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RESEARCH NOTES

Design Blueprint for Stress-Sensitive Adaptive Enterprise Systems

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Abstract Stress is a major problem in the human society, impairing the well-being, health, performance, and productivity of many people worldwide. Most notably, people increasingly experience stress during human-computer interactions because of the ubiquity of and permanent connection to information and communication technologies. This phenomenon is referred to as technostress. Enterprise systems, designed to improve the productivity of organizations, frequently contribute to this technostress and thereby counteract their objective. Based on theoretical foundations and input from exploratory interviews and focus group discussions, the paper presents a design blueprint for stress-sensitive adaptive enterprise systems (SSAESes). A major characteristic of SSAESes is that biosignals (e.g., heart rate or skin conductance) are integrated as real-time stress measures, with the goal that systems automatically adapt to the users' stress levels, thereby improving human-computer interactions. Various design interventions on the individual, technological, and organizational levels promise to directly affect stressors or moderate the impact of stressors on important negative effects (e.g., health or performance). However, designing and deploying SSAESes pose significant challenges with respect to technical feasibility, social and ethical acceptability, as well as adoption and use. Considering these challenges, the paper proposes a 4-stage step-by-step implementation approach. With this Research Note on technostress in organizations, the authors seek to stimulate the discussion about a timely and important phenomenon, particularly from a design science research perspective.

Keywords Adaptive automation · Affective computing · Enterprise systems · Biofeedback · NeuroIS · Stress · Technostress · Design science research

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1 Introduction

While the tremendous advances in the field of information and communication technology (ICT) have resulted in significant benefits for the human society, growing evidence shows the "dark side" of ICT for individual users and organizations (e.g., Salanova et al. 2013; Tarafdar et al. 2013). Technostress (TS), defined as "stress experienced by end users in organizations as a result of their use of ICTs" (Ragu-Nathan et al. 2008, pp. 417–418), is one major "dark side" of ICT. While TS is not a new phenomenon (Brod 1984), it has gained significant momentum during the past few years, primarily because of ICT's high penetration of the human society. Today, at least in Western countries, it is difficult to imagine people without a personal computer, smartphone, or tablet; similarly, in business life, it is difficult to imagine companies without packaged application systems, including groupware, enterprise resource planning (ERP), or business intelligence and analytics (BI&A).

Organizational TS contributes to a general trend of an increasing stress perception in human society with detrimental effects on human health and performance (Riedl 2013). The pervasiveness of ICT in firms, along with daily incidents of computer hassles (e.g., system breakdown, waiting times, or printer problems) can negatively affect employees' psychological and physiological conditions (e.g., Ayyagari et al. 2011; Maier et al. 2015b; Riedl et al. 2012). Motivated by an increasing number of staff complaints and by empirical research (e.g., Barley et al. 2011), enterprises have already started to counteract TS and its negative consequences by implementing interventions. In 2011, for instance, the automobile manufacturer Volkswagen agreed to stop mail servers when employees are off-shift in order to reduce stress levels (BBC News Technology 2012).

However, increasing penetration of organizational tasks and business processes with ICT, along with the intensive use of devices and packaged application systems, does not necessarily constitute a negative development for the human society. The trade-off between maximizing the benefits of ICT and minimizing TS levels and its negative consequences needs to be taken care of with design and intervention measures. In this context, Riedl (2013, p. 44) wrote recently: "Design science researchers could contribute to the development of information systems, which use bio-signals as real-time system input in order to make human-computer interactions less stressful."

In this Research Note, we intend to promote a discussion among scholars, managers, and engineers by proposing a design blueprint for how enterprise systems (ESes) can use bio-signals in order to mitigate stress by means of interventions on the individual, technological, and organizational levels. We refer to such systems as stress-sensitive adaptive enterprise systems (SSAESes). The blueprint addresses the following objective:

Design Objective: Support humans via information systems (1) in managing stress in an enterprise context, and (2) in reducing stress in order to increase well-being and health, performance and productivity, and user satisfaction.

Design is an iterative search process (Hevner et al. 2004). In order to structure this process, we followed the objective-centered design science research process (Peffers et al. 2007) and used a hybrid approach that balances deductive, inductive, and abductive reasoning (Gregor 2009; Gregory and Muntermann 2011). In particular, we integrate a body of highly fragmented theoretical and empirical literature from various disciplines (deduction), conduct a series of qualitative exploratory expert interviews and focus groups (induction), and propose a design blueprint consisting of a set of design guidelines, an architecture, a roadmap for implementation, and a plan for empirical evaluation (abduction). Several interviewees emphasized the relevance of this research. The occupational health and safety officer at Private Customer E (see the Appendix; available online via http://link.springer.com), for example, stated: "We believe that productivity and innovation arise from a 'healthy corporate climate' and, thus, have detailed corporate policies to foster well-being. In these policies, 'well-being' reflects a holistic approach including prevention of accidents, workplace ergonomics, nutritional and physical activity choices, as well as stress management. […] Your approach to stress management is very innovative and promising. We would like to explore it in our organization." Other potential users of SSAESes supported this perspective in our interviews.

In total, we conducted 71 interviews with 39 different experts (30 practitioners and 9 academics) from 25 different organizations and two focus groups to capture the multiple realms of creativity, insight, and knowledge required in designing SSAESes. We followed an interdisciplinary approach by involving technology-oriented practitioners who demonstrated subject matter expertise (e.g., through innovative technology development or consulting experience) as well as application-oriented practitioners dealing with the challenges of technostress from a company, labor organization or government point of view. Furthermore, academics from the fields of electrical engineering, psychology, computer science, and information systems were interviewed. By doing so, we were able to gather insights of subject matter experts from a diverse set of industries (high-tech industry, manufacturing firms, consulting services) as well as non-profit organizations (trade unions, governmental regulatory agencies, research organizations). Please see the Appendix for details on our sample. Interviews varied in focus, length, and format depending on the varying needs during the design process. Early interviews were non-directive in-depth informant interviews. During the design process, interviews gradually turned towards semi-structured, directed participant interviews (Easterby-Smith et al. 2002, Ch. 5). These interviews featured graphical and textual descriptions of the current state of the design blueprint for participants (1) to evaluate them descriptively (informed arguments and scenarios) and analytically (static analysis and architectural analysis), and (2) to suggest specific refinements. Expert sampling and interview analysis followed the general notions of theoretical sampling, constant comparison, and theoretical saturation as introduced by Glaser and Strauss (1967) in the context of grounded theory. However, we did not transcribe and formally code the interviews and did not apply the full methodological toolbox associated with grounded theory. Expert input rather served as inspiration as well as a contribution to problem awareness and understanding. The integration of theoretical and empirical literature from various disciplines finally constituted the foundation to compile a design blueprint for SSAESes.

The remainder of this article is organized as follows: Sect. 2 discusses the theoretical basis of the design blueprint, Sect. 3 presents the design blueprint, and Sect. 4 outlines the limitations and discusses directions for future IS design science research in the area of TS.

2 Theoretical Foundations

This section conceptualizes the theoretical foundations and building blocks of SSAESes. The lower part of Fig. 1 outlines a simplified model of TS in organizations, while the upper part sketches how the individual, technological, and organizational dimensions of ESes can interfere at different stages with the process of stress elicitation. Our model of TS is based on the Transactional Model of Stress developed by Lazarus and Folkman (1984), which is one of the most influential frameworks to study stress perceptions and coping mechanisms in psychological and in IS research (e.g., Ayyagari et al. 2011; Ragu-Nathan et al. 2008). Moreover, our model is informed by a stress model developed by Hancock and Warm (1989) and a TS model developed by Riedl (2013). Our model of TS is intended to be used as a guideline for investigating stress in the context of ES, for identifying possible interventions, and for informing the design and evaluation of SSAESes.

2.1 Transactional Model of Stress

Based on a number of empirical investigations by Richard Lazarus at the nexus of physiology and psychology in the 1960s and 1970s, Lazarus and Folkman (1984) presented a seminal theory to explain human stress reactions. The major characteristic of this Transactional Model of Stress is

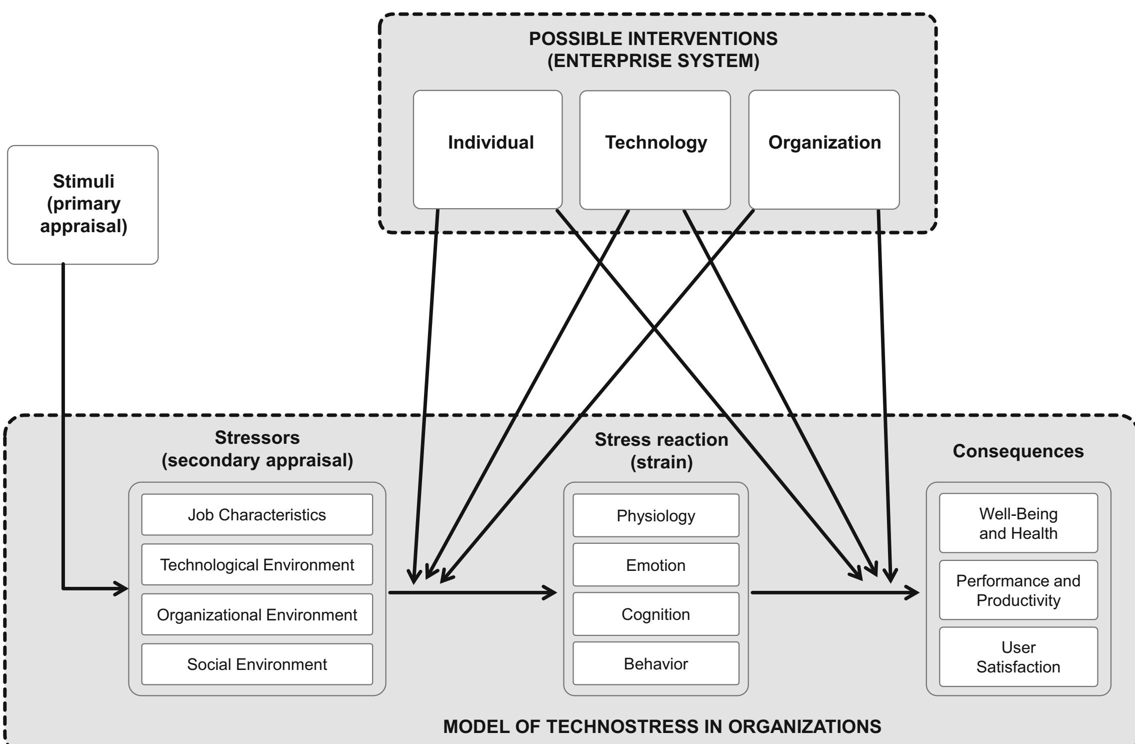

Fig. 1 Model of technostress in organizations and possible interventions in enterprise systems

that stress is not solely conceptualized as a biological phenomenon, but as a complex construct that results from the interplay between an individual and the environment (hence, the term "transactional"). In particular, the theory states that stress (1) emerges from an imbalance between demands from the environment and an individual's resources, and (2) is subject to the meaning of a stimulus to the perceiver, implying that the same stimulus may differently affect the stress of different individuals.

According to the seminal stress theory by Lazarus and Folkman (1984), the underlying rationale is that when faced with stimuli (see Fig. 1), an individual evaluates whether they are irrelevant, benign-positive, or stressful (primary appraisal). In the latter case, another evaluation process takes place (secondary appraisal). Here, the individual assesses whether he/she can cope with the stimulus (stressor) by using the available resources (e.g., institutional, personal, and social). Two outcomes are possible: the resources are either sufficient or they are not. In the latter case, stress reactions are possible on four levels: physiology, emotion, cognition, and behavior [see "Stress reaction" in Fig. 1; note that the term "strain" is used as a synonym in seminal research on organizational stress, see Hakanen et al. (2006, p. 496), and this is consistent with Lazarus and Folkman (1984, p. 4), who equate stress with strain and explicitly define the latter, based on Wolff (1953), as "a disturbed state of the body"; also note that consistent with our model in Fig. 1 organizational TS research grouped strain into different types, such as physical, emotional, and cognitive/mental, see Boucsein and Thum (1997)]. Next, to mitigate these stress reactions, an individual applies different coping strategies, which can be either problem-focused or emotion-focused (Hudiburg and Necessary 1996; Lazarus and Folkman 1984). The former strategy has the goal to actively change the person-environment realities related to a stressful situation (e.g., by increasing the amount or quality of resources), while the latter seeks to reduce negative feelings by changing the primary and/or secondary appraisal of a given stressful situation.

Applying the rationale of the Transactional Model of Stress in organizational settings, we find that stress is generated as a dynamic process that is triggered by a set of acute and chronic stressors (i.e., stress-creating factors and conditions), and involves individual stress reactions, which, in turn, have a number of consequences on well-being and health, performance and productivity, and user satisfaction (see "Consequences" in Fig. 1) (Hancock and Warm 1989; Lazarus 1991; Riedl 2013). This dynamic process includes conscious changes in perception; however, there are also unconscious changes in body physiology that usually set in before conscious stress perception (e.g., Riedl 2013; Tams et al. 2014b). This includes, for example, the release of the stress hormones adrenaline (Johannsson and Aronsson 1984), noradrenaline (Korunka et al. 1996), and cortisol (Riedl et al. 2012) and other chemical substances related to stress such as alpha-amylase (Tams et al. 2014b), as well as changes in heart rate (Trimmel et al. 2003), heart rate variability (Hjortskov et al. 2004), blood pressure (Boucsein 2009), muscle tension (Emurian 1993; Hazlett and Benedek 2007), pupil dilation (Partala and Surakka 2003; Buettner et al. 2013), and skin conductance (Léger et al. 2010; Riedl et al. 2013).

Importantly, it needs to be emphasized that there is more to the cognitive side than perception alone. Users can cognitively intervene at an earlier stage of the process. As explained by Lazarus and Folkman (1984), the elicitation of stress is subject to the users' appraisal of the overall situation, availability of resources, and coping strategies. In this vein, users can apply, for example, information avoidance, stress management, and other coping strategies in order to mitigate the elicitation of stress and its negative consequences (Denson et al. 2009; Bostock et al. 2011). Thus, the impact of stressors heavily depends on the users' individual capabilities and stress-coping strategies.

2.2 Stressors

In an ES context, a large number of stressors exist. One interviewee from a workers union indicated: "Many factors are relevant for workplace stress, for example, sufficient staffing levels, leadership culture, corporate culture, and certainly also individual stress coping strategies." In order to facilitate stress interventions, we introduce a high-level distinction among stressors related to (1) job characteristics, (2) technological environment, (3) organizational environment, and (4) social environment. These categories have recently been described as crucial in organizational TS (Fischer and Riedl 2015). These stressor types can induce stress reactions in the users, both individually and collectively. The categorization is useful for our goal of SSAESes, as the context and usage data of the individual users help to better understand their current situation and trigger context-sensitive interventions at the level of the current task, the technology, the organization, or the social environment.

In the context of a specific task (i.e., job characteristics), possible stressors are, for example, task monotony, task complexity, and multi-tasking (Friend 1982; Tarafdar et al. 2011; Riedl 2013). As for technology-related stressors, Tarafdar et al. (2007, 2011, pp. 116–117) identified five different TS creators: techno-overload (i.e., too much, ICT forces users to work faster and do more work than they can handle), techno-invasion (i.e., always connected, blurring boundaries between private life and work), techno-complexity (i.e., devices have many features and their usage is difficult to learn), techno-insecurity (i.e., fear of being replaced by users with better ICT knowledge), and techno-uncertainty (i.e., constant software and hardware changes). We add techno-unreliability (i.e., system malfunctions and other IT hassles) to the category of technology-related stressors (Fischer and Riedl 2015). Organizational stressors refer to the potential causes of stress originating in the organizational structure. This covers, for example, role overload (i.e., level of difficulty or amount of work exceeding capacity) and role conflict (i.e., contradictory and incongruent role requirements) (Rizzo et al. 1970; Tarafdar et al. 2007). The social environment may also affect the employees' stress levels (e.g., social pressure to use specific system features) (Edwards 1998).

While stressors from all four categories can each induce stress in the users, it is important to highlight that technology-related stressors have been found to exacerbate the others. For example, Tarafdar et al. (2011) found that due to the pervasiveness of ICT in human society, techno-invasion amplifies task-related and organizational stressors resulting in increased round-the-clock stress levels – at work and at home. More generally, packaged application systems (as a major part of the technological environment, see Fig. 1) may constitute a source of stress for six main reasons [see the sources cited in Fischer and Riedl (2015, p. 1462), Ragu-Nathan et al. (2008) and Tarafdar et al. (2007, 2011)], namely techno-overload, techno-invasion, techno-complexity, techno-insecurity, techno-uncertainty, and techno-unreliability. It is important to note that the first five factors were derived by Ragu-Nathan, Tarafdar, and colleagues, and this list of five factors was later complemented by a sixth factor, namely techno-unreliability (defined as "users face system malfunctions and other IT hassles", see Fischer and Riedl 2015, p. 1462). It is further of importance that this sixth factor, while (surprisingly) not conceptualized as TS creator in Ragu-Nathan et al. (2008) and Tarafdar et al. (2007, 2011), has been shown to constitute a major source of TS throughout the entire history of TS research. Specifically, since the 1980s up until today overwhelming evidence in the TS literature [see, for example, Brod (1984, p. 43), Weil and Rosen (1997, p. 5), or Ayyagari et al. (2011), and several studies reviewed in Riedl (2013)] has conceptually substantiated and/or empirically shown that techno-unreliability may lead to notable stress reactions in users.

2.3 Stress

Stress manifests in neurophysiological changes in the body, which usually set on before conscious stress perception (e.g., Riedl 2013; Tams et al. 2014b). In the context of SSAESes, a variety of these changes can be measured to assess stress correlates. Cortisol, a stress hormone released by the adrenal glands in response to stimulation by the hypothalamus, plays a critical role in internal stress processes. Cortisol can be assessed by means of saliva samples and provides a well-established measure for increased stress levels (Dickerson and Kemeny 2004). For example, Riedl et al. (2012) showed that cortisol levels significantly increased in response to system breakdown. Therefore, in combination with context data, it is a valuable measure for assessing the users' stress levels in offline analysis. Moreover, a number of other neurophysiological stress parameters can be assessed with online measurements. These include pupil dilation, heart rate, heart rate variability, mouse pressure, muscle tension, pulse transit time, and skin conductance, which, based on modern sensor technology and advances in battery technology, can be continuously and unobtrusively assessed over periods of several days (Hancock and Szalma 2007; Schaaff et al. 2012; Riedl 2013; Zhai and Barreto 2006). Therefore, an assessment of these parameters allows enterprise-system-context data to be mapped with neurophysiological stress data in order to make systems stress sensitive and to trigger context-sensitive interventions (cf. Guideline 3 in the next section).

2.4 Consequences

When investigating stress, it is critical to take into account its possible consequences (Hancock and Warm 1989); therefore, assessing specific indicators for consequences should also play an important role in SSAESes (see Fig. 1, right). First, according to the Yerkes and Dodson (1908) law, the relationship between physiological arousal and performance resembles an inverted U-shaped curve, whereat arousal levels that are too low or too high impair performance. Therefore, in order to maximize performance, humans should aim at reaching a task-dependent midrange arousal level that balances detrimental influences of under-arousal and over-arousal (Kaufman 1999; Hancock and Szalma 2007).

Moreover, research on users' physiological stress reactions suggest, or even directly show (e.g., Arnetz and Berg 1996), that TS may have detrimental effects on well-being and health (e.g., Arnetz and Wiholm 1997; Boucsein 2009; Maier et al. 2015b; Riedl et al. 2012). For example, stress has been linked to chronic headaches, burnout, obesity, stroke, and cardiovascular diseases (e.g., Bakker et al. 2005; De Kloet et al. 2005; McEwen 2006). SSAESes can help the user to link private health issues to his/her monitored stress data.

In addition to these severe health issues, stress has been shown to decrease performance and productivity, which in turn has detrimental effects on the organizations' overall success (e.g., Tarafdar et al. 2007). In particular, several studies have shown that self-reported stress perceptions may negatively affect performance, productivity, and user satisfaction (e.g., Ayyagari et al. 2011; Ragu-Nathan et al. 2008; Tarafdar et al. 2007, 2010, 2011, 2015), among other variables (e.g., Maier et al. 2015a, c). Moreover, users can build on the stress data collected in SSAESes to reflect on their own performance.

2.5 Enterprise Systems

In our conceptualization, we consider enterprise systems (ESes) a socio-technical phenomenon (Bostrom et al. 2009) accounting for the individual, technological, and organizational components involved (Lauterbach et al. 2013). ESes are traditionally seen as a specific category of information systems used in a professional environment. From a technological point of view, ESes offer a set of functional modules, generally based on industry best practices implemented in the form of packaged software. Packaged software builds the technological core for the resulting packaged application systems in enterprises. Historically, the term ES has often been used as a synonym for enterprise resource planning (ERP) packaged application systems. This rather process- or transaction-oriented perspective has been extended with packages targeting the large-scale integration of information and people (e.g., Groupware). Consequently, the term ES has grown to refer to all large organization-wide packaged application systems, including customer relationship management (CRM), data warehouses (DWHs), ERP, and BI&A (Seddon and Calvert 2010). In the past decade, these organization-wide packaged application systems have been increasingly extended with mobile applications enabling ubiquitous access to business-critical information. To summarize, ES in our work is considered from a technological perspective as a comprehensive and complex application system landscape established and managed by the organization with the intention to support professional activities.

The organizational dimension of ESes can be described by organizational characteristics (e.g., size and industry), organizational resources, and organizational structure. The latter can be decomposed into a functional (e.g., departments and roles) and procedural view (e.g., business processes and tasks). In general, the complexity of ESes is typically higher than in traditional information systems, as they tend to have an organization-wide impact rather than localized effect (Strong and Volkoff 2010). Finally, individuals can be described by individual characteristics (e.g., age, gender, and personality), as well as by their actual behavior (e.g., Tams et al. 2014a). From an individual point of view, employees are expected to execute actions in an organizational environment according to the defined tasks by leveraging the available information and communication technologies.

Focusing on ESes for reducing organizational TS is important for three main reasons. First, ESes have been shown to induce considerable stress levels and users interact with such systems many hours every day. Thus, directly dealing with the major source of the problem is essential. Second, ESes have direct access to a wide range of stress-relevant context data, which are, in turn, essential for stress analytics. Importantly, the collection of such context data would be difficult, or even impossible, on the basis of other sources. Third, ESes provide the technological foundations for effective interventions on the individual, technological, and organizational levels, because the large-scale integration of these different dimensions has always been one of their core functions.

With respect to possible intervention mechanisms (see Fig. 1), in this paper we refer to three levels. First, interventions on the individual level are designed to directly focus on the user (e.g., by training the user to acquire stress coping abilities or by increasing stress awareness through live biofeedback). Second, interventions on the technological level refer to automated technological adaptations that seek to decrease stress emergence and/or emergence of the negative consequences of stress (e.g., temporary interruption of mail servers to reduce the amount of incoming e-mails or application of wizards in case of human-computer interaction problems). Third, interventions on the organizational level refer to task-related measures that may decrease stress emergence and/or emergence of the negative consequences of stress (e.g., reallocation of roles and responsibilities or break schedules when using the ES). Collectively, interventions on all three levels are expected to contribute to reduction of organizational technostress and mitigation of the negative consequences of technostress.

3 Stress-Sensitive Adaptive Enterprise Systems: Design Blueprint

In this section, we propose a design blueprint for SSAESes consisting of (1) design guidelines, (2) an architecture, (3) a roadmap for implementation, and (4) approaches for evaluation. Following a hybrid approach, the proposed design blueprint builds on the theoretical model of TS introduced in Sect. 2 (cf. Fig. 1), and on a series of qualitative exploratory expert interviews and focus groups (see Sect. 1 and Appendix).

3.1 Design Guidelines

The design guidelines are summarized in Table 1. We emphasize that the seven guidelines are intended to assist managers and systems engineers in the development of

Table 1 Design guidelines for SSAESes

Design guideline	Brief description
1. Assess users' individual stress levels continuously and unobtrusively	Stress is a highly individual phenomenon varying over time. It needs to be assessed by appropriate sensors for each individual user continuously or in short time intervals. Importantly, such measurements should be unobtrusive such that measurement-related distractions are avoided at work. This can be accomplished by measuring neurophysiological parameters such as pupil dilation, heart rate, mouse pressure, muscle tension, pulse transit time, and skin conductance
2. Facilitate local interventions at the individual level	The data measured for assessing users' stress levels can be used to actively support users with intervening at the individual level in the stress elicitation process. This can be accomplished (1) by providing users with trainings to increase their stress coping abilities and (2) by providing users with live biofeedback to increase their stress awareness
3. Collect and enrich stress data centrally to build user models	Enrich measurements of current and historic stress data with data on the users' personal characteristics, historic information, and context data to build individual user models and identify for each user stressors related to job characteristics, technological environment, organizational environment, and social environment
4. Analyze and identify common themes and patterns of stress	Analyze similarities of individual user models to extract common themes and patterns on an organizational level. Leverage analysis results to further enrich the user models
5. Trigger user-centered automated technological adaptations	Apply interventions at the technological level on the basis of user stress models. Interventions may include information and e-mail filtering, use of wizards and decision support components, or other adaptations in system features
6. Inform interventions at the organizational level	Interventions at the organizational level of an ES (e.g., break schedules when using the system or provision of a help desk) may be informed by aggregate information on stressors and stress levels
7. Implement gradually and respect boundary conditions in technology, social acceptability, and ethical acceptability	The complexity and novelty of SSAESes suggest a staged implementation in a series of design and design science projects that have to overcome several challenges related to technology development and acceptability

SSAESes. However, it is important to note that we advise against the mandatory or rote use of our design guidelines. Organizational technostress is a complex phenomenon. Thus, while we believe that our guidelines constitute an essential foundation for research and development of SSAESes, we do not claim that our guidelines are complete. First, there is no formal measure to demonstrate completeness. Rather, based on the theoretical and empirical foundations described in this paper, we believe that both the type and number of our guidelines are reasonable. Second, with an increasing level of detail with which guidelines are formulated, it is natural that the number of possible guidelines increases too. In this Research Note, since the topic of SSAESes is novel, we have formulated design guidelines on a relatively abstract level, foreseeing that as the research field matures more guidelines will develop with a lower level of abstraction.

Guideline 1 refers to the continuous and unobtrusive measurement of the users' individual stress levels. The response to stressors and the impact of stress strongly depend on individual characteristics, behaviors, and stress coping strategies (cf. Sect. 3.1). As an example, Ayyagari et al. (2011) found that negative affectivity (defined as "a dispositional factor that reflects a tendency to experience negative emotional states and low self-esteem", p. 842) is significantly positively related to strain (defined as "an individual's psychological response to the stressors", p. 833; also see Podsakoff et al. 2007; note that other TS researchers do not confine strain to a psychological response only, but also include other responses such as physiological, see Boucsein and Thum 1997). It follows, then, that stress reactions, as well as subsequent negative stress consequences (e.g., health or user satisfaction), can be explained, at least partially, by individuals' tendency to evaluate situations more negatively. Importantly, in addition to negative affectivity, a recent review discusses further factors related to personality which may be related to technostress (e.g., neuroticism or impulsiveness; Riedl 2013). Hence, traditional occupational health preventive measures following a one-size-fits-all approach are generally not as effective as measures that allow for contextual and behavioral preventive measures targeted to an individual person. Traditional approaches for assessing stress in an organizational context typically involve questionnaires or manual monitoring of work practice.

We extensively discussed these practices in our four interviews with a workers union. In these interviews it became evident that such assessment procedures are too time-consuming and expensive for SSAESes. Thus, we concluded that unobtrusive measures are preferable for SSAESes. This perspective was explicitly supported by various interviewees, from technology companies (specifically Enterprise Systems Company B and Mobile Software Company A), a company focusing on user experience (Design Company), potential customers of SSAESes (specifically Private Customer A and Public Customer B), and in interviews with IS researchers. A psychologist working in research on occupational health summarized the point as follows: "Today, the assessment of workplace stress is periodic and very time consuming. It would be a strong improvement to have real-time measures of stress […]. For this, you need unobtrusive, incidental measurement techniques." In the other interviews, none of the interviewees questioned the need for unobtrusive measures as basis for SSAESes. However, interviewees from three organizations suggested that this need for continuous and unobtrusive assessment of stress levels poses a challenge to the concept of SSAES in general. Specifically, the workers union, a data privacy and security company, and Private Customer G pointed to the fact that employees might not accept and use a system that invades privacy with continuous assessment of the user's stress level. This concern is reflected in Guideline 7, the SSAES architecture (Sect. 3.2 below), and the roadmap for implementation (Sect. 3.3 below) and, ultimately, will be a matter of empirical evaluation.

Stress levels typically vary over time and depend on the user's current activity (cf. Riedl 2013; Riedl et al. 2013). Thus, for optimal efficacy of an SSAES, stress levels need to be measured continuously or at least at short time intervals, to allow for prompt interventions and stress analytics. This can be achieved by measuring neurophysiological parameters such as pupil dilation, heart rate, mouse pressure, muscle tension, pulse transit time, and skin conductance (cf. Sect. 2).

In *Guideline 2*, we address how data on the users' individual stress levels can be used to facilitate interventions at the individual level. On this account, the mentioned psychologist stated: "Based on detected stress levels […] multiple measures are conceivable: you can adapt the work equipment including, for example, software ergonomics […] and you can take preventive measures at the individual level." As illustrated in Fig. 1, the dynamic process of stress elicitation is moderated by different levels of the ES: individual, technology, and organization. At the individual level, evidence suggests that personal characteristics, abilities, and behavior may affect stress reactions. Men, for example, experience more TS than women (e.g., Riedl et al. 2013), and professionals with greater computer confidence experience less TS than people with lower confidence (e.g., Tarafdar et al. 2011). Moreover, users' self-reported coping strategies (emotion-focused versus problem-focused) are related to self-reported computer-stress, a precursor stress form of today's technostress (i.e., high-computer stress users tended to focus on emotion-focused strategies, while low-computer stress users tended to focus on problem-focused coping; Hudiburg and Necessary 1996). Hence, interventions may include providing users with live biofeedback on their own neurophysiological processes in order to make them aware of their own stress levels and to support them with the application of stress-coping strategies (Ahmed et al. 2011; Astor et al. 2014). This is of particular importance because physiological stress reactions precede the individuals' awareness of stress, and only when stress levels exceed a specific threshold, do people start to consciously perceive the stress (e.g., on the basis of an intense heartbeat or when they feel completely drained after a long working day) (Riedl 2013, p. 36). Live biofeedback may help users to increase interoception and apply stress-coping strategies in the short term, while trainings can support them in expanding their stress-coping capabilities in the mid- and long-term (Picard 1997; Gimpel et al. 2013b; Astor et al. 2014).

Guideline 3 addresses how stress data can be collected and enriched to identify specific stressors of individual users. Stress reactions and their impact are not only highly dependent on the individual user but also on the context of specific tasks, technologies, and social environment. Therefore, stress data need to be collected and enriched with data on the user's personal characteristics, historic information, and context data to build individual user models, and to identify for each user stressors related to job characteristics, technological environment, organizational environment, and social environment. We refer to this kind of analysis as stress analytics. Such analysis can be accomplished, for instance, by granting access to private and enterprise context data such as business processes, calendars, and e-mails. This information needs to be combined with individual user models improving as more and more evidence on the user's specifics become apparent. Some interviewees stated that circumstantial factors do not only play an important role in identifying stressors but also in understanding the currently feasible and appropriate technological adaptations. The use of ambient lighting to provide biofeedback, for example, might be appropriate when the user is by himself/herself but not in an open plan office. This perspective was emphasized by all of the enterprise systems companies we interviewed (labeled as Enterprise Systems Company A, B, C in the Appendix), by the user experience company, and by some potential customers of SSAESes (Private Customer A, B, E). The role of circumstantial factors in the identification of currently feasible and appropriate technological adaptations was no major point of discussion in the other interviews.

Next, in comparing these models across users, *Guideline 4* has the potential to further improve individual models where data are still sparse, and to identify recurring themes across users, which may be the basis for designing further interventions at the individual, technological, or organizational level of the SSAES. In the Volkswagen e-mail example discussed in the Sect. 1, the application of Guideline 4 would enable the management to assess the degree to which e-mails outside business hours affect employees' stress levels. Guidelines 1–3 confine data on an individual user and keep it under the user's individual control. Guideline 4 opens data to the benefit of others on an aggregate and anonymous level.

Most of our interviewees supported the idea that the sharing of data on an aggregate and anonymous level will be accepted by users when they are transparently informed about the exact nature and benefits of data usage. The Human Resource Director at Public Customer A, for example, stated: "Such a system offers great potential for our employees in service units like HR, finance, purchasing, and logistics." However, some interviewees uttered concerns: Most prominently, the representative of the Data Privacy and Security Company addressed this point in our interview: "A continuous and extensive recording of employees' activities is questionable when it allows managers to judge the efficiency of individual employees and to increase pressure to perform." Likewise, the workers union suggested that implementation of Guideline 4 needs to very carefully guarantee legal privacy regulations and potentially applicable labor-management contracts. They suggested that data needs to be aggregated over sufficiently many users (without providing exact numbers on how many users) to hinder inference on individuals. The data privacy expert stated: "Privacy needs to be handled with care here, but that is no rocket-science. Developing a privacy concept for such a system is mostly routine work for a privacy officer like me."

The interviewee from Private Customer G anticipated that a system implementing Guideline 4 would not be acceptable in his organization. While we believe that privacy can be preserved and several interviews suggest that this will be acceptable, this qualitative difference between confining and opening data has led to the separation of Guidelines 3 and 4 and is one reason for suggesting different stages of implementation (see Guideline 7 and Sect. 3.3 below).

In *Guideline 5*, we build on the NeuroIS framework introduced by vom Brocke et al. (2013) and discuss how interventions at the technology level can support the individual in mitigating stress through user-centered automatic adaptations. Adaptation is to be understood as "a process of modifying existing conditions in an effort to achieve alignment" (Majchrzak et al. 2000, p. 572). ESes, particularly the complex structures of packaged software, impose substantial limitations on potential adaptations. However, based on the interviews with three enterprise systems companies, it appears reasonable that policies and rules can be adapted in real time. The interviewee from Enterprise Systems Company B, for example, stated: "We could develop an extension to our call center software, for example. If we would have real-time information on individual stress levels, our software could adapt in real-time to better support the individual call center agent." Two information systems researchers with experience in the design of enterprise systems supported this perspective. The other interviewees did not have a distinct perspective on this issue. Such adaptations can delay, accelerate, reorganize, or automate processes when there is evidence that this will positively affect the users' stress levels. Adaptation does not necessarily need to take place only on the backend process instance level. The user's frontend interface to the packaged software may also be adapted (e.g., via information filtering, changes in screen color, or adaptations in the information presentation mode such as textual vs. graphical), to positively affect stressors or the users' responses to stressors. In addition to changes in the visual display of information, evidence indicates that pleasant music can ameliorate physiological stress, primarily by reducing the activity of the sympathetic division of the autonomic nervous system (e.g., Knight and Rickard 2001; Pelletier 2004). Accordingly, music may play a significant role in SSAES technology.

Guideline 6 addresses interventions at the organizational level. The organizational level of an ES clearly affects stressors and stress reactions, primarily by its structures (e.g., roles, responsibilities, and processes), resources (e.g., staffing levels and technology support), and characteristics (e.g., organizational culture). Adaptation at this level requires overcoming inertia, an organization's inability to change as rapidly as the environment. Countermeasures, whose effectiveness has already been demonstrated empirically, include professionally organized stress management programs such as relaxation techniques (Arnetz 1996), well-designed breaks from work at computers (Boucsein and Thum 1997), computer literacy support, technical support provision, technology involvement facilitation, and innovation support (Tarafdar et al. 2011), and implementation strategies that prepare employees for business process changes (Wastell and Cooper 1996). Thus, organizational structures and resources may be adapted for leveraging knowledge about employees' stress.

However, the difference between SSAESes and existing approaches is that by building on Guidelines 1–5, interventions at the organizational level are informed by stress analytics. Aggregated and anonymized data provide regulators, employee representatives, and managers with information on which stressors can and should be addressed and which countermeasures have been effective or ineffective thus far. On the assumption that employees' privacy remains secured, no interviewee contested the potential benefit of this approach. On the contrary, the potential from implementing Guideline 6 was especially supported by our interviewees from Private Customers B, D, and E.

SSAESes as conceptualized in this article are a major extension of the traditional ES. Technical challenges have to be overcome and users have to get familiar with SSAESes. A staged implementation appears advisable for both the technical and the social aspects of the socio-technical system (*Guideline 7*). Challenges in technical feasibility include hardware and signal processing for long-term, unobtrusive, continuous, and reliable physiological and behavioral stress measurement and analytics. Second, the technical feasibility of the adaptation of the ES to incorporate real-time feedback needs to be tested and proven. Even if technically feasible, the social and ethical acceptability of the SSAES is critical. Exploring data privacy issues and the implications of the SSAES for future work environments and users is an open research challenge. At the level of individual technology acceptance, the determinants of technology adoption and use are well known (e.g., Venkatesh et al. 2003); however, the challenge is to design the SSAES that account for these determinants and to study their relevance for the SSAES. Furthermore, post-adoption IS research specifically investigating user behavior from a dynamic process perspective needs to be considered when designing the SSAES (e.g., Ortiz de Guinea and Webster 2013).

3.2 SSAES Architecture

On the basis of the design guidelines, we propose a high-level reference architecture for the SSAES (Fig. 2). The architecture presented here serves as an illustration and explication of the design guidelines. It is inspired by the existing ES architectures and iterated and refined in a series of interviews. Clearly, however, this SSAES architecture is neither the only nor necessarily the best architecture implementing the design guidelines. Evaluating and refining it in future research will require a series of design science research projects. The architecture follows the distinction between individual, technological, and organizational components introduced in the theoretical background section. The technological component is split into interface services on the user device, a dedicated intelligence service, and the existing packaged application systems embedded within the organization.

In this architecture, Guideline 1 is reflected in the use of sensors and sensor data preprocessing at the individual and technological levels of the ES. For efficiency and privacy preservation, we suggest performing sensor data preprocessing locally on the user device. Analogously, Guideline 2 plays out in the interplay of the user with the local user device. For Guidelines 3 and 4, we foresee an intelligence service that integrates stress assessments and context data,

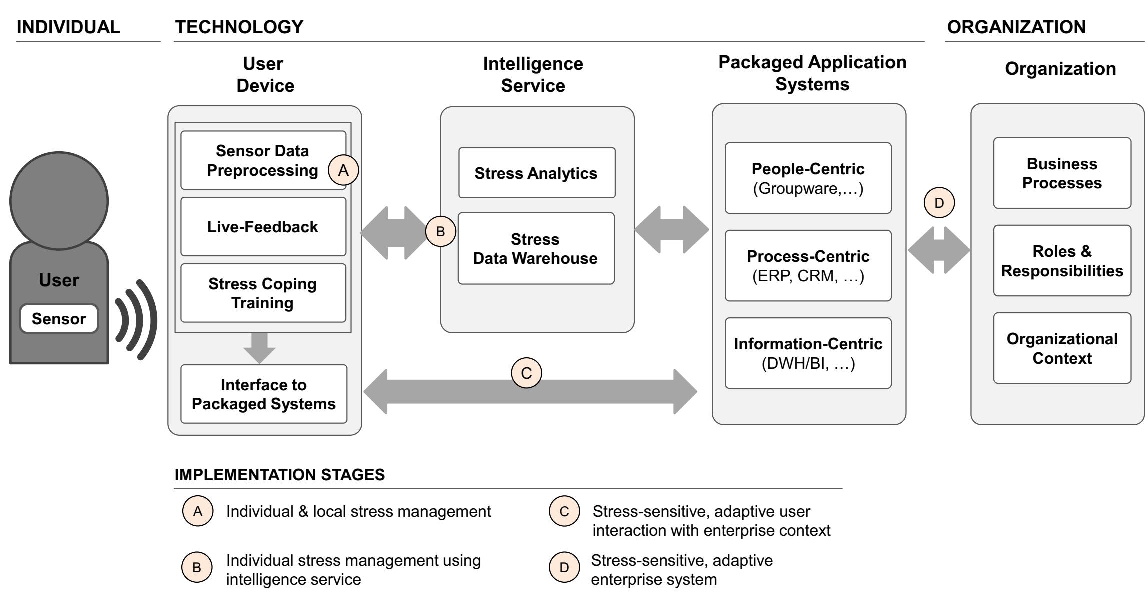

Fig. 2 High-level architecture for the SSAES

performs stress analytics, and manages a stress data warehouse to be assessed for cross-user analyses. Technically, the intelligence service might be located at different levels. For Guideline 3, it might be located either at the user device or a central place. The implementation of Guideline 4 requires the service to be placed centrally in order to facilitate aggregation. Guideline 5 is implemented in form of an adaptive user interface at the user device and adaptive packaged application systems in the technological backend. Guideline 6, consequently, affects the organizational level of the SSAES. Guideline 7, finally, concerns the interplay of the entire architecture.

3.3 Roadmap for Implementation

The realization of a SSAES following a socio-technical paradigm is a complex endeavor. Therefore, on the basis of the architecture and the interviews, we suggest a roadmap for implementation including multiple stages, incrementally increasing the powerfulness of the overall approach (Guideline 7). Empirical evaluation against the articulated design objective should be performed on each stage independently before proceeding to the next stage.

Stage A is individual and local stress management implementing Guidelines 1 and 2. The individual user is equipped with sensors to measure the current stress level and feed data into a user device. While other user devices are conceivable, smartphones appear promising due to their functionality, availability, pervasiveness, and personal control. The device (pre)processes sensor data and, if desired by the user, provides interventions to increase user awareness and training comparable to the "quantified self" movement (Gimpel et al. 2013a), but with an important difference, namely the integration in an ES use context. An example for measurement is a smartphone app provided by SOMA Analytics (Germany, UK) that assesses stress levels via an analysis of voice modulation, typing behavior, and movement detection during the night. An example for live feedback is a technology called "Rationalizer" developed by Philips and ABN AMRO (Netherlands); this device "acts as a kind of 'emotion mirror' in which the user sees reflected the intensity of his feelings in the form of dynamic lighting patterns" (Djajadiningrat et al. 2009, p. 39). Originally developed to make private online investors aware of their emotions, this technology could also be adapted for real-time stress measurement and feedback.

Stage B is individual stress management using a central intelligence service (Guidelines 3 and 4). The underlying architectural paradigm follows established concepts from BI&A systems (Watson 2009). In the first step, a data warehouse as a subject-oriented, integrated, time-variant, and non-volatile collection of stress data is created. By building on these data, we can deploy advanced analytics. For example, similar to fraud management in telecommunications, user profiles may be created and deviation from "normal" behavior may be discovered. Predictive analytics may be leveraged to estimate stress trends in individual users. The advantages of this approach are twofold: First, a central intelligence service can provide more computing and storage capacity and enable more advanced stress analytics and longer histories of personal records as compared to limited user devices. Second, coordination of multiple devices might be easier to realize via a central service than via bilateral interfaces. Moreover, users can optionally feed in personal context, which in turn can enrich stress analytics. The possible interventions remain qualitatively the same but might become more powerful. As a downside, communication between the user device and the central service and the central data storage might lead to increased privacy and security issues (Fairclough 2014).

Stage C is a stress-sensitive, adaptive user interaction with the enterprise context. It implements Guideline 5. By building on the intelligence service, we can adapt the user's local interface to the application systems in real time on the basis of the stress analytics results. One possible approach could be to enrich the existing applications with an assistance or guidance capability providing feedback to the user and leveraging the rich enterprise context combined with individual stress data. In addition to enabling adaptive user interaction with enterprise context, the intelligence service may directly provide information and advanced analytics results on the users' stress levels to the packaged application systems. Information can either refer to an individual user or be aggregated, reflecting the stress level in an organizational unit or in the entire organization. Real-time adaptations in the backend application system could, for example, reprioritize e-mails, re-route phone calls, or re-allocate process instances to other users in the organization. Furthermore, computing power may be allocated differently; for example, when the user is stressed and urgently waiting for analytics results, a business intelligence system may leverage this background knowledge. Key to these adaptions is that privacy remains assured as adaptations are performed locally.

Stage D realizes the full scope of an SSAES. It implements Guideline 6, goes beyond technology-driven adaptations, and allows for interventions at the organizational level. An adaptive organization based on aggregated stress data could, for example, identify general stressors by means of stress analytics and re-engineer business processes to eliminate these stressors. As another example, roles and responsibilities could be re-allocated to reduce the users' stress levels. However, these visions come along with a multitude of legal, ethical, and social aspects, which need to be explored in further research.

3.4 Plan for Empirical Evaluation

The evaluation of the extent to which a design artifact achieves the design objective is an important element of any design process (Hevner et al. 2004). In order to evaluate an SSAES, the architecture needs to be converted to expository instantiations to allow for qualitative and quantitative testing.

We foresee a series of design science research projects that test and refine our blueprint by using laboratory experiments in the beginning, followed by field experiments and naturalistic evaluations combined with use observation, questionnaires, and physiological measurements. As an example, laboratory experiments are needed to systematically study the sensitivity (defined as "a property of a measure that describes how well it differentiates values along the continuum inherent in a construct") and diagnosticity (defined as "a property of a measure that describes how precisely it captures a target construct as opposed to other constructs") of different physiological stress measures (e.g., pupil dilation, electrodermal activity, heart rate) (definitions taken from Riedl et al. 2014, p. xxix). Moreover, field studies have to evaluate the findings from laboratory studies, and must develop solutions to problems that may emerge when SSAES technology is applied in natural settings. For example, pupil dilation is a possible stress indicator in human-computer interaction situations (e.g., Zhai et al. 2005); pupils dilate in situations of stress and constrict in situations of relaxation. However, pupil dilation is also a function of other factors, including lighting conditions; the darker the conditions, the more the pupils dilate. It follows that SSAES technology using pupil dilation as a stress indicator must consider the effects of lighting conditions, among the effects of other factors, an endeavor that is much easier in laboratory conditions than in real-world office conditions.

Moreover, the evaluation of SSAES instantiations should address validity for different individuals, in different organizations, with different ESes, and for different stressors. We suggest that such evaluation studies be structured along four areas: (1) testing the moderating influence of SSAES interventions on the relationship between stressors and stress reactions, (2) testing the moderating influence of the SSAES on the relationship between the stress reaction and the impact (consequences), (3) investigating technical feasibility and usability, and (4) investigating social and ethical acceptability.

In parallel to designing and evaluating this series of SSAESes, design guidelines, architecture, and stages should be evolved with the ultimate goal to develop the blueprint presented here into a design theory. This process may be inspired by the action design research (ADR) method proposed by Sein et al. (2011). In particular, we foresee conscious reflection and learning to go beyond individual instantiations and apply learnings to the design guidelines, architecture, and stages (ADR stage 3). These learnings should be further developed into general solution concepts and be formalized (ADR stage 4).

4 Discussion and Conclusion

In this Research Note, we proposed a design blueprint for SSAESes, a new form of ESes, which are stress sensitive. This sensitivity is a precondition for the SSAES technology to be able to reduce the users' stress levels in order to improve their well-being, health, performance, and productivity, and create positive effects on user satisfaction. This article contributes to the literature by building on and responding to recent IS papers that made explicit calls for the development of neuro-adaptive information systems (Riedl 2013; vom Brocke et al. 2013). In particular, we consider our design blueprint to provide a conceptual foundation for the development of SSAESes.

In terms of the knowledge contributions of design science research (Gregor and Hevner 2013), the SSAES blueprint is an invention, applying a new solution (stress-sensitive ES) to a new problem (organizational TS in the context of ES). Inventions differ from routine design, improvements, and exaptation (i.e., a shift in the function of an object's property during its evolution) by possessing a particularly low application domain maturity and solution maturity. Against this backdrop, this Research Note's key contribution is the SSAES design blueprint, which "may be viewed as a 'freshly planted' conjecture (a proposition that is yet unproven but is believed to be true and has not been disproven)" (Gregory and Muntermann 2011, p. 8). This blueprint extends our existing understanding of the role of ES and the ability to support stress management by information systems; hence, it may potentially "grow" into an emerging theory.

The present work has certain limitations, offering potential for future research. Firstly, while it was our intention to present a high-level design blueprint, it is clear that all components of the architecture (Fig. 2) must be specified in detail in future design efforts. However, the first evaluation results of the development projects are promising (e.g., Astor et al. 2014), substantiating the conclusion that the basic development of stress-sensitive systems with a biofeedback functionality is technically feasible. The presented projects from practice provide further support for this conclusion. Secondly, we consider our design blueprint as a starting point for further discussion and refinement. Based on iterative and incremental design and evaluation processes, the concepts presented in this paper must be further extended and validated. Future work on this topic should follow a theory-guided design approach, strongly involving theoretical and empirical work, particularly including laboratory research and field studies. Thirdly, TS is an individual, organizational, and societal problem caused by ICT; hence, solving the problem technologically (i.e., by using an SSAES) is by no means the only way, or necessarily, the most effective one. Our interview partner from the workers union supported this perspective: "The topic stress has multiple facets beyond IT-based solutions: Sufficient staffing levels, leadership and corporate culture as well as individual stress coping strategies are, for example, important. Technological systems are one option for stress management but we do not yet see empirical evidence for their effectiveness." We need to evaluate the effectiveness of SSAES and whether the SSAES technology itself is a stressor. In this context, Ragu-Nathan et al. (2008) have introduced the concept of techno-invasion, described as "the invasive effect of ICTs in situations where employees can be reached anytime and feel the need to be constantly connected, thus blurring work-related and personal contexts" (p. 427). Therefore, whether or not users are stressed by SSAES technology itself depends on techno-invasion perceptions, and is also influenced by other factors such as the users' tendency to accept the lifelogging concept, "a phenomenon whereby people can digitally record their own daily lives" (Gurrin et al. 2014, p. 2). Fourth, by offering a design blueprint, the paper deals with the problem primarily from a technical perspective; hence, future research must delve into organizational, societal, ethical, and legal issues that result from our approach. As an example from the domain of ethical and legal issues related to our SSAES, a recent commentary paper on psychophysiological adaptation published in *Nature* raised important questions such as "Who owns the data?" and "Who should be allowed to gather and store this information?" (Fairclough 2014). In general, because TS is a highly interdisciplinary phenomenon, we expect a number of different disciplines to contribute to this research (e.g., information systems, computer science, law, medicine, organization science, and psychology). Fifth, we have not yet explored the incentives for employees to use the SSAES. Finally, future research could consider that increasingly more employees use private life systems (e.g., smartphones) for professional activities.

In a recent TS contribution in this journal, Riedl et al. (2012, p. 67) ended their paper with the following statement: "Ironically, it may be the case that future technology, based on biological states of users, is so 'intelligent' as to automatically mitigate stress perceptions of which it is the cause." Firstly, throughout history, humans have always developed technologies that at least partly solved problems created by previous technologies. Secondly, we hope that the present design blueprint contributes to the development of a stress-sensitive ES that makes human-computer interactions in organizational settings less stressful. This should not only advance the accomplishment of instrumental goals such as performance and productivity but also contribute to a user's well-being, health, and satisfaction, thus highlighting the humanistic perspective.

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