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myStress: Unobtrusive Smartphone-Based Stress Detection

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MYSTRESS: UNOBTRUSIVE SMARTPHONE-BASED STRESS DETECTION

Research in Progress

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Abstract

Life is becoming increasingly stressful in many aspects, e.g., due to technology-induced stress and stress in organizational context. The assessment of stress experienced by individuals enables stress management and prevention with the long-term aim to avoid psychological and physiological harm from excessive stress. Commonly this assessment is performed through questionnaires on perceived stress or physiological measurements evaluating body reactions to stress. We explore a third assessment method: Our design science approach aims to unobtrusively assess perceived stress based on smartphone data while waiving additional devices and explicit user input. The presented design artefact, myStress, reads 36 hardware and software sensors to infer users' perceived stress levels. A prototypical instantiation of myStress for the Android platform is distributed to test users. For evaluation purposes, the stress level additionally is determined by a questionnaire consisting of the Perceived Stress Scale. By analyzing data from test users, we gain first insights into the feasibility of unobtrusive, continuous stress assessment considering exclusively data from smartphone sensors. We find that several sensors seem to correlate with perceived stress, e.g., the frequency of switching the display on/off. For future research, behavioral and situational prevention measures can build on this method of unobtrusive stress assessment.

Keywords: human stress detection, mobile sensing, smartphone application, design science.

1 Introduction

Today stress is omnipresent as never before. A facet increasingly discussed in information systems literature is technostress. It contributes to a general trend of growing overall stress perception in human society with detrimental effects for human health and performance (Riedl, 2013). This increase in stress is not limited to an organizational context and not only induced by technology, but in many aspects life generally is becoming more stressful (Ferreira et al., 2009).

In spite of the fact that stress is neither per se good nor bad (Ferreira et al., 2009; Lu et al., 2012), excessive stress is the second most frequent health problem in the European Union (Varvogli and Darviri, 2011). Besides that, stress influences the personal wellbeing (Riedl, 2013) and attains growing attention in the German economy and legislation, especially in the industrial sector (Berufsgenossenschaft Handel und Warendistribution, 2013). Moreover, stress can also negatively affect important decisions (Astor et al., 2013). To address this problem, biofeedback is seen as a possible solution (Varvogli and Darviri, 2011). Preceding this feedback or any behavioral or situational stress prevention measure, however, an assessment of the level of stress is required.

This assessment is commonly performed through questionnaires (e.g. Perceived Stress Scale (Cohen et al., 1983), Perceived Stress Questionnaire (Levenstein et al., 1993)) or physiological measurements (e.g. Cortisol levels (Riedl, 2012), skin conductance (Riedl et al., 2013)). While questionnaires focus on perceived stress, physiological measurements assess stress premised on the physiological reaction. Our research aims to unobtrusively assess people's perceived stress level during daily life. While additional devices like wearables do not gain much attention in public yet (Statista, 2014c), smartphones as a part of everyday life (Abdelzaher et al., 2007) are an appropriate data source to gather environmental and behavioral information associated with stressors and strains. Thus, we waive additional devices and periodical questionnaires, which could burden the user and potentially be stressors themselves.

During our design science research, we designed and developed the Android application myStress with 36 integrated sensors to infer the perceived stress level of the user. For evaluation but not as part of the future system, perceived stress is determined by a questionnaire that appears three times a day. Data privacy, usability and resource efficiency are important non-functional requirements. Our research provides first insights into the feasibility of exclusively smartphone-based unobtrusive stress detection (e.g. frequency of switching display on/off correlates with stress) and its limits (e.g. need for frequent usage of one smartphone).

This paper is structured according to the suggestions by Gregor and Hevner (2013): The next section provides background on both the physiological and psychological nature of stress. Section 3 reviews related work on smartphone-based sensing. Section 4 outlines the research setup, Section 5 describes the design and distribution, Section 6 shows first evaluation results, and Section 7 concludes with an outlook on ongoing and future research.

2 Theoretical Background on Stress

There exist several definitions for the term *stress*. According to Varvogli and Darviri (2011) "stress is defined as a state of threatened or perceived by the individual as threatened homeostasis and it is re-established by a complex repertoire of behavioral and physiologic adaptive responses of the organism". Another definition describes stress from a purely response-based view (Aamodt, 2012). Others explain stress as an independent variable, which causes a reaction to people (Earnshaw and Cooper, 2000). In this paper we build on the Transactional Model of Stress by Lazarus and Folkman (1984), one of the most referenced frameworks for understanding human stress (Google Scholar lists over 30,000 quotes). Lazarus and Folkman (1984, p. 9) conceptualize stress as a two-way process that involves the production of and responses to stressors: "Stress occurs when an individual perceives that the demands of an external situation are beyond his or her perceived ability to cope with them".

The human mind is permanently challenged by *stressors*, which are internal or external stimuli with a certain influence on our mental or physiological resources (Varvogli and Darviri, 2011). These stressors can be both physical (e.g. temperature, humidity, noise, lack of sleep) and psychological (e.g. social problems) (Riedl, 2012; Lu et al., 2012). Yet, the respective effect and consequences depend on the individual. Each stressor has to pass a filtering perception to get recognized. An internal process called primary appraisal classifies invading stressors into three categories: positive, irrelevant or danger. The latter category is further divided into challenges, threats and harms. In a secondary appraisal, mind and body try to struggle with the stressors that were categorized as "danger" by the primary appraisal (Lazarus and Folkman, 1984). This initial response to stressors is defined as the stress syndrome (Varvogli and Darviri, 2011). If an individual lacks resources to cope with these dangerous stressors, the result is stress, which further leads to *strains* (Lazarus and Folkman, 1984).

To deal with strains, different response strategies can be applied. This process is called coping and Lazarus and Folkman (1984) distinguish two different types: Problem-focused coping and emotion-focused coping. With problem-focused coping, the strained person tries to change or influence the situation that causes the stressor. Requesting assistance (e.g. seeking social support (Thoits, 1995)) or simply removing the stressor (e.g. turning down loud music) can be potential response strategies. If the

situation itself cannot be changed, then emotion-focused coping can be applied. In this case people try to influence the emotional arousal, which is caused by stressors during the primary or secondary appraisal. A typical emotion-focused coping strategy is Diaphragmatic Breathing, in which the user tries to reset the autonomic nervous system by slow deep breathing (Varvogli and Darviri, 2011). Lastly, the used response strategy and its consequences are evaluated. This step, called reappraisal, is basically a learning process that affects future primary appraisals.

In order to assess the perceived stress level, we focus on stressors and strains while neglecting coping and appraising for the purpose of stress detection. The integration of biofeedback, which takes coping strategies into consideration, will be part of our future work. There exist two categories for potential stressors: physical and psychological (Varvogli and Darviri, 2011). Physical stimuli like unwanted sound (Smith and Jones, 1992), temperature (Jewell, 1998) and vibration (Ayyagari, Grover and Purvis, 2011) can be stressors. Also the ambient temperature in combination with the ambient humidity can affect the human wellbeing (Thom, 1959). But besides these physical stressors, the range of psychological stressors is much broader. Psychological stressors, in an enterprise context, can be distinguished into three categories: organizational, technological and incidental (Adam et al., 2015). Since Adam et al. (2015) examined work environments, we replace the incidental category by a personal that considers all private and individual aspects of human life. Organizational stressors are external stimuli with the origin at the workplace. Work overload (Cooper, Dewe and O'Driscoll, 2001) and role overload (Narayanan, Menon and Spector, 1999) are common organizational stressors along with, e.g., corporate culture (Cooper and Cartwright, 1994) and job insecurity (Tarafdar et al., 2007). The second category refers to technostress, which has gained growing attention in the past years and can be counted as psychological stressor (Riedl, 2012). Techno-overload, techno-insecurity and techno-complexity are already included above. "Techno-invasion describes situations where professionals can potentially be reached anywhere and anytime and feel the need to be constantly connected" and "techno-uncertainty refers to contexts where continuing changes and upgrades to IS do not give professionals a chance to develop a base of experience for a particular application or system." (Tarafdar et al., 2007). As last category, personal stimuli can be stressors: Examples are a bad work-home balance or special – both good and bad – life events (e.g. marriage, child leaving home, death of a loved one) (Holmes and Rahe, 1967).

Parker and Ettinger (2007) distinguish four different levels of strains: physiology, emotion, cognition, and behavior. A physiological reaction to stress, for example, can be the release of the stress hormone cortisol (Riedl, 2013). Other examples are increased heart rate (Trimmel et al., 2003) and elevated blood pressure (Boucsein, 2009). Emotional und cognitive strains affect the psyche of the human being, e.g. a lack of resources leading to poor judgment (Smith, Segal and Segal, 2014) or moodiness (The American Institute of Stress, 2014). Finally, strains may also change the behavior. This could result in isolation from others (Partners Healthcare, 2004), addiction (Mayo Clinic, 2013) or nervous habits (The American Institute of Stress, 2014).

Figure 1 summarizes a transactional model on stressors and strains from a high-level point of view. The preceding discussion and Figure 1 are not exhaustive but aim to shed some light on the concept of stress as basis for assessing stress levels.
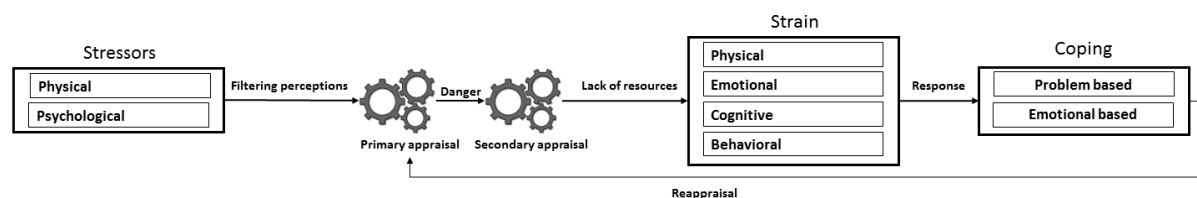

Figure 1.   Transactional model of stress based on Lazarus and Folkman (1984)

3   Related Work

The objective of myStress is to unobtrusively and continuously detect an individual's level of perceived stress exclusively with one smartphone (see section 1). Related work falls into three categories: (1) assessing stress via a single smartphone, (2) detecting stress through several different devices (e.g. two smartphones or an additional Bluetooth device), (3) recognizing not stress but emotions, mood or activity (e.g. walking, running, cycling) with similarities in measurement techniques. The following paragraphs address these categories one after another.

Assessing stress using solely one smartphone is rare. A literature review revealed two applications from research at Dartmouth College: BeWell (Lane et al., 2011) and StudentLife (Wang et al., 2014) are Android applications to assess the stress level of the smartphone user by tracking activities that affect physical, social and mental wellbeing. The relevant data is collected by continuously reading several smartphone sensors like microphone, accelerometer and light sensor. BeWell extends this data by additional user information entered through a web portal. StudentLife pushes multiple questionnaires to the smartphone, which have to be answered by the user, and extend the collected data by special Dartmouth College location-based information (e.g. WiFi logs to measure the traveled distance inside buildings). Since both applications require the user to answer multiple (an average of 8) questionnaires daily, these systems are rather obtrusive.

Several applications assess stress with a smartphone plus additional devices. Lu et al. (2012) use a second smartphone, while both Ferreira et al. (2009) and Kocielnik et al. (2013) use external devices to measure body reactions (e.g. increased sweating, rapid heartbeats). Lu et al. (2012) measure stress by analyzing the human voice and use the second phone to distinguish between speakers.

Artefacts related to stress detection include emotion, mood, and activity detection systems. Most technical systems aiming at assessing these conditions use exclusively smartphone-based data, with the exception of Choudhury et al. (2008). They use an external device to measure additional parameter (e.g. humidity). This gathering of data can be done unobtrusively (Rachuri et al., 2010; Lee et al., 2012) or be enriched by additional user input (LiKamWa et al., 2013; Chang et al., 2011).

In general, different research projects have shown that the assessment of stress or stress-related psychological factors based on human voice (Lu et al., 2012; Chang et al., 2011), sleep (Wang et al., 2014; Lane et al., 2011), social interaction (Wang et al., 2014), location information (Lee et al., 2012; Rachuri et al., 2010), ambient information (Lee et al., 2012), body reactions (Kocielnik et al., 2013), activity recognition (Choudhury et al., 2008) and behavioral patterns (Ferreira et al., 2009; Kocielnik et al., 2013; Lee et al., 2012; LiKamWa et al., 2013) is possible.

Table 1 summarizes key features of related systems. To the best of our knowledge, myStress is the first scientific approach to an unobtrusive, continuous and solely smartphone-based detection of stress.

Related systems	Stress	Solely one smartphone	Unobtrusive (no user input)
Lane et al. (2011)	x	x	
Wang et al. (2014)	x	x	
Ferreira et al. (2009)	x		x
Lu et al. (2012)	x		x
Kocielnik et al. (2013)	x		
Rachuri et al. (2010)		x	x
Lee et al. (2012)		x	x
LiKamWa et al. (2013)		x	
Chang et al. (2011)		x	x
Choudhury et al. (2008)			x
myStress (this paper)	x	x	x

Table 1.   Overview of related stress detection systems

Additionally, first commercial systems for smartphone-based stress detection are available, most notably Kelaa by SOMA Analytics UG assessing sleep quality and emotions in speech. Details on parameters and performance are, however, not disclosed.

4   Research Methodology

To achieve our research objective (see Section 1) we follow the design science guidelines by Hevner et al. (2004) and the design science research methodology (DSRM) by Peffers et al. (2007). This methodology suggests design science researchers to run through a total of six activities: 1) identify problem and motivate, 2) define objectives for solution, 3) design and develop, 4) demonstrate, 5) evaluate, 6) communicate. Peffers et al. (2007) identify steps 1 through 4 as possible entry points for research. Here we apply the objective-centered approach, thus, start by defining our objectives and aim on the solution domain. Since we evolve a new solution (unobtrusive smartphone-based stress detection) for a known problem (stress) our research can be categorized as "improvement" in the Knowledge Contribution Framework by Gregor and Hevner (2013).

Hence, we design myStress as an abstract design blueprint of a smartphone application with the objectives to unobtrusively and continuously assess the user's stress level and implement a prototypical instantiation on Android. We started design and development with an analysis of literature on both stress theory and smartphone-based sensing of physiological features to build a theoretical foundation (see Sections 2 and 3). Feedback of potential users revealed a strong focus on usability, resource-friendliness and consideration of data privacy to be critical non-functional success factors. During development we applied an iterative and agile process model in order to early and directly address user feedback. Additionally, first releases of myStress were published to a selected community of beta testers before opening a stable version to the public. A public field study was chosen as evaluation method in order to maintain high external validity and generalizability.

As outlined above, our research process in general follows the DSRM, but moreover consists of two layers, each applying the DSRM process: In the first layer, we develop the design blueprint and an Android prototype for the measurement of data related to and possibly applicable for stress detection. In the second layer, we aim to actually assess the user's perceived stress based on the findings from the first layer. After taking first design decisions that affect both layers we follow the DSRM process in layer one through the steps objective definition, design/development and evaluation on the defined subtask (Peffers et al., 2007). Currently our research is in progress – we are working on the evaluation in the first layer and will subsequently continue with design and development in layer two.

5   Design and Distribution of myStress

In layer one myStress is designed to read a total of 36 hardware (HW) and software (SW) smartphone sensors in order to empirically identify sensors that might be applicable for stress detection. These sensors are the outcome of a conceptual evaluation of unobtrusive smartphone-based measurability of stressors and strains from the stress model (Section 2). We reviewed the hardware and software sensors made available by the Android smartphone operating system. Sensors were included in myStress when an intense dialog in the research team and with supporting experts and users or related scientific work suggested at least one reasonable link to the stress model. Each sensor may be related to multiple facets of the stress model, e.g. both to a psychological stressor and a behavioral strain. The number of links is irrelevant at this point, as a single reasonable link to the stress model suffices for incorporating the sensor. Its individual correlation with perceived stress and its ability to contribute to stress detection in a portfolio of sensors are a question for subsequent empirical evaluation. We do not hypothesize and evaluate a causal relationship between sensors and stressors or strains from the stress model, but aim on stress prediction. Table 2 lists the resulting selection of sensors with one respective stress model reference per sensor. This selection has a clear focus on physical and psychological stressors as

well as behavioral strains, but also covers single aspects of physical and cognitive strains (e.g. reduced typing accuracy). Yet, many items of the presented stress model require contextual data (e.g. information about the workplace), explicit user input (e.g. about evoked emotions) or physiological measurements (e.g. sweating) and, thus, cannot be measured unobtrusively in a generalized field study.

Type	Sensor	Type	Sensor	Type	Sensor
Psychological stressors		*Physical stressors*		*Behavioral strains*	
SW	Battery charging status	HW	Ambient temperature	SW	Activity variance
SW	Battery level	HW	Ambient humidity	SW	Activity assessment
SW	Calendar events	HW	Ambient pressure	SW	Phone call log
SW	Cellular Cell Identifier	HW	Ambient light	SW	Received SMS
SW	Cellular Location Area Code	HW	Audio amplitude	SW	Screen switching
SW	Cellular Network Code	HW	Audio frequency	SW	Sent SMS
SW	Data connection status	HW	Battery temperature	HW	Step counter
SW	Notifications	HW	Orientation (Azimuth)	SW	Stress questionnaire meta
SW	RAM available	HW	Orientation (Pitch)	SW	Text information
SW	Roaming status	HW	Orientation (Roll)		
SW	Running apps	HW	Proximity	*Cognitive strains*	
SW	Visible apps			SW	Deleted characters
SW	Weather	*Physical strains*			
SW	WiFi status	SW	Voice analysis		

Table 2.   List of the 36 sensors of myStress

The implemented sensors can be divided into time-triggered and event-triggered. While time-triggered sensors are probed in intervals of 5 minutes (e.g. orientation, ambient temperature, audio frequency and amplitude), event-triggered sensors catch and react to certain events on the smartphone (e.g. SMS, WhatsApp or Facebook messages sent and received, voice analysis during phone calls, text sentiment). The interval of 5 minutes was chosen in order to trade-off granularity of measurement and resource efficiency (e.g. battery consumption, data volume).

We selected the Android platform starting with version 2.3.3 to reach approx. 80% of smartphone users (Statista, 2014a, 2014b). The architecture of myStress is based on the AIRS sensor framework by Trossen (2014) and adjusted to fit our sensor list. In order to assess the association of different smartphone sensors with perceived stress, users of myStress are asked to answer a short questionnaire on their smartphone three times a day. While this questionnaire is not unobtrusive, it is, however, only included for researching how to assess stress unobtrusively – we aim to make it redundant and spare it within the final system. The questionnaire consists of the 4-item Perceived Stress Scale (PSS-4) proposed by Cohen, Kamarck and Mermelstein (1983). PSS was shown to be a valid measure for linguistically quantifying stress sensed by a human being and is frequently used in research (e.g. Hobfoll (1989), Heidt et al. (2014), Haushofer and Fehr (2014)). Although the PSS-4 has lower internal reliability than PSS-14, it provides much more usability for measuring perceived stress over phone (Cohen et al., 1983). In this trade-off between internal reliability and usability, usability was chosen to be an important aspect for the present study. We try to eliminate the questionnaire as a confounding variable, because studies highlight the stress-inducing aspect of questionnaires (Scollon, Kim-Prieto and Diener, 2003; Intille et al., 2003). Despite the classic version of PSS-4 using a period of one month, it remains valid on significantly smaller periods (Cohen, 2010). We adapted the original PSS-4 wording from "In the last month […]" to "Since the last survey […]". During the evaluation, PSS-4 scores are matched with data from the 36 smartphone sensors. On the resulting data set we explore associations of sensors and perceived stress using correlation tables and supervised learning algorithms.

To maintain data privacy, data collection has to be manually activated by the user after the installation of myStress and can be paused at any time. Every 12 hours the collected data is uploaded to a cloud storage. This interval was chosen as a trade-off between data timeliness and resource usage. In order to spare the user's limited data connection, the upload only occurs with an existing WiFi connection.

In order to make it publicly available and reach a broad and diverse audience for the field study, myStress has been published in the Google Play Store. We promoted participation via snowball sampling on Facebook and Twitter as well as through posts in Quantified Self forums and e-mails to colleagues and friends. All participants have been asked to answer the questionnaire at least 33 times before ending the study – the exact number is a trade-off between a rich data set with statistical significance and burden to the participants.

Although the first version of myStress is not yet completely unobtrusive, we posit that a) the evaluation of the results can be a good indicator for the feasibility of unobtrusive and continuous smartphone-based stress detection and b) it is already less obtrusive than existing artifacts and approaches (e.g. Ferreira et al. (2009), Kocielnik et al. (2013), Lu et al. (2012)). The objective of resource-friendliness has been met after fixing some power-consuming bugs in first versions of the application and myStress now causes only up to approximately 7 % of the smartphone's energy consumption in use at any given time. Data privacy, as requested by potential users, has been implemented through basic privacy measures: anonymity through hashed device IMEI to distinguish but not identify users and abandonment of raising personal data. The lean user interface that has been designed together with usability professionals makes myStress easy to use and offers the opportunity to keep an eye on own activity data.

In future versions the actual stress prediction through the application of online supervised machine learning is planned to be integrated into myStress. Calculation directly on the smartphone prevents data privacy concerns. The PSS-4 questionnaire will be abandoned after an initial learning phase, making myStress considerably less obtrusive. Furthermore, it is intended to reduce the number of sensors by opting for those that shape up as indicators with high predictive power in out-of-sample tested statistical models. This selection will be done using variance inflation factors and stepwise regressions.

6   Preliminary Data Analysis

At the time of writing this paper, data collection and analysis are in progress. Since its release 157 users installed myStress, although only 77 actually provided data and 42 of them answered at least one questionnaire. Several different explanations might be imaginable for this phenomenon, for example a non-existing WiFi connection, data privacy concerns (downloaded, but not started yet) or installation out of curiosity. Out of these 157 installations, a major part (92) comes from Germany, followed by 28 from the US, 10 from India and 8 from Brazil. MyStress was installed on a total of 91 different devices with Samsung Galaxy S4 (9 installations), S3 Mini (9), S4 Mini (7), S3 (7), HTC One M7 (7) and Google Nexus 5 (7) being the most popular devices among our users. A handful of participants already reached the desired goal of 33 answered questionnaires and currently a dozen further contributed 10 or more observations. Up to now 483 questionnaires have been answered across the 42 participants. Relations between installation-based information and usage information, e.g. information about the installation status for a certain participant, cannot be examined because of data privacy measures.

One preliminary insight into data concerns the overall distribution of PSS-4 values in our user base, which agrees with representative surveys on the distribution of stress (Statista, 2010) (cf. Figure 2a). Although this shows a clear trend to low levels of perceived stress, we observe differences in stress intensity over time and users. Furthermore, first evaluation shows correlations between, e.g., high stress levels and high smartphone usage as operationalized by multiple sensors – maximum number of running applications (Pearson correlation 0.38 with a p-value <0.001) and average battery temperature (cf. Figure 2b; Pearson correlation 0.20 with a p-value <0.001). With the frequency of switching the display on or off, we also examined a nervous habit as suggested by The American Institute of Stress (2014) and noticed a positive Pearson correlation of 0.20 with a p-value <0.001 with perceived stress.

These bivariate correlations might seem low. Future data analysis will use multivariate models with higher overall predictive power as single sensors are not perfectly correlated. In the end, the system's usefulness will strongly depend on the level of accuracy of sensing and will have to be evaluated in

future research. Because of the ongoing data collection and analysis, in this research-in-progress paper we refrain from providing further preliminary statistics which might not hold true once the rigorous analysis and testing are concluded.
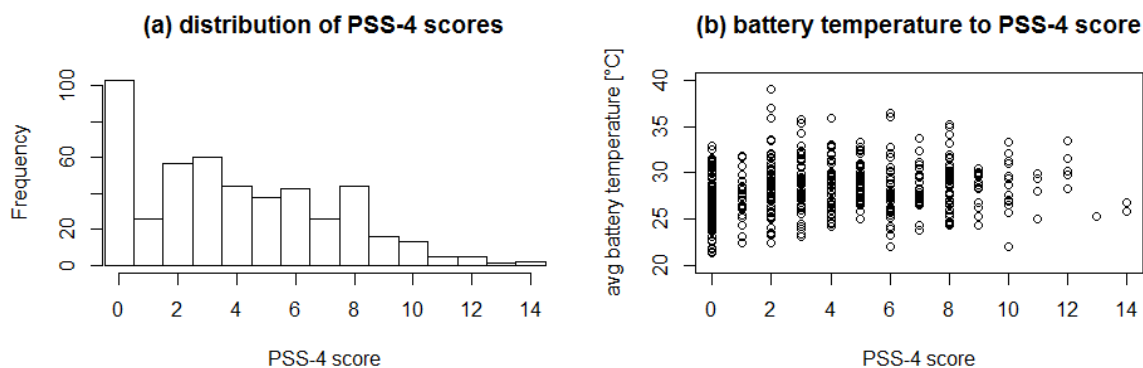

Figure 2.   (a) distribution of PSS-4 scores;   (b) relation to average battery temperature (n=483)

7   Conclusion and Future Work

Our aim is to design a system able to unobtrusively assess an individual's perceived stress exclusively based on smartphone data. Hence, we presented the design and prototypical implementation of myStress – a software artefact capable of measuring smartphone hardware and software sensors that could allow the detection of stress – and gave first insights into the ongoing data collection and evaluation. Latter gave reason to the hypothesis that unobtrusive stress detection might be feasible to some degree solely based on smartphone data. This, however, needs to be confirmed through thorough formal evaluation after finishing data collection.

One apparent limitation of our overall research is the restriction to sense perceived stress in contrast to actual stress, which are not necessarily identical (Riedl, 2013). In addition, our approach is constrained by the diversity of smartphone devices, and thereby the variety of different hardware sensor implementations, that can be used for data collection. Although we recruited people with Android smartphones around the globe, most participants are based in Germany and cannot be assumed to be representative for any specific user group. Furthermore, myStress relies on a continuous usage of one smartphone. Hence, we assume that myStress is capable to assess stress for people, which regularly use solely one smartphone for private and business purposes. Finally it is by no means clear, that a technological solution for perceived stress detection is the most appropriate solution, since smartphones itself are potential stressors (Lee et al., 2014). Nevertheless, we contend that it is worth exploring and evaluating how smartphone-based sensing can support stress management. In future work, one aspect of this will be finding ways for assessing in how far non-usage of the smartphone associated with a lack of meaningful sensor data is associated with stress perception or coping.

Future work will additionally include, first, a thorough statistical data analysis and, second, extending myStress to actually detect perceived stress by means of sensors that were found to be relevant in our evaluation. Detection will be based upon a pre-trained general, unpersonalized classifier that improves prediction results through subsequent personalization, similar to Rachuri et al. (2010). Further consideration will aim on the selection of an appropriate online learning algorithm that can achieve this personalization. In a next step, literature-backed biofeedback and suggested measures against stress can be included into the application to provide an additional benefit to the user. In addition, an unobtrusive and continuous perceived stress detection can be the foundation for a stress adaptive computing system suggested by Picard and Liu (2007) and Adam et al. (2014; 2015).

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