Technostress from a Neurobiological Perspective

System Breakdown Increases the Stress Hormone Cortisol in Computer Users

Both scientific research and anecdotal evidence indicate that human-computer interaction may lead to notable stress perceptions in users. This type of stress is referred to as technostress. So far, most studies used questionnaires to investigate technostress. In this article, we draw upon a different conceptual perspective, namely neurobiology, thereby adding a new theoretical lens to the technostress literature. We report on a laboratory experiment in which we investigated the effects of system breakdown on changes in users' levels of cortisol, which is a major stress hormone in humans. The results of our study show that cortisol levels increase significantly as a consequence of system breakdown in a human-computer interaction task. In demonstrating this effect, our study has major implications for information and communication technology research, development, management, and health policy. We argue that future research investigating human-computer interactions should consider the neurobiological perspective as a valuable complement to traditional concepts.

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1 Introduction and Research Question

In 2008, the number of personal computers in use worldwide reached one billion, and another billion is predicted to be reached by 2014 (Gartner Group 2008). Moreover, today approximately two billion people use the Internet (Internet World Stats 2010). In today's society, as computers and the Internet pervade almost every corner of life, the impact of Information and Communication Technology (ICT) on humans is definitive.

Individuals, organizations, and society in general have gained significant benefits through the use of ICT – examples include increased access to information, as well as enhanced performance and productivity (Brynjolfsson 1996; Brynjolfsson and Hitt 2000; Keeney 1999). Despite this positive impact, however, the design, implementation, use, and maintenance of ICT may involve high costs. In addition to ICT product and service costs, hidden costs should also be taken into account when evaluating the impact of ICT on humans (Ayyagari et al. 2011). Specifically, scientific research and anecdotal evidence indicate that human-machine interaction, both in a private and organizational context, may lead to notable stress perceptions in users. This type of stress is referred to as *technostress*, a concept coined by Craig Brod in the 1980s (Brod 1984), and later advanced by Michelle Weil and Larry Rosen, who defined it as "any negative impact on attitudes, thoughts, behaviors, or body physiology that is caused either directly or in-directly by technology" (Weil and Rosen 1997, p. 5).

A review of the literature reveals that most studies have used questionnaires to empirically investigate the nature, antecedents, and consequences of technostress. A research program by Richard Hudiburg on the *nature* of technostress may serve as an example. In this program, an instrument, the "Computer Technology Hassles Scale," was developed to measure technostress. In its most extensive form, the instrument consisted of 69 items for each of which a user is asked to indicate (i) which hassles (e.g., computer system is down, slow program speed, crashed program, incomprehensible computer instructions, too much computer information) have happened to her or him in the past two months and (ii) their severity (Hudiburg 1989, 1995). In addition to this research program, many other studies have also used questionnaires to investigate further facets of technostress.

With respect to the antecedents of technostress, one comprehensive study (Ayyagari et al. 2011), for example, hypothesized that technology characteristics (e.g., usefulness, complexity, reliability) are related to specific manifestations of stress (e.g., work overload). Survey data from 661 working professionals confirmed this hypothesis. Altogether, this stream of research has identified a number of ICT-related factors which may cause stress perceptions in users (Ayyagari et al. 2011; Day et al. 2010; Huston et al. 1993; Ragu-Nathan et al. 2008; Tarafdar et al. 2007). Such stressors may be acute or chronic. While malfunctions (e.g., system breakdown), information overload, or incompatible technologies are stress factors which are of an acute nature, other stressors are of a more chronic nature, such as security demands, expectations for continuous learning, loss of control over time and space due to permanent connectivity, user behavior and performance monitoring, or changes in organizational tasks due to ICT-driven business process reengineering initiatives. However, acute stressors which occur repeatedly may also result in chronic stress perceptions (Day et al. 2010).

In addition to the antecedents of technostress (i.e., acute and chronic stressors), a number of consequences are also reported in the literature; examples are estrangement, irritation, dissatisfaction, computerphobia, lack of task involvement, poor performance, low productivity, and health problems (Brillhart 2004; Hung et al. 2011; Ragu-Nathan et al. 2008; Tarafdar et al. 2007, 2010, 2011a, 2011b; Weil and Rosen 1997). One study (Ragu-Nathan et al. 2008), for example, investigated the influence of technostress on job satisfaction, commitment to the organization, and intention to stay. Based on survey data from 608 users from various organizations, it was found that technostress reduces job satisfaction, as well as organizational and continuance commitment. A further study (Tarafdar et al. 2007), drawing upon data from users in 223 organizations, found that technostress is negatively related to individual productivity and positively related to role stress (i.e., stress created due to role conflict and role overload). Moreover, a research program by Kanliang Wang and Qiang Tu, using survey data from Chinese populations, found that (i) unlike the findings of studies in North America, technostress seems to have no significant effect on employee productivity (Tu et al. 2005), and (ii) employees from companies with both a high degree of centralization and innovation perceive higher levels of technostress than employees in organizations with both a low degree of centralization and innovation (Wang et al. 2008). Finally, one study (Tarafdar et al. 2011b) found, among other results, that men experience more technostress than women.

To sum up, there is consensus in the literature that technostress is a multidimensional construct, which has various antecedents and consequences. Moreover, different moderators (e.g., culture and gender) may affect the relationships between technostress and its antecedents, as well as its consequences.

Despite the value of the vast amount of questionnaire-based technostress research (for a recent review, see Day et al. 2010), in this article we draw upon a different conceptual perspective, namely neurobiology, thereby adding a new theoretical lens to the technostress literature in the information systems (IS) discipline. Our neurobiological approach is substantiated by empirical evidence, which shows that *conscious* stress perceptions of humans, measured by means of questionnaires (e.g., perceived stress scale, PSS, Cohen et al. 1983), hardly correlate with the typically *unconscious* elevations of stress hormones, in particular cortisol increases (Van Eck et al. 1996; Vedhara et al. 2000, 2003). Because repeated and chronic elevations of the stress hormone cortisol may have detrimental effects on health (De Kloet et al. 2005; McEwen 2006; Melamed et al. 1999; Walker 2007), our neurobiological approach constitutes a valuable complement to the existing technostress literature.

In this article, we report on a laboratory experiment in which we investigated a fundamental research question:

Does system breakdown in a human-computer interaction (HCI) task increase users' levels of the stress hormone cortisol?

The scientific value of our study results from the fact that, to the best of our knowledge, research has not yet investigated cortisol responses in users who interact with systems which break down while performing a specific task. Thus, it is not clear whether this type of acute stressor in HCI increases cortisol levels, whereas in human-human interactions it is an established fact that acute stressors (e.g., public speaking) may cause increased cortisol levels (for reviews, see Dickerson and Kemeny 2004; Foley and Kirschbaum 2010). In contrast to other acute stressors in HCI, particularly long and variable system response times (for a recent review, see Boucsein 2009), system breakdowns have been addressed less extensively in the scientific literature. Hence, we decided to investigate this under-explored, yet highly prevalent stressor, thereby closing a significant research gap. The main practical value, of course, primarily pertains to the possible negative health effects of repeated ICT malfunctions, as well as coping strategies which may mitigate the negative effects (Lazarus 1993; Lazarus and Folkman 1984).

Altogether, the present study contributes to a more complete understanding of users' technostress reactions from an endocrinological perspective, thereby providing insights that are of particular significance for scientific fields which connect ICT-related research to neurobiology, namely NeuroIS (e.g., Riedl et al. 2010b), neuroergonomics (e.g., Hancock and Szalma 2008; Parasuraman and Rizzo 2008), and affective computing (e.g., Picard 1997).

The remainder of this article is structured as follows: In the next section, we outline fundamentals of biological stress reactions in humans, as well as some of their harmful effects, particularly those related to health. Afterwards, we describe our laboratory experiment, followed by the presentation of the results and the discussion, as well as suggestions for possible directions of future research.

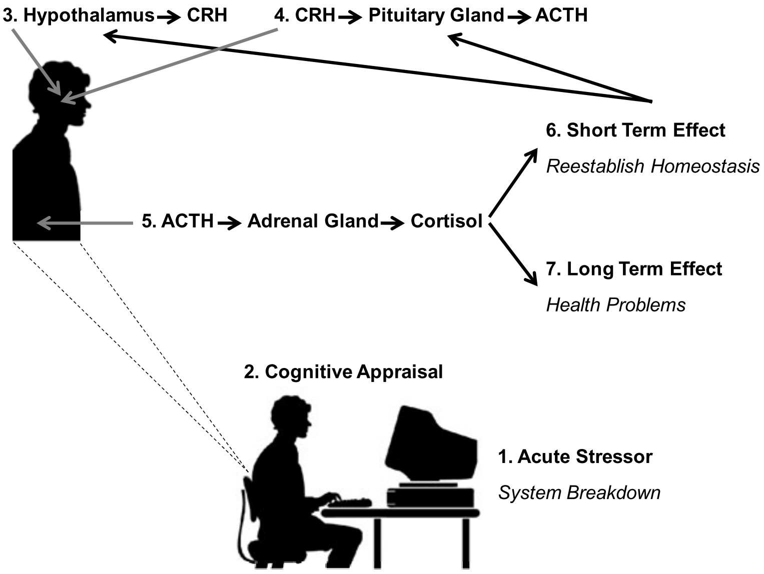


Fig. 1 Hypothalamic-Pituitary-Adrenal (HPA) system in the context of HCI. *Notes*: *Numbers* indicate the temporal order of events, *black arrows* indicate causal directions, *gray arrows* indicate approximate locations; *ACTH*: adrenocorticotropic hormone, *CRH*: corticotropin releasing hormone, *HCI*: human-computer interaction

2 The Neurobiology of Stress

Threats to well-being pervade human life. Thus, humans have to cope with an almost unlimited number of stressors, both physical (e.g., noise, prolonged exercise) and psychological (e.g., public speaking, human-machine interaction). Because of the ubiquity of stress since the most ancient times of mankind, neurobiological systems have evolved to master stressful situations. We outline the major system, the *hypothalamic-pituitary-adrenal* (*HPA*) *axis* (e.g., Tsigos and Chrousos 2002), in the following to provide a conceptual basis for the remainder of this article.

Stressors, particularly psychological ones, affect physiology by activating specific cognitive and affective processes and underlying brain mechanisms (Dickerson and Kemeny 2004; Foley and Kirschbaum 2010). First, specific brain regions (in particular the thalamus and frontal cortex) integrate sensory information based on the perception of an acute stressor such as the breakdown of a computer system. Second, the brain appraises, often in an unconscious manner, the meaning of an environmental stimulus in a specific context, and this cognitive appraisal may result in the generation of emotional responses which are mediated by the limbic system (a major part of the human brain which is related to the processing of affective information), of which the hypothalamus is a fundamental structure. Third, this structure, which acts as a control center for the neuroendocrine system, releases the corticotropin-releasing hormone (CRH). Fourth, CRH influences activity in the pituitary gland, which then releases the adrenocorticotropic hormone (ACTH). Fifth, ACTH travels in the blood to the adrenal glands, where it stimulates the release of cortisol into the bloodstream. The functioning of the human HPA system (Kolb and Whishaw 2009, p. 193) is illustrated in **Fig. 1** in the context of an HCI task.

Cortisol mediates physiological and behavioral stress responses (Dickerson and Kemeny 2004; Foley and Kirschbaum 2010). Among other functions, it enhances blood sugar and delays bodily processes that are not important in a stressful situation (e.g., digestion). Besides cortisol, epinephrine (also known as adrenaline) plays a crucial role in stress situations. However, in contrast to epinephrine, which primarily generates a state of arousal (e.g., by increasing heart rate) thereby mediating a "fight-or-flight" response, cortisol also serves the function to counteract this primary response to stress and thus helps reestablish a stable and constant condition, known as homeostasis. This effect of cortisol acts as a negative feedback inhibition, thereby supporting the establishment of normal activation in the hypothalamus and pituitary gland (see **Fig. 1**). The biological stress processes that have the objective to establish homeostasis are known as the General Adaptation Syndrome (GAS), a concept coined by the stress researcher Hans Selye in the 1940s (Selye 1946).

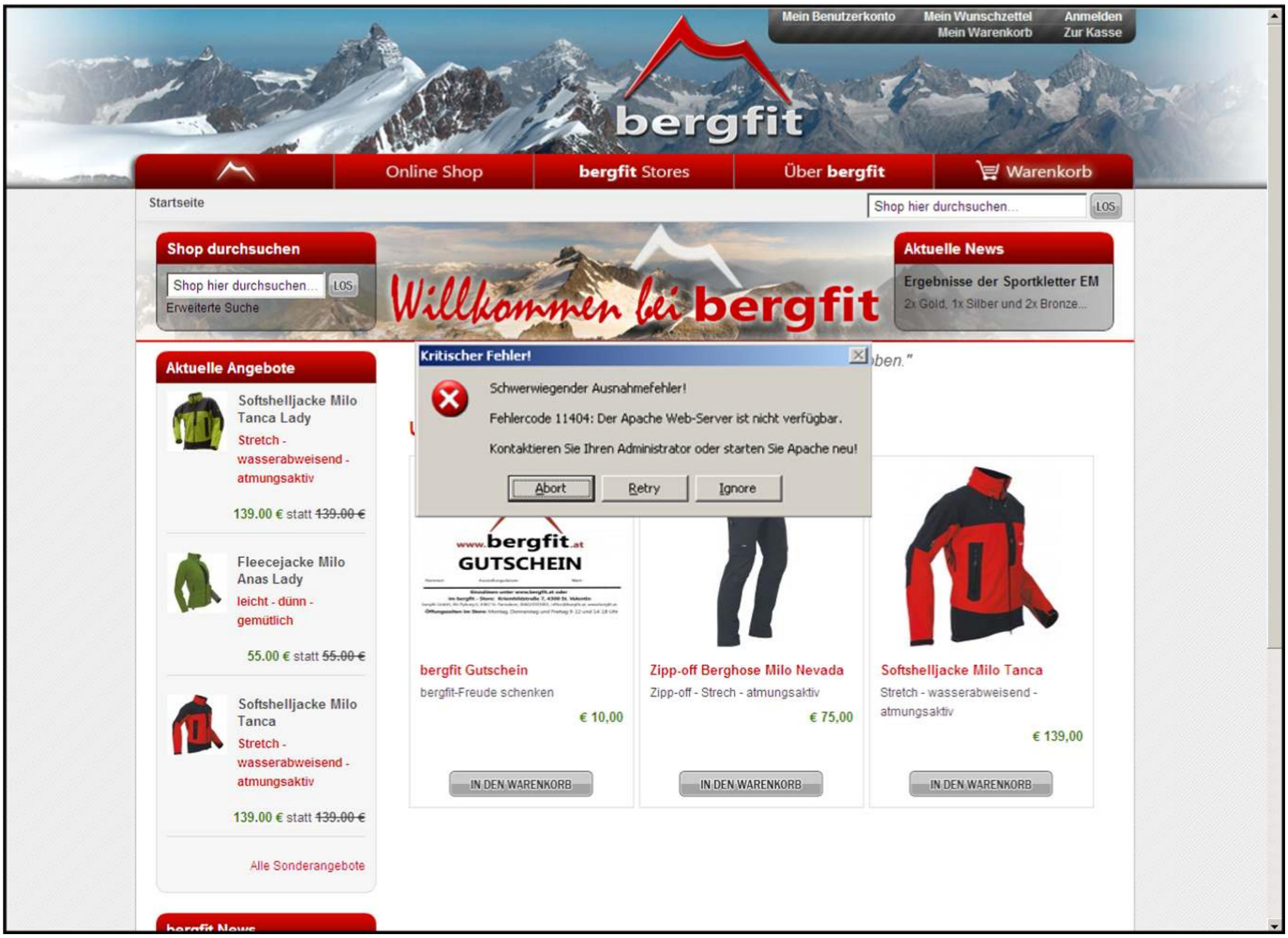
Cortisol increase in stress situations is accompanied by changes in perception, cognition, affect, behavior, and health. It has been demonstrated, for example, that experimentally administered cortisol ameliorates emotional states (Reuter 2002). Moreover, research (e.g., Nater et al. 2006) indicates that acute cortisol responses in stressful situations enhance memory (for a review, see Het et al. 2005). However, despite these positive short term effects, enduring or repeated enhancements of stress hormones may have detrimental long term effects.

Empirical studies show that elevated levels of stress hormones negatively affect human health. Among other consequences of elevated cortisol levels, chronic burnout, depression, abdominal obesity, suppression of immune function, chronic hypertension (high blood pressure), and atherosclerosis (hardening of the arteries) have been reported in the literature (e.g., De Kloet et al. 2005; McEwen 2006; Melamed et al. 1999; Walker 2007). Also, stress can contribute to sleep loss; increased levels of cortisol can delay the onset of sleep, and sleep deprivation raises cortisol levels, setting off a vicious cycle (Society for Neuroscience 2008, p. 32). Altogether, there is overwhelming evidence that elevated levels of stress hormones may significantly influence the development of severe diseases (see, for example, a special issue on stress published in *Dialogues in Clinical Neuroscience*, Vol. 8, No. 4).

3 Methods

3.1 Stimulus Material and Task

The research question we address is whether an acute stressor in HCI increases users' cortisol levels. Because a large number of different acute stressors



Kritischer Fehler!

Schwerwiegender Ausnahmefehler!

Fehlercode 11404: Der Apache Web-Server ist nicht verfügbar.

Kontaktieren Sie Ihren Administrator oder starten Sie Apache neu!

Fig. 2 System Breakdown in the Form of an Error Message. *Notes*: The screenshot illustrates the error message which popped up in the treatment condition. In the control condition, no error message popped up. All stimulus material was presented in German. The error message contains the following text (literal translation): *"Critical Error! Fatal exception error! Error code 11404: The Apache Web server is not available. Contact your administrator or restart Apache!"*

exists in HCI, we had to make a decision about which specific stressor to investigate. We decided to examine the breakdown of a computer system in the form of an error message. Three reasons were crucial for this decision. First, research (Hudiburg 1989, 1995; Weil and Rosen 1997, p. 189) indicates that system breakdowns are among the most significant and prevalent ICT hassles. Second, presumably each user has experienced at some point the breakdown of a system. Third, system breakdown is a stressor which can be implemented in the context of a laboratory experiment more easily than other types of ICT hassles, which are dependent on the actions of the user (e.g., forgetting to save system input) (Hudiburg 1989, p. 1394).

Once we had selected system breakdown as the type of stressor to be investigated, we embedded this stressor into a user interface (see **Fig. 2**). We developed an interface from scratch for the experiment instead of using an existing and therefore potentially familiar system. Thus, we ruled out the possibility that experience with a specific interface affects our results.

The task for the subjects was to search for twelve specific products (e.g., clothing and footwear) and to put them into the shopping cart. The twelve products were illustrated and characterized on the basis of short product descriptions on a sheet of paper, which was placed next to the computer. There was no time pressure to complete the task. Subjects were told that the objective of the experiment is to study the usability of the online shop.

Cortisol elevations typically occur, if (i) central goals are threatened, (ii) the situation is uncontrollable, and/or (iii) task performance could be negatively judged by others (Dickerson and Kemeny 2004). We designed our experimental task to meet all three conditions. First, our participants used computers to accomplish a goal (searching for products and putting them into the shopping cart), which was threatened by system breakdown. Second, once system breakdown occurred, participants were not able to solve the technical problem without external help. Thus, the situation was uncontrollable. Third, participants were aware of the fact that their task performance (putting twelve products in the shopping cart) could be evaluated easily by the experimenter. Thus, there was social-evaluative threat.

3.2 Participants and Sample Characteristics

Based on a between-subjects design, $N = 20$ persons participated in the study (age: $M = 24.7$ years, $SD = 5.5$). To avoid the effects of a menstrual hormonal cycle,

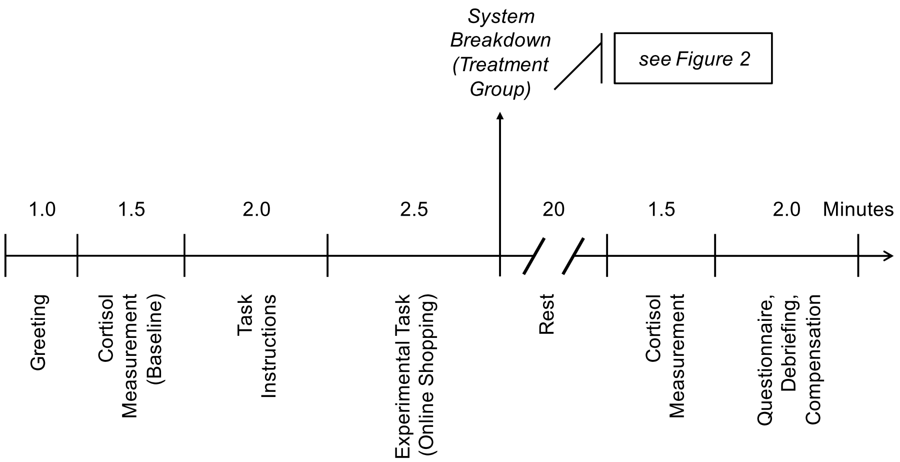


Fig. 3 Experimental protocol

only male subjects participated in our experiment. Each subject was randomly assigned either to the treatment ($N = 10$, with system breakdown) or control group ($N = 10$, no breakdown).

Because the stress effects of system breakdown in a simulated Internet environment (here online shopping) may be related to actual Internet usage, it is important that there is no significant difference between the treatment and control groups on this variable. Because we recruited our subjects via announcements at an Austrian university that mainly offers programs related to ICT, our sample was very homogeneous with respect to "Internet usage." An ANOVA showed no significant difference between the treatment and control groups: $F(1, 19) = 0.212$, $p = 0.651$ (five-point Likert scale with 1 = "very often" and 5 = "never," treatment group: $1.35M/0.34SD$, control group: $1.45M/0.60SD$).

All subjects gave written informed consent to participate in the study, and were financially compensated for their participation. A review board approved the study. Standard exclusion criteria were applied (Takahashi et al. 2005): smoking, drinking, taking medicine, suffering from acute or chronic hormonal dysregulations, as well as psychosomatic or psychiatric diseases. All participants were given instructions not to drink anything containing alcohol or caffeine, nor to do physical exercises from 7.00 p.m. on the day before their participation. Moreover, they were instructed not to eat and drink anything except water within two hours prior to their participation. Because cortisol levels in humans naturally decrease in the morning but are relatively stable in the afternoon (Dickerson and Kemeny 2004), experimental sessions were conducted between 2.00 p.m. and 6.00 p.m.

When compared to traditional behavioral research (both in the behavioral sciences and the IS discipline), sample sizes tend to be relatively small in neurobiological studies. A recent review of papers, including studies in highly prestigious journals such as *Neuron*, *Science*, and *Nature*, found that, for example, the average sample size is $N = 18$ in neuroscience studies (Lieberman et al. 2009, p. 301). Moreover, we investigated the sample sizes of recent neuroscience studies published in IS outlets: $N = 6$ (Dimoka and Davis 2008, *ICIS*), $N = 15$ (Dimoka 2010, *MIS Quarterly*), $N = 18$ (Riedl et al. 2011, *ICIS*), $N = 20$ (Riedl et al. 2010a, *MIS Quarterly*), and $N = 24$ (Benbasat et al. 2010, *ICIS*). Based on these inquiries, we conclude that our sample size is similar to those reported in other neurobiological studies, both in other neuroscience disciplines (e.g., neuropsychology, social neuroscience, neuroeconomics) and IS research. Importantly, a sample size of $N = 20$, as well as the fact that we recruited only males, are typical characteristics of cortisol studies (Nater et al. 2006; Takahashi et al. 2005). Finally, it is crucial to note that statistical power in hypotheses testing is defined as the probability of rejecting H_0 when it is false; major factors that influence this power are effect size *and* sample size (Desmond and Glover 2002). Thus, reaching a statistically significant result based on a small sample size implies a large effect size.

3.3 Experimental Procedure and Data Analyses

Once a participant arrived in the room in which the experiment was conducted and was greeted, the first saliva sample was taken to determine the baseline cortisol level. Because cortisol levels measured in saliva are similar to free cortisol levels measured in blood and cortisol levels in the brain (e.g., $r > 0.90$ between saliva and blood, Foley and Kirschbaum 2010), it was not necessary to take blood samples or spinal fluid samples to obtain valid assessments of cortisol, which in turn provide information about biological stress states. Cortisol data were obtained with Salivette (Sarstedt®) devices. Subjects placed a cotton swab in the mouth and chewed it for approximately 1.5 minutes. Then, the swab with the absorbed saliva was returned to the Salivette. The saliva samples were stored at −20°C immediately on collection until they were brought to a medical laboratory in which biochemical analyses were carried out.

After the first saliva sample was taken, a subject was seated comfortably in front of a computer and the experimenter explained the task. Then, the subject started the HCI task using the list with the twelve products. In the treatment group, we implemented a system breakdown in the form of an error message which occurred exactly 2.5 minutes after the participant's first click in the online shop (see **Fig. 2**); in the control group, no system breakdown was implemented. Following system breakdown, the experimenter came back into the room and pretended that an unplanned technical problem had occurred and that the HCI task therefore had to be stopped. In the control group, the experimenter also returned to the room after 2.5 minutes after the start of the HCI task and explained that the usability test could be stopped. Both in the treatment and control groups, each subject stayed in the room for another 20 minutes until the second saliva sample was taken; cortisol levels have been shown to peak 10–40 minutes after stressor onset, depending on stressor type

(Dickerson and Kemeny 2004; Takahashi 2005).

After the second cortisol collection was completed, subjects filled out a questionnaire (with questions about age, Internet usage, smoking, drinking, medication, acute or chronic hormonal dysregulations, as well as psychosomatic and psychiatric diseases). Then, they were debriefed, financially compensated, and dismissed. **Figure 3** summarizes the experimental protocol. The entire experimental session lasted approximately 30 minutes for each subject.

Biochemical analyses were conducted based on an electrochemiluminescence immunoassay (ECLIA) with high sensitivity (lower detection limit: 0.018 µg/dl) in the medical laboratory of an Austrian hospital, having experience with cortisol measurement in daily clinical routine. Mean intra- and inter-assay coefficients of variation were 3.42% and 6.90%, indicating good measurement reliability (Schultheiss and Stanton 2009). All statistical analyses were performed using SPSS®.

4 Results

The baseline cortisol levels, both in the control and treatment groups, were within the normal concentration range (Takahashi 2005). Importantly, there was no significant difference between the average baseline cortisol level in the control group ($M = 0.248$ µg/dl) and treatment group ($M = 0.254$ µg/dl) ($F(1, 19) = 0.61$, $p = 0.939$). The results of our analyses are illustrated in **Fig. 4**.

After system breakdown, the salivary cortisol level in the treatment group increased sharply and reached an average level of $M = 0.353$ µg/dl. In the control group, in which no system breakdown occurred, we could not observe such an increase in the average cortisol level ($M = 0.252$ µg/dl).

To statistically test whether system breakdown significantly increased cortisol levels, we calculated the differences in cortisol levels between the first and second measurement of the control and treatment groups. This difference in the treatment group ($\Delta = 0.099$) is much larger than in the control group ($\Delta = 0.004$) (see **Fig. 4**). Importantly, the cortisol increase is significant in the treatment group ($z = -2.497$, $p = 0.013$, Wilcoxon Test), while it is *not* in the control group ($z = -0.764$, $p = 0.444$, Wilcoxon Test).

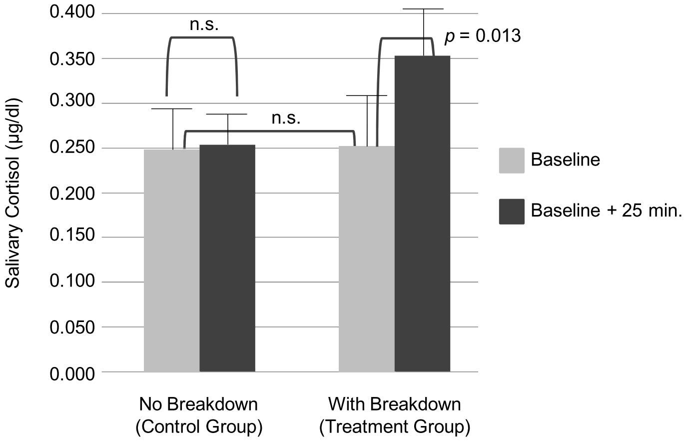


Fig. 4 Salivary cortisol changes after system breakdown. *Notes*: Salivary cortisol levels are indicated in µg/dl. *Light gray bars* indicate average baseline cortisol levels, *dark gray bars* indicate average cortisol levels 25 minutes after baseline measurement. In the treatment group, the second cortisol measurement took place 20 minutes after stressor onset (i.e., system breakdown). The baseline cortisol levels in the control and treatment groups are not significantly different from each other (n.s., $p = 0.939$). System breakdown significantly increased salivary cortisol in the treatment group ($p = 0.013$), while it did not in the control group (n.s., $p = 0.444$). *Error bars* are standard errors of the mean (SEM)

Thus, our study supports the notion that system breakdown in the form of an error message significantly increases cortisol levels in users.

Additionally, we computed a repeated measures ANOVA with timepoint of measurement (baseline, baseline +25 min) as a within-subjects factor. The results of this computation confirm that system breakdown significantly increases salivary cortisol levels of computer users. In the treatment group, we found a significant difference (i.e., increase) between the first and second measurement: $F(1, 19) = 13.642$, $p = 0.005$, $\eta^2[0, 1] = 0.603$; in the control group, we did *not* find a significant difference: $F(1, 19) = 0.039$, $p = 0.848$, $\eta^2 = 0.004$.

5 Discussion and Future Research

The present study shows that system breakdown may cause significant elevations in cortisol, a major stress hormone in humans. To fully understand the implications of this finding, it is important to put the magnitude of cortisol response which we found in the present investigation into a broader context. The standardized mean-change statistic, d, can be used to define the magnitude of the difference between pre- and poststressor cortisol values (M) in standard deviation (SD) units. This statistic is defined as (Becker 1988; Dickerson and Kemeny 2004):

$$d = (M_{\text{poststressor}} - M_{\text{prestressor}}) / SD_{\text{prestressor}}. \qquad (1)$$

A meta-analysis (Dickerson and Kemeny 2004) integrated the findings of 208 laboratory studies, each of which investigated the effect of acute stressors (e.g., public speaking, cognitive tasks, noise exposure) on cortisol response. An average value $d = 0.31$ was found across all 208 studies, and only 5 investigations report $d > 2$. Using our data and formula (1), we find that $d = 0.535$ $[(0.353 - 0.254)/0.185]$. Thus, the present study shows that system breakdown in the form of an error message is an acute stressor which may elicit cortisol elevations as high as in non-HCI stress situations such as public speaking (e.g., Trier Social Stress Test). This finding is of particular theoretical importance, as we are not aware of scientific research that has investigated (i) whether an acute stressor in HCI elicits cortisol responses in users at all, and (ii) the magnitude of such a possible cortisol response. Thus, the present study makes a contribution towards closing a significant research gap.

The health implications of ICT-related stressors are not well understood today, although technostress researchers already pointed to this problem in the 1990s: “It is important to recognize that the seemingly tiny frustrations that people experience every day have a cumulative negative impact on psychological and physical health . . . Blood pressure rises, sleep is disrupted, and people slug down tablets" (Weil and Rosen 1997, pp. 5–6). However, the research studies which have been carried out demonstrate notable effects of both acute (Trimmel et al. 2003) and chronic (Korunka et al. 1996; Wastell and Newman 1996) ICT stressors on physiological parameters, which in turn have been shown to have the potential to affect health considerably (Dickerson and Kemeny 2004). Considering this fact, we call for future studies that investigate the potentially harmful health effects of technostress. In general, drawing upon work by Turner and Karasek (1984), we argue that it is important for future IS research initiatives to consider information systems design, work performance and productivity, as well as health and well-being, as interrelated factors. Specifically, health and well-being mediate the influence of system design on performance and productivity (Wastell and Newman 1996), and thus neglecting the neurobiological perspective with its influence on health and well-being would only provide a limited view on the interaction of humans with computers.

Cultural backgrounds of users may moderate the impact of technostress on important outcome variables. One study (Tu et al. 2005) using data from China, for example, found that technostress has no significant impact on employee productivity, while studies drawing upon North American populations indicate unfavorable performance effects (e.g., Tarafdar et al. 2010). Against this background, future research could investigate whether both acute and chronic ICT stressors lead to different biological stress reactions (e.g., elevated cortisol levels) in users from different cultures. If so, the biological approach would constitute a strong predictor of the effects of ICT usage, in particular health states, thereby signifying an important complement to the traditional, often questionnaire-based approach in ICT research (e.g., Dimoka et al. 2012; Loos et al. 2010; Riedl et al. 2010b).

Given the possible negative consequences of technostress for both psychological and physiological well-being, the question for effective coping strategies arises. In essence, two broad categories of coping strategies exist: problem-focused and emotion-focused (e.g., Lazarus and Folkman 1984). The former strategy seeks to change the person-environment realities associated with a stressful situation, for example, by increasing computer knowledge to elevate the controllability of possible ICT malfunctions, while the latter attempts to reduce negative feelings by changing the appraisal of a given stressful situation, for example, by downplaying the possible negative effects of an ICT hassle on the accomplishment of a goal (Hudiburg and Necessary 1996). Independent of a user's chosen coping strategy, it would be rewarding to investigate the effects of different strategies on stress hormone changes.

Both problem- and emotion-focused coping strategies are based on a user's proactive behavior (e.g., taking a course to increase computer knowledge) and conscious thoughts (e.g., downplaying negative effects of ICT hassles). Despite the practical value of these two coping strategies, cutting-edge engineering initiatives seek to build information systems which automatically recognize and utilize a user's *unconscious* stress level in order to facilitate interaction with the system.

Such systems utilize a user's biological stress states as real-time input in order to dynamically adapt the interface so that stress levels become reduced. Based on unobtrusively measurable biosignals (e.g., pupil dilation and skin conductance) a system may recognize high levels of stress (e.g., due to information overload), and this recognition could be used to dynamically adapt the interface (e.g., reducing the quantity of information shown on the screen and/or changing the information presentation mode). System prototypes, both in academia (Gao et al. 2007; Zhai et al. 2005) and industry (http://www.mirrorofemotions.com/), already use biological stress states as real-time input (e.g., pupils dilate and skin conductance increases during stress). This input, in turn, gives the system the capability to be aware of a user's emotions, and this so-called "affective computing," in turn, may result in more meaningful, natural, and/or productive human-machine interaction (Byrne and Parasuraman 1996; Loos et al. 2010; Parasuraman and Rizzo 2008; Picard 1997, 2003). 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.

Abstract

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Technostress from a Neurobiological Perspective

System Breakdown Increases the Stress Hormone Cortisol in Computer Users

Despite the positive impact of information and communication technology (ICT) on an individual, organizational, and societal level (e.g., increased access to information, as well as enhanced performance and productivity), both scientific research and anecdotal evidence indicate that human-machine interaction, both in a private and organizational context, may lead to notable stress perceptions in users. This type of stress is referred to as technostress. A review of the literature shows that most studies used questionnaires to investigate the nature, antecedents, and consequences of technostress. Despite the value of the vast amount of questionnaire-based technostress research, we draw upon a different conceptual perspective, namely neurobiology. Specifically, we report on a laboratory experiment in which we investigated the effects of system breakdown on changes in users' levels of cortisol, which is a major stress hormone in humans. The results of our study show that cortisol levels increase significantly as a consequence of system breakdown in a human-computer interaction task. In demonstrating this effect, our study has major implications for ICT research, development, management, and health policy. We confirm the value of a category of research heretofore largely neglected in ICT-related disciplines (particularly in business and information systems engineering, BISE, as well as information systems research, ISR), and argue that future research investigating human-machine interactions should consider the neurobiological perspective as a valuable complement to traditional concepts.

Keywords: Cortisol, Hormone, Hypothalamic-Pituitary-Adrenal (HPA) axis, Neurobiology, NeuroIS, Stressor, System breakdown, Technostress

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