AAU Multimodal Cognition and Perception M.Sc Medialogy WS 17/18
Measuring physiological symptoms induced by disruption of routines within a multimedia experience

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ABSTRACT
Through growth in the gaming industry the need to convey emotional states in multimedia production increases and research material regarding the emotional state of confusion is rare. Therefore the aim is to discern if confusion induced by a multimedia experience can be physiologically measured through blood pressure, heartbeat rate, electrodermal activity, temperature change and involuntary acceleration. This paper outlines and evaluates the measurements obtained during the tests ran over a pilot group of users (n=4) that where exposed to twenty minutes of digital test. During the experiment they were guided through a multimedia experience to generate a routine which was later distorted in order to analyze the physiological response of their bodies.

The results show no direct relation between the induction of confusion and the physiological measurements, however a relation cannot be generally excluded based on this experiment alone.

The findings were discussed subsequently in terms of limitations and measuring difficulties, and possible further improvements to the experiments setup were given. In the end we summarize the paper and address the applicability of our finding in specific environments.

Author Keywords
confusion in multimedia, cognitive disequilibrium, physiological symptoms

INTRODUCTION
At the time of the writing the importance and spread of multimedia applications is rising world wide. According to Newzoo [14], the games industry grew over 7.8 percent in the year of 2017 with a total revenue worth of 108.9 billion USD and a expected growth to 128.5 billion USD until 2020. Additionally the quality of these production increases and to stay competitive the development studios aim to create ever more lasting and more immerse experiences. In order to do so they try to convey their messages and stories by inducing emotions alongside the plain visual and auditory input. Some emotions are mentioned in related papers [24] like engagement, stress, frustration but regarding the emotional state of confusion there is still a shortage.

Therefore this papers goal is to present a multimedia experiment that is suitable to induce confusion by disrupting routines and then measure the resulting physiological effects in the participants.

The term *confusion* can have different meanings depending on the area in which it is being used. The Oxford English dictionary [18] offers the following definition "The state of being bewildered or unclear in one's mind about something". In this experiment we will define it in the sense of Jean Piaget's theory definition of cognitive disequilibrium. [10] As a state of cognitive imbalance that is experienced when information is encountered that requires us to develop a new schema or modify a existing schema. In other words, something that happens when events take place that contradict earlier experiences. This definition also conforms to Graesser [4]; "The cognitive system is in disequilibrium when individuals are confronted with stimuli, problems, or situations that present obstacles to goals, anomalous events, contradictions, discrepancies, expectation violations, and obvious gaps in knowledge."

In order to enforce this cognitive disequilibrium we have to create uniform knowledge that can be contradicted later on. This can be done through the use of a routine according to the following definition; Hodgson G. states in his paper [5] that the term routine is "used loosely to refer to repeated sequences of behaviour, by individuals as well as by organizations."

In the following this paper explains the steps from researching the specific physiological measurements in section Research over developing and executing the main experiment in section Experiment to displaying the obtained results in section Results followed by their discussion and interpretation in section Discussion. Last but not least, section Conclusion rounds up the paper and looks into its appliance in other contexts.

RESEARCH

This section describes the research that was done in advance for each physiological measurement in relation to confusional states.

Heart Rate

In the measurements of heart rate (HR) the central nervous system is activated during the arousal situation, producing sweat in the eccrine glands measuraby changing the conductivity in the skin.

It is observed that disgusting images and situations can generate a deceleration in HR. Hare [21] associates this to a defensive response. Empirically we are talking of a change of approximately 1-3 beats per minute (BPM) with a time course of approximately 6 seconds [1]. If we could detect this BPM change in our tests during the moments we want to generate an emotion change we could identify an autonomic arousal.

In this study [19] HR was also used for tracking changes in a group of women during emotional change situations to measure the differences between them when facing emotional change.

Electrodermal activity

The following section will give an overview of a few previous studies related to electrodermal activity and along the way explains the most important traits and the ways of interpreting this measure.

Nourbakhsh et al. [15] give a good overview of what electrodermal activity (EDA) means. The following explanation of the term was inspired by their description.

Electrodermal activity of the skin can be split into two separate parts. *Exosomatic* activity is the conductance of the skin and *endosomatic* activity is the electrical potential difference between two surface points on the skin. Depending on the context electrical resistance may used instead of conductance for measuring exosomatic activity. Resistance and conductance represent the exact same property, but they are the multiplicative inverse of each other. However conductivity is more often used for measuring EDA, one reason of which is that close-to-zero conductivity might occur, which results in a close to infinity resistance. There are a lot of different terms that correspond to the same phenomenon as EDA or a specific property belonging to EDA. Among these are electrodermal response (EDR), sympathetic skin response (SSR), and GSR which sometimes stands for galvanic skin response and other times has a more specific meaning, galvanic skin resistance. Both endosomatic and exosomatic activity are largely affected by the activity of a specific type of sweat glands, the eccrine glands. What makes these glands unique among other sweat glands is that they respond to psychological stimuli while others mostly just take part in temperature control. GSR values are highly subject dependent. The features themselves might carry a unified meaning, but the absolute value of those features might differ among different persons.

As it has been stated the conductance is the reciprocal of the resistance. For persons newly introduced to the field this can be a great source of confusion (especially if the term GSR is used to describe conductance). In some studies like in [17] resistance and conductance does not seem to be inversely related as they should according to the fact that they are each other's reciprocals. The solution to this contradiction is that measurements usually state the *difference* of prestimulus and poststimulus resistance instead of absolute resistance. In other words these studies usually discuss the difference between the resistance just before the event and the resistance just after the event. A more detailed description can be read in the book by Stern et al. [22].

A positive correlation between high skin conductivity and high stress levels is generally accepted to be true in the field. Along with many others, Paintal [17] and Bakker et al. [2] both showed results that support this.

The work of Bakker et al. [2] has further significance that is worth mentioning here. Some environmental properties and test subject activities cause high skin conductivity but does not relate to stress levels. An example of this would be exercising which might have such an effect due to the activation of sweat glands in response to body temperature change. Although after these activities, skin conductivity drops back to the level it was before the activity. On the other hand it is not really clear what it means if the skin conductivity does not drop back to the level prior to the event. The authors show two examples of this. One of them was labeled by the subject as a stressful event, but the other one wasn't.

The paper also extensively explains the different types of noise that can disturb the EDA data. One of these is caused by the insufficient contact between the device and the skin. This typically causes the conductance signal to suddenly drop to zero for a few second or even minute long period. After contact is restored the signal suddenly jumps back around its original level.

Blood pressure

Blood pressure (BP) is a good indicator of stress in the human body. It is also notable that research [20] has pointed out that the way that individuals express their emotions (i.e. in a more open way) show reduced physiological responses to emotional stimuli in relation to less expressive individuals. However, others [12] point out that this inverse relationship is not always observed. What we can assure is that there is a direct correlation between the person's feelings and the physiological responses, including their blood pressure. In this exper-

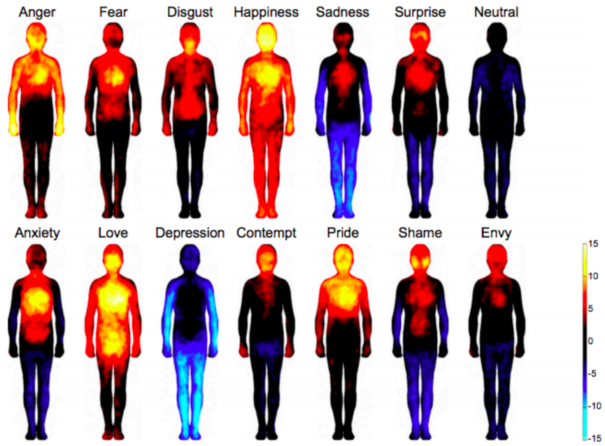

Figure 1. Body temperature mapped to different emotions

iment [3] it is pointed out that blood pressure showed a trend towards a positive association with negative expressions for some individuals (AA dyads, (b=0.41, t(24) = 1.74, p.<.09).

Another study [6] shows that anger control affect BP in children. Those ones who could reflect upon and control their anger had lower diastolic BP, so we could use BP to measure this factor.

Temperature

One aim of this paper is to determine whether the change in temperature can relate to confusion. The temperature in the human body varies from one body part to another. Whereby the temperature in the extremities of the human body is influenced more easily by environmental factors than the central core ("central temperatures"). [23] Mapping emotions to the human body temperature can be a tricky thing, therefore it should be investigated how temperature is distributed along the extremities and the central body parts.

As it can be seen in figure 1, the body temperature can be related to different emotions. However there is still a huge debate whether the bodily changes mapped with different emotions are valid enough to show emotions like anger, fear or happiness. [16]

As the experiment was conducted with a wrist mounted measuring device, we can just look at the wrist color of each silhouette which as well, in hand with the other body part's temperatures, can relate to different feelings or emotions. It can be seen that high wrist temperatures with a higher heat within the upper body can be the effect of feeling fear or disgust while high wrist temperatures that are associated with increase in temperature all over the body can be a result of feeling happiness and love.

Acceleration

Measurements regarding acceleration can be helpful for determining confusion under the following aspect. Mandler wrote about the term *mastery* that "refers to our perception that the events in our personal world may be brought under our control." [13] Assuming that confusion leads to physiological stress reactions in the body as the world that is perceived is suddenly out of control as a result of not understanding what is going on, we can glance at symptoms related to short term effects of stress. The signs we are looking for are slight sudden movements as a result of the muscles tensing up, tremors, jerks or other forms of heightened muscle activity.

Figure 2. Screenshot exhibiting the house structure

Acceleration is measured when agitation is detected and it is correlated to the velocity of the movement. Therefore this can be used to catch cues about induced stress in order to relate that to the expected confusional state.

EXPERIMENT

The goal of this experiment is to measure and analyze the physiological symptoms that arise when an established routine within a multimedia context is distorted.

This chapter describes the experiment starting with the design of the experiment in section Method followed by the Evaluation Procedure.

Method

The experiment is divided into two parts. In the first part we are going to establish a routine in a virtual environment which is then, in the second part, disrupted by an unexpected event.

The experiment takes place inside a house in which the avatar lives. The house has one bigger sized area where the living room is located with an open-plan kitchen. There are four other rooms which are all separated through walls from each other and other parts of the house. These rooms can be accessed from a hallway. Figure 2 was taken looking from the living room towards the hallway. The main structuring element in the multimedia experiment is a virtual day.

Establishing a routine

In order to establish the routine, the player is presented with the same tasks everyday that must always be executed in the same order. During the first few days, the game guides the player carefully by highlighting the next object that should be interacted with and displaying an

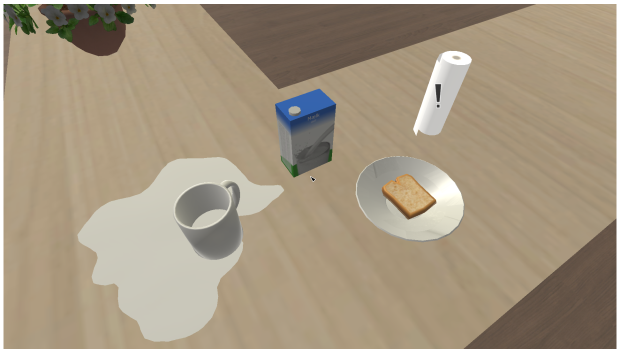

Figure 3. An image from the game showing the spilled milk, and the highlighted paper towel.

exclamation mark on the screen, directing the attention of the viewer towards the highlighted object.

The participant has to experience three virtual days that are structured similarly. A day features a hypothetical morning routine of a teenager, starting with a ringing alarm clock in the morning. After this the participant has to pour a glass of milk for breakfast. If the participant spills the milk, the table has to be cleaned. Afterwards the plates have to be cleaned and stored away in an assigned kitchen cabinet. Last but not least the participant has to go to the room where the experience started to get himself ready for the day. According to our definition of a routine, three repetitions are enough to induce as sense of confidence or *mastery* in accomplishing the required tasks. [13]

On the fourth day the tasks are still the same, and there are no changes in the environment, but starting from this day, the objects are not highlighted any longer. This period is used to check whether the participants fully understand the tasks at hand, which leads us to the assumption that the desired routine has successfully been established in the participants.

Disrupting a routine

The first disruption happens on the fifth day of the experiment. The participants have to do the tasks as usual that means pouring the milk, having breakfast, cleaning and storing the plates. But when they try to reach their room, they cannot find it at the familiar location anymore. The rooms have changed their position. This very moment when the participants are entering the wrong room and realizing that something is not right is where we hope to find some cues for physiological reactions to the experienced confusion. This unexpected event is introduced to disrupt the learned routine from the beginning of the experiment. After that there is one last day that is exactly like the fifth day but with the exception that the rooms are changed again.

Evaluation Procedure

This section explains the evaluation procedure that is used to collect information about induced confusion during the multimedia experiment described in section Method.

Figure 4. Empatica E4 wristband [9]

In order to gather all the data mentioned in section Research we used an Empatica E4 4 with four embedded sensors: A Photoplethysmography sensor (PPG) which measures the blood volume pulse (BVP) and the heart rate variability. An electrodermal activity (EDA) sensor which measures the changes in electrical properties of the skin. A 3-axis accelerometer that captures motion-based activity and an optical infrared thermometer which reads peripheral skin temperature. The device also has an internal real-time clock which allows exact time alignement of the recorded data. Furthermore it features an event mark button which is used for labeling events during the recording in order to associate them to the physiological measurements.

The experiment is setup in the following way. It takes place inside the facilities of an international dormitory in Denmark. The test group consists of four students from Denmark, Lithuania and Spain aged between 15 and 26 years. At the beginning the mediator explains the circumstances of the experiment without mentioning too much detail about what is going on in the multimedia environment as every participant should experience it on their own for the first time. Each participant takes part in the experiment separately. For that, a workstation was prepared with a mouse and headphones attached and the multimedia experiment described in section Method was installed and running. First the participants had to fill out a consent declaration form and then the mediator attaches the Empatica E4 to the non active (non mouse) hand, starts the recording and labels the start. The participants were instructed to press the labeling button at the start of each virtual day in order to differentiate the measurement later on. A screen recording was running during the experiment. This allowed the recorded biomedical signals to be later compared with the recorded video in order to find out what might have caused any disturbance in the biosignals.

A session is complete when the participant finished the sixth and last day of the multimedia experiment. The mediator then stops the data recording and removes the wristband. Afterwards the sessions were extracted from the Empatica E4 and uploaded to the empatica webinterface [7] for the analysis. This process is described in the sections Results and Discussion.

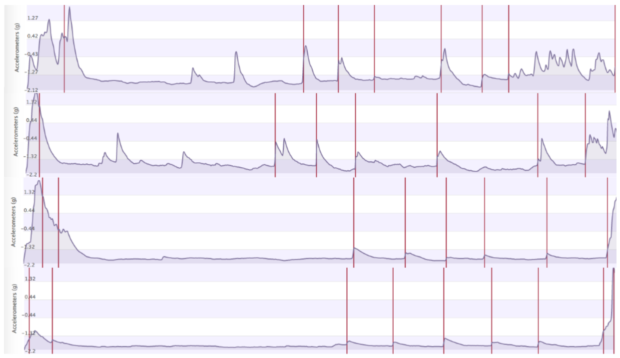

Figure 5. Acceleration measured at the non active hand of the participants (1-4)

Figure 6. Electrodermal activity of subjects in test execution order.

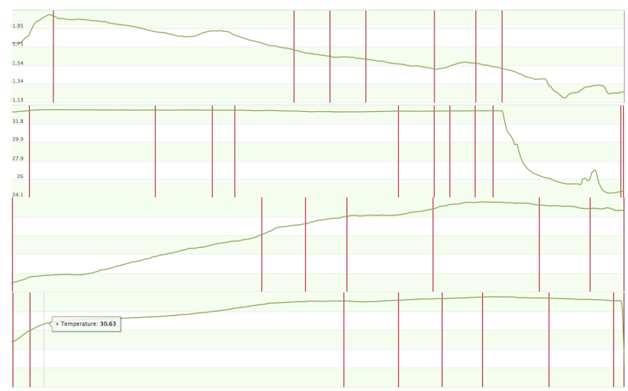

Figure 7. Body temperature measured during each experiment (1-4)

RESULTS

This section displays the results we obtained from the experiment described in section Experiment.

As it can be seen in Figure 7, the body temperature of each participant shows different patterns. The optimal temperature that the human body has around the extremities is 32°C. The Empatica E4 is worn on the wrist, therefore it can be seen that the starting temperatures are always around the above-mentioned value. The data is split in two groups, with two of the participants having an increase in heat during their experience and two with a loss of body heat. Concerning the first two participants, which present a loss in body heat, shows no big difference between the starting and ending point. The first participant's temperature is only decreasing by 0.60°C while the second one has a stable temperature throughout the whole experience with fluctuations and a big decrease of heat in the last level of the game. The other two participants that had an increase of body heat during the evaluation, show small changes as well. The third participant shows a bigger fluctuation than the fourth one, both of them with small differences in temperature.

The acceleration sensor of the Empatica E4 is a 3-axis accelerometer that provides XYZ-accleration data at 32Hz. [8] The obtained results of the acceleration meassurements can be seen in Figure 5.

The skin conductance was measured in micro Siemens (μS). Figure 6 shows the skin conductance as a function of time. The first participant (top row) had mostly stable values very few fluctuations are visible during the test. The fluctuations visible at the end of the time-line were recorded after the test. Notable changes in the signal happen at the mark points, in between the days in the virtual experience when a button is pressed on the measurement device attached to the subject's wrist to create the mark. The second participant has much more interesting signals at the first half of the experiment but at the second half some gaps appear where the signal drops down to practically zero. The third participant produced another completely different pattern. In this case the conductance slowly approaches and reaches 0.07 μS and only changes temporarily at the marking points when the device is physically disturbed. The last participant keeps a conductance level at around 0.56 μS, although the signal seems to have relatively high frequency component throughout the whole experiment.

The blood volume Figure 8 shows a regular pattern through the sessions, with only an irregular areas at the beginning and at the end of each session. This can be related with the time when the participant was talking with the test supervisors, right before starting the first day of the interactive experience and after finishing the last one, when the participants were asked to fill up a form. There are some peaks during some unrelated points during the sessions (Contrasted with the screen recordings), but they don't seem to be correlated with any of the events inside the experience.

The Heart Rate Figure 9 was measured in Beats Per Minute (BPM) during the sessions.

The first test user shows a clear rise in the BPMs after finishing the first day. Then they are reduced progressively until they reach the lowest point of the whole measurement (54.08 BPMs) on the 4$^{\text{th}}$ day, when the routine has been fully established. Then it raises again in the 5$^{\text{th}}$ day when the disruption appears (According to the screen recording), and maintains that high rate until the end.

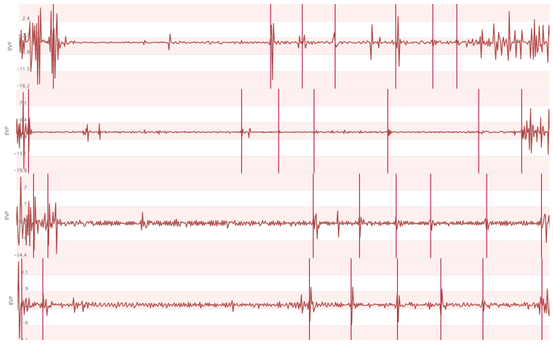

Figure 8. Blood volume pressure measured during each experiment (1-4)

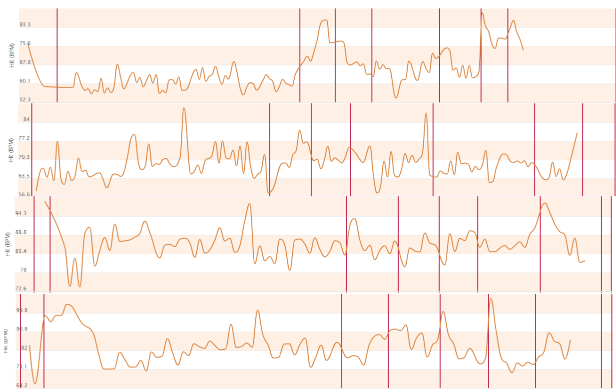

Figure 9. Heart rate measured during each experiment (1-4)

The second test user shows a more irregular evolution of its BPMs, but it also shows the lowest point in the 4th day. The third test user shows the most stable pattern of them all in the average, but with peaks in the last days. The fourth test user shows irregularity in the pattern, registering the highest peak at the beginning of the first day (Probably because of the new visual stimulus induced by the experience).

DISCUSSION

The acceleration measurements as shown in Figure 5 do not show any correlation with the confusion induced in level five of the experiment. What can be seen is that most of the peaks are directly aligned with the data labeling, which is applied by pressing a physical button on the device and therefore causing the measured acceleration. Other than that the first two participants show more physical activity than the last two participants. But since this higher activity was measured throughout the entire experiment it cannot be accounted to a confusional state.

Regarding the temperature, the body heat does not seem to be related to the confusional state. The data is not showing major differences related to the game experience and there are no indicators that body temperature changed because of an in-game event. The graphs show a constant temperature with a small deviation of $\pm$ 2°C for each participant. As these results can relate to external factors that caused the temperature fluctuations, the location where the experiment took place needs to be taken into consideration. As a matter of fact two of the participants completed the experiment in a common study room while the other two were tested in the basement. Therefore one explanation is that due to the different locations the results show the effect of thermoregulation, a physiological process where the body tries to balance the internal heat between certain boundaries, despite the surrounding environment. Nevertheless the outer body parts for example the limbs and especially exposed skin cool down first. However, this is not relevant to the main focus of this paper, confusion.

Just like the body temperature information obtained during the test, the EDA signals of the different subjects don't show many similarities. According to Mandler [13] the inability to complete a sequence may lead to helplessness. He also states that helplessness and disorganization are anxiety. This gives us a very powerful tool because this is the key to connecting the EDA data to confusion. We expect the subjects to be confused exactly when we temporarily take away their ability to complete a sequence. Relying on Mandler's thoughts we assume that this situation would evoke traces of anxiety which manifests itself as *spikes* in the skin conductivity signal. We define a *spike* to be a change in the skin conductivity over time in the following way: conductivity increases, arouses for a short period of time, and then decreases eventually getting back or close to the level before the arousal.

An arousal of the conductivity is visible at the label points, which might be a cause of the device being shifted on the skin or might be a signal of a psychological reaction to the event of briefly interrupting the virtual experience. The screen recordings were inspected at other parts where similar spikes are visible in the EDA signal. Although some relation to excitement or frustration can be suspected but examples of these were based on highly subjective and not well supported assumptions.

On the signal of the second subject a few gaps are visible. These were explained in Electrodermal activity. These suggest that either the measurement device was not attached appropriately or the subject may have moved the device. The signal obtained form the third subject is also worth mentioning as it shows a conductivity of 0.07 μS most of the time. Considering that this might be the minimal value reported by the device it is likely that the wristband was not attached correctly in this case. Although the gradual decrease of conductance contradicts this speculation.

The blood volume pressure measurements don't show anything clarifying according to our experiment. The measurements are stable in general, with only remarkable peaks in the beginning and the end of the experiment. As said before in Results this can be due to the participants talking with the test coordinators before and after going through the whole interactive session.

According to the analysis done in the Results section the heart rate shows a decrease of BPM in some of the users (1^{st}, 2^{nd} and 4^{th}) during the 4^{th} day, when the routine is theoretically fully implemented. This could be a sign of relaxation after the users are familiar with the tasks they have to do for the routine, but further testing should be done to obtain a conclusive answer to this. Some of the test subjects (1^{st} and 4^{th}) showed a rise in BPM in the 5^{th}, when the routine was distorted, but knowing that the 2^{nd} and 3^{rd} test subjects didn't show anything remarkable in that points we cannot give a final conclusion about it.

CONCLUSION

Despite that the original goal was to find traces of deviations in the physiological measurements corresponding the the disruptions of a routine, we cannot conclude that there was a direct connection to the interactive experience. This is partially due to the differences of measurements in the test subjects. However, this paper does not claim to disprove such a relation. The sample size was inadequately low with only four subjects to derive such a conclusion. Additionally the test did not take place within a controlled environment.

Thinking about application areas for the induction of confusion, Lehman et al. [11] wrote about its appliance in educational environments as a method of teaching, that uses contradictions to enhance learning opportunities. Thus creating a new generation of educational multimedia applications that can be superior to common static teaching methods in classrooms.

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APPENDIX

Empatica E4 measurements

These are the collected measurements from the pilot study conducted with the Empatica E4. The graphs where directly taken from the Empatica Connect+ website. [7]

Figure 10. Empatica E4 measurement - participant 1

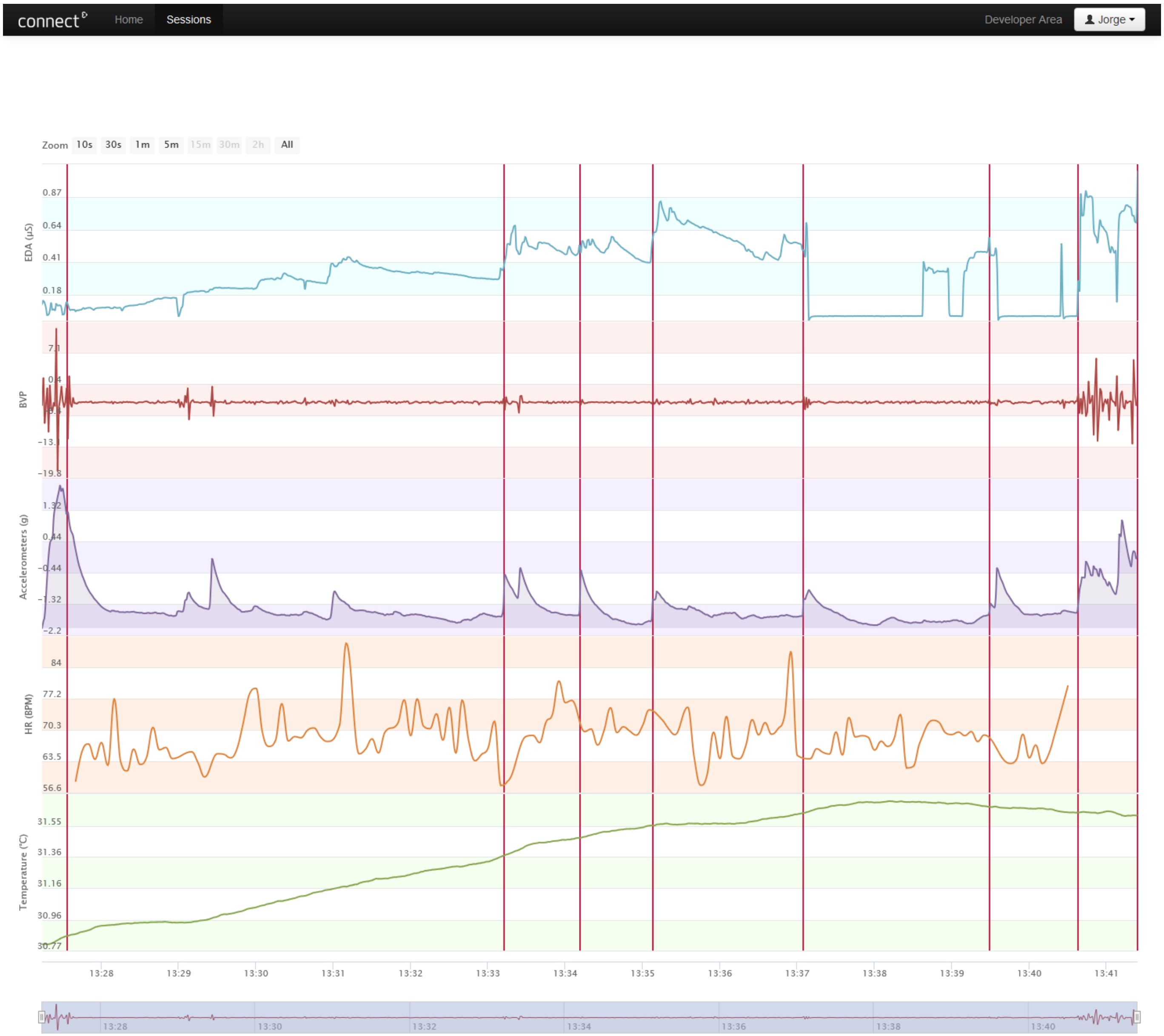

Figure 11. Empatica E4 measurement - participant 2

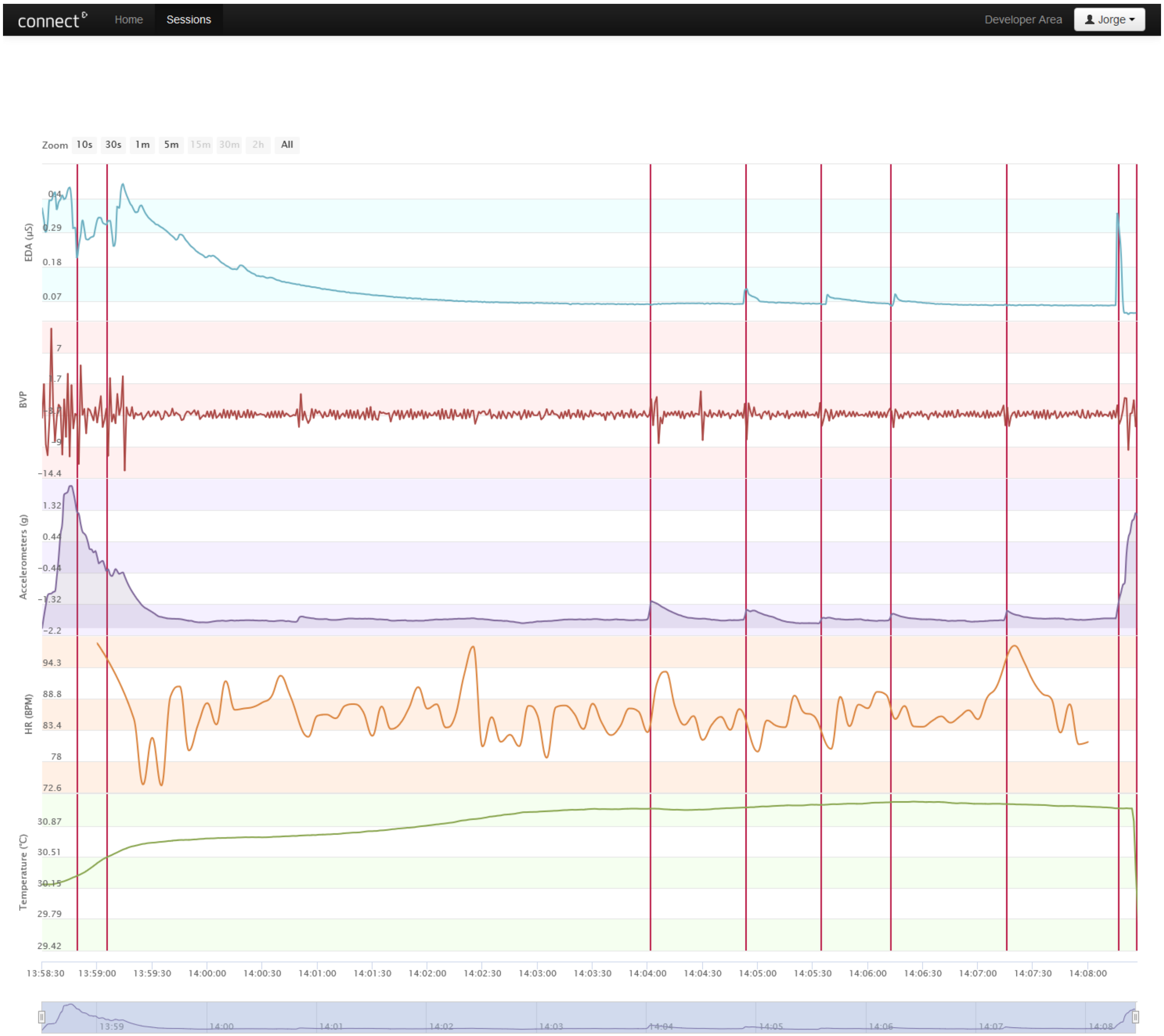

Figure 12. Empatica E4 measurement - participant 3

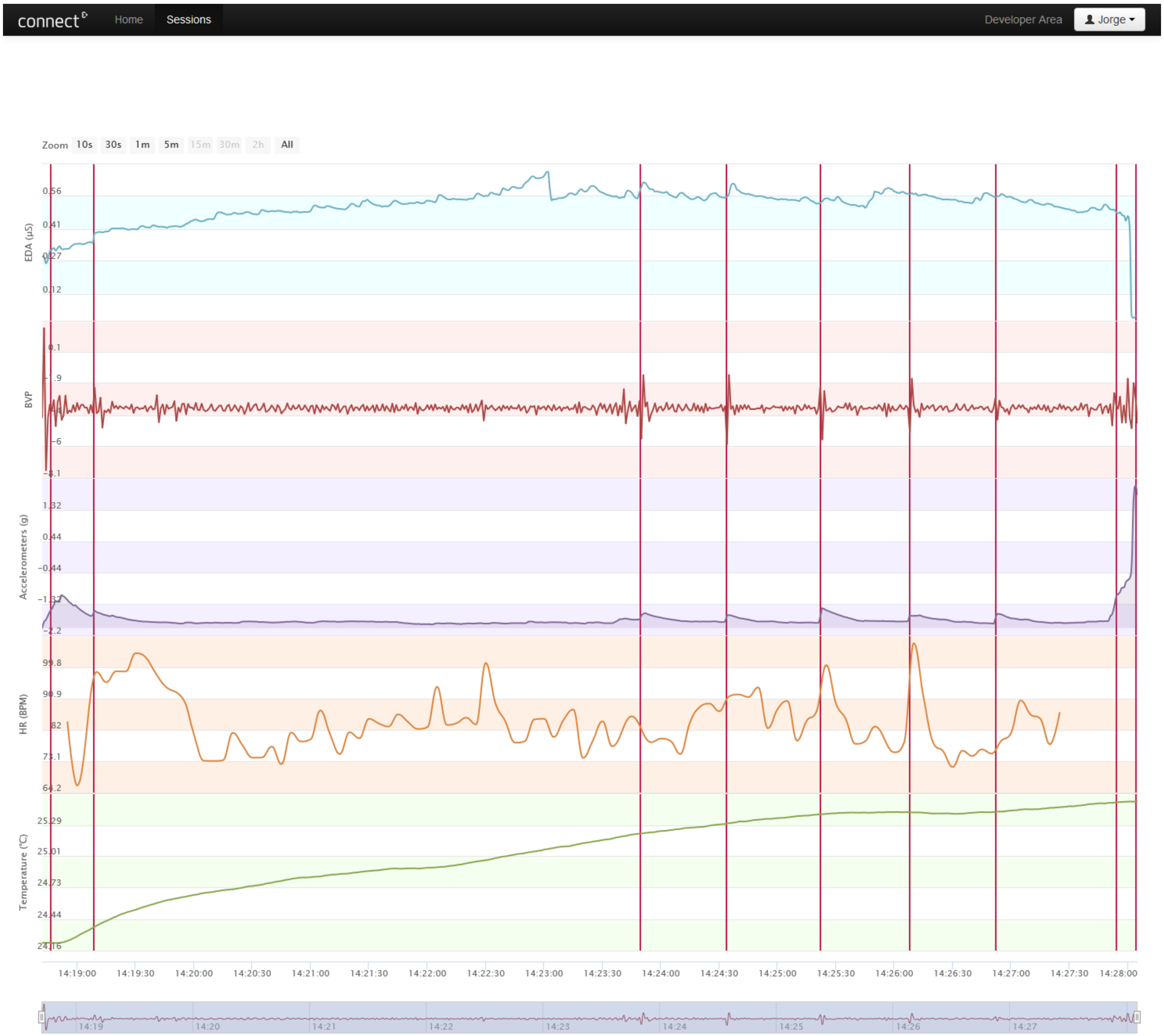

Figure 13. Empatica E4 measurement - participant 4