary appraisal, the process of bringing to mind a potential response to the threat, and (3) coping, the process of executing the response. In the field of cognitive behavioral therapy, it has been found to be effective to manage stress by anticipating personal risk situations and preparing coping responses [18]. Anticipation helps people adapt to a situation through appropriate action. Reduction of future risk may be achieved by visualizing and planning for specific events in advance [19]. Psychologists also point out that as people imagine the future more specifically, they can prepare for the future more confidently, and coping plans to prepare for challenging situations is one way to overcome future risk [1]. Thus, anticipation is comprised of two key elements: forecasting possible scenarios/barriers (*i.e.* expectations) and planning concrete responses to the future situations (*i.e.* preparations). These two elements are also significant constructs of *coping planning*, a prospective self-regulatory strategy that links concrete interventions to the anticipated stressful situations [52]. In this work, we incorporate the theoretical constructs—expectations and preparations—into the design of a personal informatics tool that addresses the domain of mental well-being, in particular, daily stress management. The specifications of how theory leads to our design are discussed in the app design section

Personal Informatics Models for Mental Health

Various PI models have been suggested to describe stages of user behaviors when interacting with the data [8, 13, 29, 30, 41, 47]. Li *et al.* describe the PI system by introducing five stages: (1) preparation, (2) data collection, (3) integration, (4) reflection , and (5) action [30]. Users iteratively perform the PI process, often called *self-experimentation* to gain self-understanding and change behaviors to attain a desired outcome[8, 27]. Self-experimentation has been widely applied in the domain of personalized health, such as in sleep [11] and irritable bowel syndrome [22]. Much of the work on diagnostic self-experimentation highlights the scientific process of formulating a hypothesis, testing a hypothesis, and interpreting a result to determine health indicators or symptoms aiming at providing rigorous answers to specific health questions [22, 23]. In this work, we rather view self-experimentation as an exploratory, complementary approach for supporting user-generated coping plans through iterative goal-setting and evaluation in the context of everyday personal health. Our work extends the concept of self-experimentation to the design of an interactive system for stress management. However, prior PI and self-experiment models do not adequately account for unique factors of stress management that requires grasping a sense of self–an individual's current status, challenge, intervening strategy, and expected consequences or impacts–all factors that should be considered prior to beginning of the preparation stage [30], or the stage of deciding and selecting what data to track [13]. Of particular interest to this study was the identification of opportunities to advance existing models by incorporating the concepts of self-experimentation and anticipation of stress.

Future-Centric Personal Informatics

Increasingly, more research has focused on examining PI practices and tools for promoting mental health [24, 29, 49]. However, the collection of mental health-related data on factors such as mood and stress has been proved as challenging due to the highly subjective and invisible nature of these factors. To overcome this hurdle, researchers have suggested engaging users in the creative data collection about their own mental health state [3, 28] . In addition, the advent of digital tracking technologies has enabled users to monitor various stress-related aspects of their daily lives [31, 55]. However, these tools have yet to support the users' engagement in self-generated intervention to promote positive behavioral outcomes.

Nevertheless, some behavioral outcomes may only be achieved by setting goals that require explication through anticipation, and the majority of current PI systems are limited to providing support for anticipation practice. Past-centric data collection tools only provide tracking for events that are already been completed or fully experienced, and researchers have found that merely presenting visualizations and analysis of such data may not be motivating, which can lead to lapses in or abandonment of PI practice [13].Rather than focusing on past reflections, more momentary, adaptive interactions close to the site of an intervention—namely, just-in-time (JIT) intervention—has been suggested to better motivate users to engage in a desired behavior [37]. Recent studies have developed algorithmic approaches to provide the right type of interventions, at the right time, by adapting to each individual's internal and contextual state at present [21, 38].

Meanwhile, a recent work emphasizing a prospective approach suggests that the process of imagining the future can have a motivational impact on current behavior and cognition [45]. The results of the study indicate that setting future weight goals and estimating goal achievement rates based on prior performance could induce dieters to imagine their future selves. Similarly, the results of another recent study show that the prediction of future mood states encourages users to improve their moods with activities selected by forecasting the users' predicted emotions [20]. Inspired by this prior research, we explore a future-centric approach to motivating users to manage their daily stress. In particular, we attempt to verify future-centric PI tools that can empower individuals to anticipate upcoming stress and prepare for it.

METHODOLOGY

We first specify how the MindForecaster application was designed. We then explain how the participants can use this tool. Finally, we address the analysis process.

The Design of MindForecaster App

We designed MindForecaster to assist users in managing daily stress through the practice of anticipation (*i.e.,* the ability to expect and prepare for future events). Derived from coping planning theory [52], we aimed to design a mobile application that support mental simulation of future stressful situations and preparation of coping strategies to mitigate the negative consequence of the situations. Identifying stressors is the first step to develop more concrete and elaborated coping plans. Since many of the stressors are closely associated with daily activities and events [40], we proposed a calendar-based application to help individuals anticipate their upcoming stress in advance and generate intervention plans on a daily-basis based on behavioral activation and psychological treatment [6, 12]. Through this process, we finally developed an Android-based smartphone application, MindForecaster, which allows users to 1) expect stressful events in advance by reporting user's activities and situations with scores, 2) prepare behavioral change interventions based on examining and monitoring the reported record, and 3) evaluate actual stress levels compared to previously estimated stress levels and reflect on effects through repetitive reports and action. We sought to examine whether our system informed by coping planning theory impact on the level of daily stress, resilience, and the overall perceived stress scale.

Anticipating Stressful Events

Events are registered on MindForecaster in the same way as on the existing calendar application as presented in Figure1. To do this, we created a centralized API server for storing user data comparable to Google Calendar API, but more flexible in terms of stress assessment corresponding to each event and registration of corresponding intervention if necessary. Users set an event title, start and end times, repetition, and notification for each upcoming event. For the four-week study,

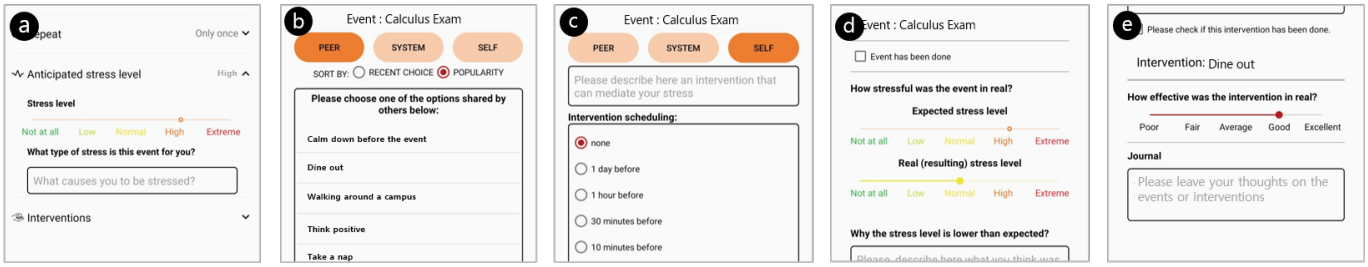

Figure 2. MindForecaster; (a) Anticipating Stressful Events; (b) Creating Interventions; (c) Creating Interventions in 'Self' mode; (d) Evaluating Prior Events; (e) Evaluating Interventions

users were asked to register possible events at the beginning of the study, but they were able to add events at any time. As shown in Figure 2-a, the scheduling of an event results in the display of a special tab containing a five-point scale assessment form to anticipate the stress level (*i.e.* none, low, normal, high, or extreme) associated with the event. The tab also provides a field to enter possible causes of the stress. The created events will be displayed on a calendar view as presented in Figure 1. Since color embodies emotion, we color-coded each event based on the values of expected stress using a diverging color scheme (*i.e.* no stress: green, extreme stress: red).

Creating Interventions

After the anticipation of stressful events, users established their own intervention plans to mitigate their expected stress. Regardless of the rated stress levels, the application allows the users to generate interventions according to their preferences. As shown in Figure 2-b, when users reach the intervention tab, they can create intervention plan under three modes. First, the "Peers" mode presents a list of interventions shared by fellow participants. Second, the "System" mode shows 270 suggested remedial activities that people might enjoy and find interesting pulled from the "Pleasant Events Schedule (PES) " scale [33]. Although PES was considered as an inspirational source for generating a personalized coping intervention rather than a clinically validated therapeutic suggestion, 50 items considered ethically inappropriate and stimulating misbehaviors (*e.g.* being in a fight, driving fast, shoplifting) were initially screened not to be presented to the users. When presenting interventions to users, the list of interventions in the "Peer" and "System" modes were sorted in two ways (a radio button titled as SORT BY): most recently used (MRU), or by their popularity (frequencies from all participants).Users select their desired activities provided by the two modes and modify them based on their context and personal preferences. Finally, the "Self" mode provides an open space for users to enter desired interventions as text. They could devise ways to relieve stress, either one they may have used in the past or one that they would like to try. After generating an intervention plan, the user is able to set a reminder to decide when the user wants to perform the intervention (see Figure 2-c).

Evaluating Prior Events and Interventions

Users are able to evaluate their events and the corresponding interventions after completing their schedules. MindForecaster delivers a reminder every night, or at another designated time to encourage users to evaluate their experiences while avoiding unwanted interference. The top of the evaluation tab displays a question allowing the user to check whether the event actually occurred. The application then provides the five-point assessment form to measure the stress actually perceived after the completion of the event. The application also shows the level of anticipated stress to help users compare the relative values, and they can write a note addressing the reasons for the different values (see Figure 2-d). Finally, the application asks users to check whether they completed the corresponding planned intervention and rate how the intervention helped to mitigate the stress on the five-point scale (see Figure 2-e).

Field Study

We conducted a four-week field deployment study with the 47 participants using MindForecaster to examine how the practice of anticipation through MindForecaster affects an individual's daily stress. To do this, we developed two versions of a calendar-based stress management system; a *complete* version of MindForecaster, which included stress expectation, intervention planning, and events/interventions assessment, and a *basic* version of MindForecaster which excluded intervention planning from the complete version. The basic version was intended to determine which of the theoretical constructs of anticipation most impacted on the stress reduction. Using these two versions, we ran a between-subjects experiment with two conditions: The complete version users experienced the entire process of anticipation from expectations to preparations, and the users of the basic version only performed stress expectation and assessment tasks. In other words, users of the basic version only experienced stress prediction without implementing and executing remedial interventions. We differentiated the app by including a preparation component that allows users to implement coping plans to address expected stress for the experimental group and excluding the component for the control group. The study was composed of three parts: (1) a 30-minute introductory session to provide the background for the study, introduce MindForecaster; (2) a four-week MindForecaster usage study in the field; and (3) a 30-minute debriefing interview to elicit feedback on the perceived impact and challenges of the process of expecting stressful event and for preparing interventions using MindForecaster. Participants were also asked to complete pre-questionnaire after the introductory session and post-questionnaire between the end of the study date and the debriefing interview. Our study was approved by IRB, and informed consent was obtained from each participant.

Recruitment

We recruited participants through online communities of three universities. In the initial recruiting phase, 65 people expressed interest in the study. We enrolled 47 participants composed of 25 males (age M=24.36, SD=4.49) and 22 females (age M=21.09, SD=2.04) who were over 18 years old and managed their daily schedules using Android calendar applications. Most of participants were students whose majors were diverse, including statistics, nursing, electrical engineering, etc. We compensated each volunteer $50 for his/her participation, which entailed an introductory session and four-week usage study. Additional $10 compensation was provided to people who were willing to have debriefing interview. Participants were randomly assigned to two groups (complete and basic versions of MindForecaster) and they were blind to which group they were in and were not informed that there were different groups. In the complete-version group, there were 25 participants composed of 13 females (age M=21.31, SD=2.32) and 12 males (age M=23.25, SD = 2.49); in the basic version group, there were 22 participants composed of nine females (age M=20.78, SD=1.64) and 13 males (age M=25.38, SD=5.68).

Data Collected

We examined the MindForcaster's impact on instant stress reduction but also to observe the overall changes in perceived stress reduction (PSS) and stress resilience (RQT), which are the mental health-related indicators requiring long-term observation.

Stress Level Assessment

MindForecaster provided a five-point assessment form to measure the stress level anticipated when generating the corresponding event as well as the stress level actually perceived after the completion of the event. Thus, the difference between the former and the latter assessments could determine effects on the stress level corresponding to each event.

Questionnaire

To gauge the impact of MindForecaster on various aspects of stress, we developed a set of questionnaires to be completed both before and after the usage of MindForecaster. We adopted the validated questionnaires to determine the impact of MindForecaster on the participants' perceptions of stress and resilience. These questionnaires allowed us to identify the underlying mechanisms of stress reductions. We embedded the questionnaires into the MindForecaster application so that users could easily access them.

Perceived Stress Scale (PSS): To investigate the change of the overall stress, we used the PSS questionnaire, the most widely used psychological instrument for measuring the perception of stress before and after the study [10]. The questionnaire consists of ten items, each scored on a scale of 0–4. The results of the survey are expressed as the sum of the scores provided by the participants for the ten items, with higher results indicating greater stress.

Resilient Quotient Test (RQT): RQT questionnaire is an indirect measure of stress [44]. It assesses how resilient the participants are by measuring crucial factors of resilience to stress. The RQT has 56 items rated on a 1–5 scale, with higher scores indicating greater resilience and evaluates the following seven resilience factors: emotional regulation, impulse control, causal analysis, self-efficacy, realistic optimism, empathy, reaching out. Each factor is evaluated with eight items.

Analysis

We audio-recorded both the introductory sessions and the debriefing interviews, and generated transcripts of these sessions. We also had access to the participants' MindForecaster data, including their events, interventions, and questionnaires. To compare effects of two versions of MindForecaster (*basic* considered as a control condition and *complete* considered as an experimental condition) on our stress measures, we ran t-tests based on group, intervention factors as well as time (pre- and post-tests). The dependent variables included (1) the difference between the stress level assessed after events and the stress level estimated before events; (2) perceived stress scale (PSS); (3) stress resilience quotient test (RQT). To correct possible errors for multiple comparisons, we applied Bonferroni correction for the statistical analysis [2]. To understand how participants anticipated stressful events and created interventions, we analyzed their data both qualitatively and quantitatively. All identifiable personal information was coded to preserve anonymity and to protect the privacy of the participants. We also analyzed usage logs and data generated through the MindForecaster using descriptive statistics. To characterize the types of interventions, we used multidimensional coping inventory [7]], a method by which people respond to stress as a codebook. Three researchers performed the initial categorization for the 30 sampled items to ensure consistent use of codes. After confirming that inter-rater agreement is acceptable (<80%), raters coded remaining items individually. Regarding qualitative analysis, we aggregated data from different sources to conduct an inductive analysis [53]. Three members of the research team individually read the interview transcripts, application data, and questionnaire responses and generated open codes. The open codes were then discussed among all research team members to resolve any disagreements and to identify patterns from the multiple passes. We then generated larger themes from these open codes. We coded the themes of the result with opinions of at least five participants (about 10%) mentioned with similar nuances in interview and chose the most representative quote as the example to illustrate each theme as presented in qualitative analysis section. In that section, "participants" will refer to more than five participants unless otherwise specified.

RESULTS

First, we provide descriptive statistics results illustrating how participants engaged in the use of MindForecaster. Then, we present statistical findings showing effects of anticipating and preparing for stress on the various aspects of stress, followed by an analysis of user-generated data and interviews to identify the potential of, and challenges in, stress anticipation.

Descriptive Statistics

Usage Patterns

Our recruitment statement drew 65 candidates during the recruitment period. Many reported that they were attracted by

MindForecaster's statement of purpose (to anticipate and prepare for stressful events through a new type of digital calendar). We found 48 participants who meet our selection criteria and who could be engaged in the study for a month. During the four-week study, only one participant dropped out due to an unexpected situation. The remaining 47 participants registered 1,082 events (about 1.44 per person each day) and completed stress assessments for 991 events. We examined how participants in each group (*basic* and *complete* versions) predicted their stress associated with an event prior to that event and how they perceived their stress after the event by comparing the estimated *expected stress level* when registering an event with the *actual stress level* evaluated after the associated event's completion. We found that the expected and evaluated stress levels were the same in 478 cases (48.2%; complete version: 242; basic version: 236). In the debriefing interview, our participants reported that they estimated their expected stress level based on their previous knowledge and experience. In total, 268 cases (27.1%; complete version: 146; basic version: 122) indicated that perceived stress level at the time of evaluation was lower than anticipated at the event creation time. Participants were likely to feel relieved when they recognized that their actual workload was lower than they had estimated. In 245 cases (24.7%; complete version: 117; basic version: 128), participants felt an increased perceived stress level after completing an event or intervention. Negative mood at the evaluation time was the most-cited factor to explain these cases. When they performed their job poorly, participants were more likely to be stressed than they had expected. Unexpected circumstances such as sudden conflicts with friends, work overload, or canceled appointments also contributed to stress level increases at the time of evaluation.

Modes of Intervention Creation: Peers, Self, System

The 25 complete-version users planned 459 interventions (*i.e.,* remedial events or plans to relieve stress) during the experiment (about 0.82 per person each day). The number of interventions generated by peers, self, and system modes were 232 (50.55%), 122 (26.58%), and 105 (22.87%), respectively. Our participants shared various reasons for using each type of intervention. First, participants who chose peer interventions mentioned that they were looking at what others had added if they could not find a proper method for an intervention themselves. In addition, they mentioned that it was interesting to read over a list of the interventions created by others. Second, for the self-intervention mode, participants mentioned that they had added a new intervention because they could not find a good choice in either the peers or system modes. Third, participants used the system mode the least. The briefing interviews confirmed that the system mode was less useful because it was too general to apply to each user's specific context. In addition, some users found browsing a list of about 270 interventions was overwhelming.

Types of Interventions: Problem-focused vs. Emotion-focused

We categorized the interventions for 25 complete-version users into two types—-problem-focused or emotion-focused [7]. Prior to this categorization, we first examined the proportion of problem-focused interventions and emotion-focused ones in the PES shown in the System mode. We found that there were 190 problem-focused methods and 80 emotion-focused methods. We then analyzed the total 459 interventions generated through the Peers, System, and Self modes. Among them, 247 problem-focused coping plans were created to solve problems or do activities to alleviate the sources of stress. User-generated problem-focused interventions included active coping (n = 199; e.g., playing games or going out), planning (n = 41; *e.g.,* setting up project deadlines), suppression of competing activities (n = 3; *e.g.,* study first, then put other projects aside), restraint coping (n = 1; *e.g.,* not using YouTube during final exam week), seeking instrumental social support (n = 3; *e.g.,* asking for help). Meanwhile, participants registered 212 emotion-focused coping plans, an approach to regulating the emotional distress elicited by stressful situations, on their calendars. Interventions in these criteria included mental disengagement (n = 88; smiling, sleeping, taking naps, stepping back, doing nothing), behavioral disengagement (n = 67; *e.g.,* giving up and finding another way), positive reinterpretation (n = 46; *e.g.,* being positive to the confronting obstacle), seeking emotional social support (n = 10; *e.g.,*, talking to friends), acceptance (n = 7; *e.g.,* accepting the challenge), denial (n = 1; *e.g.,*, cursing), and turning to religion (n = 1; *e.g.,* praying).

Table 1. Results of the difference in stress level (after/before the event) between two groups in three cases: (1) Control group (basic version users) vs. experimental group (complete version users), (2) Intervention planned vs. not planned (experimental group only), (3) Intervention executed vs. not executed (experimental group only).

	Type	Stress level diff	*t*	*p*
Group	Control	-0.06	0.12	.83
	Exp.	-0.05		
Intervention planned**	Planned	-0.12	4.28	.001
	Not planned	0.47		
Intervention executed**	Executed	-0.11	4.06	.001
	Not executed	0.47		

** $p < .001$

Table 2. Results of the difference in stress level (after/before the event) by executed intervention type (Problem-focused vs. Emotion-focused).

	Type	Stress level diff	*t*	*p*
Executed Intervention Type	Problem-focused **	-0.29	3.60	.001
	Emotion-focused	0.06	0.62	.53

** $p < .001$

Statistical Findings

To summarize the results, the stress level, which was directly assessed for each event, decreased when the user planned or executed the personalize interventions. In addition, exploiting constructive alternate activities as problem-focused interventions can be an effective method to cope with stress. Despite the significant impact on actual stress level, the PSS and RQT scores–the overall, indirect measures of one's ability to resist stress–showed no statistically significant changes. Note that we did not find any significant influence of age or gender on the analysis results through manipulation checks.

No Significant Impact on Perceived Stress and Resilience

The pre- and post-questionnaire scores for PSS and RQT rarely changed. The results of the PSS assessment presented non-significant (p=.55) difference between the scores measured before and after the use of MindForecaster for users in both

conditions (experimental: from 18.82 to 18.17, control: from 18.68 to 17.17). In contrary to our assumption, the reduction in PSS scores among the control group was slightly greater than that among the experimental group, though not statistically significant (p=.65). In addition, the results of the RQT questionnaire showed that there were neither significant changes in total RQT score between pre- and post-assessment in either group (experimental: p=.46, control: p=.45) nor significant differences in the seven resilience factors between the experimental and control groups (emotional regulation: p=.56, impulse control: p=.13, optimism: p=.23, causal analysis: p=.97, empathy: p=.07, self-efficacy: p=.24, reaching out: p=.18).

Changes of the Stress Level: Experimental vs Control Groups

Beyond the analysis on the impact of MindForecaster on the overall perceived stress (*i.e.,* PSS) and resilience (*i.e.,* RQT), we examined whether the actual, instant stress level changes differed between the control and experimental groups (Table 1). However, the result indicates no significant difference between the groups. This may mean that whether intervention creation features are provided is not a critical factor. Thus, we carried out an analysis to determine whether the practice of intervention planning and execution affected the stress level of complete version users.

Intervention Planning and Execution Lowered the Stress Level

One of our analyses seeks to determine the effectiveness of the intervention on lowering the stress level for the corresponding event. Since we did not enforce the complete version user participants to enter and complete the intervention for every event they created, there were some events with no interventions planned and some events (even if the intervention was planned) where the intervention was not executed. Here, we examined two cases regarding the difference in stress level before and after the event: (1) between events with planned interventions and those without, and (2) between events with completed interventions and those without. Table 1 summarizes the results. Clearly, both intervention planning and execution have a positive influence that lowers events' stress levels.

Problem-focused Interventions More Effective

Since we found that stress reduction is associated with intervention planning and execution, we carried out an additional analysis to examine what kinds of interventions are effective at reducing stress levels. Table 2 shows the results that the actual stress levels of events to which problem-focused interventions are applied were significantly reduced, while those to which emotion-focused interventions were applied were slightly increased.

Summary of Statistical Analysis

Our results show that MindForecaster had little impact on the overall stress qualities such as PSS and RQT. In addition, there was no significant difference between the experimental group (the *complete* version users) and the condition group (the *basic* version users), which indicates that the existence of the intervention preparation feature itself did not affect the stress reduction for corresponding events, perceived stress scale, or resilience. However, analyzing the difference of the instant stress level among the complete-version users presents that the stress level was likely to be lower when the corresponding intervention was planned and executed. Moreover, the type of intervention was an important factor in reducing the stress level. In particular, we found that problem-focused interventions that exploited constructive alternate activities can be an effective method to cope with stress, while emotion-focused interventions that elicit positive emotions may not. However, the subjectivity of stress perception means that we could not confirm that the obtained results were solely due to the use of MindForecaster. In the following section, we report on the qualitative analysis to identify how anticipation functioned throughout the MindForecaster trial, from estimation of expected stress at event creation to evaluation of actual stress upon event completion.

Qualitative Analysis

This paper presents the identified themes that we found to be most relevant to our primary interests: (1) how the practice of anticipation supported stress management; (2) how participants generated interventions to cope with stress; and (3) what challenges remained in anticipating stress.

Anticipation of Stressful Events

Our usage patterns showed that over half of participants precisely predicted stress associated with upcoming events. Since MindForecaster provided a field to enter what possible stressors corresponded to events, participants indicated that they were able to identify the type and causes of upcoming stress.

Identifying the Stressors: Several MindForecaster features helped participants anticipate the perceived stress of upcoming events. For instance, MindForecaster's five-point Likert scale stress-assessment feature afforded them the ability to quantify stress. Participants reported that they were able to measure the impact of upcoming events on their future mood and imagine the potential consequences depending on whether they chose to employ an intervention to address it. While estimating the stress level, participants were also asked to explicate the causes of their stress. Thus, acquiring a solid understanding of stress using MindForecaster resulted in self-confidence: *"I thought that the event itself was a strong stressor but I could identify the real reasons behind it while writing down the cause of stress."* (P32).

Increased Self-Awareness: MindForecaster's anticipation process also allowed participants to make sense of their present. P3 mentioned,*"...This experiment has helped me recognize that I was much more stressed than I thought."* In addition, the app's color-coded events provided an overview of their current status:*"It was nice to see how stressful I am going to be over this week just by checking the colors on the calendar. This is like a warning sign."* (P11). Participants noted that they could clearly identify their personal traits, preferences, strengths, and weakness, leading them to set personalized goals to alleviate negative moods and enhance positive moods. According to P10,*"Through this experiment, I was able to reflect on my personality and understand what makes me get stressed, such as sudden appointments or work I did not expect."*

Preparation of Personalized Coping Interventions

Resonated with the statistical findings highlighting the importance of intervention planning and execution, the complete

version users appreciated the app's capability to identify potential remedial plans, add the plans to one's calendar, and appropriate fellow participants' plans. While basic-version users had no opportunity to use the intervention planning feature, at least five users commented that they were able to create stress-reduction plans immediately after practicing stress anticipation. Three basic-version users also suggested a feature that could help them explicitly create a strategy to cope with predicted stress, indicating that preparing interventions is crucial for stress management: *"I would suggest a new feature, entering possible solutions to reduce anticipated stress by taking immediate action rather than just anticipating."* (P36).

Bringing to Mind a Potential Response to the Threat: Participants generated intervention plans based on self-knowledge gained from anticipation, such as what they like, what they can or cannot manipulate, and what their goals are. In particular, they tried to create interventions that are best suited to their contexts while taking into account their conditions and a limited timeframe. P6 said,*"When I set up a coping plan, I chose the one that worked best for me. I was satisfied when I chose the option that made me the happiest in a short timeframe."*

As previously mentioned, coping plans can be generally divided into two types. First, participants applied a problem-focused strategy when they could eliminate or directly address stressors through an alternative approach. P25 who created the "watching YouTube while doing chores" intervention said,*"House chores like washing dishes are trivial, but annoying and stressful tasks for me. So, I often turn on my favorite YouTube game channel while I am doing the least enjoyable tasks."* On the other hand, we found that participants were likely to apply an emotion-focused strategy to enhance their mood or foster positive thinking if the cause of stress could be enduring and could not be easily eliminated (*e.g.,* weather, loneliness, and career anxiety). P2 noted,*"I love soccer and play often. When it rains, I become negative because I cannot play soccer. This time, I set a goal 'be positive' and not be stressed out."* Prior study suggested emotion-focused interventions were more likely to be generated when anticipated stressors were inevitable or might have lasted long [16]. We confirmed that our participants also generated emotion-focused interventions in that way while problem-focused interventions were regarded when there were constructive alternate actions.

Scheduling Coping Plans: We found that Mindforecaster provided users with the unusual experience of asking them to write coping interventions explicitly and turn the interventions into a schedule. Participants expressed great satisfaction that even an emotional task could be registered as an intervention. In fact, the emotion-focused interventions used to boost moods became more concrete and elaborate over time with deliberation and experience. For example, P47 conducted an intervention before a stressful event, noting,*"I bought a delicious drink on my way to work to reduce stress."* Although our participants applied a variety of ways to relieve stress even before participating in the study, they liked the fact that MindForecaster confirmed the effectiveness of their stress coping methods through the stress estimation and assessment:*"I relieved stress in the same way as I did before the experiment, but I was able to know for sure how I relieved stress by using this app."* (P11). Simply by setting up an intervention, positive effects on stress mitigation could be achieved with the practice of preparation as this might help participants recognize the fact that interventions are necessary to reduce stress.

Peer-generated Interventions as a Reference: The analysis of user logs indicated that the most used mode of intervention generation was "Peers." We were able to identify why participants preferred the Peers mode most through interviews. First, the Peers mode helped participants generate their own interventions by looking at others' interventions as sources of inspiration: *"I had no idea where to start so I started by looking at what others had done."* (P2). Second, the Peers mode allowed participants to investigate how other participants cope with stress. P25 said, *"Honestly, I used Self mode the most when setting up the interventions but I explored the Peers mode a lot before making my own because I was curious about how others cope with stress."* In addition, browsing peer's interventions broadened perspectives when designing coping strategies: *"I adopted a lot of the methods from the list others made. Before participating in this study, I had repetitively tried common activities to reduce stress, such as sleeping and listening to my favorite songs. I realized that there are very creative ways to cope with stress."* (P10).

Challenges in Anticipating Stress using MindForecaster

Despite the benefits of executing personalized interventions generated through MindForecaster, participants reported several challenges. Three participants reported feeling burdened by entering an event and assessing stress levels in a repeated schedule. P18 suggested a short-cut or macro that would allow them to immediately repeat what they inputted: *"It was annoying to keep repeatedly enter events. It would have been better if the app had an Autocomplete function to fill in the remaining fields when I enter the same event that I did last week."* It was common for both planned and unexpected changes to happen. Thus, a desire to generate contingency coping plans corresponding to unexpected situations was frequently noted by participants: *"Life is full of uncertainty. What if I had a big panic attack that I hadn't expected, or what if the scheduled events went wrong? It would be useful to have a list of interventions that I could immediately apply whenever I needed to, like a pillbox."* (P11).

The MindForecaster system lacked several features that could help participants better utilize the process of creating interventions for stress mitigation. First, the complete version of MindForecaster did not provide a search function at the preparation stage. Thus, it was difficult for participants to query the interventions they wanted: *"It would be better to have a textbox to query when creating an intervention so I could get suggestions by just entering keywords."* (P25). Furthermore, the system could not provide enough references and analytics based on the data created by the participants in the evaluation phase to help them in creating and preparing the next schedule. Both basic-version and complete-version users also also expressed the need for automated recommendations of coping strategies adapted to their current contexts. A participant suggested an ability to recommend adequate interventions by

identifying a user's current contexts or previous activities: *"An algorithm that suggests effective interventions regarding my current situations given the previous activities I have done would make the app more effective."* (P40).

While participants were satisfied with the post-assessments of stress and the evaluations of interventions, they sometimes reported feeling burdened by having to evaluate all the schedules and interventions. The schedule-based stress assessment might not be accurate due to potential confounding variables such as the mood at the moment of assessment. Thus, an additional feature was requested to assess overall stress estimation and evaluation on a daily basis: *"Evaluation seems to be as important as anticipation but I was a little disappointed that there was nothing to evaluate the mood of the day."* (P3).

DISCUSSION

Reflection on MindForecaster Study

In this study, we aimed to investigate how anticipation could be used to manage daily stressors through Mindforecaster, a mobile app that incorporates theoretical constructs of anticipation. We found that stress could be alleviated by anticipation comprised of two key elements: expectation and preparation. More precisely, expecting stressors (e.g., threats and challenging situations) partly helped people manage them better. Interestingly, preparation and execution followed by solidified coping plans (*i.e.,* interventions) turned out to be more effective on stress reduction than just expectation. More than half of the interventions were created under the Peers mode, indicating that the social nature might facilitate PI practices. Among the interventions, problem-focused coping plans compared to emotion-focused ones showed distinctive advantages for stress reduction since these were accompanied by constructive alternative actions. Thus, we suggest that the advanced future-centric PI system should support users to prepare concrete interventions to mitigate stress and execute the effective interventions reflecting on the individual's characteristics and contexts at the right time using a JIT strategy [37].

Design Opportunities for Future-Centric PI Systems

The MindForecaster study demonstrates the importance of anticipating stress from upcoming situations, preparing for them, and evaluating the consequences. Informed by the MindForecaster study findings and challenges, we highlight the importance of anticipation in the coping planning process and propose design guidelines for better mental health through effective reflections on stress management. We also discuss the future-centric version of the current PI model by incorporating the properties of anticipation.

Expectation

To expect is to create concrete imaginings of the future. In this phase, users identified and predicted stress that would result from an upcoming schedule based on their self-knowledge and experience. First, they understood their situation through this phase. They determined what kind of stress they were under, how severely they felt stress, and to what extent they perceived the situation as stressful by identifying the stressor. This process provided users an opportunity to think beyond the usual levels of stress and become aware of their capacity to handle upcoming stress. They could prepare themselves for the upcoming stressors and arrange their schedules for themselves. Second, to identify future stress accurately, the users quantified the expected stress levels and contemplated the causes of stress. Using the repetitive experience of predicting expected stressors, users were able to establish their standards for stress and prepare for similar events with effective stress relief planning. However, expecting for an upcoming event may not always be positive. Anticipation may not help the user's preparation phase in some cases but rather may be stressful. Therefore, we must pay attention to the potential risk that this expectation phase can amplify the user's anxiety. In addition, despite the expectation phase's potential, collecting all data through user's self-reporting places a heavy burden on the users that may lead to stop tracking [13, 17]. Also, unexpected events and contingencies can cause greater stress on the user because they are often beyond the control of the user.

To overcome these challenges, it is important to reduce the burden on the users in the expectation phase and help them prepare for possible stressful scenarios based on the identification of stress and themselves. One then can consider a system that exploits a wide range of data from user-generated data (*e.g.,* events on a calendar, assessed stress level, causes of stress) to automatically collect data relevant to a user's context (*e.g.,* time, weather, activities) to help the user better predict upcoming stressors and better understand themselves. In addition, the system should reduce the burden of user tasks such as repeated entering of repetitive schedules. The appropriate automated predictions can provide a valid and convenient experience for the user. Hollis et al. applied algorithms that could predict emotions by analyzing empirical data accumulated from past users[20]. Although the prediction results were not very accurate, the study showed the possibility of mood prediction based on a user's past data. In the case of a user who experiences repeated or similar schedules, it would be possible to predict the cause or level of stress. Finally, the system should help users consider possible contingencies in the expected stressful events. Although not all accidentals can be predicted, users should be asked to provide solutions against possible contingencies based on past experiences.

Preparation

Health behavior researchers suggest that preparation of intervention plans can mediate between intention and action [48]. To prepare is to establish strategies for stress relief. In this phase, users create intervention plans to mitigate the stress identified in the expectation phase. They generate interventions by considering collected data, such as the causes of stress and prior experiences. They also integrate their strength of character, their schedule, and other variables. By evaluating intervention plans, users learn to understand themselves better and personalize interventions with their own criteria and experiences. They also benefit from actual stress reduction through the establishment and practice of interventions. However, it is often difficult for users to establish the appropriate intervention plans, and this aspect of the process might lower compliance and engagement. The users also amass a variety of experiences from repeated practice, but they cannot prepare for all unexpected situations. Additionally, if the user fails

to perform the intervention set for the stress reduction, this planning may be rather a burden to the user.

We propose a system to encourage users to observe closely to what they like and what has worked so they can find a suitable way forward. Therefore, the system should help users to understand themselves by doing iterative self-experiments [23]. As mentioned in the expectation phase, it is necessary to analyze the types and properties of interventions created by users and provide statistical data on the interventions that were effective. Therefore, users can be provided a reference point for reflection when setting up a new intervention. To enable users to generate effective coping plans, the system should recommend the appropriate type of interventions that are alternative, concrete, and actionable coping plans by reflecting upon the user's personality and preferences. In addition, the future system should encourage users not only to plan, but also to execute the interventions to reduce actual stress. Users could enhance the possibility of executing interventions by considering context, time, and unexpected situations based on their past experiences when setting up the intervention. The system also could support users execute interventions at an appropriate moment by combining the just in time (JIT) components mechanism [21, 38], intelligent coaching systems suggesting adaptive tasks [4, 25], activity recommendations based on automatic mood prediction [20], or enhancements of a programs' social nature [3, 42, 43]. In our study, we found that "Peers" was the most frequently used mode when preparing for the stressful event indicating participants valued the coping interventions generated by their cohorts. This highlights the importance of providing social data from the early phase of PI, preparation or even expectation phase. Resonated with findings in prior studies on interpersonal informatics [5, 15], making cohort data available to users of a PI system benefits the individuals comparing themselves with others, understanding norms, broadening one's perspective during the coping planning task. To maximize the benefit of sharing the cohort data, the system should help users elaborate details (*e.g.,* personal goals, preferences, and lifestyles) so that others can identify and appropriate coping methods that best suit them.

Evaluation

Evaluating planning has been found to be an effective tool in digital interventions [50]. In the evaluation phase, users assessed both the perceived stress level of the event and the effectiveness of the intervention. For each event, they quantified the actual stress level and compared it with the expected stress level. For the interventions, users also quantified and recorded their effectiveness. This process helped users build their criteria through repeated evaluations. These criteria not only play a key role in constructing a possible self and in creating personalized interventions by interacting with expectations and preparation, but they also provide a variety of experiences to use in preparing for unexpected situations.

However, evaluating all scheduled events and interventions puts a strain on users in maintaining self-tracking, and it is difficult to know the overall mood or situations of any given day. Thus, the PI system needs to devise a technology that can grasp a user's context and overall mood without imposing too much of a burden on the user. In this way, users will be encouraged to evaluate their set goals or behaviors during the self-tracking process so that they can make positive changes.

LIMITATIONS AND FUTURE WORK

Our study features several limitations related to experimental design, technical and ethical issues. Some PES methods used in the system mode could be problematic. However, we could not judge if each method was absolutely positive or negative. Because each individual perceives the methods' benefits differently, filtering out negative methods considered undesirable based on the researchers' decision may lead to potential bias and benefit reduction. Nevertheless, we decided to filter out 50 high-risk methods suggesting illegal, ethically inappropriate behaviors. Despite MindForecaster's impact on instant stress reduction, we were not able to determine significant impact on PSS and RQT indicating long-term, overall perceived stress and resilience. To complement our results, we conducted in-depth interviews with all participants to reveal their perspectives and how they did or did not perceive the effect of anticipation. In addition, there could be a sampling bias because our recruitment statement was likely to target people who might be eager to regulate stress through this opportunity. Future work should compensate for these weaknesses and we hope that a system combining components of just-in-time mechanism that recommends appropriate interventions at the right time based on the benefits of anticipation process for possible stressful scenarios could be developed.

CONCLUSION

This paper addressed the importance of anticipation in managing stress and design opportunities for future-centric PI systems. MindForecaster is a PI tool designed to explore how people perceive stress associated with upcoming events, how they generate interventions to cope with the stress, and whether it affects their stress reduction. We provided empirical evidence of the impact of anticipation on stress reduction. We also identified a range of ways to generate personalized interventions—problem-focused and emotion-focused—while referencing fellow participants' coping plans to prepare for upcoming stress. Our findings indicate that predicting stressful events can be a good, though not sufficient, starting point for stress management. Preparing and executing interventions is more important for directly reducing the stress. When it comes to planning an intervention, a problem-focused coping planning strategy that specifically incorporates alternative actions is more effective for reducing stress. Drawing upon the present findings, we propose that the properties of anticipation should be used to guide designers in addressing the challenges of stress management.

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