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Measuring stress in virtual reality

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Abstract

Virtual Reality Exposure Therapy (VRET) is an effective way of treating anxiety disorders. However, it has one significant drawback: a doctor always has to be present to control the amount of stimuli in the virtual environment. This drawback can be overcome by the future development of an algorithm that adapts the amount of stressful stimuli in the environment based on stress levels. This thesis researches the possibilities of measuring stress levels based on the movements that are measured by the movement sensors incorporated in the VR equipment. The conclusion drawn, based on the results of an experiment, is that the variability of movements decreases in stressful environments. This bodes well for the possibility of measuring stress based on movements, however, more research is needed on measuring stress in real time for the development of the algorithm.

Index

Introduction	Page 3
Literature review	Page 6
Methodology	Page 13
Discussion	Page 16
Conclusion	Page 19
Appendix	Page 20
Acknowledgments	Page 29
References	Page 30

Introduction

Anxiety disorders are amongst the most prevalent mental health conditions. Occurring in 2.6% to 5.2% of children under 12 and 5% to 19% of children and adolescents (Costello 2004), they are fairly common. Anxiety disorders often persist into adolescence and early adulthood (Last, 1996), however, many times it remains untreated and diagnoses are established late after the onset. A variety of different forms of anxiety exist. Most of these forms have very similar behavioural manifestations, making it a hard disorder to diagnose (Craske, 2016). For example, an individual might experience fear from being in crowds of people. The underlying anxiety can be social anxiety disorder (fear of assessment by others), agoraphobia (fear of incapacitation), panic disorder (fear of panic attacks), separation anxiety disorder (fear of separation from an attachment figure), or a specific phobia. Individuals with an anxiety disorder are excessively fearful and anxious, or avoidant of perceived threats in the environment, or internal to oneself. The response is out of proportion with the actual danger or risk posed (Craske, 2016). Anxiety disorders can arise from a variety of different mechanisms including confrontations with dangerous stimuli, having no sense of control over one's situation, experiencing rejection or overprotection, experiencing symptoms specific to an illness, or unpredictable events (Pinquart, 2011).

There are both psychological and pharmacological ways to treat anxiety. Psychological treatment is based on the idea that anxiety and fear are learnt responses that can be unlearnt (James et al, 2015). The most empirically supported psychological treatment is cognitive behavioural therapy (CBT). CBT is a goal-oriented, skills-based treatment that aims to treat anxiety on the short-term (10-20 weeks). It reduces anxiety-driven biases that interpret ambiguous stimuli threatening, encourages approach and coping behaviours instead of avoidant and safety seeking behaviours, and reduces excessive out of proportion autonomic arousal through relaxation or breathing training (Craske, 2016). Cognitive strategies, as self-control strategies that rely on self-observation, self-evaluation, self-reward, and self-modification, are used during CBT (James et al, 2015). Key to CBT treatment is exposure. This involves pairing anxiety stimuli with competing relaxing stimuli such as muscle relaxation or pleasant images in a systematic method (Silverman, 1996).

Pharmacological therapies are also available for all anxiety disorders. With the exception of specific phobias, antidepressants are usually the first line of pharmacological treatment. Additionally, a significant amount of patients with anxiety also have depressions, therefore the use of antidepressants enables joint treatment (Ravindran, 2010). Meta-analysis shows that the combination of pharmacological treatment and psychological treatment, mostly CBT, is more beneficial that just pharmacological treatment alone (Cuijpers et al, 2014).

Although existing treatments are proven to be effective, there are some uncertainties and drawbacks. Little evidence exists about how to select a certain treatment for the individual patient, and what the optimal duration of treatment is. Furthermore there are limitations to classical exposure techniques that is necessary for CBT. They involve low control of the situation, financial and time costs, development of aversion, low control of the situation, and dependency on the patient's ability to recreate the phobic stimulus (Emmelkamp, 2005). Due to the uncertainties and limitations of personalized treatments, treatments follow a trail-and-error approach both within and across treatment methods (Porter, 2015). More research is needed for the personalization of treatments.

E-health interventions might be a solution to these limitations and drawbacks. E-health is an emerging and fast-developing field of research that utilizes digital technologies as health treatments. Most e-health for anxiety are CBT (Craske, 2016). An advantage of e-health programs is that they increase access to treatment. Patients who live in rural areas, are on long waiting lists, have economic limitations, or prefer anonymity can access treatment at their own convenience. Furthermore patients can receive treatment at their own pace (Thabrew et al, 2017). Especially e-health exposure therapies carry advantages over the classical exposure therapy: they are safer, can be repeated as many times as needed, are cost efficient, can be individualized, and the therapist has more control over the amount of anxiety stimuli and the exposure rhythm (Emmelkamp, 2005).

Virtual reality exposure therapy (VRET) is a growing field within the e-health interventions. Qualitative systematic reviews have shown that VRET is an effective and efficient treatment for flight anxiety, and that it is comparable or superior to in vivo exposure, progressive muscle relaxation, group therapy, or cognitive therapy (Cardoş et al, 2017). Other research on VRET has shown that age of participants is a good predictor for the effectiveness of the treatment. The lower the age of the participant, the higher the effect of the treatment. This is result can be explained by the fact that young people are major consumers of technology, and adapt more easily to new technologies (Horgan and Sweeney, 2010).

One of the only drawbacks of VRET is that a doctor or therapist still has to be present during the therapy to control the virtual environment, and as mentioned before, more research needs to be done about personalized treatment. Schelte Meinsma aims to overcome this drawback and personalize treatment with his company Vrroom Ultimate VR Experience (Vrroom for short). The company develops its own virtual reality content in the shape of games and experiences. So far Vrroom has developed an elaborate virtual reality escape room, and has built virtual environments for companies to simulate practical cases for training purposes. Now Vrroom wishes to develop a VRET that systematically adapts the level of anxiety stimuli in the digital environment based on stress levels in the form of an algorithm. This will make the therapy both autonomous and personalized. Further applications of a digital environment adapting to stress levels are video games. If the difficulty of videogames would adapt itself to stress levels, players would always play at a level that is too easy or too difficult.

The stress levels would preferably be measured with the a minimum amount of equipment, in order to make it as convenient as possible for the patient. The HTC Vive, which is the virtual reality hardware that Vrroom uses, has motion sensors in the headgear and in the two hand controllers.

Ideally, the stress levels would be measured by means of movements, since this entails patients do not need any additional hardware next to the virtual reality set. This is the topic of this bachelor thesis, it aims to answer the question: “To what extent is it possible to measure stress based on the movements measured by the sensors in the HTC Vive?”.

Literature Review

This part reviews literature in order to gain knowledge to answer the research question "To what extent is it possible to measure stress based on the movements measured by the sensors in the HTC Vive?". In order to answer the question, certain sub questions need to be recognized and researched. This section reviews what stress exactly is, what the relationship is between stress and emotions, what the relationship is between stress and anxiety, what factors induce and decrease stress, and how to measure stress.

What is stress?

The definition of stress

The word stress is derived from the Latin verb 'stringo', which means to bind, draw tight, to graze, touch, pluck, or prune. It made its first appearance in the English language in the 14th century resembling the words distress or distrain. Back then, it referred to physical hardships or trials, but by the 16th century it also meant physical injury. What these definitions had in common was that stress solely referred to unpleasant conditions in the environment rather than unpleasant conditions of the individual. From the 17th century on the word started to refer to an inner state (Hayward, 2005).

Nowadays, despite of its common usage, the definition of the word varies widely. This is partially because stress tends to be viewed in two ways: as a cause and as a result. A possible reason for this confusion can be that stress is a borrowed term from physics, where the word has a precise meaning. There, stress describes the forces which adjacent particles within a continuous material exert on each other (Persson, 2016). Hans Selye first used the word 'stress' as a concept for what he had observed as the 'syndrome of just being sick' (Goodheart, 2012). In his later work, Selye admitted to using the term to describe both the words 'strain' and 'stress', because his unfamiliarity with the English language left him unable to make a distinction between the two words. He resolved this by replacing the word 'strains', which he defined as the cause of stress, by the word 'stressors', and defining stress as 'the nonspecific response of the body to any demand made upon it' (Selye, 1974). Selye first studied stress as a biological phenomenon, with his initial subjects not being human.

Over time, more psychologists started to research the psychological aspects of stress in humans. The most influential one is Richard Lazarus, who defined stress as 'any event in which environmental demands, internal demands, or both exceed the adaptive resources of an individual, social system, or tissue system' (Monat and Lazarus, 1991). This is the definition that most psychologist upkeep nowadays.

The stress response

The psychological and physiological bodily responses to environmental or internal stressors is called the stress response, and although stress has a negative connotation in everyday life, it is actually a survival mechanism. The stress response is meant to solve short-term, life-threatening problems by gearing up the body for flight or fight (Persson, 2016). Stressors that initiate the stress response can either be environmental, during extremely cold weather, physical, during intense physical exercise like running, or psychological, during grief (Goodheart, 2012).

All these types of stressors trigger specific biochemical pathways in the brain which also depend on the length and the intensity of the stressor. However, after years of research one major set of responses occur across all research categories. This response initiates in the hypothalamus, pituitary, adrenal axis (HPA Axis). When these interrelated endocrine glands are excited, they initiate the cascade of responses that are known as the stress response. The hypothalamus produces the hormones corticotropin-releasing hormone (CRH) and arginine vasopressin (AVP). These hormones acting together excite the pituitary to produce adrenal corticotropic hormone (ACTH). In normal non-stressful situations, baseline levels of these hormones are produced with cyclical variations throughout the day, and these levels can be affected by stress. ACTH has its effect on the adrenal glands as it affects the production of adrenal androgens and glucocorticoids and the control of aldosterone. These adrenal glucocorticoids are the main effectors of stress throughout the whole body on cellular levels regarding that glucocorticoids receptors are present everywhere in the body (Tsigos and Chrousos, 1994). Thus, producing glucocorticoids above baseline level, which is what stressors cause, affects the whole body.

Additional to having biochemical effects, stressors also affects neurological processes and the sympathetic and parasympathetic nervous system. During the stress response the body initiates a chain reaction of events to maximize reaction speed by activating the sympathetic nervous system, which is responsible for the flight or fight response, and downregulating the parasympathetic nervous system (Schneiderman et al, 2005). This means that heart rate and muscle tension increase and intestinal blood flow reduces. Neurological consequences include the possible impairment of the prefrontal cortex. This part of the brain is responsible for managing processes like attention and problem-solving. Therefore stressors can have severe consequences on our problem-solving capacities (McEwen and Morrison, 2013).

This section so far has reviewed the physical consequences that stress has on the body. Appendix 1a shows a figure of the relationship between stressors and stress responses.

Stress and emotions

Feeling stressed can arouse angry, sad, or fearful emotions, and thus it is logical to think that emotions and stress are interlinked. However, emotions and stress were seen as completely independent fields for a long time. In the past, stress was seen as a unidimensional concept, a continuum ranging from high to low depending on activation (Duffy, 1962). On the other hand, emotions were viewed as complex and versatile.

An influential early attempt to divide stress into types comes from Hans Selye. He divided stress into two types: distress and eustress. Distress is a destructive type that damages health, and is fueled by anger and aggression. Eustress is constructive type that is protective of good health, and is fueled by empathetic concerns for others (Selye, 1974). Although this important hypothesis remains vague, it still has not been adequately supported or refuted by empirical evidence (Lazarus, 2006).

Another important attempt to divide stress in multiple types comes from Richard Lazarus, who called the separation between the fields of stress and emotion an absurdity, and that it reflected the highly fractionated nature of the social sciences. He called people working in these fields specialists in increasingly narrow topics whilst remaining parochial in outlook (Lazarus, 2006).

Lazarus made a distinction in 15 types of emotions and three types of psychological stress, harm/loss, threat, and challenge. Harm/loss deals with damage that has already taken place. Threat deals with damage that is possible or likely to happen in the future. Challenge deals with possible damages that might stand in the way of gain, but can be overcome with self-confidence and persistence. Coping with each of these three types of stress has different performance and psychophysiological outcomes (Lazarus, 1966). However, the stress response is a mechanism that is evolved to adapt or cope with problems, and it remains too simplified in comparison to emotions.

Regardless of the three distinguished types, stress tells us relatively little about the details of an individual’s ability to adapt. Knowing if an individual feels anxious, sad, happy, or mad says much more about his/her ability to adapt than merely if he/she feels harmed, threatened, or challenged (Lazarus, 1993). More research on the relationship between has been done after Lazarus came up with his theories.

One theory describes that our emotions and judgements under stress become more simplified. This theory is based on the fact that stress causes the level of uncertainty to increase (Cassel, 1975). Under circumstances of uncertainty, the demands for information increases. However, due to the negative effects stress has on out prefrontal cortex, which is responsible for our problem solving abilities, our cognitive capacities to process affective information decreases (McEwen and Morrison, 2013). As a consequence, emotion processing is compressed, becomes more black and white, more definite and less tentative; in a word, simplified (Zautra, 2003).

The narrowing of our emotional field under stress

That stress simplifies emotions entails that stress narrows our emotional field. The narrowing of the emotional field makes sense if you look at the purpose of the stress response, which is to adapt or overcome an external or internal demand. Human attention is more averted towards the crisis at hand during stressful circumstances. A smaller condensed affective space allows for more rapid and adaptive responses during times of threat. Additionally, the condensed space causes your internal resources, both mental and physical, to be better focussed so you can more efficiently take care of the task at hand (Zautra, 2003).

A theory of the narrowing of the emotional field comes from AJ Zautra. She imagines that the ranges of emotional experiences can be represented in a graph. The extent of positive emotions would be represented on the vertical axes, and the extent of negative emotions would be represented on the horizontal axes (Zautra, 2002). Under circumstances of low stress, emotions would we represented as flat, broad, Cartesian space, with the positive and negative emotions crossing each other at right angles, perpendicular to one another. The level of positive emotions would be independent of the level of negative emotions. Appendix 1B represents what would happen to our emotional experiences under stress. Stress acts like gravity, bending the two-dimensional map in such a way that negative and positive emotions bend towards each other, narrowing our emotional capacity towards a more one-dimensional shape. It is no longer how good and how bad we feel, but to what extent we feel good or bad. The inverse becomes true: the more negative emotions a person expresses during stress, the less positive emotions will be expressed. The opposite, the more positive emotions the less negative emotions, is present under a lesser extent (Zautra, 2002).

A problem with Zautra's theory is that positive and negative emotions do not necessarily have to be perpendicular and independent of one another. Therefore, a better theory for the narrowing of the emotional field might be core affect of James A. Russell. Core affect are the most simplified consciously accessible feelings that are evident in moods and emotions (Russell, 2003). At any given moment, a conscious experience is an integral blend of two dimensions, and can be described as a point in a circle. On the horizontal axes you have displeasure on one side, and pleasure on the other. The vertical axes ranges from activation to deactivation. Core affect influences stands at the base of experiencing emotions. For example, excitement can be simplified as a state with high pleasure and activation. A visualisation of core affect can be found in appendix 1C.

Core affect affects reflexes, perception, behaviour, cognition, and complex decision making (Lang, 1995), and its constantly changing. A change in core affect can be caused by stressors, regardless if they are internal or external. The change can bias your cognitive resources to better focus and more efficiently take care of the task at hand. As a side effect, your conscious experience of emotion is simplified to a positive or negative mood, which can be put in terms of pleasure or displeasure with high or low activity.

Stress and anxiety

As mentioned in previous parts, the stress response is meant to solve short-term, life-threatening problems by gearing up the body for flight or fight (Persson, 2016). If stress persists on the long-term, it can have severe physical and mental consequences, and can lead to illness. Physically, stress causes an increased production of adrenal glucocorticoids. A long-term glucocorticoids exposure can be broadly destructive since receptors for glucocorticoids are present throughout the whole body. Destructive consequences include tissue breakdown, inappropriate fat conversion, immune system suppression, affected growth, and affected reproduction (Goodheart, 2012).

Mentally, stress causes emotional experiences to be simplified to either positive or negative moods. Long-term stress exposure can cause a person to feel negative for a long period of time, with negative consequences for mental health. Furthermore, the stress response often backfires due to our sedentary lives (Persson, 2016). We no longer live in an environment that corresponds with the flight or fight response, we cannot simply attack our bosses or run away from your office when work gets stressful.

The physical and mental consequences of longterm stress, and the backfiring of our biological system result in stress-related illness, which have cost the EU an estimation of 61.7 billion euros in 2014 alone (EU-OSHA, 2015). Stress-related diseases include post-traumatic stress disorder (PTSD), eating disorders, anxiety, and depression.

The difference between stress, fear, and anxiety

Stress, fear, and anxiety are terms that are often used interchangeable. However, this is not correct. Although there is some overlap in the physical behaviour of stress, fear, and anxiety, and the three are interrelated, there are some distinctive differences. Fear is an emotion, whereas stress a physical reaction, and anxiety is a mood. Fear occurs as a result of a specific immediate threat, while anxiety is a state of anticipation for any specific future threats (Craske, 2016). Furthermore, anxiety, in comparison to fear, is an out of proportion reaction to the actual presented threat, hence impairing daily functioning. Panic attacks are a defining consequence of a particular type of fear response.

Stress is strongly related to fear, considering that neurologically the fear network is sensitive to stress (Maeng and Milad, 2015). As mentioned previously, stress influences the structure of vital brain structures like the hippocampus and the prefrontal cortex leading to behavioural consequences/impairments (Arnsten, 2009). A brain structure that is also influenced by stress is the amygdala, the part of the brain that is responsible for emotional reactions including fear. For instance, when there is an acute stress response, the rise in baseline level of glucocorticoids induces neuronal hypertrophy within the amygdala, and heightens the sense of fear (Maeng and Milad, 2015).

The distinction between anxiety and stress is harder to make, considering that the two share many physical symptoms. However, stress is a response to an immediate internal or external demand, whereas anxiety is a response to anticipation of a demand. Therefore anxiety often leads to a feeling of helplessness and hopelessness (Keltner, 2013). This won't happen as fast with stress, since it is usually clear what exactly the stressor is. Research so far has not yet determined the exact causal relationship between stress and anxiety, but it is clear that they are closely interrelated and often occur simultaneously.

Inducing and decreasing stress

To measure stress, it is useful to know what type of stimuli are stress inducing. However, a feature of stress is that what one person considers stressful can be different for someone else. There are large individual differences in subjective experiences and mental capabilities that play a part differences in stress inducing stimuli (Karthikeyan, 2011). Furthermore, inducing the stress response in individuals depends on several factors such as gender, living environment, age, and culture.

Regardless of these individual differences, research has shown that stress can be induced when an individual perceives a danger or threat to his/her needs, goals, desires, and expectations (Keltner, 2013). Stressors that fit this description include, depending on task difficulty, time limited events, or threatening stimuli like annoying sounds. A good example of a stress inducing task in the Stroop task. The Stroop task shows participants written words describing colors, however the word has a different color than it describes. The task is to name the color of the word, and to not read the word. This is counterintuitive, and therefore stress inducing (Karthikeyan, 2011).

Video games are also effective to induce stress, and by varying the difficulty, different levels of stress can be pertained (Rani, 2002). Research has been done to investigate whether there is a difference in stress response between pictures of real objects and computer-generated ones (Courtney et al, 2010). No significant difference was found, while the computer-generated videos elicited a great physiological response. That there is no significant difference between the ‘real’ and the virtual bides positive for VRET.

Decreasing stress is more straightforward than inducing stress. Stress decreases by removing stressful stimuli out of the environment. However, some individuals experience stress without the actual stimuli being present in the environment. In that case the statement changes from decreasing stress to coping with stress.

Coping with stress refers to the constantly changing cognitive and behavioral efforts to manage specific external or internal demands that are appraised as exceeding the resources of the person (Pandey and Pestonjee, 2013). Coping is a dynamic process that changes on the basis of how successful the current coping method is. The end goal is to gain the ability to manage stressful situations rather than gaining mastery over them. There are many different coping methods, and there is some overlap between the methods, but there are three basic dimensions: task-oriented coping, emotion-oriented coping, and avoidance-oriented coping. Task-oriented coping entails using strategies to solve problems or minimize its effects. Emotion-oriented coping refers to strategies to manage emotions regarding the problem. Avoidance-oriented coping uses strategies to avoid stressful situation. Since coping is a dynamic process, the coping process differs per individual. Coping strategies include seeking social support, venting emotions, aggression, self-reflection, wishful thinking, being confrontative, being humorous, being mindful, relaxing, and distraction (Goodheart, 2013).

Measuring stress

The goal of this bachelor thesis is measuring stress. This can be challenging, especially when you want to measure stress in real time. There are three factors that bound the limitation of measuring stress in realtime. First, it is challenging to collect physiological data in real time. Second, there are large individual differences in levels of stress. Third, it is difficult to estimate the level of stress without being arbitrary (Karthikeyan, 2011).

Furthermore, there is a difference between the subjective experience of stress and the physiological measurements of stress. However, stress does arouse physical responses, and these responses are measurable. Electrocardiograms, heart rate, blood pressure, skin conductance response, skin temperature, and electroencephalograms can be used to measure stress using non invasive methods (Lin et al, 2011). Using multiple physiological signals always gives a better estimation than using just one (Jing and Armando, 2006). Some researchers use a combination of electrocardiograms and blood pressure, others use heart rate and skin conductance. The conclusion is that electrocardiograms, blood pressure, and skin conductance are the most reliable measures since findings regarding change in heart rate are less consistent. (Karthikeyan, 2011). Measuring psychological experiences of stress is usually done through questionnaires.

Methodology

This section reviews how to answer the research question "To what extent is it possible to measure stress based on the movements measured by the sensors in the HTC Vive?". This is done by means of an experiment which the literature review helped shape.

Experiment description

The virtual reality hardware that is used for this research is the HTC Vive. The HTC Vive consists out of the headgear that will create the virtual environment, and two hand controllers which allow you to interact directly with the virtual environment. Appendix 2A shows a picture of the HTC Vive hardware. Together with Erik de Vries, an employee at Vrroom, we have designed a virtual reality video game that gets more stressful every 30 seconds. Sensors in the HTC vive hardware will record movement data of the headgear and the two hand controllers. Appendix 2B shows the type of data the sensors measure.

During the experiment participants will play the video game. Before and after playing blood pressure will be measured, during playing heart rate variability will be measured, and afterwards participants will fill in a questionnaire. This data can be used as reference material whilst analyzing the movement data.

The video game

The video game has a duration of 150 seconds, and can be separated in five phases of 30 seconds. The first 30 seconds function as the 'relaxed' phase. After the first phase, every 30 seconds a new variable will be added to the game that induces more stress. The game has the shape of a visual search task. The player is placed in a virtual environment where he/she is surrounded by distractors in the shape of cubes. The task is to locate a bright red ball that appears on a random location around you, and 'touch' this orb by using the hand controllers.

In the first phase, the distractors will be black cubes to ensure that the target 'pops out', and the player can use efficient search once the target enters the visual field. On the floor of the environment there is a clock present that counts down from 30 to 0. During the second phase the black cubes will become a shade of dark red so the visual search task becomes more difficult. Additionally, a heartbeat sound will be added that slightly speeds up every time a target is found. The sound will act as a stressor. In the third phase the cubes will change into all different shades of red, this will remove the 'pop out' effect completely, and participants will have to use inefficient search throughout the rest of the game. Furthermore a clock sound will be added as a stressor. The literature has showed that time-limited events are stressful, and the clock sound will emphasize the time limit. During the fourth phase the lighting of the environment will change. Instead of all the environment being visible at all times, the lighting will change in such a manner that only one area of the environment is lit at the time.

The cubes will be rounded off at the edges so they will resemble the target more, and thus increasing the difficulty of the visual search task. In the fifth, and final, phase the cubes will start to move slightly.

Heart rate variability, blood pressure, and questionnaire

Since nothing is known about measuring stress with solely using movements, other measurement need to be made to use as reference material. The literature review has shown that heart rate and blood pressure can be physical indicators of stress, and that questionnaires can be used to indicate the psychological experience of stress.

In this experiment the heart rate variability (HRV) of the participants will be measured in real time. HRV measures the beat-to-beat changes in heart rate. Heart rate at rest was once thought to be a steady, regular rhythm. However, this is not the case. The time interval between heartbeats constantly changes. The variability in heart rate is caused by the two branches of the autonomous nervous system: the sympathetic and the parasympathetic nervous system. The sympathetic nervous system accelerates heart rate while the parasympathetic nervous slows down the heart rate. These two systems are constantly interacting to maintain heart rate in its optimal range to ensure suitable reactions to changing internal and external conditions. HRV therefore reflects the balance of the autonomous nervous system.

HRV is an important indicator of health and fitness, and is strongly influenced by internal and external demands. These demands can be anything from heavy physical exercise to our feelings and emotion. When your autonomous nervous system is in sync, HRV takes on the shape of a smooth wave. When your autonomous nervous system is out of sync, due to emotional stress, HRV takes on a pattern that is irregular with jagged peaks. Appendix 2C shows two graphs of HRV when the autonomous nervous system is in sync and out of sync. The clear distinction between the two graphs makes HRV a suitable indicator of emotional stress.

As the literature review has shown, blood pressure rises when a person experiences stress. Unfortunately, with the equipment available, it is not possible to measure blood pressure in real time. The blood pressure will therefore be measured before and after the playing of the videogame. If the blood pressure rises, this can be an indication of experiencing emotional stress.

Since there isn't a clear coherence between the physiological measurement of stress and the subjective experience of stress, a questionnaire is made to try to confirm the subjective experience of stress. Appendix 2D shows the questionnaire used for this experiment.

Data Analysis

Since only data of participants that actually experience emotional stress should be taken into further analysis, analyzing the questionnaires will be the first step. When participants do not indicate experiencing any negative emotions on the questionnaire, their data will not be used for further analysis. Analyzing the questionnaires will also point out which parts in the videogame were experienced as most stressful.

After filtering the data with the questionnaires, the next step is to analyse the rest of the data in MatLab. MatLab is a program that lends itself well for mathematical analysis. As shown by the literature review, stress affects the whole body since glucocorticoids receptors are present everywhere in the body (Tsigos and Chrousos, 1994). The experiment tries to find out what effects stress has on the muscles. The hypothesis is that muscles get more tense when under stress, and less able to perform finer movement. Analyzing this hypothesis goes through using a moving average over the movement data.

First the movement data for the x, y, and z coordinates will be plotted separately. Then a moving average will be plotted for each of these coordinates. The moving average takes a point, then calculates the average of 100 points that are adjacent to that point, and plots it. The moving average plot is much flatter than the actual plot as you can see in Appendix 2E.

The difference between the moving average and the actual plot will be the most informative to see if movements actually become more rigid due to increased muscle tension. Appendix 2F shows a plot of this difference. When free movements are possible due to experiencing no stress, the difference should be greater than when movements are rigid due to experiencing stress. Therefore I will compare the mean and the standard deviation of the difference between the moving average and the actual data in the first half of the videogame, where stress levels are low, and the second half, where stress levels are high. If the mean and the standard deviation are lower, it can be concluded that stress has a measurable effect on movements. Concluding, I will test the hypothesis if the variability of movements decreases when a person is under stress.

Discussion

This section reviews the experiment and elaborates on the implications of the results. First, it reflects on the validity of the different measurements that were made during the experiment and on the experiment itself. Second, it elaborates on the movement analysis with the moving average and cross references it with the blood pressure, heart rate variability, and the questionnaires.

Reflection on the experiment

30 people signed up to partake in the experiment. From those 30 people, 26 showed up for their assigned times. For 16 people of these 26, partaking in this experiment was their first experience with virtual reality. Overall, after analyzing the questionnaires, it is possible to conclude that the video game did arise the emotions in the participants that were initially intended. Almost all participants indicated to experience negative emotions during the third, fourth, and fifth phase of the video game.

The transition to the fourth phase, where all the distractor cubes are rounded off in the corners and the lighting changes, was experienced as the most difficult transition. The only other transitions that came forward in the questionnaire as being experienced the most difficult were the one to the third phase, where all the distractors cubes were all randomly colored in different shades of red, and to the fifth phase, where all the distractors cubes started shaking. This confirms the idea that it is best to compare the mean and the standard deviation of the difference between the moving average and the actual data in the first half of the video game, where participants still experience positive emotions, with the second half, where participants experience negative emotions.

Even though the overall experiment was a success in its execution, there are two matters that are worth mentioning. First, the video game might have been too difficult in its last two phases. What shows with some participants, is that they experience a point where they cannot find the target anymore. Instead of this inflicting more stress, which was the goal, it inflicted frustration and a sense of ‘giving up’. This reflects in both the questionnaire, where participants filled in ‘frustration’ or ‘confusion’ as their most present emotion, and in the heart rate variability.

Appendix 3A shows a heart rate coherence graph where this sense of giving up can be seen. When the plot is in the green area of the graph, it means that the heart rate is in coherence and the parasympathetic and the sympathetic nervous system are in sync. When the plot is in the blue or red area, the heart rate is not in coherence, and the parasympathetic and the sympathetic nervous system are out of sync. The participant that corresponds with appendix 3A, experienced a point where he/she could not find the target anymore. From this point on, all extra stressors that were added in the phases following did not have the effect of adding more stress, and the heart rate variability goes back into coherence.

I believe this phenomenon could have been prevented with a reward system in. If participants were told to try and find the highest amount of target orbs for a prize, or told that not finding a certain amount of target orbs results in losing the game, they would have experienced more pressure to perform. Giving participants a goal would have caused that the increasing difficulty every phase would correspond to an increase in stress, due to the fact that the increased difficulty jeopardizes reaching their goal. The pressure to perform during this experiment was incorporated in the form of the clock that counted down from 30 to 0 every phase. However, as the results show, this was not enough in every case.

Second, the blood pressure did not turn out to be a reliable measurement for increasing stress. Of the 26 participants, the blood pressure only increased in ten participants. This can simply be explained because many of the participants engaged in physical activity prior to the experiment: they were biking shortly beforehand, and they walked up two flights of stairs. Therefore, I chose not to use the blood pressure measurements in any of my further analysis.

The heart rate variability was very useful. Even though not all of the measurements are exactly as long as the 2.5 minutes the video game lasts, the coherence over time often overlaps with the negative emotions that participants describe experiencing in the questionnaire.

Data analysis

Of the 26 participants that participated in the experiment, six indicated not to experience any negative emotions throughout playing the video game. The data of these six participants is not taken into further analysis, leaving the data of twenty suitable participants. Appendix 3B shows the table were the results after data analysis are filled in. The means and standard deviations of the difference between the moving average and the actual data of the x,y, and z coordinates are then compared. Calculating these means and standard deviations happens through two MatLab codes that are described in appendix 3C.

After analysis, forteen out of twenty tables have a majority of means and standard deviations that decrease in value. Appendix 3D shows some examples of tables with filled in results. The fact that the majority of the tables have decreasing values corresponds with the hypothesis that variability in movements decrease under stress. However, before the conclusion can be drawn that stress has a measurable effect on movements, it needs to be explained why the values of the means and the standard deviations did not decrease for the other six participants.

In order to analyze why the decrease in values is not observed in six participants, the questionnaires and the heart rate variability of these participants are reviewed. Solely looking at heart rate variability, two different patterns are observed for these participants. First, that the heart rate stays coherent throughout the whole second half of the video game. Second, that the amount of time spent with heart rate not in coherence is about the same in both halves. Examples of these patterns can be found in appendix 3E. However, observing these patterns alone is not enough to explain why the values in the table did not decrease, since these patterns are observed in some other participants as well.

Analyzing question six of the questionnaires is the most helpful to clarify why the decrease in values is not observed of six participants. Appendix 3F shows the answers of the six participants to this question. Here again, two different cases are observed. First, that negative emotions are not experienced up until at least the fourth phase. Second, that negative emotions are experienced during the last two phases, however, on a low scale (ranging from 4-7). This is significant, since experiencing negative emotions on such a low scale is only observed with the six participants who did not have decreasing values. All other participants who experienced negative emotions always indicated a scale higher than 8.

Solely based on the results of this experiment and their analysis, the hypothesis that variability in movements decreases under stress is confirmed. The intensity of experiencing negative emotions has a measurable effect on movements.

Conclusion

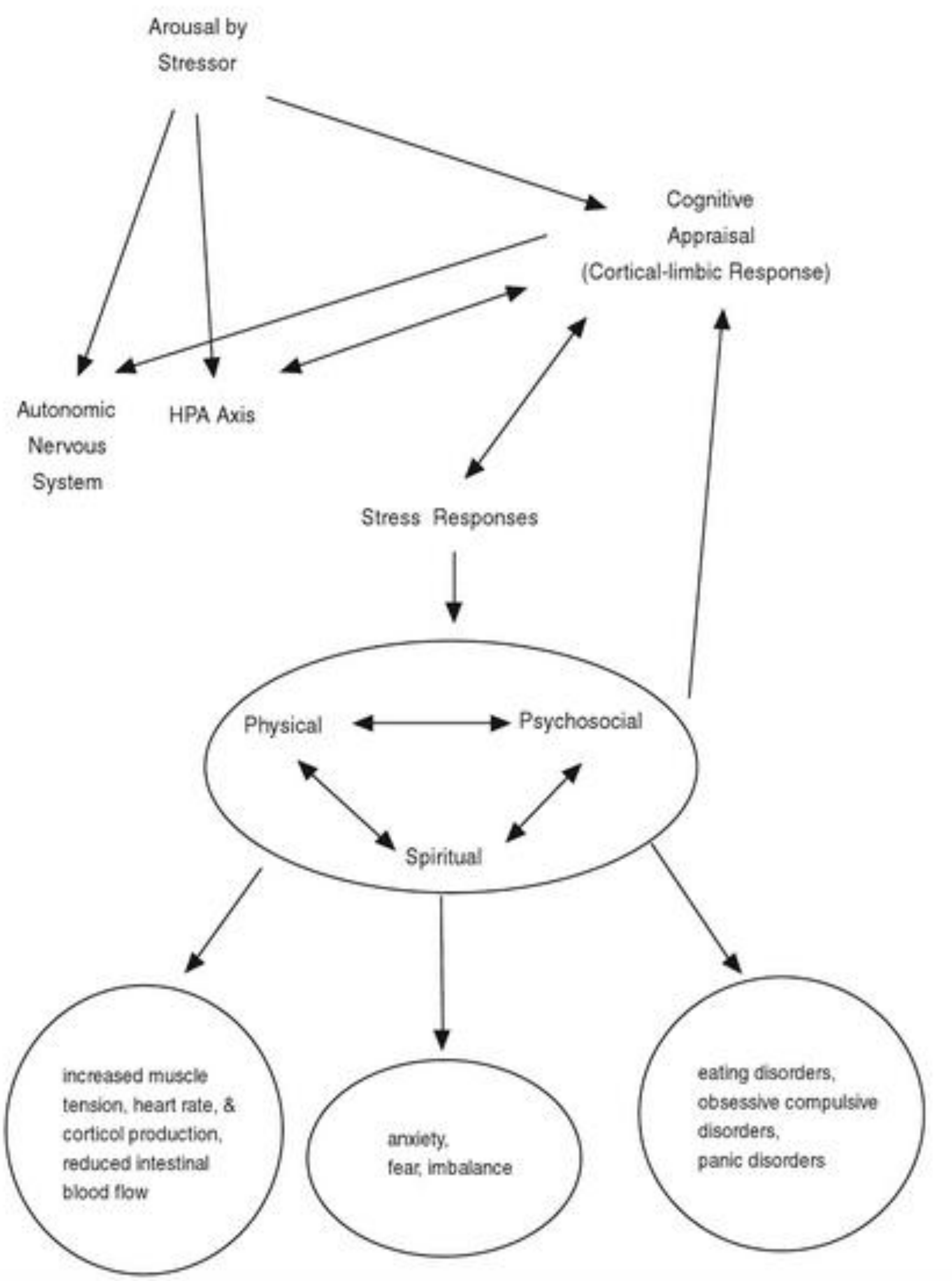
Serving as a feasibility study, this thesis has been a success. The research question “To what extent is it possible to measure stress based on the movements measured by the sensors in the HTC Vive?” is partially answered with positive results. What we have observed in the experiment, is that the variability of movements is lower in stressful situations than in situations that are not stressful. Whenever this decrease in variability was not observed in an individual, he/she indicated in the questionnaire not to experience negative emotions on a high scale. This leads to the conclusion that stress definitely has a measurable effect on movements, however, more research is needed to answer to what extent this effect is.

Different types of analysis of the movement data will help with researching the further extent of the effect of stress on movements. For example, now that a decrease in variability in movements under stress is observed, what does the rate of decrease say about the levels of experienced stress? Furthermore, it will be useful to use a different method of analysis, for example fast fourier transformations (FFT). Lastly, analysis of smaller parts of the data could be significant. With regards to the experiment of this thesis, there could be a difference between the effect of stress on movement when a participant is searching for a target in comparison to when he/she has found a target.

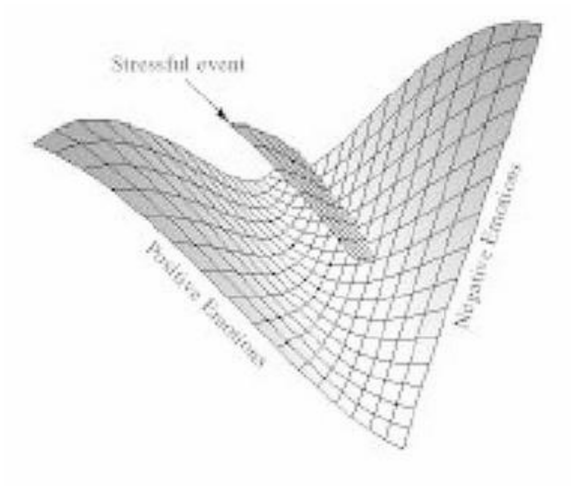
The overall goal of this thesis was to lay the foundation of the future development of an algorithm that can serve as an autonomous VRET program. This algorithm would adapt the amount stressful stimuli in the digital environment based on the stress levels on an individual. For this to be possible, more research is needed about measuring stress in real time. However, knowing that stress has a measurable effect on movements is a good basis to engage in further research, and has taken the firsts steps in the development of this algorithm.

Appendix

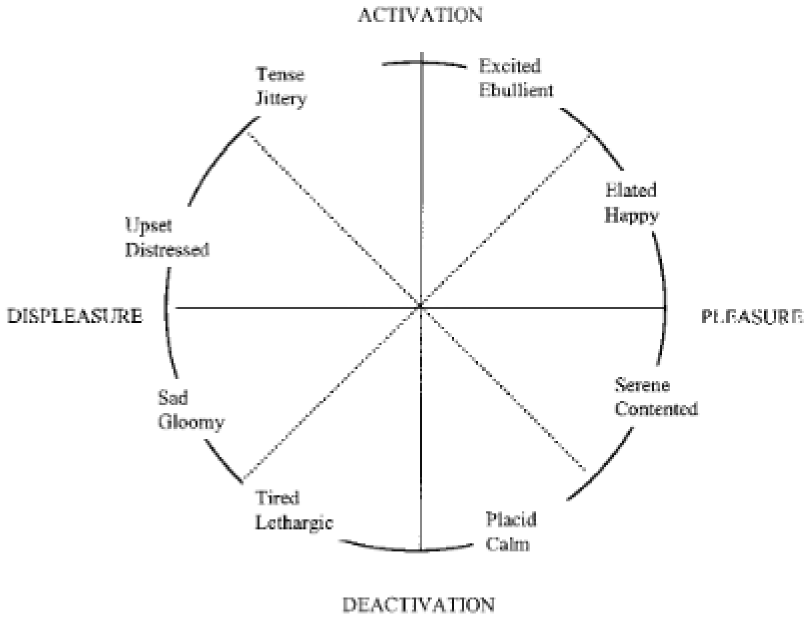
Appendix 1a: The relationship between stressors and stress responses (Goodheart, 2012)



Appendix 1b: The narrowing of the emotional field according to Zautra's theory (Zautra, 2003)



Appendix 1C: Core Affect (Russell, 2003)

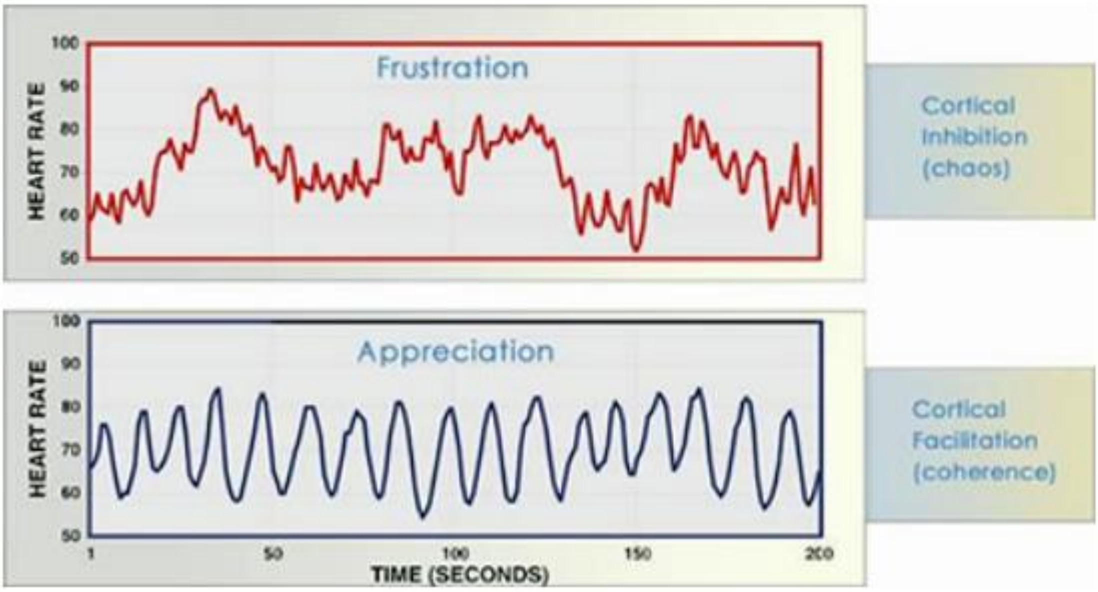


Appendix 2A: HTC Vive hardware

Appendix 2B: Movement data retrieved from the HTC Vive sensors

Data from the headgear			
X-coordinate	Y-coordinate	Z-coordinate	Difference in time
0.0117863	0.4381726	0.3622845	0.18126747
0.01235896	0.4389333	0.3620965	0.1807604
0.01451404	0.4394112	0.3619076	0.1797013
0.006641784	0.439841	0.3616849	0.1776581
0.01116367	0.4402793	0.3615121	0.1776581
0.0114144	0.44051	0.3613263	0.1764646
0.01096749	0.4406226	0.361167	0.175393

Appendix 2C: Heart rate variability (Source: https://www.heartmath.com/science-behind-emwave/)



Appendix 2D: Questionnaire used during the experiment

Participants number:

Today you will be participating in a virtual reality experiment for a bachelor thesis. The goal of the experiment is to find out if there is a systematic way in which coordination changes when a task gets more demanding/difficult over time. You will be playing a videogame in VR that lasts 2.5 minutes. The task in the game is to find a red orb, and touch it with both hand controllers. Every 30 seconds, another distraction will be added, making the overall task more difficult. To use as a reference for the movement data, your heart rate variability and your blood pressure will be measured.

Signature:

1. Have you ever done virtual reality before?
   A. Yes
   B. No

2. Did you experience the search task getting more difficult over time?
   A. Yes
   B. No

3. What was the most difficult transition and why?

4. Did you experience a point where the game wasn't enjoyable anymore? If yes, when?

5. What emotions did you experience during the game? (multiple answers possible)

A. Enjoyment	F. Fear	K. Other, namely:
B. Content	G. Excitement	
C. Frustration	H. Disappointment	
D. Sadness	I. Insecurity	
E. Stress	J. Anger	

6. What emotion was most present during which stage, and how much did you experience the emotion on a scale of 1 to 10 (1 being not present and 10 being very present)?

   Stage 1: Distractors black, target red, no sound
   Most present emotion:
   Scale:

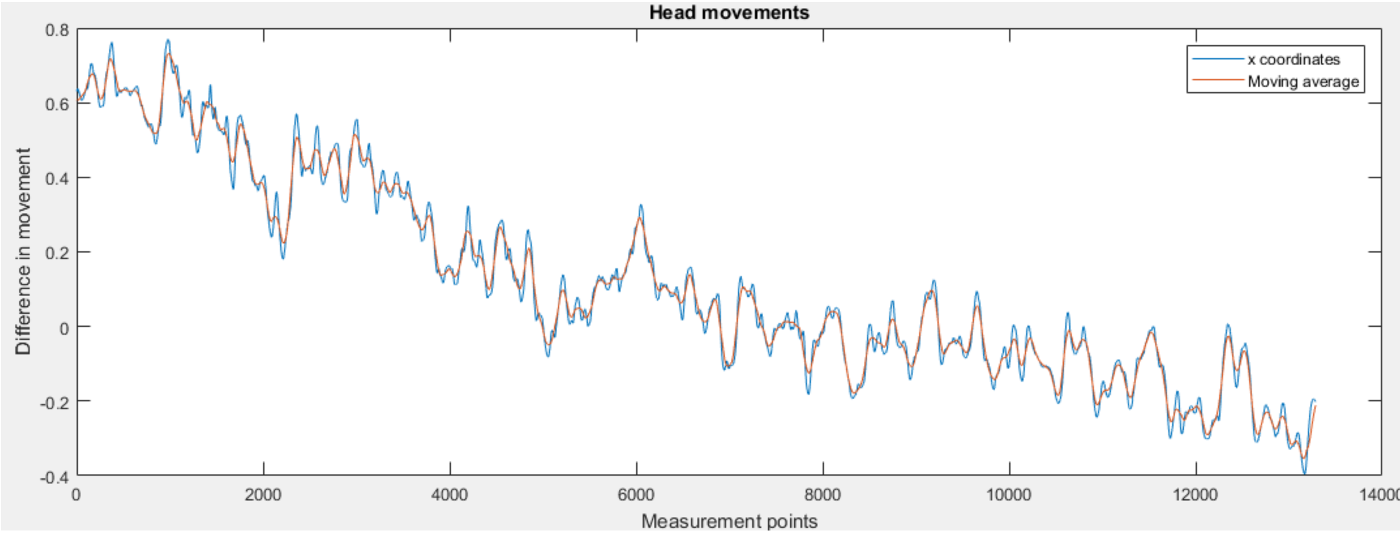
   Stage 2: Distractors dark red, target red, heartbeat sound
   Most present emotion:
   Scale:

   Stage 3: Distractors random colored, target red, ticking clock sound
   Most present emotion:
   Scale:

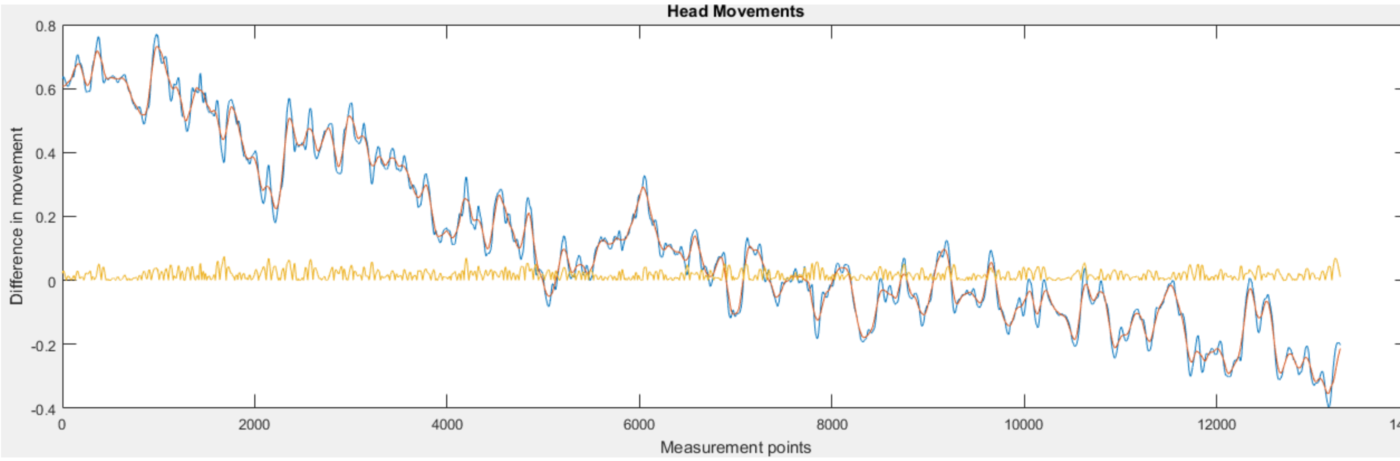
   Stage 4: Distractors rounder, target red, spinning light
   Most present emotion:
   Scale:

   Stage 5: Distractors shake, target red
   Most present emotion:
   Scale:

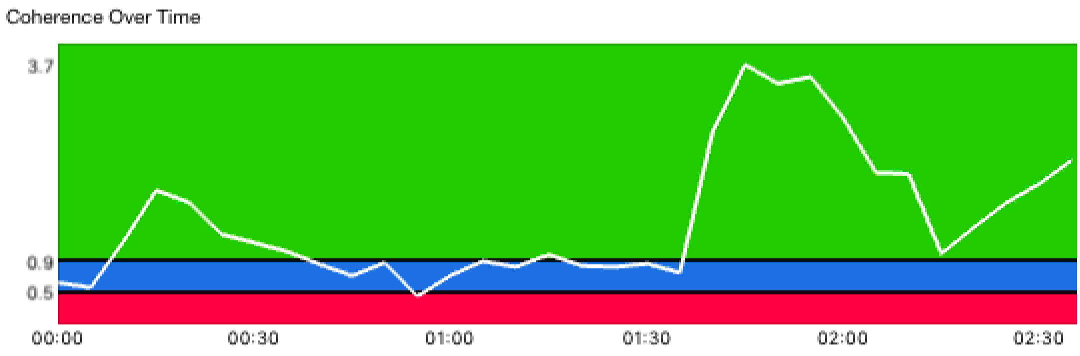
Appendix 2E: Movement data and moving average



Appendix 2F: Plotted difference between data and moving average



Appendix 3a: Heart rate coherence graph



Appendix 3B: Table used to fill in data

Participant	Means x (1st/2nd half)	Std x (1st/2nd half)	Means y (1st/2nd half)	Std y (1st/2nd half)	Means z (1st/2nd half)	Std z (1st/2nd half)
Head						
Left Hand						
Right Hand						

*Std = Standard deviation

Appendix 3C: MatLab codes used for analyzing data

1. Code used for calculating the moving average

```
function M=movAv(M,Y,X)
% M=movAv(M,Y,X) moving average Y denotes collunm-wise scope, X
denotes
% row-wise scope. Works only for odd values of Y and X%
y1=ceil(Y/2);
y2=y1-1;
x1=ceil(X/2);
x2=x1-1;
M=conv2(M(y1:end-y2,x1:end-x2), ones(Y,X)./(Y*X));
Xcor=1./[(1:X-1)/X fliplr((1:X-1)/X)];
M(:,[1:X-1 end-X+2:end])=M(:,[1:X-1 end-
X+2:end]).*(ones(size(M,1),1)*Xcor);
Ycor=1./[(1:Y-1)/Y fliplr((1:Y-1)/Y)]';
M([1:Y-1 end-Y+2:end],:)=M([1:Y-1 end-
Y+2:end],:).*(Ycor*ones(1,size(M,2)));
```

2. Code used for calculating the means and standard deviations in the two halves of the data

```
%importing data
data = dlmread('HeadData20.txt');
data_matrix = reshape(data, [], 4);

%Seperating the data
x_data = data_matrix(:,2);
y_data = data_matrix(:,3);
z_data = data_matrix(:,4);

%calculating the running average and the difference
run_average_x = movAv(x_data, 100, 1);
dif_x = x_data' - run_average_x;
run_average_y = movAv(y_data, 100, 1);
dif_y = y_data' - run_average_y;
run_average_z = movAv(z_data, 100, 1);
dif_z = z_data' - run_average_z;

%calculating the means and the standard deviations
mean_x1 = mean(abs(dif_x(1:round(end/2))))
mean_x2 = mean(abs(dif_x(round(end/2):end)))
std_x1 = std(abs(dif_x(1:round(end/2))))
std_x2 = std(abs(dif_x(round(end/2):end)))
```

```
mean_y1 = mean(abs(dif_y(1:round(end/2))))
mean_y2 = mean(abs(dif_y(round(end/2):end)))
std_y1 = std(abs(dif_y(1:round(end/2))))
std_y2 = std(abs(dif_y(round(end/2):end)))

mean_z1 = mean(abs(dif_z(1:round(end/2))))
mean_z2 = mean(abs(dif_z(round(end/2):end)))
std_z1 = std(abs(dif_z(1:round(end/2))))
std_z2 = std(abs(dif_z(round(end/2):end)))
```

Appendix 3D: Filled out table with data

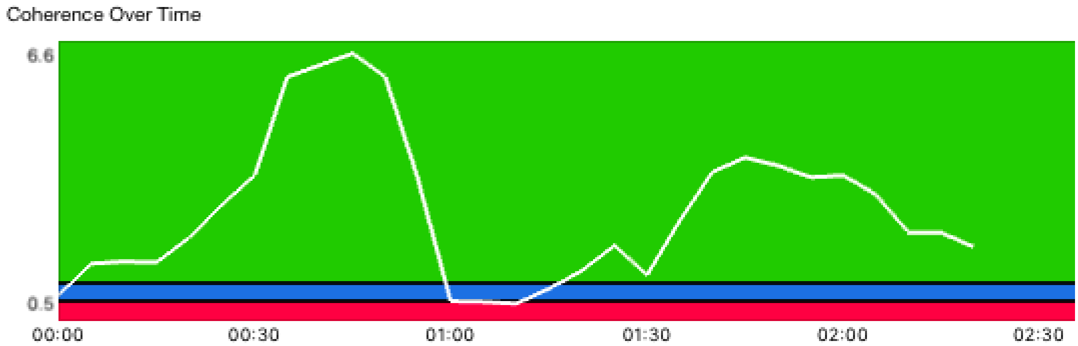
Participant 9	Means x (1st/2nd half)	Std x (1st/2nd half)	Means y (1st/2nd half)	Std y (1st/2nd half)	Means z (1st/2nd half)	Std z (1st/2nd half)
Head	0.2797/0.2651	0.2098/0.1999	0.0985/0.0972	0.0863/0.0823	0.1819/0.2085	0.1347/0.1519
Left Hand	0.2902/0.2721	0.2142/0.2045	0.0930/0.0782	0.0709/0.0686	0.1769/0.1646	0.1352/0.1278
Right Hand	0.2768/0.2550	0.2122/0.1957	0.0939/0.0827	0.0711/0.0685	0.1843/0.1804	0.1352/0.1331

Participant 3	Means x (1st/2nd half)	Std x (1st/2nd half)	Means y (1st/2nd half)	Std y (1st/2nd half)	Means z (1st/2nd half)	Std z (1st/2nd half)
Head	0.1716/0.1781	0.1259/0.1245	0.0428/0.0392	0.0346/0.0315	0.0989/0.1209	0.0758/0.0941
Left Hand	0.2936/0.2696	0.2136/0.1978	0.1484/0.1557	0.1221/0.1213	0.2547/0.2822	0.1833/0.1987
Right Hand	0.3032/0.3138	0.2200/0.2242	0.1315/0.1381	0.1051/0.0996	0.2609/0.2841	0.1877/0.2013

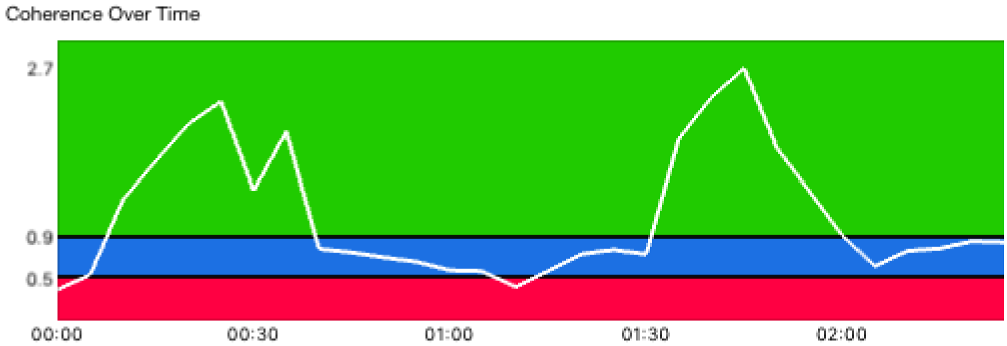
Participant 15	Means x (1st/2nd half)	Std x (1st/2nd half)	Means y (1st/2nd half)	Std y (1st/2nd half)	Means z (1st/2nd half)	Std z (1st/2nd half)
Head	0.1289/0.1015	0.0996/0.0883	0.0596/0.0584	0.0486/0.0449	0.1745/0.1179	0.1455/0.1115
Left Hand	0.2262/0.2191	0.1624/0.1565	0.1112/0.0775	0.0913/0.0763	0.2343/0.2133	0.1726/0.1583
Right Hand	0.2112/0.1859	0.1657/0.1402	0.1227/0.0838	0.0983/0.0809	0.2612/0.1996	0.2048/0.1668

Appendix 3E: Heart rate coherence graphs

1. Heart rate stays in coherence throughout the second half



2. Same amount of time spent out of coherence in both halves



Appendix 3F: Answer of the six participants to questions six of the questionnaire

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
Stage 3	Challenged (7)	Suprise (4)	Enjoyment (4)	Excitement (7)	Excitement	Excitement (8)
Stage 4	Confused (6)	Frustration (6)	Frustration (4)	Stress (5)	Pride	Frustration (5)
Stage 5	Frustration (5)	Stress (5)	Frustration (5)	Stress (6)	Pride	Frustration (7)

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