

Deriving requirements for pervasive well-being technology from work stress and intervention theory: Framework and case study

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February 14, 2016

Abstract

Background. Stress in office environments is a big concern, in the worst case leading to burn-out. New technologies are emerging, such as easily available sensors, contextual reasoning and e-coaching apps. In the SWELL project we explore the potential of using such new pervasive technologies to provide support for the self-management of well-being, with a focus on individual's stress-coping.

Objective. Ideally, these new pervasive systems should be grounded in existing work stress and intervention theory. However, there is a large diversity of theories and these theories do hardly provide explicit directions for technology design. Here, we present a comprehensive and concise framework that can be used to design pervasive technologies that support knowledge workers to decrease stress.

Methods. Based on a literature study, we 1) identify concepts relevant to well-being at work, and 2) select different work stress models to find causes of work stress that can be addressed. From a technical perspective, we then 3) describe how sensors can be used to infer stress and the context in which it appears, and 4) use intervention theory to further specify interventions that can be provided by means of pervasive technology.

Results. The resulting general framework relates several relevant theories: We relate 'engagement and burnout' to 'stress', and describe how relevant aspects can be quantified by means of sensors. We also outline underlying causes of work stress, and how these can be addressed with interventions, in particular utilizing new technologies, integrating behavioral change theory. Based upon this framework we were able to derive requirements for our case study, the pervasive SWELL system, and we implemented two prototypes. Small scale user studies proved the value of the derived technology supported interventions.

Conclusions. The presented framework can be used to systematically develop theory-based technology supported interventions to address work stress. In the area of pervasive systems for well-being, we identified 6 key research challenges/opportunities: 1) performing multi-disciplinary

research, 2) interpreting personal sensor data, 3) relating measurable aspects to burn-out, 4) combining strengths of human and technology, 5) privacy, 6) ethics.

Keywords: Psychological stress, professional burn-out, behavioral symptoms, self-management, health technology, early medical intervention.

Introduction

Employees often report the experience of stress at work, which is related to their well-being. In this research we focus on the population of knowledge workers, who are predominantly concerned with interpreting and generating information. Stress is easily caused by their typical working conditions [34]. Several tasks that need to be finished before a deadline, and their course of action is not always self-planned but also determined by external causes, like phone calls, mails, information requests, other persons or appointments [11]. Following the definition by Selye [46], an employee complaining about stress might mean that his working conditions are very demanding (the stressor), or that he feels that demands put upon him are higher than he can take (the perception of stressors) or that he feels stress reactions in his body, e.g. neck pain or headaches (the experience of stress). To date, the problem of work stress is often approached with questionnaires in which employees are asked to rate various aspects of their work (e.g. 55, 28), followed by department wide interventions (e.g. providing trainings). However, interventions trying to reduce stress have often failed, e.g. a recent study with mindfulness at the workplace found no effect on stress levels [21]. Another common approach is finding help with others via group therapy.

As knowledge workers are relatively flexible in their work (when they do what and how they work), there is great potential for them to contribute to the improvement of their own well-being. New technologies are emerging, such as sensors available in smart phones, smart reasoning and e-coaching apps. In the SWELL project (Smart Reasoning for Well-being at Home and at Work [4]) we see potential in using such new pervasive technologies to address well-being at work at an individual level [24]. We see possibilities in using unobtrusive and easily available sensors to capture the knowledge workers behavior (e.g. computer interactions, webcam for facial expressions) and infer stress and the context in which it appears. Based upon this information, we aim to develop a system with a suite of support applications, that are context aware, i.e. optimally adapted to the situation and state of the user. Knowledge workers can then directly act, gaining a more healthy work style, preventing stress building up and curing stress related problems like neck pain or headaches. An app could also provide a platform to come into contact with peers for support. Trends like ‘quantified self’ already show the potential of collecting personal sensor data (e.g. heart rate, activity patterns) for health improvement. In their paper on technology for well-being, IJsselsteijn et al. [19] describe that advancements in sensing and interpretation are promising. They further state that using technology for improving well-being has many advantages, e.g. its persistence or objectiveness, the possibility to provide just-in-time notifications with relevant, actionable information or their supportive and motivating role.

To develop a theoretically and empirically grounded stress self-management system, we take a multi-disciplinary approach. By means of situated cognitive engineering [36] we combine theory on work stress with input on user needs, taking in mind technological possibilities (see Figure 1). In this way, we generate a functional system specification with core functions and claims, which is then evaluated with users. The main focus of this paper is the theoretical foundation. The general objective of the SWELL system is to improve well-being at work. An important question is: What defines well-being at work and what causes well-being? Many relevant theories are provided by several disciplines,

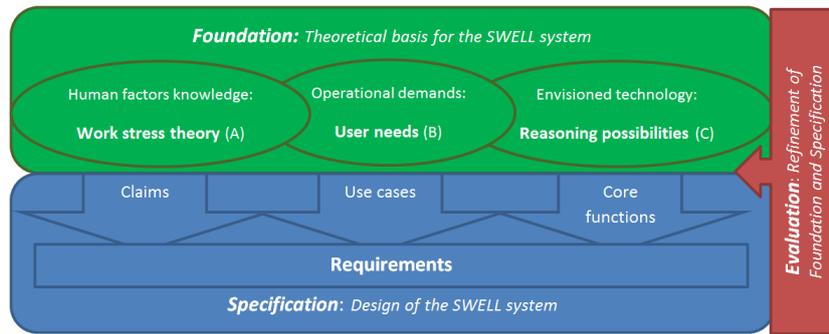


Figure 1: Situated Cognitive Engineering (sCE) approach.

e.g. Work Psychology, Biology or Behavioral Psychology. However, theories are diverse and different disciplines view the world from different angles, e.g. using different levels of abstraction. The big question is: How do different concepts relate to each other? One comprehensive and practical framework, that can be used as theoretical basis for the design of the envisioned self-management support, is still lacking. Moreover, psychological theories are often rather abstract and for implementing a solution many choices need to be made. We investigate the role of new technologies, which also provide new opportunities to study behavior, as well as new means to influence behavior.

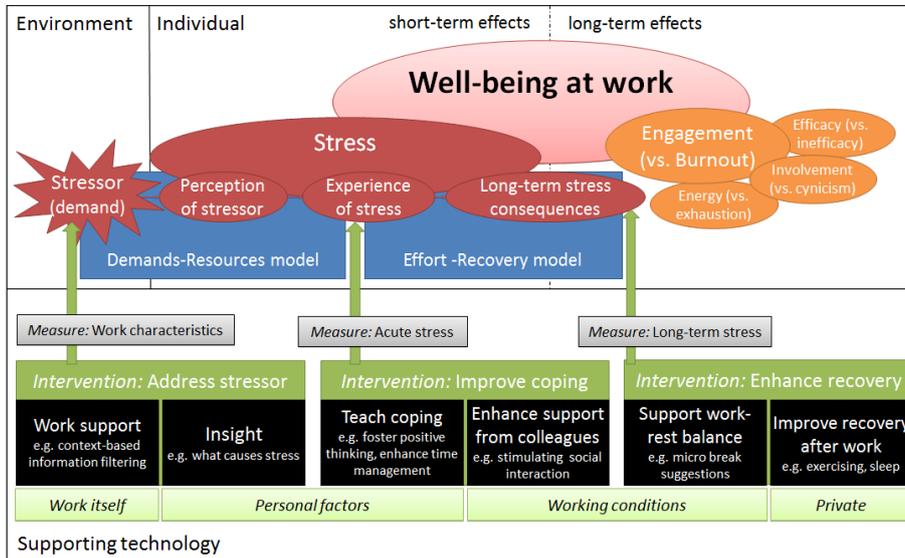


Figure 2: Our framework, combining various stress and intervention theories, as well as possibilities for real-time measurements and interventions with technology.

The main contribution of this paper is therefore a general and pragmatic framework (see Figure 2), which combines various stress and intervention the-

ories, as well as possibilities for real-time measurements and interventions with technology. This framework can be used for developing technologies addressing well-being at work, as is demonstrated in our SWELL use case. Moreover, we show that, vice versa, new technologies can also be used for theory building. Our research questions and the remainder of the paper are structured around our framework in the following way:

- First, an initial study on user needs is shortly described, as a starting point for the system design.
- Then, we investigate by means of a literature study, which aspects are relevant to include in the pervasive support system. We answer our *first research question*: Which concepts are relevant with respect to well-being at work? Several concepts are presented: ‘burn-out’, ‘engagement’ and ‘stress’ (red/ orange parts).
- We then use a literature study to investigate which causes of work stress our pervasive system could address. We answer our *second research question*: Which person, work and context conditions can lead to negative stress? We present different work stress models (blue parts).
- Then, we integrate knowledge on technical possibilities to define how the pervasive system could quantify relevant concepts (gray parts). We answer our *third research question*: How can sensors be applied to automatically infer stress and the context in which it appears?
- Finally, we combine insights gained thus far with a literature study on intervention theory (green parts). We answer our *fourth research question*: Which interventions can be provided by means of pervasive technology to help a knowledge worker improve his well-being at work? Based on technical possibilities, we define several technology based interventions (black parts).
- All parts together form our general framework, which was used to derive requirements for our case study, the pervasive well-being support system SWELL. We present the envisioned system and first prototypes of technical support that were implemented, as well as results from evaluation studies with potential end users.
- We finish our paper with our conclusions, a discussion of limitations of our work, and a more general reflection, where we present 6 research challenges that we identified.

Initial study on user needs

Following the situated cognitive engineering methodology [36], we start with input from potential end users.

We held interviews with 5 knowledge workers who had experienced burn-out and organized a workshop with 7 employees to establish user needs. Knowledge workers indicated that the system should provide them an overview of performed work, preferably in combination with work behavior and the associated subjective experience. This information can then be used by the user to gain insight in work processes. For example, at the end of the day an overview could be provided on how time was spent and how stress evolved. Moreover, users indicated that they would want help in the form of tips. Ideally the tips are also well-timed, taking into account the user's current context. Finally, users indicated that the system could actively support them during their work. The system can take an active role in supporting the user, e.g. by filtering irrelevant emails or finding information relevant to the current work topic. We also identified some important factors to address, e.g. not irritating users and addressing privacy.

This user input was used to guide the further design of the system. In the next sections we focus on important relevant domain knowledge.

Well-being at work concepts

In this section we aim to answer our *first research question*: Which concepts are relevant with respect to well-being at work? To answer this question, we performed a literature review [52]. The search engine ‘Web of science’ was used with the keywords: well being, commitment, satisfaction, stress and engagement. Based on 23 scientific publications an overview of the different concepts was made. The literature review revealed that there are many different related concepts and a many different models. Finally, the concepts ‘engagement’ and ‘stress’ were chosen, as they seemed most suitable to capture with sensors. In this section, we first describe the concept of engagement in more detail (see Figure 2). Then, literature regarding stress and its consequences is presented.

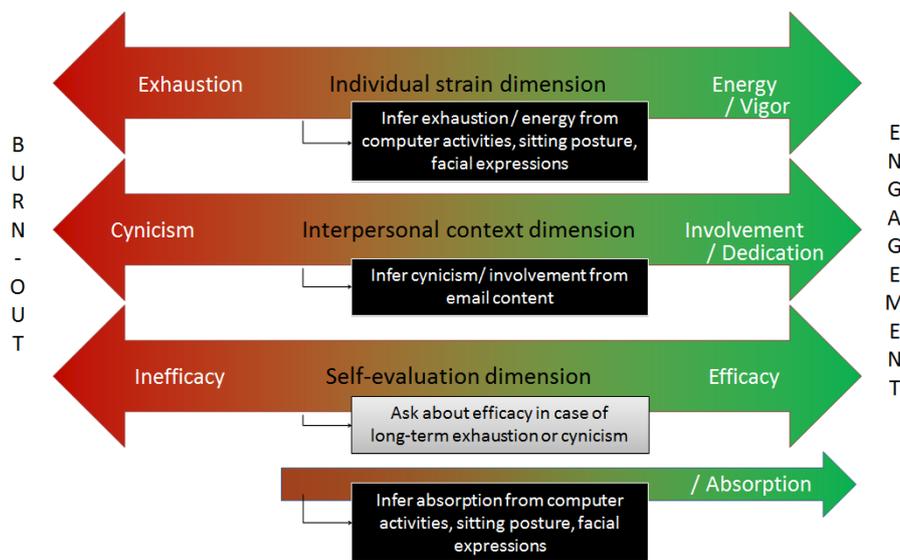


Figure 3: Well-being at work concepts ‘burnout’ and ‘engagement’, and ideas to infer certain aspects from captured (sensor) data.

Engagement and burn-out

The relationship people have with their jobs can be described as continuum between engagement and burn-out according to Maslach and Leiter [31], see Figure 3. They distinguish 3 dimensions: 1) Individual strain (exhaustion vs. energy), 2) Interpersonal context (cynicism vs. involvement), and 3) Self-evaluation (inefficacy vs. efficacy). According to this terminology, an engaged employee feels energy, involvement and efficacy. His state can be characterized as worrisome when he feels exhaustion, cynicism and/or inefficacy, which characterizes burnout [32]. According to Maslach and Leiter [31] “engagement represents a desired goal for any burnout interventions.” (p. 499).

Schaufeli et al. [41] describe engagement as the combination of vigor, dedication and absorption. The first two concepts are similar to those described

by Maslach and Leiter [31]. The main difference lies in the third dimension, absorption, which is not the opposite of inefficacy, but a different aspect.

Stress

Besides engagement or burn-out, a relevant concept that can be experienced in the office from day to day is stress. In research we find that the term stress is often used to refer to different things.

In our work we use the definition by Selye (Selye [46], see Figure 2). An environmental demand, or stressor, leads to a perception of the stressor, which is dependent on the particular characteristics of the individual. The individual's perception of the stressor results in a particular experience of stress. An employee complaining about stress might thus mean that his working conditions are very demanding (the stressor), or that he feels that demands put upon him are higher than he can take (the perception of stressors) or that he feels stress reactions in his body (the experience of stress).

Selye [47] distinguishes good stress (eustress) and bad stress (distress). Some amount of stress is not harmful and might even be beneficial to gain concentration and focus. Eustress occurs when the person experiences the right amount of demand. Distress occurs when a person experiences too much or too little demand. This is related to the Yerkes Dodson Law [54], which describes that (empirically) performance improves with arousal, up to a certain point, after which it declines again.

Individual characteristics and appraisal play an important role in the experience of stress. The same stressor can be seen as problem, leading to negative emotions, causing distress, or as challenge, leading to positive emotions, causing eustress [29]. This can depend on the amount of resources or feeling of control that the individual has. So even changing the mind-set of a knowledge worker could help him cope better with stressors. More details on the balance of demands and personal resources can be found in the section on work stress models.

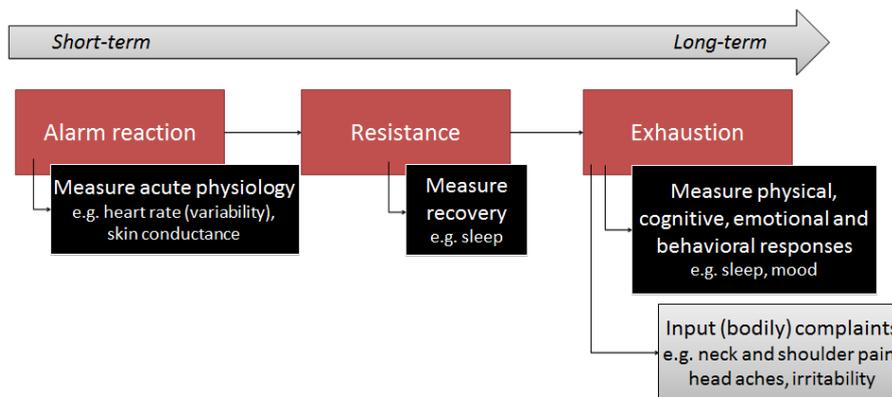


Figure 4: Stress reactions of the body, and measuring possibilities.

The body's short and long term reactions to stress can, from biological per-

spective, be captured in 3 stages (General Adaptation Syndrome; 45, see Figure 4): 1) Alarm reaction - the fight or flight response; 2) Resistance - the body adapts to the stressor; and 3) Exhaustion - the bodies resistance decreases due to long-term stress. The alarm reaction causes adrenaline to spread through the body and blood pressure rises (reaction of the nervous system). Under very stressful conditions, a shift in hormone production may take place, increasing stress hormones like cortisol, which increases blood sugar, but also suppresses the immune system (reaction of the hormonal system). This stress response system works well for dealing with short term stressors. When the stressor disappears the body gains back its natural balance. When the level of the stress hormone cortisol is high for a prolonged time, however, this has negative effects, e.g. on the brain. This shows the importance of recovery.

With lack of recovery, stress can accumulate and lead to health problems. Extended periods of stress can cause (see e.g. [8]): Physical reactions (e.g. increased blood pressure, muscle tension, headache and sleeping problems); Cognitive reactions (e.g. problems with concentrating, problems with setting priorities and decreased efficiency in work); Emotions (e.g. irritation, feeling restless, tense and anxious); Changes in behavior (e.g. avoiding social contact, more risk taking, not being able to relax and increased complaining). Moreover, Bakker et al. [7] explain that stress can not only directly lead to illness through its physiological effects, but also indirectly, through maladaptive health behavior, like smoking, poor eating habits or lack of sleep.

Conclusions: Relevant concepts for the system

In this section we aimed to answer our *first research question*: Which concepts are relevant with respect to well-being at work? We identified the following concepts (see Figure 2, orange/ red parts): stress and engagement (vs. burn-out), with the three underlying dimensions: energy, involvement and efficacy (or absorption).

Moreover, we found that stress is a normal process and in form of eustress also good for well-being and performance. It cannot be the goal to prevent stress. Rather, employees should be helped to handle distress and prevent negative long term consequences. In a pervasive system, we could measure the stressor itself (e.g. work characteristics), as well as the individual's perception of the stressor (e.g. acute stress). In addition, we could analyze long term patterns in which stress is building up. We could therefore measure recovery, e.g. sleep time or the amount of physical activity.

Core functions of the system: Based upon this part of the theoretical framework, we formulated the following core functions for the pervasive well-being system, together with the associated claim:

- **F1:** The SWELL system could collect information about: aspects of engagement, work characteristics, acute stress, and long-term stress/ recovery.
- **Claim:** This information is useful for data-driven and context-aware coaching.

Causes of work stress

After having described the concepts related to well-being at work, we now turn to models describing underlying causes. We aim to answer our *second research question*: Which person, work and context conditions can lead to negative stress? We present the four most influential work stress models, which all describe a balance between two variables, see Figure 5. The basic idea is that work becomes stressful when high demands are combined with: 1) insufficient resources (such as low job control and little social support), 2) little rewards, 3) little recovery, or 4) an environment that mismatches with personal characteristics. We now outline each model in more detail. Based on each model, we identify aspects that can be addressed by means of technology. (Each identified technology has an identifier for later reference, see Table 1 for an overview.)

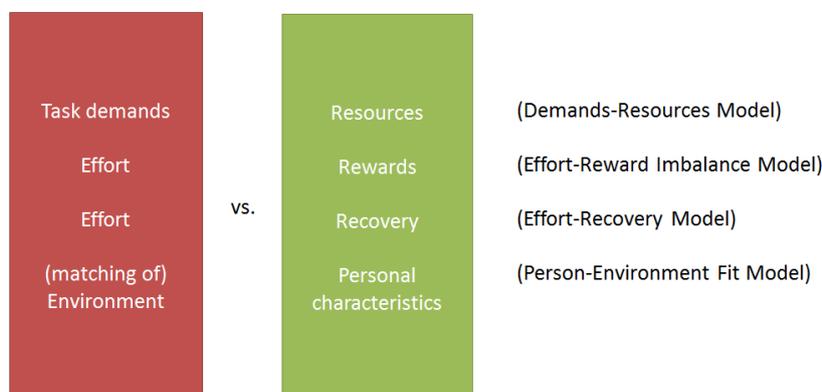


Figure 5: Different work stress models.

Job Demands-Resources Model

The first model can be characterized by a balance between job demands on the one hand and resources on the other hand (see Figure 6).

Karasek Jr [23] developed the initial model called the Job Demands Control (JDC) model.

The model was later extended by Demerouti et al. [12] to the Job Demands-Resources model (JD-R model). Here the more general interplay between job demands and job resources is described [12]:

- Job demands are aspects of the job that require effort. Examples are: physical workload, time pressure, emotional demands and the physical environment. High job demands in itself are not problematic; problems arise when the necessary resources lack.
- Job resources are aspects of the job that help in achieving work goals, reduce demands or stimulate personal growth and development. Examples are: autonomy, job control, social support (from colleagues, supervisor, family, peer groups), feedback, rewards, task variety and role clarity.

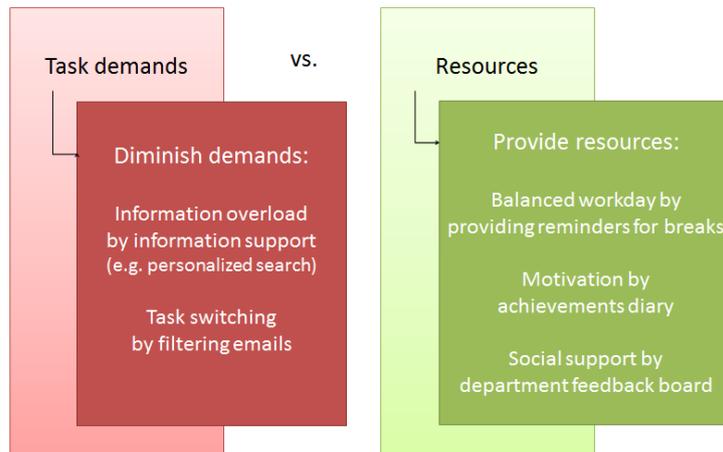


Figure 6: Job Demands-Resources model by Demerouti et al. [12], and possibilities for technological support.

The WEB (Werkstressoren- Energiebronnen-Burnoutmodel) model [6] is another variant of the JD-R model, in which a direct link between demands, resources and the three aspects of burn-out is made: High demands cause exhaustion, whereas a lack of resources can lead to a decreased feeling of competence (inefficacy) and distancing oneself from work (cynicism).

Supporting technology. Based upon the Resources-Demands model, we can address the well-being at work from two sides: We can diminish the demands placed upon knowledge workers or provide additional resources.

Examples for diminishing demands: A typical demand on a knowledge worker is to deal with large amounts of information. We can make technology that can try to diminish information overload by providing information support, for example in the form of filtering context-relevant from irrelevant emails (Technology T01) or by enabling personalized search (T02). Another demanding aspect of the work is task switching. A computer tool could diminish this demand by helping employees to remain focused on the task at hand, e.g. by filtering irrelevant emails (T01 again) or with gamification, motivating employees to stay focused by giving points for less task switching (T03).

Examples for providing resources: A resource that the knowledge worker has is his motivation and self-efficacy. The computer tool can support motivation, e.g. by providing an achievements diary (T04), which is in line with work by Amabile and Kramer [5] who showed that the feeling of making progress leads to more motivation and better performance. We could also facilitate social support, which is an important resource, e.g. facilitate support by peers by use of a department-wide feedback board (T05). Another resource is a good work-rest balance, with variation in tasks. The system could help to have a balanced workday by providing insights in what gives and costs energy, e.g. by providing an activity and workload overview, promoting better planning (T06). Taking enough recovery breaks could also be traced and supported with technology

(T07). Important to take into consideration is keeping the knowledge worker in control and not posing additional demands.

Effort-Reward Imbalance Model

The Effort-Reward Imbalance (ERI) model by Siegrist [49] can be characterized as a balance between effort on the one side and rewards on the other side. As long as the rewards are in balance with the efforts of the employee there is no problem. An imbalance might occur when the employee's efforts are higher than his rewards, which might happen for example due to overcommitment. Such an imbalance may result in stress and negative consequences for health.

Supporting technology. Based upon the Effort-Reward Imbalance model, we can address well-being at work by helping employees to match their efforts to the expected rewards. We might for example support realistic goal setting and in this way diminish pressure and disappointments. Insight regarding planned time versus the real time may facilitate better (re)planning and setting more realistic goals (T06 again). Moreover, looking back at ones achievements could help employees to get a better feeling of their productivity (T04 again). Also aspects of gamification might provide employees small motivating rewards, e.g. collecting points for staying focused (T03 again).

Effort-Recovery Model

The Effort-Recovery (E-R) model by Meijman et al. [33] can be characterized as a balance between effort and recovery, see Figure 7.

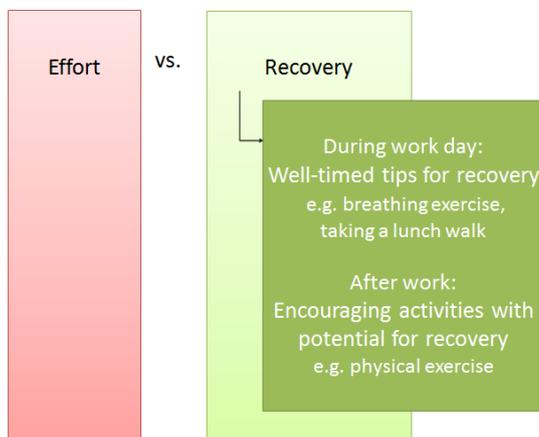


Figure 7: Effort-Recovery model by Meijman et al. [33], and possibilities for technological support.

In their model they describe that job demands and resources lead to negative strain during work. After work, home demands and resources lead to strain reactions when home. The individual can perform activities which can have a positive effect on recovery, leading to a particular psychological and energetic

state at bedtime. By means of sleep, additional recovery can be gained and the individual starts the next workday with a certain psychological and energetic state before work. Failing to recover enough from strain can make the experience of work demands the next day higher and the experienced resources lower, leading to even more strain. This process can be a vicious circle. According to Demerouti et al. [13] lack of recovery can “result in an accumulative process developing into chronic load reactions (or ‘allostatic load’ according to McEwen’s (1998) allostatic load theory), such as chronically elevated heart rate, hypertension, chronic fatigue, and persistent sleep problems (Sluiter, Frings-Dresen, Van der Beek, & Meijman, 2001).” (p. 88).

Four important dimensions play a role in recovery [50]: psychological detachment, relaxation, mastery and control. Psychological detachment from work can bring the psychophysical system back to its normal state. Relaxation causes decrease in physical activation. Controlling what activity to perform can improve esteem and efficacy. Mastery in performing challenging activities can cause improvement of skills, competence and esteem.

In general, physical activity seems to be a good means for recovery. Research by Norris et al. [37] showed that “in an adolescent population aerobic training does appear to provide some benefits with regard to psychological stress and well-being” (p.64). Hassmen et al. [17] found that “individuals who exercised at least two to three times a week experienced significantly less depression, anger, cynical distrust, and stress than those exercising less frequently or not at all.” (p. 17).

Supporting technology. Based upon the Effort-Recovery model, we can address well-being at work by making employees aware that recovery during work and non-work time is very important. Interventions could be aimed at taking well-timed breaks during the work day (again T07). Passive, as well as active breaks could be suggested, e.g. relaxation or taking a lunch walk. On the other side, an important aspect of improving well-being at work is also what someone does in his free time. We see that activities after work give potential for recovery. This model is interesting within the SWELL project, as it can combine the domains of well-being at work and at home. Interventions for more well-being could be aimed at better relaxation or detaching from work, e.g. by means of a hobby (T08). Addressing physical fitness could also be a good intervention (T09).

Person-Environment Fit Model

The Person-Environment (P-E) Fit model was initially proposed by French et al. [16] and describes a fit between person and environment characteristics. A misfit between the person and his environment can lead to strain, with the danger of illness. There can for example be a misfit between personal abilities and environmental demands or between personal needs and environmental supplies [9]. Leiter and Maslach [30] developed the Areas of Worklife Scale (AWS) around this idea. They say that “the greater the perceived gap between the person and the job, the greater the likelihood of burnout; conversely, the greater the consistency, the greater the likelihood of engagement with work” (p. 101). The AWS has items on 6 aspects: workload, control, reward, community, fairness and values.

Supporting technology. Based upon the Person-Environment Fit model, we can address well-being at work by helping employees realize that performing tasks that fit their personal preference is very important for their well-being. Tasks that give energy and tasks that cost energy could be identified by providing an overview over tasks and energy levels over the day (again T06). In future, the employee can then try to find work fitting his preferences more.

Conclusions: Addressing causes of work stress

In this section we aimed to answer our *second research question*: Which personal, work and context conditions can lead to negative stress? We elaborated on several work stress models, that describe how stress in working environments is caused. The different models all have a different focus and complement each other. There are no specific personal, work or context conditions that generally lead to stress. Work becomes stressful when high demands are combined with: 1) insufficient resources, 2) little rewards, 3) little recovery, or 4) an environment that mismatches with personal characteristics. The most useful models for developing pervasive systems are the Job Resources-Demands model and the Effort-Recovery model, which we integrated into our framework (see Figure 2, blue parts). The Job Resources-Demands model describes how (environmental) stressors can cause the experience of stress. The Effort-Recovery model describes how the experience of stress can lead to long term stress consequences. We presented several ideas how technology can provide additional demands, enhance resources or help with recovery. Table 1 provides an overview of identified technologies, the underlying models, and the associated claims.

Note that all models describe work stress in qualitative terms. Our aim is to quantify several aspects by using sensors. Demands could be quantified by measuring work characteristics (e.g. tasks and content worked on). Personal resources could be quantified by measuring the associated acute stress (e.g. physiological stress responses, mental effort). Recovery of the individual could be quantified by measuring long-term stress aspects (e.g. sleep time, physical activity). We elaborate on inferring these aspects from sensor data in the next section.

Table 1: Overview of identified technologies and associated claims.

ID	Possibility for technological support	Underlying theory	Claim
T01	Filtering emails	JD-R Model	Diminishes demands by reducing information overload.
T02	Personalized search	JD-R Model	Diminishes demands by reducing information overload.
T03	Gamification facilitating focus	JD-R Model, ERI model	Diminishes demands by diminishing fragmentation, enhances motivation by means of small rewards.
T04	Achievements diary	JD-R Model, ERI Model	Enhances resources or rewards by fostering motivation.
T05	Department-wide feedback board for peer support	JD-R Model	Enhances resources by means of social support.
T06	Activity and workload overview for insight	JD-R Model, ERI Model, P-E Fit Model	Provides insight in the balance between demands/ resources, efforts/ rewards or person-environment fit.
T07	E-coach for taking enough recovery breaks	JD-R Model, E-R Model	Enhances resources or recovery by taking rest breaks.
T08	E-coach for relaxation or detaching after work	E-R Model	Enhances recovery by detaching.
T09	E-coach addressing physical fitness	E-R Model	Enhances recovery by releasing stress with physical activity.

Inferring stress and its context

After having described concepts related to well-being at work, and causes of work stress, we now focus on assessing stress and its context. In current practices, most often questionnaires are being used (e.g. 55, 28). However, this data collection has several shortcomings: Data is self-reported, suffering from recall bias and subjectivity, and data is only collected once a year for example. Using sensors overcomes these shortcomings. Data can be collected in a objective way, real-time, in an office context. Such data about stress together with the context in which it appears can give insights that can more directly be acted upon by an employee.

Therefore, we now aim to answer our *third research question*: How can sensors be applied to automatically infer stress and the context in which it appears? We focus on (physically) unobtrusive, relatively cheap sensors that can easily be used in office environments. Following the situated cognitive engineering methodology [36], we integrate knowledge on technical possibilities here. We also investigate user choices regarding data collection.

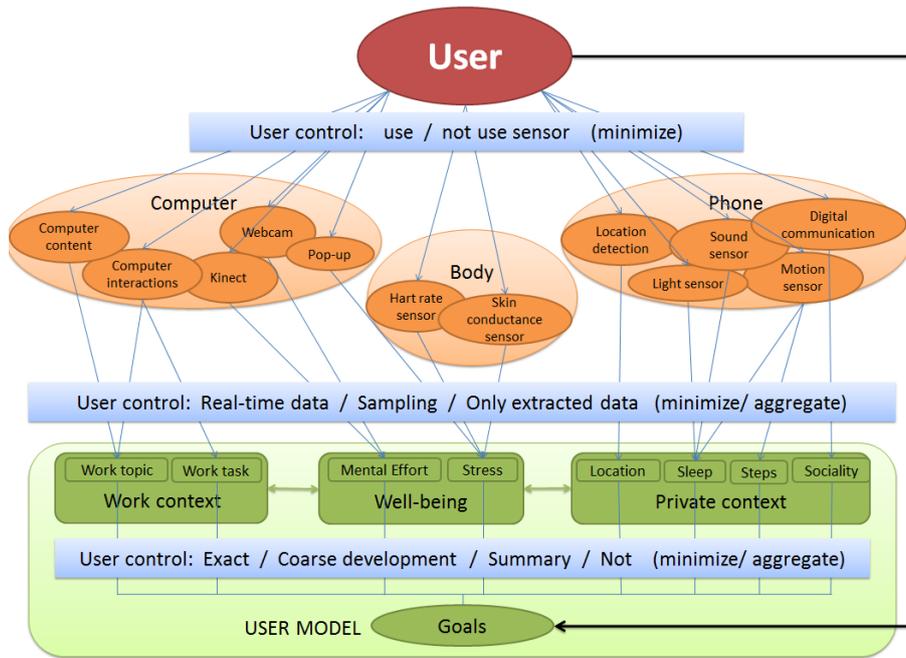


Figure 8: Overview of the system and its user model, which holds information on the users work context and his well-being. Moreover, information on the private context may be included. The user can decide on not using particular sensors and restrict in which detail data is collected.

Technical possibilities

In the previous sections, we identified several relevant concepts that the system could measure to provide data-driven coaching and context-aware support:

work characteristics, acute stress, long-term stress/ recovery, and aspects of engagement. In Figure 8 we present an overview of the types of information and the sensors that can be used in the pervasive system to infer these aspects.

Work characteristics. First of all, we can measure work characteristics. The task (e.g. write report, search information) someone is performing can be inferred from computer interaction data. We present algorithms for real time task inference in Koldijk et al. [25]. Moreover, which project someone is working on can be detected by analyzing the content of accessed documents and websites. We present algorithms for topic detection in Sappelli [40]. The combination of tasks and topics can provide valuable information on the context in which stress appears. Based upon information on what someone was working on when, we can also infer the amount of task switching, variation in tasks, and the work-rest-balance. Most informative are probably deviations from usual behavior of the specific user.

Acute stress With respect to inferring of stress from sensor data, Sharma and Gedeon [48] provide a compact survey. Often, body sensors are used to measure the physiological stress response directly, e.g. skin conductance [7] or heart rate [18]. More and more unobtrusive devices are entering the market, like measuring watches, so this might be a potentially interesting measure to use. As a critical side note however, these devices may not be accurate enough to determine the more insightful variable of heart rate variability (HRV). Moreover, many external influences on physiology exists, e.g. drinking coffee or physical activity. Asking the user himself for input on stress may be useful.

There also is potential in using outward characteristics, such as facial expressions, postures or computer interactions as indicators for the user’s mental state. Facial expressions are currently mainly used for inferring emotions, but facial expressions could also show cues to infer other mental states that might be more relevant in a working context. In earlier work, where working conditions were manipulated with stressors, we found that specific facial action units may be indicative of experienced mental effort [26]. Research by Dinges et al. [14] suggest that facial activity in mouth and eyebrow regions could be used to detect stress. Moreover, Craig et al. [10] looked at facial expressions while students worked with an online tutoring system. Association rule mining identified that frustration and confusion were associated with specific facial activity. Mental states are also being estimated from computer interaction data. Results by Vizer et al. [51] indicate that stress can produce changes in typing patterns. Finally, Kapoor and Picard [22] describe work on recognizing interest in students by means of computer interaction and posture. Currently, we are therefore also investigating in how far we can infer stress or experienced mental effort from facial expressions, computer interactions and postures [26]. Due to individual differences, general models will have to be adapted to the specific user for reliable estimates.

Long-term stress/ recovery To measure the more long-term physical, cognitive, emotional and behavioral responses, as well as recovery from stress (see Figure 4), it may be interesting to include aspects of the private context, outside work. With mobile phone sensors, a rough estimate of sleep time can be

provided by the combination of darkness, silence and recharging of the phone battery (see e.g. [3]). Moreover, the amount of physical exercise, which is a good relief for stress, can be measured by means of sensors (e.g. via mobile phone [3], via band [2]). Moreover, a very rough estimate of sociality can be made, based upon the amount of phone communication. Besides, location information (e.g. GPS) can be useful, e.g. enhance the timing of feedback.

Aspects of engagement Besides the aspects already included in Figure 8, we have some initial ideas to measure certain aspects of engagement (see Figure 3) during work. Based on sensor data, energy (vs. exhaustion) may be a concept that can be inferred, e.g. by looking at someones sitting posture, computer interactions, or maybe facial expressions. This could give longitudinal information on the individual strain of an employee. Moreover, we could get a first indication of involvement (vs. cynicism) from textual analysis of email content. A state of absorption, like ‘flow’, might be recognizable based on computer behavior (e.g. focus on one application), typical postures (e.g. leaning forward, sitting still) or facial expressions. The concept of efficacy (vs. inefficacy) however, might probably best be assessed with questions to the knowledge worker. For example, when the longitudinal data shows little energy, the employee might want to fill in some questions on feelings about his efficacy, to be able to give an early warning and provide help in time.

User choices regarding data collection

To estimate the identified states, various sensors are necessary, see Figure 8. Applying sensor technology to monitor personal activities most probably raises concerns related to privacy. Therefore, we performed a user study to investigate what the general perception of using various types of information and sensors is. We briefly describe the main findings here.

Nine participants tested a sensing and e-coaching prototype for two weeks. In a questionnaire, they were then asked to set the configurations for data collection to be used for own insight and for improving the e-coaching app.

We found that some sensors are in general perceived as more privacy sensitive (e.g. webcam, sound sensor, computer content, digital communication), others as less privacy sensitive (e.g. motion sensors, heart rate, skin conductance). However, preferences regarding data collection are diverse and depend on the goal for which they want to use the system and the trade-offs they make for themselves regarding privacy. The system should therefore be configurable, such that the user can 1) decide which sensors to use, 2) decide in which detail information is extracted from the sensors, and 3) decide to store information in exact or only aggregated form (see Figure8). Users may want to experiment how much functionality they can gain with disclosing certain types of data.

Conclusions: Using sensing and reasoning

In this section we aimed to answer our *third research question*: How can sensors be applied to automatically infer stress and the context in which it appears? We provide an overview of all possibilities for real-time measurements in Table 2. The user study showed that user’s are only interested to collect data that is necessary for supporting their specific goal, so the system should be configurable.

Core functions of the system: We now sum up the identified core functions of the system, together with the associated claims:

- F1.1: The SWELL system shall infer relevant information from unobtrusive sensors to provide real-time objective measurements.
- Claim: Sensors provide real-time information on stress and the context in which it appears, which the employee can directly act upon.
- F1.2: The SWELL system shall only collect data that is necessary to support the user’s goal.
- Claim: User’s are only willing to collect information relevant to their personal goal (due to privacy).

Table 2: Overview. From left to right: The 3 aspects in the stress chain. For each aspect, several indicative factors can be measured (upper part), and different (technology based) interventions can be provided (lower part).

Problem	Stressors: ‘My environment poses high demands.’	Experience of stress: ‘I feel I cannot handle all demands.’	Stress consequences: ‘I experience stress symptoms.’
Measure	Work characteristics	Acute stress	Long-term stress/ recovery
Concept & how to infer	Tasks and content worked on: computer activity. Variation in tasks, task switching, work-rest balance: computer activity (also calendar).	Physiological stress responses: skin conductance and heart rate (variability) from measuring watch. Mental effort: infer from facial expressions, posture, computer activity.	Sleep time: mobile phone sensing, e.g. using the combination of silence, darkness and recharging of the phone battery. Physical activity accelerometer, GPS.
Intervention	Address stressors (primary prevention)	Enhance coping (secondary prevention)	Enhance recovery (tertiary prevention)
Example technology	Providing work support: e.g. filtering emails (T01) and personalized search (T02). Providing insight in the sources of stress: e.g. activity and workload overview (T06).	Helping to improve coping abilities: e.g. gamification for focus (T03) and achievements diary (T04). Fostering support by colleagues: e.g. department-wide feedback for peer support (T05).	Supporting work-rest balance: e.g. e-coach for recovery breaks (T07). Helping to improve recovery after work: e.g. e-coach for detaching after work (T08) and e-coach for physical fitness (T09).

Improving well-being at work

We now have described concepts related to well-being at work, causes that play a role in the experience of stress, and means to assess relevant aspects with sensors. As a next step we aim to find an answers to our *fourth research question*: Which interventions can be provided by means of pervasive technology to help a knowledge worker improve his well-being at work? We describe intervention and behavioral change theory.

Intervention theory

There are different possibilities to address well-being at work and diminish stress. First of all, one can distinguish prevention approaches aimed at *different stages* in the stress chain (Ivancevich et al. [20]; see Figure 2, upper green parts). Primary prevention is aimed at the stressors, e.g. changing the work or work situation, to prevent risks. Secondary prevention is aimed at the (short-term) stress reactions, e.g. helping employees to develop good coping strategies, to handle stress risks and their consequences. Tertiary prevention is aimed at addressing (long-term) stress consequences, e.g. promoting a balanced life style, to recover.

Moreover, interventions can target *different areas* (see Figure 2, lower green parts). Based on literature, we identified four areas: the work itself, personal factors, the working conditions and private circumstances [52]. To support the employee to reach more well-being, the intervention should be targeted at the problem area. One could, first of all, change the work itself, improve work planning, or get a more focused work-flow. Secondly, the intervention can target personal factors. One could enhance self-knowledge (e.g. what causes my stress), or improve active coping. Fourth, the intervention can target working conditions. One can address organizational aspects, social aspects (e.g. support from colleagues), or the work-rest balance. Finally, the intervention can address private circumstances. One can address social aspects (e.g. support from friends), or recovery.

Finally, we can distinguish *various types* of stress reducing interventions (e.g. 39). The most suitable type of intervention may depend on the employee's preference: cognitive-behavioral (e.g. coping skills and being more assertive), creativity, exercise, food, journaling, relaxation, social, or time-management/organizational. Note that an intervention can e.g. be social and creative at the same time.

Behavioral change

Until now, we explained what aspects interventions may address to improve well-being at work. However, changing the behavior of an individual may be difficult, especially in case of (bad) habits. Therefore we now consider behavioral change theory (see e.g. [38]).

People may know that particular behavior may be good for them, but still they may sustain their old behavior. Fogg [15] identified three main hurdles preventing humans to perform the right or healthy behavior: lack of ability, lack of motivation and lack of a well-timed trigger. The interventions should be designed in a way that they address these hurdles. More specific relevant

determinants to address are: risk awareness, motivation, social influences, skills, self-efficacy, supportive environment, attention and behavioral awareness.

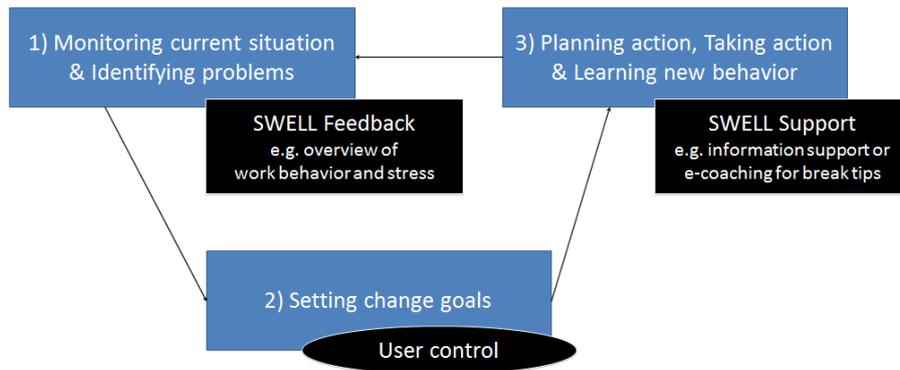


Figure 9: Behavior change and how technology could support.

For someone to successfully change his behavior, the following 3 main aspects should be supported in the system (see Figure 9): 1) Monitoring current situation and identifying problems; 2) Setting change goals and planning action; and 3) Taking action and learning new behavior.

We identified the most appropriate Behavior Change Techniques [35] for the pervasive system, based on the list presented in Korte et al. [27]. These are: feedback, self-monitoring, contextual risk communication, and reminders or cues to action.

Conclusions: Technology based interventions

In this section we aimed to answer our *fourth research question*: Which interventions can be provided by means of pervasive technology to help a knowledge worker improve his well-being at work? The system can address different stages in the stress chain (see Figure 2): the stressor, improving coping and enhancing recovery. We also found several areas to address: the work itself, personal factors, working conditions or private aspects.

Finally, the pervasive system should also support the employee throughout the behavioral change chain, and specifically address barriers towards changing behavior.

In Figure 10, we show how the specific supporting technologies (T) identified in the section on work stress models can be placed into this framework. Also further technology supported interventions can be designed based upon our framework, some ideas are included in Figure 2 (black parts).

Core functions of the system: We now sum up the identified core functions of the system, based upon this part of the theoretical framework, together with the associated claims:

- **F2:** The SWELL system shall address 3 different causes of stress: address the stressor (F2.1), coping (F2.2) and recovery (F2.3).

- Claim: By providing different types of interventions, different causes of stress can be addressed with the system, making it usable in more situations.
- F3: The SWELL system shall foster behavioral change by: helping to monitor the current situation and identifying problems (F3.1), letting the user set personal goals and enable specific functionality (F3.2), and helping to learn new behavior, by fostering the ability, motivation or trigger to take action (F3.3).
- Claim: By using behavior change theory the system will be more effective in actually bringing about behavioral change regarding well-being at work.

Envisioned system and evaluation of prototypes

Throughout the paper, we formulated several core functions for the system. We sum them up here. The envisioned pervasive SWELL system supports the knowledge worker to improve well-being at work (OBJ). The SWELL system could collect information about: aspects of engagement, work characteristics, acute stress, and long-term stress/ recovery (F1). The SWELL system shall infer relevant information from unobtrusive sensors to provide real-time objective measurements (F1.1). The system only collects data that is necessary to support the user’s goal (F1.2). With respect to behavioral change, the user will start with getting insight in his situation and identifying problems that he wants to address (F3.1). Based on these insights the user can then set personal goals and enable specific desired SWELL functionality (F3.2). In case the environment poses high demands, the user may decide to address some of his stressors (F2.1). In case the user feels overwhelmed by demands placed upon him, he may decide to address some of his coping abilities (F2.2). In case the employee experiences stress symptoms, he may decide to enhance recovery (F2.3). Behavior change techniques are used to foster motivation, ability and triggers to take action (F3.3).

We built first prototypes of different SWELL functionality. Figure 10 shows how the prototypes fall into our framework. All systems are aimed at improving well-being at work. Most prototypes make use of sensor information.

- The SWELL Workload Mirror is an implementation of T06 “activity and workload overview” and provides insights regarding stress and the context in which it appears. It tries to tackle stress in the beginning of the stress chain (e.g. ‘what causes stress?’) with the aim of helping employees to address the stressor itself. Based on these insights, the user might want to use one of the other SWELL systems for support.
- The SWELL HappyWorker system is an implementation of T02 “personalized search” and helps employees find relevant information. It tries to tackle stress in the beginning of the stress chain (diminishing demands) with the aim of addressing the stressor itself.
- The SWELL Fishualization is an implementation of T05 “department-wide feedback for peer support” and is aimed at fostering awareness and communication about stress at work. It tries to tackle stress in the middle of the stress chain, helping employees to cope with stress.
- The SWELL NiceWork app is an implementation of T07 “e-coach for recovery breaks” and provides interventions aimed at improving coping, and enhancing recovery. It tries to tackle stress in the middle and end of the stress chain.

We now describe two of the prototypes (SWELL Fishualization and SWELL NiceWork app) in more detail, together with first small-scale user studies.

Fostering colleague support - SWELL Fishualization

The SWELL Fishualization (for details we refer to the original work presented in Schavemaker et al. [42] and Schavemaker et al. [43]) is aimed at enabling

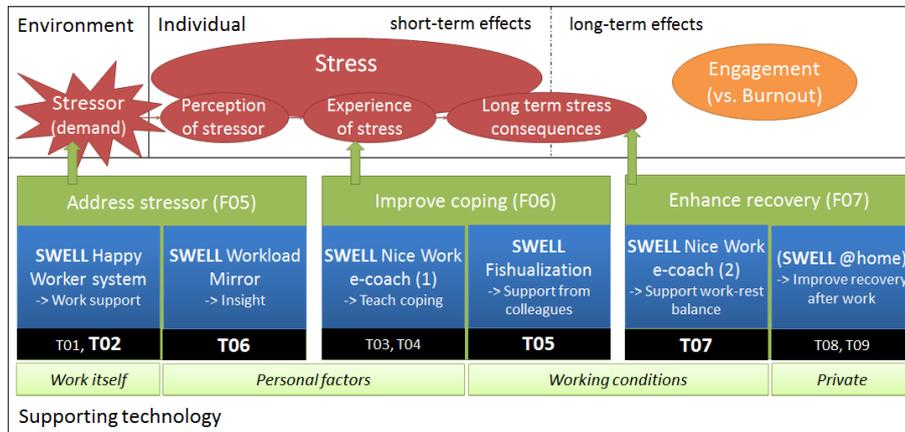


Figure 10: SWELL system functionality in our general framework.

employees to gain insights into their working habits and encourage social interaction about healthy working, in order to improve well-being at work (T05). It provides a feedback screen in the form of a digital fish tank (see Figure 11), which is placed at a central location in the office. The primary sensor is currently a key-logging software that is installed on the user's computers. Other sensors could also be coupled to add information on, e.g. heart rate, dominant facial expression or e-mail sentiments. Each fish in the Fishualization represents an individual employee. The speed of a fish is determined by how fast the corresponding employee is interacting with their computer (number of clicks and keystrokes) and the number of changes in direction represents the number of task or context switches. The y-position of each fish currently represents the (self-reported) energy level of the corresponding employee. 'Plants' at the bottom of the screen represent performed tasks, for example writing e-mail, editing document, browsing, or preparing presentation. The more people worked on a tasks, the larger the plant.

Regarding our framework, the SWELL Fishualization tries to tackle stress in the middle of the stress chain, helping employees to cope with stress (secondary prevention). It is aimed at enhancing support from colleagues, thus addressing the working conditions. Its main basis is the Job Resources-Demands model (providing additional resources). It measures work characteristics and assesses the energy dimension of engagement by means of user input. With respect to behavioral change it helps with monitoring the current situation. Moreover, it fosters the motivation to take action by means of a playful approach and social influences.

Evaluation study. We evaluated the prototype in a real-world environment. The Fishualization trial at the Media and Network Services group at TNO ran for about 2.5 months (March - May 2014). The Fishualization screen (a large computer display) was placed in the coffee corner. A subset of 10 employees volunteered to couple their computer interactions and subjective input of their energy level to one of the fish. In order to measure the effects of the deployment

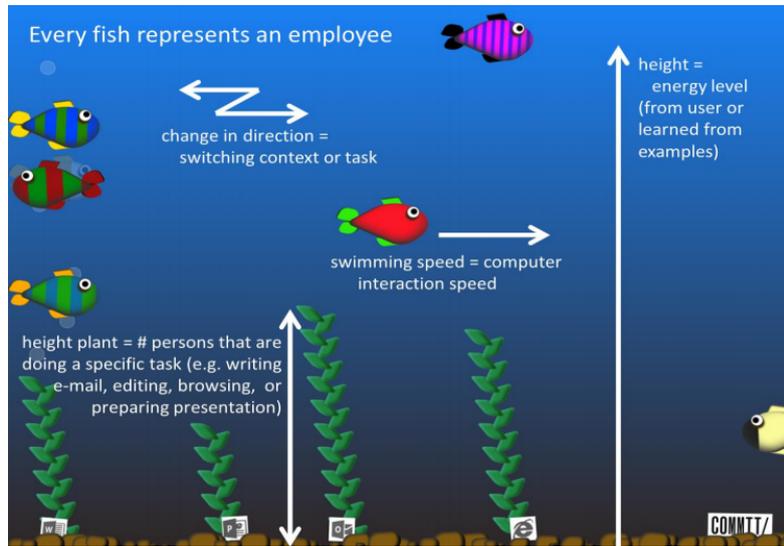


Figure 11: SWELL Fishualization. This screen is placed in the coffee corner and provides department feedback.

of the Fishualization, all employees who use the coffee corner were asked to fill in pre- and post-questionnaires on personal awareness of working patterns and well-being at work, group awareness and interactions with colleagues. Furthermore, camera and microphone recordings were used to measure activity at the coffee corner. To ensure privacy, only the number of detected faces, the amount of video motion and the average sound level were deduced and stored (no video or sound was stored). This data collection started 3 weeks before the Fishualization was turned on and continued during the trial, to compare activity in the coffee corner before and after deployment of the Fishualization.

30 employees filled in the pre-questionnaire and 14 employees filled in the post-questionnaire. (The subset of respondents did not differ significantly in their current level of well-being or how content they were about their well-being.) We used independent samples t-tests to compare the pre- and post-test results. A significant effect on the following item was found: “I am aware of typical patterns in working behavior throughout the day or week (e.g. mailbox on Monday morning, project work after lunch...)” ($p = 0.004$). Awareness of working patterns was higher in the post-test ($M = 4.79$, $SD = 1.626$) than in the pre-test ($M = 3.27$, $SD = 1.530$) (scale from 1: ‘not’ to 7: ‘very much’). Moreover, we found a significant effect on the item “I know how I can change my working behavior to gain a better level of well-being (e.g. becoming more productive, reducing stress...)” ($p = 0.005$). Scores were higher in the post-test ($M = 5.14$, $SD = 1.231$) than in the pre-test ($M = 3.9$, $SD = 1.322$).

We can conclude that the Fishualization caused more personal awareness on working behavior and its relation with well-being among employees. However, we did not find significant effects on items related to group awareness and interactions with colleagues. In the further development of the Fishualization we should focus on fostering social interaction among colleagues more (e.g. by

adding new functionality), as this may be a good buffer against stress. Moreover, most participants were enthusiastic about the Fishualization. A playful manner of feedback turned out to be engaging. Finally, we used sensor technology to quantify activity in the coffee corner, which shows the potential of new technology for experimental evaluation.

Providing tips - SWELL NiceWork e-coach

The SWELL NiceWork app (for details we refer to the original work presented in Wabeke [53]) is designed to provide coaching for short recovery breaks (T07). The app provides simple tips, 3 times a day, aimed at promoting well-being at work (see Figure 12). Various scientific articles, websites and magazines on well-being at work were reviewed to collect appropriate tips, which resulted in a list of 54 tips. Each tip does not take more than three minutes, and no special materials or specific locations are required. The recommended well-being tips are of different types: cognitive-behavioral, creative, physical exercises, food, journaling, relaxing, social, and time-management.

We found that different people had different preferences for tips (pilot study, in which 26 employees rated their preferences for the 54 tips). Therefore, a recommendation approach was chosen to adapt which tips are given to the specific user. After each recommendation, the user can indicate whether he performed the tip and the system learns over time to give better tips.

The SWELL NiceWork e-coach is mainly aimed at supporting the work-rest balance. Regarding our framework, the app provides as well tips aimed at preventing the experience of stress (secondary prevention), as tips on recovery from coping with high demands (tertiary prevention). The tips focus on personal factors or the working context. Its main basis is the Effort-Recovery model (focusing on recovery). It does not yet measure anything. The system does assesses whether the user has followed up a tip by means of user input. With respect to behavioral change it helps with taking action and learning new behavior by providing triggers and suggestions.

Evaluation study. To evaluate the NiceWork app with users, 35 employees tested the e-coach for 2 weeks. The first hypothesis was that knowledge workers have a positive attitude towards the e-coach. This hypothesis was confirmed in the user study. The number of followed-up tips was high (2 out of 3 per day) and most participants agreed that it is pleasant to receive automatic notifications. The study also showed that three recommendations per day seemed a right amount of suggestions. Moreover, indicating whether a tip was followed-up and asking for a short motivation when a tip was rejected turned out to be a well-design method for providing feedback. Our second hypothesis was that tailored recommendations are followed-up more often compared to randomized suggestions. We did not find strong evidence for this hypothesis. Results show that our recommendation method, which provides tailored suggestions, did not substantially increase the number of tips that were performed compared to a method that provided randomized suggestions.

Furthermore, results show that only a few tips were not followed-up, because the tip was disliked (13%). Instead, tips were mostly rejected, because the moment of recommendation was somehow inappropriate (wrong timing: 46%, tip

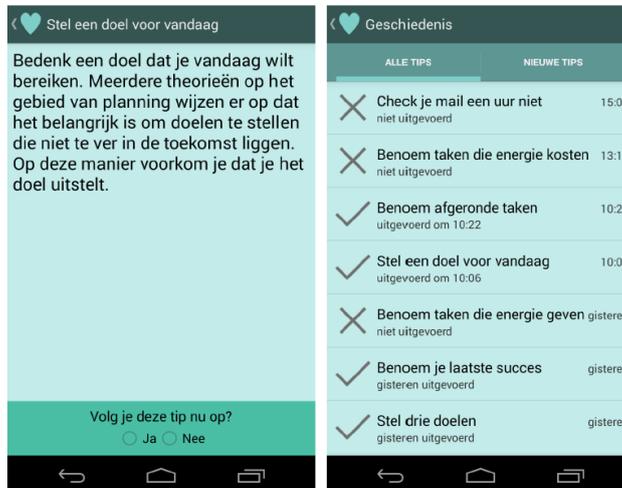


Figure 12: SWELL NiceWork app. Left: Intervention is provided. Right: Overview of provided interventions.

not relevant: 15%, not at work: 14%). This finding suggests that future e-coaches may increase their effectiveness by recommending tips at appropriate times. Using sensor information to ensure that tips are suggested just-in-time, was the most important personalization method that needed to be further explored. (This was done in Schendel [44].) Moreover, we demonstrated that technology can be used to investigate the effects of an intervention, i.e. via the app we directly investigated how many interventions were said to be followed up, and we directly asked for reasons for not following up a suggestion.

Conclusions: Evaluation of prototypes

In this section we presented the general SWELL functionality and described two prototypes and their evaluation. (Within the SWELL project also other prototypes were developed and evaluated, e.g. Bri [1].)

In general we can say that we made working implementations of some pervasive technologies for improving well-being at work. Our evaluation until now was mainly aimed at user experience and testing underlying technologies. The evaluation yielded several additional requirements for our system. Moreover, we showed how technology can be used to investigate the effects of an intervention. In further research we should also evaluate whether the prototypes have the expected positive effect on employee's well-being at work. From our small scale pilot studies we got some first insights, but ideally the systems are evaluated with in a much larger field test.

Conclusions and Discussion

By means of situated cognitive engineering [36] we combined stress and intervention theory with knowledge of technological possibilities and input by users, to design a pervasive system that helps knowledge workers to improve well-being at work.

Conclusions

We answered the following research questions:

1) Which concepts are relevant with respect to well-being at work? We found that the relationship that people have with their jobs can be described as a continuum between engagement and burn-out [31]. Engagement is characterized by energy, involvement and efficacy or absorption. Biology describes more short term effects of stress [46]. A stressor causes a particular perception of the stressor in the individual. This can lead to acute physiological stress responses and, on the long run (due to lack of recovery) to long term physical, cognitive, emotional and behavioral stress consequences.

2) Which person, work and context conditions can lead to negative stress? There are no specific personal, work or context conditions that generally lead to stress. Work becomes stressful when high demands are combined with: insufficient resources; little rewards; little recovery; or an environment that mismatches with personal characteristics. The most useful models for developing technology based interventions are the Job Resources-Demands model [12] and the Effort-Recovery model [33]. We presented several ideas to provide additional demands, enhance resources or help with recovery.

3) How can sensors be applied to automatically infer stress and the context in which it appears? We can use technology to sense work characteristics (e.g. tasks and topics worked on), measure acute physiological stress responses in the body (e.g. HRV), or assess cognitive, emotional and behavioral effects of stress (e.g. sleep duration). The user study showed that users are only interested to collect data that is necessary for supporting their specific goal, so the system should be configurable.

4) Which interventions can be provided by means of pervasive technology to help a knowledge worker improve his well-being at work? In general, three stress prevention approaches are distinguished, aimed at different stages in the stress chain [20]. Technology can thus either address the stressor (e.g. by providing work support), address short-term stress reactions (e.g. by enhancing coping), or address long-term stress consequences (e.g. helping to improve recovery). Suitable behavioral change techniques [35] should be used to address the motivation, ability or trigger to take action (e.g. self-monitoring and reminders to action).

We presented the resulting general framework in which we related several relevant theories: We related work on engagement and burnout [31] to work on stress [46], and described how relevant aspects can be quantified by means of sensors. We also outlined underlying causes of work stress [12, 33], and described how interventions can address these [20], in particular by means of new technologies, utilizing behavioral change theory [35]. This framework can be used by other researchers to design pervasive systems that address well-being at work.

Finally, we described the envisioned SWELL system, and core functionality that was identified. We also presented some built prototypes. The SWELL Fishualization [42, 43] provides department wide feedback for peer support, designed to improve coping. The SWELL NiceWork e-coach [53] provides well-being tips, designed to improve coping or recovery. All in all, we demonstrated the (technological) feasibility of our ideas. First evaluations with users were positive and provided further insights to refine the systems.

Discussion and Limitations of our Work

The biggest challenge in developing our comprehensive and practical framework was the vast amount of available concepts and models regarding well-being at work. We consulted experts in the field. We finally, had to make choices on what concepts and theories to include. Our selection may reflect our specific scoping, e.g. addressing work stress in the population of knowledge workers. We focused on providing a general and simple overview, combining different areas of research.

Another big challenge in this respect was relating concepts of different fields to each other. These concepts differ in their level of abstraction: Organizational Psychology provides the most high-level terms, i.e. the relation between resources vs. demands, or recovery [31]. Biological theories provide more low-level terms, i.e. physiological stress responses in the body [46]. Our aim was to make several of these aspects quantifiable. This means, translating these concepts into even more low-level terms, i.e. a specific sensor, the data to be collected and the interpretation of this data.

Besides the high-level vs. low-level continuum, there is also a temporal continuum, from short-term stress [46] to developing a burn-out [31]. In traditional approaches with questionnaires, mainly long-term aspects are assessed. Sensing, however, enables real-time measurements in real world work settings. We aimed to translate relevant aspects identified based on theories, into variables that are measurable at the workplace.

The resulting general and pragmatic framework provides a structure to develop pervasive technology for improving well-being at work. We noticed that far more diverse technology based interventions can be developed, than initially assumed. The theoretical foundation gave many different pointers of how well-being at work can be improved: from coaching during work, over fostering social support, to addressing recovery after work. Besides the ideas and prototypes presented here, many more (technological) solutions can be developed based upon this general framework. To mention just a few examples: teaching coping in an online course, building a social network for peer support, or enhancing recovery by letting people play a computer game.

Moreover, we built prototypes of some pervasive technologies for improving well-being at work [42, 43, 53]. Our evaluation until now was mainly aimed at user experience and testing underlying technologies. Further research should evaluate whether the prototypes have the expected positive effect on employee's well-being at work. From our small scale pilot studies we got some first insights, but ideally the systems are evaluated with in a much larger field test.

As a final note, we need to be cautious to put responsibility for managing work stress at the individual level. Certainly the company and management also play a role. Therefore, an intervention provided one on one at an individual by

means of a pervasive system, is ideally part of a larger intervention program. In case many employees struggle with similar problems, a department wide intervention may be more effective. Furthermore, specific problems at work may not be solvable by the employee himself. In this case, the management or organization may need to be approached.

Reflection

All in all, we think a pervasive system aimed at an individual's abilities to cope with stress and improve well-being at work poses many new opportunities. A system used real-time during work can provide much valuable information on work stress. Moreover, employees can be empowered to self-manage their well-being at work by means of tailored interventions. Throughout our work we encountered several challenges and opportunities for further research in several categories:

1. **Multi-disciplinary, theory and data-driven research and development.** New technology brings new possibilities to the field of stress and intervention research. Technical experts and social scientists should aim to work together. It is therefore necessary that the experts understand each others domains well, which is challenging.
2. **Interpreting personal sensor data.** Sensor data is relatively easy to collect, the challenge is making sense of this data, e.g. in terms of stress and its context. Future studies should investigate the possibilities of real-world data interpretation.
3. **Relation between measurable aspects and burn-out.** Ideally, a system would be able to give a warning in case it predicts that the current behavior will cause long-term problems. Therefore, research should be done on how longitudinal patterns in sensor data relate to long-term stress consequences and burn-out.
4. **Combining strengths of human and technology.** The challenge is to provide support, without irritating the user. Ideally, the strengths of technology (e.g. being objective or persistent) and the strengths of a human (e.g. being good in interpretation) are combined.
5. **Privacy.** The success of pervasive systems collecting context data depends on the acceptance by users. A system that collects personal data raises many privacy questions. Therefore, privacy should be integral part of the design process.
6. **Ethics.** Measuring and trying to change the behavior of individuals poses all kinds of ethical questions. It is difficult to predict how such new pervasive e-coaching systems will be perceived and used (or even misused) when applied in real-world work settings.

Acknowledgments

This publication was supported by the Dutch national program COMMIT (project P7 SWELL).

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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