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stressOUT: Design, Implementation and Evaluation of a Mouse-based Stress Management Service

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Abstract. Work-related stress has the potential to increase the risk of chronic stress, major depression and other non-communicable diseases. Organizational stress monitoring usually applies long-term self-report instruments that are designed in a retrospective manner, and thus, is obtrusive, time-consuming and, most important, fails to detect and predict short-term episodes of stress. To address this shortcoming, we apply design science research with the goal to design, implement and evaluate a stress management service for knowledge workers (stressOUT) that senses the degree of work-related stress solely based on mouse movements. Using stress theory as justificatory knowledge, we implemented stressOUT that tracks mouse movements and perceived stress levels randomly twice a day with the goal to learn features of mouse movements that are related to stress perceptions. Results of a first longitudinal field study indicate that mouse cursor speed is negatively related to perceived stress. Future work is discussed.

Keywords: Stress monitoring · Mouse tracking · Human-computer interaction · Neuromotor noise · Stress theory · Longitudinal observational field study.

1 Introduction

Work has changed over the past decades, resulting in steadily increasing workloads [9]. By 2020, approximately five out of ten health issues worldwide will be stress-related and the workplace will constitute the primary source of stress [4]. In this work, stress is defined as the "psychological and physical state that results when the resources of the individual are not sufficient to cope with the demands and pressures of the situation" [25, p. 67]. It negatively impacts the health condition of employees and thus, also the performance of their organizations. That is, stress has a negative relationship with perceived quality of life, work-related goals, self-esteem or personal development [25, 27].

Detection of work-related stress represents therefore a prerequisite not only to anticipate any negative health effects in the long term but also to offer just-in-time (organizational) health promotion interventions [26]. Beyond organizational and psychological barriers to directly report stress to colleagues or supervisors [7], there already exist several self-report instruments for measuring individual stress levels [5, 6, 18, 30].

However, applying these instruments has two major limitations: First, stress polls are usually conducted at a low frequency with several weeks or even months in between [33]. The resulting granularity of stress data is low, i.e. short-term episodes of stress with serious negative health outcomes cannot be identified reliably. Second, conducting work-related surveys several times a year, is time-consuming, obtrusive and costly due to data collection, analysis and interpretation activities. The measurement itself affects the performance of employees, too.

Recent findings in the field of human-computer interaction indicate a link between mouse movements and affective states of individuals [14, 17, 29]. It has been even shown a link between mouse movements and stress perceptions [32]. However, shortcomings of current findings are either the artificial mouse tasks employed or that the studies were conducted in a laboratory or experimental [14, 17, 32] or a highly-controlled field setup [17, 29]. Our research aims to address these shortcomings and thus, formulates the following research question: *Which features of mouse movements are related to stress perceptions at the workplace in the field?*

To address this question, we apply design science research [1, 16] with the goal to design, implement and evaluate a stress management service, denoted as stressOUT, that senses knowledge workers' stress solely based on mouse movements. We focus on knowledge workers, i.e. employees that are seen as "the most valuable asset of a 21st-century" [8, p. 79], because they usually use a computer mouse rendering these interactions a mirror of their work. We further adopt stress theory and its neuromotor noise concept [34] as justificatory knowledge to build stressOUT. In this research-in-progress paper, we describe the design and evaluation of a first version of stressOUT. This version does not yet automatically detect work-related stress but does record mouse movements together with subjective perceptions of stress with the goal to identify relevant mouse movement features that are related to these stress perceptions. To motivate employees to use this first and still obtrusive version of stressOUT, i.e. to provide their stress perceptions on a regular basis, the application also visualizes perceived stress over time in the form of a quantified-self diary and provides weekly intervention tips to support employees to better cope with their work-related stress.

The remainder of this work is structured as follows. Next, we present the justificatory knowledge of stressOUT from which concrete design requirements are derived. Then, the stressOUT application is described. With a focus on our research question, i.e. the identification of relevant mouse features, we describe a longitudinal field study and present preliminary findings. We finally discuss the results and provide an outlook on future work.

2 Justificatory Knowledge and Hypothesis

The goal of this section is to outline the theoretical underpinnings of the envisioned stressOUT application. Stress theory, as introduced by van Gemmert and van Galen [34] and adopted by research in human-computer interaction [e.g. 14, 22], is considered in the current work because it aims at explaining the relationship between work-related stress, variations in the motor system through the concept of neuromotor noise, and human performance. It allows us therefore to theorize about the relationship between an employee's motor performance as reflected by mouse movements and the degree of work-related stress.

In contrast to organizational stress detection approaches that employ self-report instruments [2], stress theory is derived from neurophysiology [34]. The theory suggests that an imbalance of high job demands and low job resources is reflected by increased information processing demands. These "increased processing demands (e.g. in dual-task situations) lead to increased levels of neuromotor noise and, therefore, to decreased signal-to-noise ratios in the [motor, the author(s)] system." (ibid., p. 1300) Here, neuromotor noise is a key concept and outcome of stress that is generated by cognitive activities in the brain. In high-demand work situations, neuromotor noise results from a competition of individuals' information processing resources (ibid.). The resulting decrease of the signal-to-noise ratio has direct effects on the motor system, which can be measured by increased variations of human movements. Against this background, mouse movements have already been shown to be valid proxies of cognitive and affective processing in laboratory settings [14, 23, 36] because they provide "continuous streams of output that can reveal ongoing dynamics of processing, potentially capturing the mind in motion with fine-grained temporal sensitivity." [12, p. 1]

With respect to these considerations, we assume that mouse movements under work-related stress will still follow a trajectory towards a pre-defined mouse target, for example, a button or a position within a paragraph in a word processing application. However, in the sense of an neuromotor noise overlay, this trajectory will be *overwritten* by micro-movements ("shivering") and needs to be re-adjusted several times as depicted in Fig. 1. First visual inspections support this assumption (see Fig. 2). Here subjects had to move the mouse pointer several times 600 pixels from the left to the right target.

As neuromotor noise results in a decreased signal-to-noise ratio of the motor system, we assume that mouse cursor speed will naturally decrease in high-stress situations due cognitive load required for these re-adjustments. Therefore, we hypothesize the following relationship with respect to our research question:

Hypothesis: Mouse cursor speed is negatively associated with perceived stress.

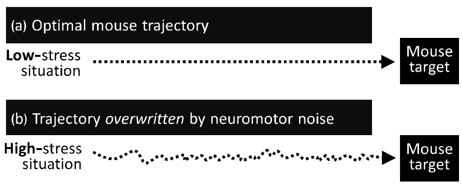

Fig 1. Assumed mouse trajectories in low-stress (a) and high-stress (b) situations

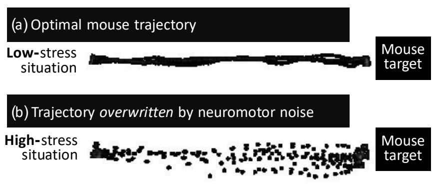

Fig 2. Actual mouse trajectories of one single subject in a low-stress (a) and high-stress (b) situation

3 Design Requirements for stressOUT

To test the hypothesis and to build the envisioned stressOUT service for knowledge workers, the following two design requirements (DR) were defined:

DR1: stressOUT must be able to record mouse movements unobtrusively.

DR2: stressOUT must provide a user interface to record subjective stress levels.

Although these design requirements focus directly on the research question and hypothesis of the current work, they do not provide any utility to knowledge workers per se with the consequence that they are not using stressOUT. Consequently, employees must be motivated in the first place to use stressOUT on a regular basis. Therefore, additional requirements have been identified. For this purpose, we collected feedback from eight knowledge workers (three females) of a business organization who were interested in testing stressOUT in a longitudinal field study. Here, the primary contact was the director of the human resources (HR) department. The following requirements resulted from a three-hour focus group discussion excluding the director of the HR department:

DR3: stressOUT must visualize perceived stress data in the form of a diary to foster an individual's self-reflection capabilities.

DR4: stressOUT must provide an option to share an individual's stress data with colleagues, friends or supervisors. The goal is to encourage a discussion about critical stress events and to better handle them in future situations.

DR5: stressOUT must provide a list of strategies and / or tips to better cope with work-related stress.

DR6: stressOUT must give employees the full control of their data. That is, employees must be able to delete the complete history of their stress recordings without any limitations or negative side effects, e.g. by the HR department or any of their supervisors.

4 Implementation of stressOUT

The stressOUT app is a cross-platform Java program that runs on several operating systems. It is planned as a module for the open source behavioral intervention platform MobileCoach (www.mobile-coach.eu) [10, 15]. A schematic overview of stressOUT is shown in Fig. 3. In line with DR1/2, stressOUT consists of two sensing modules, i.e. one for mouse movements and one for stress perceptions. In particular, mouse coordinates and meta information (e.g. single-click, double click, etc.) are stored together with timestamps in a text file. While previous experimental research used artificial high sampling rates (e.g. 500Hz), special mouse hardware and dedicated software drivers [e.g. 11, 32, 35], stressOUT employs a standard sampling rate of today's operating systems and of-the-shelf computer mouse hardware, i.e. about 125Hz on average.

According to the notion that "stress and emotion should be treated as a single topic" as "emotion encompasses all the phenomena of stress" [21, p. 53], we operationalize perceived stress as an emotional response to a stressor [e.g. 19-21, 25, 31]. Consistent with prior work [13, 28], we used an adapted version of the Self-Assessment Manikin (SAM) [3] to measure the arousal and valence dimension of emotions several times a day as opposed to instruments designed to measure stress over several weeks such as the Perceived Stress Scale [5]. While arousal is used to measure the intensity of stress, i.e. it was anchored from completely relaxed (1) to fully stressed (7), valence measures whether the emotions are perceived rather negative (1) or positive (7), also known as distress and eustress [24, 31]. We did not include the dominance dimension of SAM because prior research on work-related stress focused on arousal and valence only [24]. Moreover, it has been recently shown that dominance ratings were not related to physiological stress but valence and arousal ratings [28]. A corresponding stressOUT screen is shown in Fig. 4 (all screenshots in this paper were translated into English) and pops up if an employee clicks on a small 120 square-pixel stressOUT icon on the lower right corner of the desktop, which slowly moves the eyes and hands, indicating that it is time to create a new perceived stress record. In accordance with the HR department and standard working hours of the employees of our industry partner, the stressOUT icon appears twice per day at a random point in time, once between 9:00 am and 11:00 am and once between 2:00 pm and 4:00 pm.

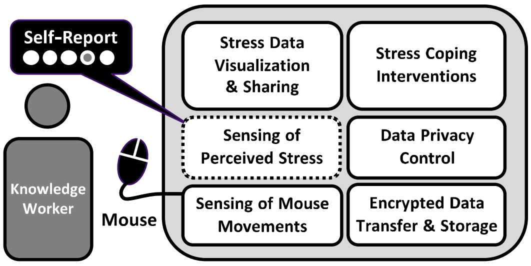

Fig. 3. Schematic overview of stressOUT. Note: The dotted sensing module is required only in the first version of stressOUT, i.e. to identify relevant features of mouse movements

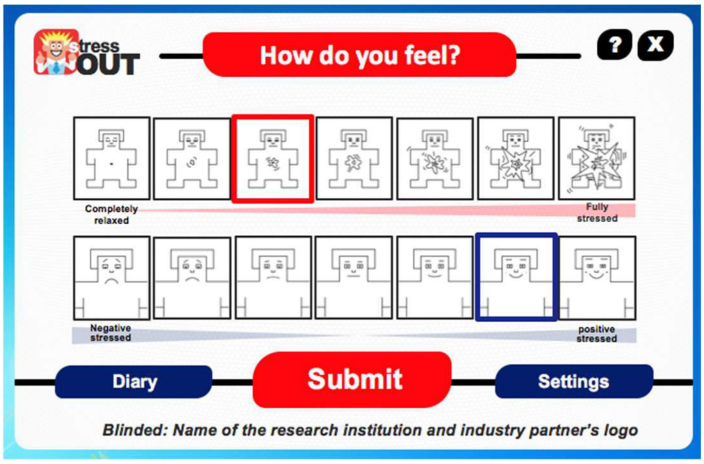

Fig. 4. Recording stress perceptions.

Furthermore, a stress visualization and sharing module (DR3 and DR4) as shown in Fig. 5 allows employees to monitor and share their stress perceptions in the form of a visual quantified-self diary. The stress intervention module (DR5) provides tips to better cope with work-related stress on a weekly basis. The tips are provided in the form of short text paragraphs as shown in Fig. 6 or audio files and covered topics such as relaxation exercises or recommendations to increase physical activity or to switch the smartphone off for several hours. In line with the last requirement, the privacy control module allows employees to take full control over their data. That is, they could use a button to share their stress data or delete the complete history of their stress reports. Finally, we implemented also an encrypted data transfer and storage module that allowed us to collect the stress data on a central server for data analyses.

Fig. 5. Visual stress diary with share option

Fig. 6. The list of relaxation tips

5 Longitudinal Observational Study and First Results

To test our hypothesis, we conducted a longitudinal field study with a business organization between December 2015 and April 2016. The study was accepted by the authors' institutional review board. The HR department of our industry partner invited 496 knowledge workers with dedicated computer workstations by email. This invitation contained a link that allowed employees to participate and to directly install the stressOUT application by the company's software delivery platform. No financial incentives for participation were offered but the employees were invited to a social stressOUT event after the study that had the objective to present and discuss the results and to gather feedback from the participants with respect to further improvements of stressOUT. Overall, 62 (12.5%) employees (28, 45% females) accepted the invitation and submitted their stress levels at least ten and at most 62 times resulting in an overall dataset of 2.086 tuples of stress perceptions, i.e. arousal and valence values, at a specific point in time. Mouse cursor speed in pixel per millisecond was calculated and averaged for the last 30 minutes before each stress report.

Because of the data collection approach and the resulting data structure, i.e. stress perceptions and mouse interactions are nested within each participant, we adopted a linear mixed-effects model to test our hypothesis. We used the lme4 package version 1.1-12 for R version 3.3.3 for this purpose and calculated first a random intercept only (RIO) model with subjects as the random effect: $RIO_{arousal}$=lmer(arousal~(1|subject)), data=stressOUT, REML=FALSE). Then, the random intercept model with cursor speed as fixed factor was calculated ($RIMCS_{arousal}$=lmer(arousal~ speed+(1|subject)…) and compared with the $RIO_{arousal}$ model by analysis of variance. We found no differences between the two models ($\chi^2(1)$=0.28, p=.600). That is, mouse cursor speed is not significantly related to arousal ratings.

The same analysis was then applied to the valence ratings. Here again, no differences of the two models were found ($\chi^2(1)$=3.24, p=.071). However, the probability to reject the null hypothesis by chance decreased considerably to .071. Here, mouse cursor speed explained R^2=0.15% of a total variance of R^2=43.7% for $RIMCS_{valence}$ (the r.squaredGLMM function of the MuMIn package version 1.15.6 for R was used to calculate marginal and conditional R^2 coefficients). That is, cursor speed increases valence ratings by about 0.15 ± 0.083 (standard errors) indicating that lower (higher) mouse cursor speed is associated with more distress (eustress).

Finally, we used the arousal ratings, i.e. the intensity of emotions, as weighting factor on the valence ratings. To separate distress from eustress, valence ratings were first recoded from -3 (negative valence) to +3 (positive valence). Cases with valence ratings of zero were dropped as multiplication with varying arousal ratings is not defined. With the resulting 209 cases, the RIO and RIMCS models differ significantly ($\chi^2(1)$=5.63, p=.018). Now, cursor speed explains R^2=2.13% of the variance from a total of R^2=48.6% for RIMCS. That is, cursor speed increases the weighted valence ratings by about 1.24 ± 0.52 (standard errors) indicating that lower (higher) mouse cursor speed is associated with more distress (eustress). The data supports therefore our hypothesis.

6 Discussion and Future Work

To the best of our knowledge, this research-in-progress presents for the very first time results from a longitudinal field study in a realistic organizational (business) context that evaluates the relationship between work-related stress and mouse movements. Indeed, we could identify a significant and negative relationship between mouse cursor speed and the degree of perceived (di)stress when arousal and valence reports are combined. We also find that lower mouse cursor speed is associated with more distress measured by valence and that there is no association with emotional arousal ratings. These findings are promising as they are consistent with prior work [14, 17] that conducted their studies in more controlled environments as opposed to this work.

We presented only preliminary findings. We will therefore expand our analysis not only to additional features of mouse movements such as the standard deviation of speed, deviation from the shortest path between two mouse clicks or the time range used to aggregate the features, but we will also control for chronic stress conditions, personality traits and additional socio-demographic factors which we have also collected. In addition, we will build and evaluate a stress classification module for the stressOUT application. To conclude, there is only first evidence from data “in-the-wild” that cursor speed is related to stress and further analyses are required to come close to the envisioned stressOUT service that detects work-related stress with high accuracy.

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