Physiology-Aware Learning Analytics Using Pedagogical Agents

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ABSTRACT: Learning analytics applications consider not only the cognitive dimension, but also the physiological dimension of the learner. This paper describes a learning analytics approach that focuses on alerting the critical stress level of the learner using a pedagogical agent. For that purpose, an existing pedagogical agent was expanded by a software component, which analyses heart rate variability data to determine the cognitive load of a user and to offer support with stress reduction. The evaluation study with the physiology-aware pedagogical agent showed an improvement of learning and a reduction of stress.

Keywords: Physiological computing, Heart rate variability, pedagogical agent

1 INTRODUCTION

One of the factors that may affect learning performance is stress (Li et al., 2017). Thus, detecting and measuring stress that occurs while learning could be used to enhance learning analytics applications. In addition to proposals to different observation techniques, e.g., facial detection and video monitoring (D'Mello, 2017). Giannacos and colleagues (Giannacos et al., 2020) suggest that physiological parameters Heart Rate, blood pressure, temperature, and electrodermal activity (EDA) level can be used as a proxy to estimate learning performance. This paper focuses on specific psychological state "stress" that might have impact on the learning process. The monitoring of physiological parameters like Heart Rate Variability (HRV) is considered a relevant indicator for the stress detection (Zangroniz et al., 2018). However, handling physiological data, to what extent they can be used to analyze excessive cognitive demands and how it can be utilized in a learning analytics context are still a research gap. The research question to be investigated in this paper is how HRV data can be used by pedagogical agents to determine the stress level of the learner and to alert the learner in a learning situation.

2 METHODOLOGY

In order to investigate the specified research question, the functionality of the web-based pedagogical agent LIZA (Le & Wartschinski, 2018) aimed at improving the decision making and reasoning of the user, was extended through three different parts. The first component provides a solution to generate, save and process the HRV data, the second one analyses the data regarding stress and the third one adapts the learning situation through selected stress reduction strategies.

To determine the effectiveness and benefits of the approach, the adjusted pedagogical agent was evaluated.

To use HRV parameters to determine stress level, the generation of data has to be ensured. A technical solution was provided by the wristband E4 of Empatica. Such a device was chosen to minimize the complexity of the handling and to provide a most comfortable position and positioning of the sensors (Gjoreski & Gjoreski, 2017) to reduce entry barriers while learning. Furthermore, Empatica provides a Software Development Kit to access the data via Bluetooth. Thus, the integrated photoplethmography sensor was utilized to determine the heart rate and calculate the time interval between two consecutive heartbeats (NN Interval) (Empatica Inc., 2016). These values are retrieved by a mobile application, which is also provided by Empatica and in which the functionality to transmit the current NN Interval and a timestamp to a server via HTTP-Post-Request was added. This implementation solution was necessary because of restrictions regarding data retrieval through web applications. The server is responsible for the storage of the values in a database and the processing of the NN Intervals. Is a specific time interval requested by the pedagogical agent, the suitable NN Intervals will be selected on the basis of the time stamp and the root mean square of successive differences in the heart rate (RMSSD) of these values will be determined.

Figure 1: Example for six NN intervals

$$\mathrm{RMSSD} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n-1} (NN_{i+1} - NN_i)^2}$$

RMSSD[1] was chosen as a metric for HRV because of the recommendation as an indicator for cognitive load in short term measurements (less than 5 minutes) by AWMF (Sammito, et al., 2014). As mentioned before, it was necessary to alter the pedagogical intervention process of the original pedagogical agent LIZA for analyzing the RMSSD data accordingly (Figure 2).

[1] NN = NN-Interval, difference in time of two consecutive R spikes; n = number of R spikes.

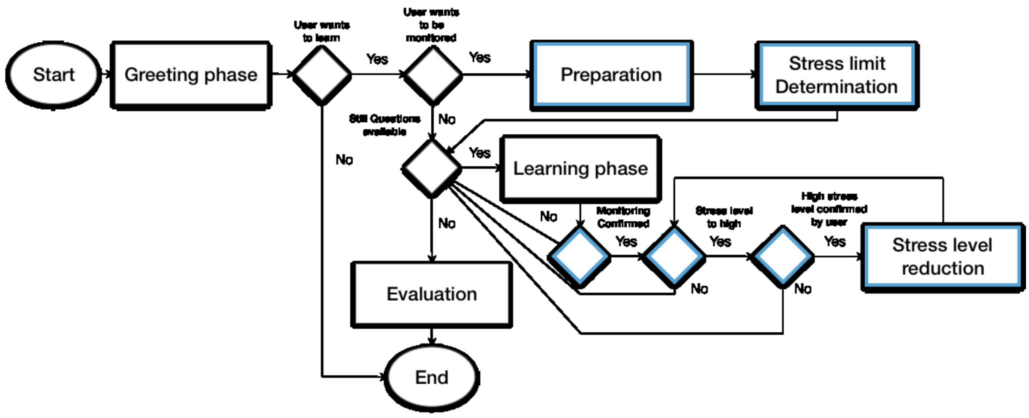

Figure 2: Intervention process

First, an enquire for the declaration of consent for monitoring the heart rate was added to the greeting phase. This guarantees that the original functionality remains unchanged in case of a missing measuring device. After that, the user is requested to apply and activate the wristband und start the mobile transmission application.

Since there are no generally accepted threshold values to determine the degree of a mental load of a person, a series of individual measurements has to be done (Sammito, et al., 2014). But that alone does not provide enough information to automatically identify an overload during a certain task. A range of cognitive load has to be identified and a specific threshold, when learning situation will be adapted, has to be defined. Because of that, a phase was added in the pedagogical intervention process, in which two different levels of stress are induced, the RMSSDs are calculated accordingly and used as an indicator for different stress levels. The arithmetic tasks were chosen after an analysis of induction methods for cognitive load of several research papers and they have been used widely to generate moderate stress level (Schneider et al., 2003).

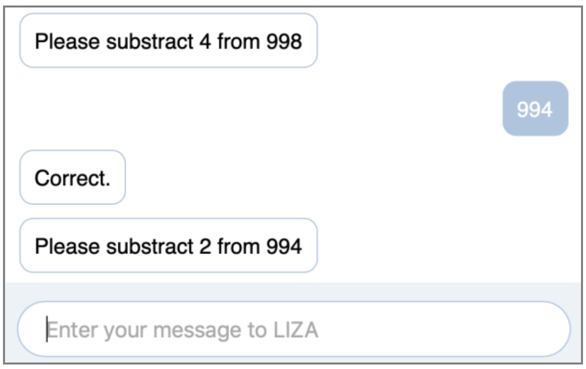

Figure 3 Arithmetic task in stress test 1

In two arithmetic stress tests (see Figure 3), with different levels of difficulty, the user had to subtract a random value from a certain number consecutively for five minutes. The result of the previous equation provides the minuend of the following. The level of difficulty is altered through the time limit for solving the equation, the number of digits of the random value and the value of the start minuend. The second and third factor determine the number of shifts during mental arithmetic, which increase the cognitive load with a growing number. Furthermore, a competition situation is created by requesting to beat LIZA in the number of correct answers under certain conditions in the second test. With that, the first test provides the RMSSD value for a moderate load, the second, which is designed with a higher difficulty level, for an overload.

Certainly, a range of cognitive load could be defined in that way, but a specific threshold, is still missing. Considering that an excessive load can result in a decrease of motivation and an abort of the learning in the long term, the learning situation has to be adapted before such a scenario materialize. Another factor, which has to be taken into account is that an adaption of the learning situation through stress reduction strategies will interrupt the process itself. So, it should be carried out as little as possible but also as much as necessary. A preliminary empirical test, where the task solutions were known and therefore low stress were induced, showed, that a threshold at 50% of the range triggers an intervention nearly every time LIZA was used. This would lead to massive interruptions of the learning process. Based on that, the threshold was increased to 2/3 of the individually defined stress range, where the intervention could be reduced to 40% of the cases.

If the current RMSSD falls below the threshold after a specific time, LIZA offers assistance in reducing the stress level through stress reduction strategies. Among different strategies (e.g., mindfulness-based stress reduction, autogenic training), two methods are proposed that are appropriate for the learning environment of a pedagogical agent. The first one distracts the user by telling jokes, the second one shows a video with relaxing content. The user decides whether it is necessary to start the offered coping process and how long the strategies are used. If the stress level is significantly reduced below the threshold, LIZA proposes the continuation of the learning process.

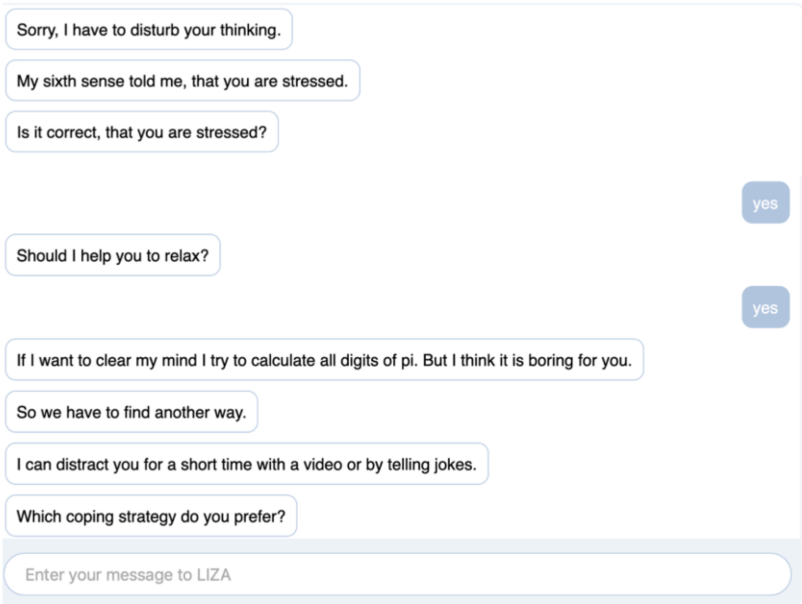

Figure 4 the pedagogical agent proposes two strategies for reducing stress

3 EVALUATION

The goal of the evaluation study is to determine the effectiveness and benefits of the pedagogical agent that was extended with the capability of measuring HRV and detecting critical stress level of learners. Amongst others, following hypotheses were examined: 1) The stress reduction strategies lead to the relaxation of learners; 2) The RMSSD is a suitable indicator for cognitive load; 3) The adaption of the learning process affects the learning performance. To examine these hypotheses a pre- and posttest was performed. For the study, 34 participants (10 males, 24 females) aged between 21 and 59 (mean 31 ± 11 years) were acquired and assigned to test- or control group by random. The test was conducted in a quiet environment under supervision.

Every participant was asked to use the pedagogical agent to perform two stress tests, each with a different level of difficulty, to determine the stress limit range and calculate the threshold. Then 4 tasks were given by the pedagogical agent to be solved, where every task covered a different problem of reasoning. After that, the RMSSD was calculated for the time frame of the first task block and squared with the previously determined stress limits. Only for the test group followed a stress reduction phase, if the current RMSSD fell below the threshold. Both groups continued with the posttest that required all participants to solve again 4 tasks. The reasoning problems of the pretest and posttest were the same, but the tasks were different. In the end, the participant got an evaluation of how successful the tasks were solved.

For every part of the process, the RMSSD was calculated so that the development of the indicator could be retraced. In addition, the participant had to self-asses its currents state of mental load with six adjective pairs of opposite meaning after each measurement cycle. A short questionnaire for the current cognitive load (KAB) (Wagner, 2012) was used the mean of all assessments was calculated.

The first hypothesis, which covers whether stress reduction leads to the relaxation of the learner, could be partly confirmed. 90% of the participants stated in a self-assessment, which indicates a relaxation, the effect of the applied stress reduction strategies. But only in nearly 50% of the cases, the RMSSD also fell below the threshold. Possible reasons for that could be deficits in stress limit determination, insufficient choice of strategies or application time. Concerning the adequacy of the RMSSD as an indicator for cognitive load, there were rough connections between the RMSSD values and the KAB-Index, but a significant correlation between both indices could not be determined. One reason could be the error-prone self-assessment like Picard points out (Picard, 2003). Another could lie in the insufficient cognitive load, which was applied during the evaluation, to reduce the RMSSD significantly. So, the adequacy could not be confirmed unqualified and the application of other physiological parameters is suggested. Finally, the effects on learning success have to be contemplated. The test group showed a significantly higher improvement while answering the questions with comparable opportunities than the control group.

4 CONCLUSION AND OUTLOOK

This paper has demonstrated the integration of physiological factors in learning analytics using wearable sensors. It showed, that the analysis of the RMSSD to determine the cognitive load of a learner can be used to improve the learning situation. But to determine the adequacy of the RMSSD as suitable indicator further test has to be conducted. Not only shows the integrating of wearable sensors a potential to improve the learning situation, but adds also the possibility to use cognitive data beyond the use in learning analytics.

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