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Towards Designing a Mobile Stress Coping Assistant

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Abstract

Stress is a major public health concern and a severe threat to everyone. Facilitated by their powerful sensing capabilities, mobile devices may assist individuals in coping with stress. Building on existing studies and mobile apps supporting stress coping, we propose the design of a mobile coping assistant that uses multimodal sensor data to reduce its user's stress. Based on sensor data, a mobile coping assistant (1) warns the user about elevated stress, (2) delivers a fundamental understanding of why they are currently stressed, (3) recommends targeted coping strategies to encourage and train effective coping behavior, and (4) executes automated actions to reduce stress exposure. The presented design comprises an architecture, good practices for designing the architectural components, and an algorithm for selecting adequate coping actions and recommendations. A prototypical instantiation indicates opportunities and challenges. Future research should evaluate the short- and long-term effectiveness of mobile coping assistants in the field.

1. Introduction

Today's work and private life are becoming increasingly stressful. People suffer from severe health impairments caused by acute or chronic stress, often resulting from unhealthy behavior in the accelerated modern world and lifestyle. Facilitated by the broad availability of powerful sensing capabilities in modern mobile devices, information and communication technologies (ICTs) such as health behavior change systems (HBCSSs) help individuals stay motivated with healthy behavior like regular physical activity, smoking cessation, or a balanced diet [1]. A HBCSS is a health-related "socio-technical information system (IS) with psychological and behavioral outcomes designed to form, alter or reinforce attitudes, behaviors or an act of complying without using coercion or deception" [1, p. 1225]. Recent literature suggests that HBCSS may assist individuals in changing their responses to stress by facilitating effective coping behavior. While various studies already examined ICTs' potential to determine the user's stress for the purpose of self-reflection [2, 3] and first efforts have been made towards informing users' self-regulation by providing detailed feedback on potential sources of their stress [4], some scholars propose further steps to support individuals' coping with stress enabled by sensor data. They suggest that IS should recommend targeted emotional and behavioral strategies for coping with stress (e.g., relax, seek support) [5, 6] or automatically execute technological actions to prevent stressful situations (e.g., turn off notifications, delegate community tasks) [6]. Although these studies reinforce that the development of a HBCSS dedicated to improving individuals' coping behavior is worth exploring, to the best of our knowledge, the question of how to design an individual IS which assists their users in coping with stress based on multimodal sensor data is yet open to research. Thus, combining these proposals, we construct the vision of a mobile coping assistant (MoCA) that exploits the sensing capabilities of mobile devices to support individuals' stress coping by facilitating a sustainable behavior change and preventing the occurrence of stress. Consequently, our study pursues the objective: *elaborate the design of a mobile app for everyday use that uses multimodal sensor data to support its user cope with daily stress.*

Our research follows standard design science research and evaluation guidelines [7, 8]. It builds

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upon stress theory and an analysis of mobile apps and studies on mobile stress coping support and explores how to design a system providing just-in-time coping support. Our design comprises the architecture of a MoCA, good practices for designing the architectural components, and an algorithm for selecting coping activities based on data on the user's behavior, characteristics, preferences, and environment.

The paper is structured as follows: Section 2 introduces stress and coping theory. Section 3 describes the methodological procedure of our research. Section 4 presents an analysis of mobile apps and studies on mobile stress coping support. Section 5 presents the design and prototype. Section 6 discusses contributions and implications. Section 7 concludes.

2. Theoretical Background

2.1. Stress

Human stress has been extensively researched in various disciplines. Hence, many models and theories exist to define and illustrate the development of stress. A widely used framework is the Transactional Model of Stress from Lazarus and Folkman [9]. The model considers both the occurrence of and the response to internal and external demands (e.g., noise, prioritization conflict) of the individual's situation relevant to the stress reaction. Thus, it comprehends stress as a two-way process that describes the interplay between these demands and the individual's available resources (e.g., knowledge, skills, mental capacity).

Demands in the individual's environmental situation trigger the perpetual process. These demands can be psychological (e.g., a bad feeling about something) or physical (e.g., low ambient temperature). In two appraisal steps, the individual evaluates if the specific demand incites a stressor and requires a coping reaction. In the primary appraisal, the individual subconsciously evaluates if the stressor falls into one of the three categories *positive*, *irrelevant*, or *stressful*. If categorized as *stressful*, the stressor may threaten the individual, who then subconsciously examines in a secondary appraisal step if the available resources are sufficient to cope with the stressor. If the individual lacks resources to cope with the stressor, the mismatch elicits a stress reaction manifesting in the form of physiological (e.g., increased heart rate, lack of sleep), emotional (e.g., fear, anger), cognitive (e.g., cognitive irritation), or behavioral (e.g., fatigue, exhaustion) short-term symptoms. In the long run, frequent exposure to high stress may produce adverse long-term outcomes such as a worsened state of physical or mental health. [9]

2.2. Stressors

Taking a deeper look into stressors that evolve in the environmental situation of the individual, stress literature considers major life events (e.g., birth of a child, divorce) and daily hassles (i.e., minor everyday events that are irritating, frustrating, or distressing to the individual; e.g., too many things to do, misplacing or losing things) as stress contributors [10]. Various studies analyzed the relation between the two as predictors of stress. Kanner et al. [10] found that daily hassles significantly influence individuals' stress experience independent of whether major life events occurred before or after the daily hassles. DeLongis et al. [11] showed that repeated or chronic everyday symptoms are more strongly tied to health than major life events and concluded from this that the assessment of daily hassles is a better predictor of individuals' stress [11]. We adopt this perspective and focus on the measurement of daily hassles to determine stress.

Almeida et al. [12] categorized daily hassles into six categories: *arguments or tensions* (e.g., family issues, interaction with the boss, timing/schedules), *work or school* (e.g., work overload, technical breakdowns), *home* (e.g., financial problems), *health care* (e.g., illness), *network or events that happen to others* (e.g., death), and *miscellaneous* (e.g., weather, traffic). IS literature discusses the use of ICTs as a highly relevant contributor to stress in modern days, commonly referred to as *technost ress* [13]. Hassles associated with the use of ICTs are, for example, interruptions from ICT [14], the unreliability of ICT [6], or the perceived overload with information, communication, or tasks through ICTs [13].

2.3. Coping

When individuals face stressors, they can apply different coping strategies to reduce stress-related symptoms. Coping is defined "as constantly changing cognitive and behavioral efforts to manage specific external and/or internal demands that are appraised as taxing or exceeding the resources of the person" [9, p. 141]. The selection of specific coping strategies depends both on individual characteristics (e.g., age, gender, personality, habits) and contextual circumstances (e.g., stressor(s), environment, time) [15]. Lazarus and Folkman [9] distinguish two types of coping strategies: problem-focused (i.e., modifying the event by identifying the cause of stress or avoiding the stressor) and emotion-focused coping (i.e., influencing the individual's view and mental evaluation, e.g., by meditating).

Skinner et al. [16] criticize this and other distinctions for not fully reflecting the complexity of coping. Instead, they propose twelve families of coping as higher-order categories (Table 1) organized around three dimensions: challenge vs. threat (i.e., the individual can handle the demand vs. is overwhelmed by the demand), the target addressed by the coping reaction (self or context), and three needs individuals strive for (competence, relatedness, and autonomy). The latter dimension refers to the three innate psychological needs introduced by Ryan and Deci [17] in the Self-determination Theory, which provides explanations for behavior changes. The fulfillment of the needs for competence (i.e., ability to effectively perform a behavior and control the outcome), relatedness (i.e., social connection to and interaction with others), and autonomy (i.e., power to make own choices) enables intrinsically motivated behavior changes as well as the integration of extrinsically motivated behavior [17]. Each coping family represents a set of functionally similar coping strategies (e.g., for problem-solving: planning, logical analysis, or diligence) contributing to one of the three overarching *adaptive processes* that enable behavior changes by addressing the needs for competence, relatedness, and autonomy.

The coping families serve different functions in the adaptive processes. Four families are each grouped into three main adaptive processes (AP) (see column 2

Table 1. Families of coping and their function in adaptive processes (AP) [27]

Family of Coping	AP	Function in AP
Problem-solving [1, S]	Coordinating individuals' activities	Modify activities to be effective
Information Seeking [1, C]		Find additional alternatives
Helplessness [2, S]		Find limits of activities
Escape [2, C]		Escape noncontingent environment
Self-reliance [1, S]	Coordinating individual reliance on others	Protect available social resources
Support Seeking [1, C]		Use available social resources
Delegation [2, S]		Find limits of resources
Social Isolation [2, C]		Withdraw from the unsupportive context
Accommo-dation [1, S]	Coordinating individuals' preferences	Flexibly adjust preferences to options
Negotiation [1, C]		Find new options
Submission [2, S]		Give up preferences
Opposition [2, C]		Remove constraints
1) Challenge, 2) Threats, S) Self, C) Context		

in Table 1): adaptive processes that coordinate an individual's activity with the eventualities in the environment (competence), adaptive processes that coordinate the individual's reliance on others with the social resources in the environment (relatedness), and adaptive processes that coordinate an individual's preferences with the options available in the environment (autonomy) [16]. For example, *problem-solving* allows an individual to alter or modify activities to be effective in the existing environment, whereas *information-seeking* aims to discover alternatives. Both families of coping foster more structured and effective activities in situations taken as a challenge but differ in the addressed target (*problem-solving*: self; *information seeking*: context) [16].

3. Methods

Our design science research project [7] strives to elaborate the design of a MoCA assisting individuals in coping with stress based on multimodal sensor data. It follows the build and evaluate cycle by Sonnenberg and vom Brocke [8] and integrates evaluation activities (Eval1-4) directly into the research process.

As a first step, we identified a problem in the lack of a design proposition on how a MoCA could be instantiated. Various prior works support the claim that there is a need for more powerful mobile coping support and indicate promising design requirements (Eval1) [5, 6]. In the second step, we iteratively designed the MoCA, building on an extensive analysis of mobile apps and studies in the context of mobile coping support (Eval2). We searched the multidisciplinary Scopus database for articles reporting an "application", "app", "tool", or other "mobile" solution associated with "stress coping" or "stress management" and included additional finds from adjacent searches. We selected relevant articles first by screening titles and abstracts and then by reading the articles. This process yielded four comprehensive reviews of mobile apps available through the Google and Apple app stores [18–21] and another 38 individual studies on mobile coping support. In the first iteration of our iterative design process, we derived a typical architecture of MoCAs and identify vital architectural components. In the second iteration, we extracted good practices on what to consider in designing these components. The third iteration produced an algorithm for selecting adequate coping recommendations and actions with respect to the user, the cause of their stress, and the context. To test the design, we developed a prototype (Eval3) instantiating MoCA's elementary architecture and providing advanced stress coping support by pointing the user to potential stressors in their behavior and environment. These prototyping activities and their testing suggest that the instantiation of a MoCA is feasible and give first indication of the design's utility to produce effective MoCA systems. Future iterations of the prototype will include the provision of coping recommendations and automated execution of actions targeting to prevent stressful situations. A real-world evaluation of MoCAs' applicability and effectiveness in the field (Eval4) is yet open to future research.

4. Analysis of Mobile Apps and Studies on Mobile Coping Support

Naturally, our research takes inspiration from similar apps and studies. Our literature analysis reveals that many approaches to mobile stress coping support exist. We divide them into three categories: 1) mobile apps assisting their users in coping with stress without collecting continuous information on their stress level, 2) studies assessing single symptoms of stress and delivering feedback to the user to motivate coping, and 3) mobile apps using many sensors to identify stressors and symptoms and provide advanced understanding of the stressful situation's context.

Many stress management apps available through the Google and Apple app stores belong into the first category [18, 19]. Here, a multitude of apps provides general educational information and training on stress coping (e.g., [2, 22]) with an emphasis on meditation, mindfulness, and other relaxation strategies. Apps in this category typically offer either on-demand coping knowledge and exercises to tackle acute stress (e.g., [20, 23]) or accompany organized programs to train coping skills (e.g., [22]), for example, by encouraging daily tasks [3]. Despite evidence for their general effectiveness [22, 23], a recent review of stress management apps investigated the apps' contents and found that few apps reinforce regular coping activity, which is required for a sustainable behavior change [24], in particular when individuals are busy. Consequently, various scholars emphasize gamification and other behavior change techniques dedicated to keeping users engaged with using the app [3, 25, 26]. An interesting approach that falls out of the typical pattern in this category was described by McDaniel and Anwar [27], who describe a mobile app that delivers coping recommendations on demand based on user input on the specific stressful situation. Although the systems in this category do not suffice our MoCA definition because they do not collect sensor data, this research stream demonstrates that mobile systems are a valuable [28], effective [22, 23], and desired [29] approach to support individuals' stress coping and that the inclusion of techniques to reinforce coping behavior [24, 26] is crucial.

Studies in the second category use physiological or psychological measures to evaluate bodily stress symptoms and provide biofeedback. This mind-body intervention externalizes the physiological state and allows the user to monitor changes in real time [30]. Many studies in this domain use a single sensor as an indicator for stress. In mobile settings, the most frequently used measures relate to heart rate [31, 32] or skin conductance [2, 33] as psycho-physiological stress indicators. A recent systematic review of biofeedback studies in stress management (not limited to mobile use) discussed that biofeedback may effectively support individuals coping with stress [34]. However, time and practice are required to develop the needed self-regulation competencies [34]. Another review on the topic found that biofeedback seems to be more effective in reducing stress for individuals who are used to operate under stressful conditions than for convenience-sampled populations [21]. These findings suggest that biofeedback may trigger self-reflection [2] but struggles to initiate a sustainable behavior change, especially when individuals do not regularly experience high stress.

To facilitate stress-related self-regulation, a better understanding of the stressed individual's situation might be helpful. Hence, the third category of related studies focuses on collecting multimodal data on the user and their environment to determine potential stressors. In this vein, several studies produced mobile apps that assess stress using various smartphone or wearable sensors [35, 36]. This sensor data may allow painting a clearer picture of the stressful situation by investigating stressors and symptoms based on contextual data such as the current time, weather, ambient noise, or the user's location, physical activity, or messaging behavior [37]. To facilitate everyday use, some apps target the unobtrusive or life-integrated assessment of stress [35] using only sensors which do not require the user's attention. To date, most of these efforts end with the assessment and reporting of stress based on multiple sensors. Few studies take the next step and deliver the broader context of the situation or targeted coping recommendations. One of few notable exceptions is Bavaresco et al. [4], who assess stress based on physiological measurement and use various sensors to determine the user's basic activity (e.g., standing still, walking, in a vehicle) in the case of stress. Similarly, Alharthi et al. [38] and Reimer et al. [5] collect further contextual data (time, location, weather) to suggest just-in-time relaxation exercises in the case of stress. The latter two studies additionally stress the importance of properly timed interventions to prevent counteracting effects potentially resulting in increased instead of decreased stress. While they constitute valuable proofs-of-concept that just-in-time recommendations can assist individuals' coping, they do not exploit coping recommendations' full potential by evaluating why the user might be stressed.

Overall, this analysis revealed that several approaches to mobile coping support aiming at different levels of user support exist.

5. How to Design and Implement MoCAs

5.1. Design Requirements

To further specify what constitutes a MoCA, we develop a set of design requirements. Several design requirements derive from the objective to design a mobile app that supports individuals cope with stress using multimodal sensor data. The analysis of existing solutions for mobile coping support presented in the previous section demonstrates that different levels of support are conceivable. From the literature, we learned that reinforcing elements are important to motivate users to use the MoCA regularly and foster a sustainable behavior change. Also, MoCA should factor in individual (e.g., age, preferences, mental health) and contextual characteristics (e.g., time, location, ICT use) when recommending or taking coping actions. Additionally, the interventions' timing needs to be well-considered.

Further inspiration for the design of coping support is taken from a recent study by Adam et al. [6]. They proposed the abstract design of a corporate information system that uses sensors to assess employees' stress and takes purposive interventions utilizing individual, technological, and organizational levers. The study presents an implementation roadmap comprising four stages of coping support at incremental levels of support. Since their envisaged system targets stress in a defined work environment, the roadmap needs to be adapted to fit the setting of MoCA supporting an individual in coping with work and personal stress. Both settings are comparable in the way that a single system (enterprise or mobile system) accompanies the user throughout the considered period of time (working day or entire day), assesses stress, and acts accordingly. Yet, two changes are necessary: First, the original roadmap features a stage involving organizational interventions. However, organizational interventions are not available to MoCA since there is no organization involved. Second, given the broader range of stressors in MoCA (due to the inclusion of private hassles and conflicts), the original roadmap lacks specificity regarding different maturity levels of stress feedback. Systems can either provide feedback on the stress level or only or deliver advanced analytics of why the person might be stressed. After these changes, we distinguish four incremental stages of implementing a MoCA with different interventions:

Stage 1 (*stress reporting*): the system determines the user's current stress level and reports it to the user.

Stage 2 (*stress understanding*): the system comes with increased analytical capabilities and delivers a more detailed understanding of why the user might be stressed based on patterns found in the sensor data.

Stage 3 (*coping recommendations*): the system determines and recommends coping strategies appropriate in the user's specific stress situation (e.g., seeking support with a complex task or taking a break to regain emotional strength).

Stage 4 (*automated coping support*): the system takes automated technological action to prevent the user from stressful situations (e.g., eliminate interruptions from notifications, reprioritize messages) within a user-defined scope of action.

From the defined scope and theoretical underpinning, several design requirements (DRs) for MoCA derive (Table 2). An effective MoCA provides interventions that help reduce the user's stress. A useful MoCA additionally induces a change of coping behavior and advances the user's coping skills.

Table 2. Design Requirements

DR		Stages
1	MoCA must continuously assess the user's stress based on sensor data	1-4
2	MoCA must facilitate just-in-time intervention when it detects elevated stress	1-4
3	MoCA must include reinforcing elements to motivate a sustainable behavior change supporting coping	1-4
4	MoCA must collect multimodal data on the user and their environment to determine stressors, symptoms, and context	2-4
5	MoCA must deliver coping actions and recommendations that fit the user, their preferences, and context	3-4
6	MoCA must execute targeted technological actions to prevent stressful situations	4

5.2. Architecture

As an important element of design knowledge, we derive a general architecture for a stage 4 MoCA from analyzing the related apps and studies (section 4) with respect to their architectural backbone. The resulting architecture expands an architectural blueprint targeting stage 1 MoCA [37] to include the other stages and is presented in Figure 1.

The architecture conceives a MoCA as a sociotechnical system in which the technical part closely interacts with its social environment, represented by the assistant's *users and their*

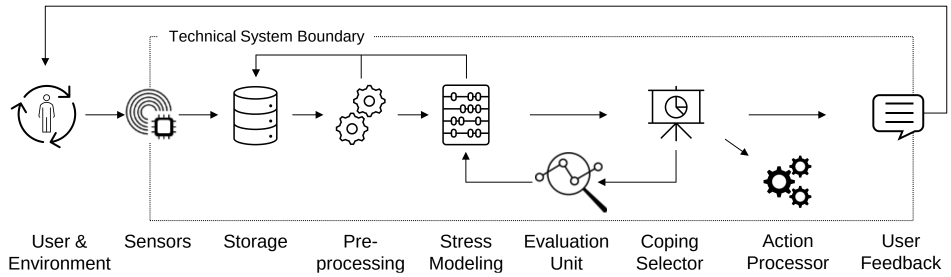

Figure 1. General architecture of a MoCA (expanded beyond [37])

environment. The MoCA uses various *sensors* to collect data on this social environment. This data is *stored* and *pre-processed* to obtain a valid and reliable data base suitable for subsequent analysis. The first step of the analysis, *stress modeling*, uses the collected sensor data to assess the user's stress level. While this first analysis is sufficient to provide basic stress feedback to the user (stage 1 MoCA), the deeper understanding of the stressful situation (stage 2), the derivation of coping recommendations (stage 3), and the automated processing of preventive technological actions (stage 4) require further analysis. Therefore, the *coping selector* analyzes which coping recommendations and technological actions might apply to the current individual and situational characteristics. The *user feedback* presents the coping recommendations to the user. The *action processor* executes technological actions within the user-defined scope of action and the *evaluation unit* assesses the MoCA's performance and informs model refinement.

The following paragraphs provide good practices on how to design these architectural components:

Sensors: Sensors represent the interface between the technical and the social part of the system. They collect data on the user's behavior (e.g., social interactions, daily activities [39]), physiology (e.g., heart rate, skin conductance [21]), psychology (e.g., mood, cognition), and environment (e.g., weather, location [40]). Different devices may be used to sense these measures (e.g., smartphones, wearables, sensory hardware such as electroencephalography headbands or sweat pads) [41]. Sensor data may serve three purposes in MoCAs: as the basis for assessing stress in the *stress modeling* component and determining the situational stressors and the context in the *coping selector*. Additionally, the MoCA should collect individual characteristics (e.g., age, gender) and coping preferences to inform the *coping selector*.

Storage & Pre-processing: The collected raw data is not directly qualified for analysis. It needs to be pre-processed and stored to be accessible for subsequent *stress modeling* and selection of coping recommendations and actions. Here, various aggregations (e.g., over a specific time frame, combining multiple measures) and transformations (e.g., maximum/minimum, deviation from the mean) may help produce a rich feature set. Since the collected data may be highly sensitive (e.g., physiology, location), significant thought should be put into the confidential and secure storage to maintain privacy.

Stress Modeling: Since a MoCA can only deliver useful coping recommendations if it reliably assesses the user's stress, this component lays the foundation for effective coping support. Here, app designers need to decide whether they prefer binary or low-leveled ordinal stress measures or if a more fine-grained scale is beneficial. While model generation may be relatively straightforward when stress assessment is based on a single or few sensors, complexity rises for systems using a large number of sensors. In all cases, it is recommendable to personalize the model as stress perception is highly individual.

Coping Selector: The *coping selector* analyzes sensor data to identify potential stressors and determines appropriate coping recommendations and actions. The algorithm is described in section 5.3.

Action Processor: This component is responsible for executing the technological actions targeting to prevent stressful situations for the user. Depending on the scope of action to be implemented, interfaces to the operating system (e.g., turn off notifications), other apps on the same mobile device (e.g., re-route messages), or larger multi-platform ecosystems connecting other systems and devices (e.g., inhibit calls on the stationary phone) may be required.

User Feedback: This component delivers stress feedback and coping recommendations to the user. In designing this, two considerations need to be made: when should the app intervene, and how should the intervention be designed? Regarding the *when*, Smyth and Heron [42] demonstrated that just-in-time stress management interventions are advantageous over feedback only at fixed times. However, other researchers recommend a short delay to prevent further interruption in high-stress cases. Regarding the *how*, considerations involve the provided functionality and their presentation. Payne et al. [24] emphasize that effective coping apps should incorporate predisposing (providing general information or knowledge), enabling (available when needed), and reinforcing (rewarding use or progress) elements to accomplish a sustainable behavior change. Schmidt-Kraepelin et al. [43] recommend developers of behavior change support systems to use gamification to motivate individuals to use the app more regularly and enable healthy behavior changes. Christmann et al. [25] also suggest a list of techniques to realize behavior change through a stress management app, including gamification elements such as (virtual) rewards (e.g., points, levels, badges) or social comparisons (e.g., leaderboards). As the use of gamification further adds to the fulfillment of the human psychological needs (competence, relatedness, and autonomy) [44], similar to the coping strategies themselves (see section 2.3), we suggest implementing gamification elements to foster long-lasting behavior changes enabled through needs fulfillment. The presentation of the feedback should factor in that the recipients are likely stressed. Audible push notifications may be inappropriate as they may interrupt and further contribute to stress. Hence, the presentation of feedback should be based on the individuals' preferences and therefore adjustable and changeable.

Evaluation Unit: To evaluate the effect of the coping recommendations, the architecture includes a feedback mechanism that monitors the stress level after the coping recommendation to determine its effectiveness. This component may also be used to refine the stress assessment if the user indicates that they are currently not stressed when presented with the coping recommendations, for example, using active learning [45].

5.3. Coping Selector Algorithm

To advance the MoCA prototype, we design an algorithm for selecting appropriate coping recommendations and actions in the *coping selector* (Figure 2). This algorithm undergoes three activities to reach MoCA stages 2 (stress understanding), 3 (coping recommendation), and 4 (automated coping support).

The algorithm starts with the *coping selector* receiving a signal from *stress modeling* that elevated stress has been detected. At stage 1, this information can be directly used to provide stress feedback based on this information to the user. To reach stage 2, the algorithm performs additional steps to understand better why the individual is stressed. Therefore, it evaluates the collected sensor data to identify relevant stressors potentially responsible for elevated stress. Now the algorithm has completed the analytical process that delivers a more detailed understanding of the stressors in the specific situation (stage 2). To reach stage 3, the algorithm further analyzes the individual's context concerning other coping-relevant factors (e.g., time of day, location) and filters potential coping strategies based on the context (*coping recommendations*). This selection is based on information on the individual, sensor data, and a pool of coping strategies (Table 1) and then presented to the user through the *user feedback* component. To reach stage 4, the algorithm selects technological actions that fit the context and lie within the user-defined scope of action to prevent further increase of stress. Finally, the *action processor* executes these actions.

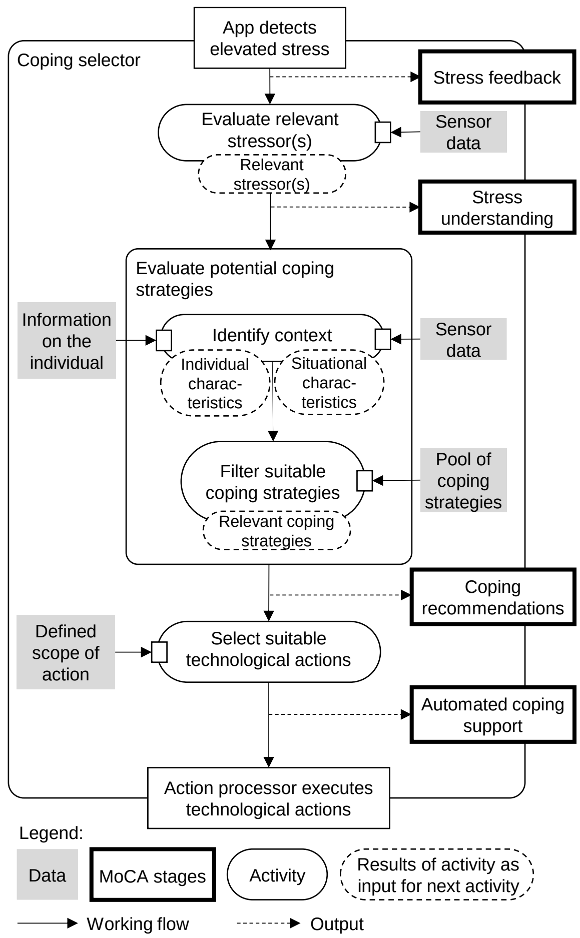

Figure 2. Coping selector algorithm

To demonstrate the algorithm, we step through it using an illustrative use case scenario: Ms. Brown works for a mid-sized company as a project manager. It's Thursday, her GPS data points to her work location, the weather is nice, the sun is shining, and her calendar is full of tasks and appointments and leaves room for only a few short breaks. Over the day, she has received many push notifications on her smartphone from different apps. MoCA detects an elevated stress level and triggers the *coping selector*. In a first step, the algorithm evaluates potential stressors based on the sensor data, for example, by searching for unusually high or low values. In our example, this step indicates high values in the ambient sound and notification sensors. It infers that environmental *noise* and *frequent interruptions* may potentially stress the user. The next step aims to collect additional information on the individual's context. Here, the algorithm finds that the GPS sensor points to the workplace, and the calendar indicates that Ms. Brown is very busy all day long. From data initially provided by her, the algorithm knows for which meetings she needs to be in front of her laptop and for which meetings a telephone call is sufficient. She also allows the MoCA to turn off notifications. Based on this contextual information, the algorithm filters coping strategies and actions that may apply in this situation and context. Due to the work environment, strategies such as exercising or sleeping may be inappropriate. However, between her current and her next meeting, she may be free to change her location within the office building or take a walk outside in the sun while participating in the next meeting via telephone conference. Based on this inference, the algorithm recommends Ms. Brown to relocate to a quiet environment or go outside for a walk (coping family *escape*) and automatically turns off the notifications (coping family *problem-solving*).

5.4. Prototype

To demonstrate the design, we prototypically implemented the MoCA architecture. In its current version, the app senses various behavioral and environmental measures, assesses and reports the user's stress, and delivers insights into potential stressors (stage 2). Stress assessment grounds on an unpersonalized model trained and evaluated in [35]. In an initial calibration phase, the model is personalized to the user. The user can access various aggregations and visualizations of the sensor data through the app to inform self-reflection and self-regulation. The current version does not yet provide targeted coping recommendations or execute automated technological actions. Stage 3 will be supported in the next version.

The successful prototyping demonstrates the general feasibility of creating HBCSS for stress coping and substantiate that the proposed design qualifies to produce effective MoCAs. Interesting insights regarding MoCA implementation could be drawn from the iterative development process and alpha (6 testers) and beta testing (8 testers), revealing, for example, that a too frequent inquiry of smartphone sensors drains the battery substantially and reduces user acceptance. Here, trade-offs between timeliness and usability need to be made [37]. In addition, personalization of stress modeling proved to increase assessment performance clearly but may decrease perceived ease of use as it typically requires user input. An initial calibration phase and sparse later re-evaluations may be bearable [37].

6. Discussion

This study addresses the rising health issue of human stress by proposing a HBCSS design to support individuals cope with increasing stress in work and private life, which we refer to as a MoCA. This design consists of a general architecture including good practices on designing the architectural components and an algorithm describing how a MoCA can use the collected data to report stress feedback (stage 1), determine details on the stressful situation (stage 2), derive appropriate coping recommendations (stage 3), and execute technological actions to prevent stressful situations (stage 4).

The design elements presented here were built and evaluated iteratively following Sonnenberg and vom Brocke [8]. The proposed design fulfills the design requirements by evaluating a continuous stream of sensor data for stress assessment (DR1), facilitating timely intervention in the case of elevated stress (DR2), motivating users towards sustainable behavior changes, for example, by integrating gamification elements (DR3), determining potential stressors, symptoms, and context based on multimodal data (DR4), delivering targeted coping actions and recommendations (DR5), and executing targeted technological stress-preventing actions (DR6). While we do not claim that our solution is the only way how MoCA can be designed, prototyping suggests that the presented design produces effective MoCA.

Our research contributes to the literature in various ways. First, it introduces the concept of a HBCSS aiming to support individuals in coping with daily stress using multimodal sensor data. It envisions an advanced approach to support individuals' stress coping that goes beyond current research, focusing either on the provision of feedback on the user's stress level [37] or on the support of coping activities without contextual knowledge of the user's stress perception and user-specific background information [19]. Second, we condense existing literature on various streams of mobile coping support and indicate challenges and directions for further research. Third, we present a general design for creating effective MoCAs using knowledge created from analyzing the literature. This design reflects good practices on how to design MoCAs from various research streams as well as an algorithm for selecting coping recommendations and actions based on the context.

Several practical implications arise from our study. Individuals benefit from a productive MoCA by experiencing fewer stress-related symptoms in their everyday lives. Further, institutions like health insurance companies or organizations whose business model aims at health promotion are concerned about mental health issues. Health insurances, for example, can offer programs around MoCAs to promote healthy behavior. Employers can introduce MoCA to improve their employees' health and productivity.

Naturally, our research is subject to limitations that require further research. First, the prototypical instantiation delivers contextually informed just-in-time stress feedback to the user (stage 2) but does not yet provide targeted coping recommendations (stage 3) or trigger technological actions targeting the prevention of further stress (stage 4). Hence, despite the theory-driven design and first evidence from related work, a real-world evaluation of the effectiveness of coping recommendations to initiate a behavior change is yet up to future research. Second, the pool of coping recommendations has not yet been designed and tested in real-world field studies. In a subsequent study, we plan to investigate what coping strategies and recommendations are helpful in what situations. Third, future research should examine which gamification elements are best to motivate behavior change in the field of stress based on individual characteristics and preferences.

7. Conclusion

Due to the rising severity of stress for individuals in work and private life, various scholars have constructed and promoted the vision of HBCSS effectively supporting their users in reducing stress by preventing stressful events and facilitating effective coping behavior. Most approaches aim to raise stress awareness and transmit knowledge on stress coping. While these approaches have proven effective, they do not yet explore the full potential of mobile coping support. Our design science research approach explored the question how to design HBCSS that assist their users in coping with stress using multimodal sensor, individual, and context data to enable a sustainable behavior change in dealing with stress. As the efficacy of coping strategies depends on individuals' characteristics and context, our proposed MoCA design exploits the sensing capabilities of mobile devices to analyze the user's current situation to provide and execute individualized, targeted, automated coping support. We encourage researchers and practitioners alike to intensify the development of MoCA to tackle the rising problem of increased stress for individuals and society and hope to make a small contribution to the ongoing research efforts to eliminate the rising threat of stress.

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