Chapter 1

Introduction

There are many jobs where professionals have to deal with negative emotions on a regular basis. Consider for example the agitated passengers in public transport that conductors and drivers encounter daily, or the aggressive individuals policemen regularly have to deal with either on the street or in the office. Currently, these types of situations are often practiced using either role-play or on-the-job training. The first has the disadvantage of being costly and time-consuming and hence often organized in groups, which is yet another downside. The latter has no control over the type of scenarios encountered and as such can obstruct learning or even be dangerous. The research presented here investigates whether a virtual training can be used to replicate such emotional scenarios and serve as a useful tool to educate and train these professionals.

This introduction is split into four sections. First, Section 1.1 describes the motivation and relevance of this research. Section 1.2 then provides an overview of the context relevant for the later chapters, including a description of the larger project this research is part of. More detail about this research is given in Section 1.3, which includes research questions and related literature as well. In Section 1.4 the outline for the rest of the thesis is presented.

1.1 Motivation

As part of a larger project STRESS (explained below), a virtual training environment is being developed to train professionals how to act on and cope with strong negative emotions. The main motivation for the research presented here lies in a desire to *understand*, *measure* and *act on* those emotions. By *understanding*, an understanding of the underlying processes is meant. Thus, how do these emotions arise, what effects do they have (both psychological and physiological/behavioral) and how should one cope with such emotions. *Measuring* implies methods that can be used to quantify the emotion experienced, ranging from simply asking for a subjective rating to applying various sensors in order to more objectively estimate the emotional response. For *acting on*, it is the virtual training environment which should be able to provide feedback, change the training scenario or otherwise support a trainee learning to cope with negative emotions. These three aspects are closely related. In order to measure, it is important to understand what is being measured. Without measurements, it is not possible to act on those emotions. And to act adequately a decent understanding of the processes involved is required.

The goals and motivations of the overarching project STRESS are explained hereafter, but why put such a specific emphasis on the emotional aspects? For one, emotions play a large role in decision making (Oatley & Johnson-Laird, 1987), preparation for (rapid) motor responses (Frijda, 1986) and serve a social function as well (Gross, 1998). Considering the fact that strong negative emotions are an important part of the aforementioned project, combined with the impact they have on many relevant aspects, makes it a clear choice for deeper investigation. But there is more to the story as negative emotions correlate somehow with health complaints (Watson & Pennebaker, 1989) and in extreme circumstances can result in posttraumatic stress disorder (PTSD) (Brewin et al., 2000). Thus, it is important to know if and with what intensity a virtual environment is able to elicit those emotions. It is clear that a virtual training should not result in any of the negative consequences that such a training aims to prevent from occurring. However, to learn to cope with those emotions they do need to be experienced to alter current responses or create new ones (Ochsner & Gross, 2005). Thus, it is important to find the right intensity for a particular emotion to be experienced such that learning can take place without the risks. And to realize this there is a need to understand, measure and act on those negative emotions.

1.2 Context

Many different aspects play a role in the research described in this thesis. To fully sketch the context, each of the following sections describes a particular subject related to the topics of the upcoming chapters. As this research is part of a larger project, Section 1.2.1 gives more details on the goals of that project first. Following in order are sections on negative emotions (Section 1.2.2), physiological measurements (Section 1.2.3), computational modeling (Section 1.2.4) and virtual training (Section 1.2.5).

1.2.1 The project STRESS

The research presented in this thesis is part of a larger project called STRESS (Simulation-based Training of Resilience in Emergencies and Stressful Situations)[1], a collaboration between VU University Amsterdam and the Netherlands Institute for the Study of Crime and Law Enforcement.[2] To illustrate

[1] http://stress.few.vu.nl (accessed 23-7-2015).
[2] NSCR, https://www.nscr.nl (accessed 23-7-2015).

the goal of this project, consider the following event that took place in Apeldoorn, the Netherlands, during the Dutch national holiday of Queen's Day.[3] At around 11.50 AM on April 30, 2009, a man drives his car at high speed into a parade which includes Queen Beatrix and other members of the Dutch royal family. The vehicle drives straight through some spectators watching the parade, leaving eight people dead and ten injured, after which it narrowly misses the open-top bus carrying the royal family and crashes into monument De Naald at the side of the road.

Due to the unexpected and stressful nature of this event, emergency service workers of the police and fire brigade are immediately faced with very difficult choices. First, they have to make sure the attacker (and his potential accomplices) are overpowered to guarantee the safety of the royal family and other people at the scene. Second, many victims of the attack need immediate medical attention. Third, spectators need to be calmed down to avoid any further accidents due to chaos. And finally, while having to decide in a split second which of these actions to pursue, they also have to regulate their own emotional response in order to stay calm and avoid developing traumatic stress.

Although this is just one example, it illustrates the difficult choices that policemen and other professionals (e.g. in the fire brigade, emergency care, public transport, security, or the military domain) face in crisis situations. Even though they usually have clear instructions on how to act, these security workers often face difficulties in making appropriate decisions, due to a combination of factors (Endsley, 1997; Janis & Mann, 1977; Loewenstein & Lerner, 2003; Loewenstein et al., 2001; Wickens, 2002). Firstly, crisis situations often require improvisation, i.e. deviation from standard protocols. Secondly, time to make decisions is often limited, which makes that the workers experience an enormous pressure. Thirdly, the extreme circumstances (e.g. many casualties, high danger level) may cause emotions that are not experienced in everyday situations. Consequently, despite extensive training, security workers in crisis situations often make ad hoc decisions that are suboptimal (Clore & Huntsinger, 2007; Loewenstein & Lerner, 2003; Ozel, 2001).

In addition, even if they make optimal decisions from an external perspective, security workers have an increased risk of developing anxiety related disorders such as posttraumatic stress disorder, especially if the situation involves extreme violence and/or human casualties (Brewin et al., 2000). Recent evidence indicates that the costs associated with PTSD, both to individuals and to society as a whole, are extremely high (Kessler, 2000; Wittchen & Jacobi, 2005). Moreover, even light variants of PTSD may lead to psychological problems, reduced professional ability, or other personal discomfort. For this

[3] http://www.nrc.nl/international/article2228360.ece/Car_ploughs_into_Queens_Day_parade (accessed 23-7-2015).

reason, reducing the number of stress-related disorders in security workers will ultimately save extensive cost and discomfort, both at an individual and a societal level.

To tackle the problem sketched above, the main aim of the STRESS project is to develop an intelligent system that is able to analyze human decision making processes in stressful circumstances, and analyze the causes of incorrect decisions and inadequate stress regulation. The system will be incorporated in an electronic training environment for security workers, based on Virtual Reality (VR), cf. Marsella & Gratch (2002). In this environment, trainees will be placed in a virtual emergency scenario in which they have to make difficult decisions while negative emotions are induced. During the scenario, state of the art techniques from Human Computer Interaction (HCI) will be applied to measure aspects of their mental state (e.g. stress level, emotional state, attention, and motivational state). This information will then be used as input for the intelligent system to determine why the trainees made certain less optimal decisions and to teach them how to improve on this. An overview of the envisioned system is shown in Figure 1.1 and will be used in Section 1.4 to explain the relevance of the various chapters in this thesis.[4]

1.2.2 Negative emotions

Stress is an important concept when considering the goals of the STRESS project. However, stress is a difficult emotion to define and thus most of the chapters use more generic terms to describe the mental state. Terms such as negative emotions, negative arousal, anxiety or fear are used, which describe a more generic concept of emotion. In the broadest sense, this can be seen as a form of physical arousal due to some negatively valenced event or situation. However, it remains important to consider this research while keeping stress in mind. Therefore, the following paragraph covers various methods to define stress, provides a global idea of what the concept entails and briefly explains posttraumatic stress disorder, which can be a result of such stress in extreme circumstances.

Stress. When looking up literature on stress it becomes clear that almost every book or article starts out by defining the concept of stress, e.g. Contrada & Baum (2010); Staal (2004); Steckler et al. (2005). Unfortunately, these definitions are not always in line with one another and the wide usage of the concept made various researchers doubt the usefulness of stress as a scientific term (Levine & Ursin, 1991; Stokes & Kite, 2001; Tepas & Price, 2001). This resulted in broader descriptions of the concept. For example, in Steckler et al.

[4] An in-depth description of this system can be found in Section 8.2 (p.148).

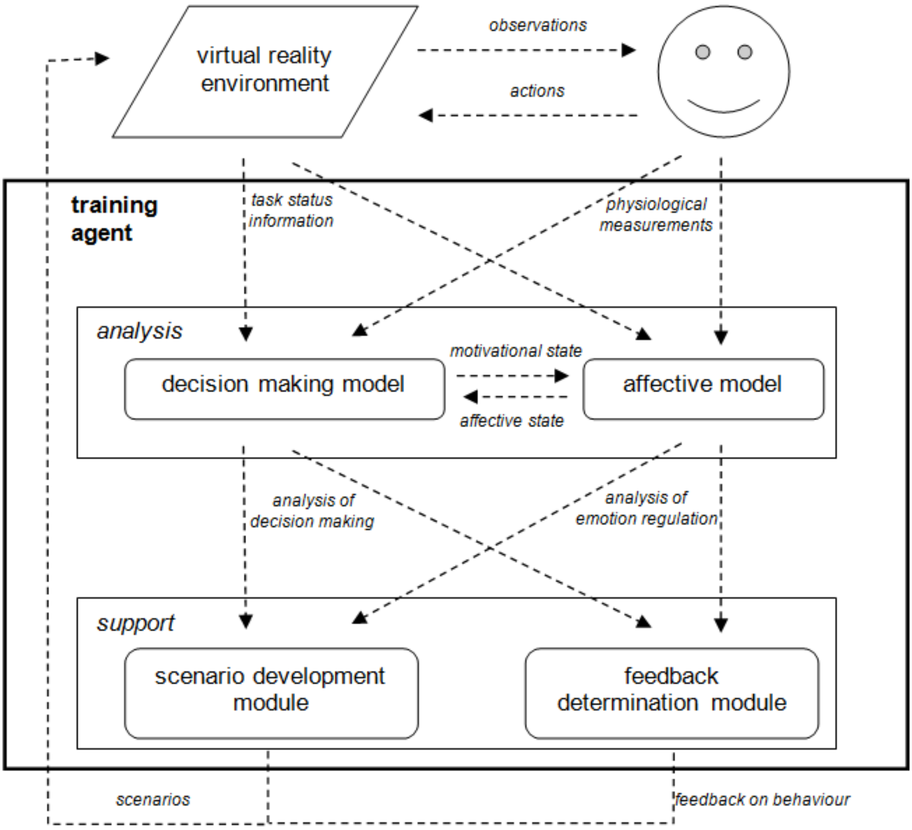

Figure 1.1: Global architecture used in the STRESS project

(2005) three components of stress are identified; 1) the input, or stress stimuli; 2) the processing system including the subjective experience; and 3) the output, or stress response. In a similar fashion, Stokes & Kite (2001) differentiate between three different approaches to stress. First, they consider a stimulus-based approach, where different types of stressors are used and the outcome is assumed to be the result of the stress caused by these stressors. On the other hand, the response-based approach defines stress by a particular pattern of responses thereby making no assumptions on the type of stressors. Finally, the transactional approach underlines the interaction between the environment and the individual. For example, a particular image is not a stressor per se, nor is an increase in heart rate always a result of stress. It is the individual's interpretation, or the appraisal of the environment that can result in stress.

Using a different approach, Sandi & Pinelo-Nava (2007) came up with five factors based on which they classified a large body of research into stress and its effect on memory in rodents. This differentiating in factors can also be applied to different species, such as humans. The first factor is the source of stress; if the stress is a result of the task itself the stress is classified as intrinsic, while an external source of stress is classified as extrinsic. A second factor is the stress duration, which can be either chronic (i.e. work stress) or acute (i.e. traumatic experience). Thirdly, they look at the stressor intensity and distinguish three and sometimes four categories, namely low, medium, high and occasionally very high. The fourth factor is related to timing of stress in relation to the memory phase in which it occurs; acquisition (the learning process), consolidation (memory storage), or retrieval (access to stored information) of information. Lastly, the fifth factor describes the learning type; examples given include implicit/non-declarative learning, explicit/declarative learning and non-associative learning. Other factors, left out due to their focus on rodents, are those of controllability and predictability (Mineka & Hendersen, 1985), which can be argued as important in differentiating between different forms of arousal (Koolhaas et al., 2011).

Posttraumatic stress disorder. In case of acute stress with an extremely high intensity, there is an increased risk of developing anxiety related disorders such as PTSD, especially if the situation involves extreme violence and/or human casualties (Brewin et al., 2000). However, not every individual is equally likely to develop such disorders after a traumatic event and the development of PTSD can not only be attributed to the traumatic experience itself, but individual risk factors also need to be considered (Yehuda & McFarlane, 1995). Although for some time PTSD was seen as a normal response to trauma, Bonanno (2004) comes forth with multiple 'pathways to resilience', such as being a hardy individual or using positive emotions to cope with the trauma. More research exists identifying factors that play a role in an individual's resilience (Bonanno et al., 2006; King et al., 1999; Connor et al., 2003).

Recent evidence indicates that the costs associated with PTSD, both to individuals and to society as a whole, are extremely high (Kessler, 2000; Wittchen & Jacobi, 2005). Existing approaches to increase resilience to (traumatic) stress can roughly be classified into three categories (Deahl, 1998), namely approaches to treat PTSD once it has already established, approaches to prevent it from developing just after some traumatic event has occurred (secondary prevention), and approaches to prevent it before any traumatic event has occurred (primary prevention). Approaches for treatment are available, but these are very costly and not always effective. A similar drawback holds for approaches for secondary prevention, such as debriefing. These methods have been found not to prevent long term PTSD symptoms, and may even have negative effects. For these reasons, primary prevention has recently been proposed as a promising alternative. Although few studies have been performed to evaluate primary preventive techniques, some evidence has been found for its effectiveness to increase resilience for military professionals (Deahl et al., 2000).

1.2.3 Physiological measurements

A great deal of research has been carried out trying to find a way to detect stress using physiological measurements. In the following sections, two of the more widely used measures are covered, namely electrodermal activity and cardiovascular responses, as these are the two types of measure most used in this research. Each section begins with explaining from a theoretical viewpoint how each of these measures is expected to behave when the subject is under stress. Following this, a number of references are given to actual research using these measurements with a summary of their results. Here, we try to focus on research involving acute, intrinsic stress as this matches the type of stress relevant to our project. Two main indicators of a stress response are reported in the literature, namely a change in heart rate and an increased skin conductance, which will be the main focus within this research.

Electrodermal activity. Electrodermal activity refers to the amount of sweat secreted by sweat-glands and is often recorded as changes in electrical resistance in the skin. The amount of sweating is related to activity in the sympathetic branch of the autonomic nervous system and has therefore often been used as a measure of sympathetic arousal and stress (Hugdahl, 1995). Figner & Murphy (2011) describe in detail various different quantitative measurements that can be recorded using electrodermal response. A first differentiation is made based on the time-scale of the measurements. Tonic changes refer to changes over longer time-intervals and are most commonly expressed as the skin conductance level (SCL), a measure of the overall skin conductance over a specific - long - time-interval. Phasic changes are short reactions that can be found in a recording of electrodermal activity, are often a reaction to some sort of stimulus and are therefore called skin conductance responses (SCR).[5]

SCL or other measures of tonic changes are assumed to be indicative of a general level of arousal (Figner & Murphy, 2011; Schuetz et al., 2008), supported for example by research using SCL (Reimer et al., 2009; Kuijpers et al., 2012) or other measures such as the number and amplitude of spontaneous

[5] Not every SCR can be matched with a stimulus. In some cases it is believed that such SCRs reflect some internal process, for example a shift of attention. However, in some research these so-called spontaneous reactions are used as a measure for tonic changes.

fluctuations (Bach et al., 2010). Research using the SCR most often makes use of the amplitude of the fluctuations and relate this measurement to the arousal of a particular stimulus (Courtney et al., 2010; Storm, 2000).

Cardiovascular responses. Measurements of cardiovascular responses are often used in stress research. However, the wide variety of factors involved in this system make it difficult to obtain a clear picture. Heart rate and blood pressure are often focused upon when measuring stress, though there are underlying mechanisms that may be more important (Geus & Doornen, 1996). For example, instead of looking at the blood pressure, cardiac output or total peripheral resistance may be considered (Ring et al., 2002). Similarly, for heart rate, one may consider whether a change is caused by sympathetic or parasympathetic activity, and whether it is caused by more action or less relaxation (Willemsen et al., 1998). There are measures that are believed to reflect more specific constructs such as threat or challenge, which can be obtained by making a distinction between the cardiac and vascular responses using for example impedance cardiography (Blascovich & Tomaka, 1996). Those types of measures (for example heart rate variability or the more accurate pre-ejection period) are often successfully used in research, but it is not entirely clear what they exactly reflect (Goedhart et al., 2008). Moreover, measuring the pre-ejection period is very complex and has to be checked manually in order to be used reliably. Furthermore, there are many confounding variables that need to be considered when measuring cardiovascular responses, such as drinking, smoking, physical activity or posture. Nevertheless, although it is difficult to get right, getting good cardiovascular measurements will provide reliable estimation of stress as shown by a large body of research discussed in the following review papers: Staal (2004); Kristensen (1996); Chida & Hamer (2008).

1.2.4 Computational modeling

In recent years, the area of cognitive modeling, which roughly put aims to understand cognitive processes by building computational models of them, has experienced a rapid progress, addressing for example computational models of human decision making, perception, attention, and learning. Nevertheless, the literature on computational models of stress is still rather scarce. Although many theories on stress exist, creating a corresponding computational model of such a negative emotion seems to impose many ambiguities that are not easy to be resolved and thus would benefit from additional research.

Some related models do exist, ranging from a simulation of the cardiovascular system (Heldt et al., 2002), to the development of PTSD (Naze & Treur, 2012). However, there have not been that many attempts at actually modeling the development of stress and its effects. Gomes et al. (2012) created a model for calculating the expected level of stress based on the Cognitive Activation Theory of Stress. As this is still a work in process, more work has yet to be done to increase precision and validate the model. Other studies more often make use of machine learning techniques to quantify stress, for example in response to emotional images (Haag et al., 2004) or car driving (Katsis et al., 2008), leaving the underlying mechanisms unclear.

1.2.5 Virtual training

As early as the fifties, the first pilots started training using virtual simulations ('Airline Pilots', 1954). Since then, much progress has been made and many methods to train and learn using computers have been developed. For example, e-learning recreates a more traditional view on learning providing informative texts, but makes use of interactive media to clarify difficult topics. However, computers provide more methods to learn and train. This section investigates a number of different usages of computers related to training under stress or stressful circumstances.

Simulations and serious games. Traditionally, learning has been viewed as the transfer of information (Ruben, 1999). For example, books may contain a lot of information and a reader is expected to learn something by reading such a book. Research has shown that adding images to a text improves the transfer of information and creates a better understanding of the material (Mayer, 2003). Going even further by making it possible for the learner to simulate particular circumstances and see the effects enables the learner to create his or her own understanding of the material (Quinn & Connor, 2005). This different method of learning is key in simulations. With a book or images, a transmission model of learning is used where a teacher (or author) tries to teach another person some knowledge. Using simulations, the learner himself forms the knowledge and this method is referred to as the studio model of learning (Andriessen & Sandberg, 1999).

Another aspect of simulations is that learning becomes more fun and engaging (Quinn & Connor, 2005). If the point is reached where to the user learning no longer appears to be the primary goal, we start to talk about serious games. Serious games in a broad sense are 'games for purposes other than entertainment' (Susi et al., 2007), but they include all aspects of education such as teaching, training and informing (Michael & Chen, 2005). Four factors are relevant for serious games to transfer knowledge well (Alexander et al., 2005). These factors are fidelity, immersion, presence and operator buy-in. Fidelity is the extent to which the virtual environment emulates the real world. Immersion is the degree to which an individual feels absorbed by a particular experience. Presence is the subjective experience of actually existing within the computer-mediated environment even when one is physically situated in another environment. Buy-in or user acceptance refers to the degree to which a person recognizes that an experience or event is useful for training. Which of these four factors are most important depends on the application. For example, research done in the area of virtual reality exposure therapy indicate an effect of presence and immersion on anxiety (Robillard et al., 2003; Wilhelm et al., 2005; Ling et al., 2014), whereas fidelity appears to have little effect (Kwon et al., 2009). Furthermore, there have also been some studies into the effect of these factors on the transfer of knowledge (for an overview see Alexander et al. (2005)). In general, the conclusion is that too little research has been done to make any conclusive statements about transfer of knowledge, but each of these factors appears to be relevant in some contexts. More recent studies, although still limited in number, begin to show effects of these factors in particular scenarios (Dede, 2009; Panait et al., 2009; Slater et al., 2009) and effects of virtual reality exposure therapy do seem to transfer to real-life (Morina et al., 2015).

Simulations and serious games have already been used in various applications related to stress or PTSD. Especially virtual exposure therapy for the treatment of PTSD has received much attention (Beck et al., 2007; Difede et al., 2006; Gamito et al., 2010; Rizzo et al., 2008; Rothbaum et al., 2001), but there has also been some research in the treatment for fear of flying (Rothbaum et al., 1996), fear of spiders (Carlin et al., 1997), public-speaking anxiety (Klinger et al., 2005; Pertaub et al., 2002) and many other phobias (for an overview see Krijn et al. (2004)). Beside treating phobias, virtual training has been used to improve decision-making under stress (Duffy et al., 2004; Ponder et al., 2003) and train procedural skills in for example surgery (Aggarwal et al., 2004; Haluck & Krummel, 2000) or firefighting (Tate et al., 1997). In conclusion, as this is by far not an exhaustive list, simulations and serious games have been used extensively for training in various stress-related contexts.

Physiological computing. Physiological measurements can also be applied for training purposes. In the medical domain, biofeedback has received much attention in the 60s and early 70s with applications ranging from relaxation therapy to paralysis (Blanchard & Young, 1974). According to the Association for Applied Psychophysiology and Biofeedback, it is 'a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance. [..] The presentation of this information - often in conjunction with changes in thinking, emotions, and behavior - supports desired physiological changes. Over time, these changes can endure without continued use of an instrument'.[6] Based on a literature review by Yucha & Montgomery (2008), biofeedback is efficacious for the treatment

[6]http://www.aapb.org (accessed 25-6-2012).

of anxiety and possibly efficacious (due to insufficient research) for the treatment of PTSD. More recent studies using biofeedback for the treatment of PTSD show mixed results with both significant added value over other therapies (Hamid & Neissi, 2009) as well as no significant added value (Arora et al., 2010). Biofeedback can also be applied in the field of Serious Gaming. For example, Bersak et al. (2001) developed a racing game in which the speed was controlled by the player's galvanic skin response; a higher resistance, commonly associated with low stress levels, resulted in a higher speed. After a few games, the players were able to control their stress level and started to perform better.

The concept of physiological measurements can be used in more ways than biofeedback. It has received attention in the field of human-computer interaction as a means of providing user context (Fairclough, 2009). The goal here is to transform physiological measurements into 'real-time computer input in order to enhance and enrich the interactive experience' (Allanson & Fairclough, 2004). This input could consist of some emotional state of the user, which for several reasons can be useful for a machine to know (Picard, 2000). How this information is used can roughly be divided into three broad categories: assistance, challenge and emotional display (Gilleade et al., 2005). In the first category, a user is provided with assistance if measures indicate for example a state of frustration (Kapoor et al., 2007) or high workload (Bosse et al., 2013; Wilson & Russell, 2007). The second category covers those applications in which a state related to boredom is detected and measures can be taken in order to maintain task engagement, for example see Rani et al. (2005). The last category consists of those applications where the emotional state is used to present some emotional display in order to improve performance or mood, see for example Ahn et al. (2007); Prendinger et al. (2005).

Psychological computing can also be used to support learning. It is commonly accepted that emotion influences learning (Bower, 1992; Pekrun, 1992) and that the process of learning consists of being in a number of different affective states over time, for example frustration, confusion, hopefulness or curiosity (Kort et al., 2001; DMello, 2012). Using knowledge of the user's affective state can help with providing the right level and type of support (Burleson & Picard, 2004). In some affective states it is better to provide a user with task-based support, while affect-based support would be more beneficial in other states (Robison et al., 2009b). Furthermore, support could be valued more or less depending on the current emotional state of a user (Robison et al., 2009a).

1.3 Research

Getting back to the specific topic of this thesis, 'Measuring and modeling negative emotions for virtual training', this section will elaborate on the research as a whole. First, the research questions guiding this thesis are given, including a more detailed description of their intent. Subsequently, the general methodology underlying most of the research contained within this thesis is described briefly, as well as a short overview of some literature specific to this research.

1.3.1 Research questions

There are four global research questions which the work presented in the upcoming chapters are trying to answer. Each of these questions are stated below, accompanied by a short explanation. In the discussion, a more detailed account of which chapters relate to which research questions is given alongside the most important findings.

RQ 1 *Is it possible to evoke negative emotions using virtual stimuli?*

For a virtual training where negative emotions are essential, it is important to know whether it is even possible to evoke those feelings using virtual stimuli. Moreover, what are the differences between various types of virtual stimuli? There is a clear difference between a still image of a real event or a virtual character playing out a custom made scenario, but is there a difference in how well those stimuli induce the desired emotions? And lastly, do the experienced emotions even come close to what would be experienced in a real setting?

RQ 2 *How can the psychological experience of negative emotions using virtual stimuli be measured accurately?*

When performing a virtual training, trainees undergo various emotions in different intensities. One method to obtain knowledge about that experience is simply by asking the trainee directly. However, having to rate your emotional experience explicitly would interfere with the training itself and it can be questioned if a person is even able to do this accurately. Thus, it would be beneficial if it were possible to extract the psychological experience using another method. More precisely, if this would be possible in real time during the training, the potential for using that information within the virtual environment is great.

RQ 3 *Is virtual training useful in learning to cope with negative emotions?*

Coping with negative emotions can be interpreted in two ways. On the one hand the question can be asked if virtual training can be used to help people better control their emotional response when faced with negative stimuli. On the other hand, training to make optimal decisions despite of the emotion experienced is relevant as well. Can virtual training be applied successfully for either of these two goals?

RQ 4 *How can computational models (of emotion) be used for virtual training?*

Only being able to measure the physiological effects of some psychological process is insufficient to improve virtual training. This thesis aims to explore areas where computational models could benefit virtual training. Not only does developing a computational model of the underlying process help to understand what is happening, there is a larger potential as it allows for easy simulation and integration in applications as well. By simulating those models for example, it might be possible to evaluate training methods beforehand. Alternatively, models could be used to guide the behavior of virtual agents within those training scenarios. Moreover, by integrating these models in a training application, the added knowledge can be used to produce valuable feedback for the trainee or adapt a scenario at runtime for better learning effects.

1.3.2 Methodology

In order to answer the questions above, first a differentiation is made between the psychological research involved as opposed to the more technical aspects of this thesis. Both RQ 1 and 2 mainly require experiments for investigation, and RQ 3 asks for validation of virtual trainings which requires similar experimental setups. RQ 4 on the other hand involves developing models and the implementation thereof. Even though at some point experiments might need to be performed in order to test such models, for now this part mainly focuses on developing those models and is added as a separate part. Not part of this thesis and left for future research is incorporating these models in the virtual training and experiment with the training agent envisioned by the STRESS project. Below, both methods (experimentation and modeling) are described in more detail.

Experimentation. A large part of the research described in this thesis involves experimentation. The first two research questions ask for a setup where a group of participants undergoes a process in which negative emotions play a role. For RQ 1 this implies presenting some form of stimuli and retrieving information from the participants about their emotional experience. In order to investigate RQ 2, a second (control) group is used to compare the physiological responses of participants experiencing negative emotions to those who perform a similar task without the negative emotions involved. This allows for the separation of the physiological effects from the emotions from those caused by the task itself. A similar method should be used for RQ 3, where trainees using a virtual training should be compared to a similar group that is not using such a method for learning.

Modeling & implementation. Besides experimentation, a number of chapters involve developing computational models of emotion, as well as modeling otherwise relevant subject-matter. Developing such models often requires the transformation of (psychological) theories into an exact and computational representation thereof. This can either be purely mathematical models or a combination of qualitative and quantitative concepts as used in the LEADSTO language (Bosse et al., 2005). Depending on the exact nature of the model, various implementations can be made. For example, Excel is very suitable for mathematical models, but can become cumbersome when working with qualitative concepts. This disadvantage can be overcome by using modeling software created for the LEADSTO language, which also employs a specific language for analyzing simulation results. However, this method has its limitations when interaction with other software is required. In those cases, broadly used languages such as Java or Matlab are supported more frequently and thus have a large advantage. Exploring different methods of implementing computational models is is at the core of RQ 4.

1.3.3 Related work

In recent years, a number of projects have started with goals similar to those of the project STRESS. One example is interSTRESS,[7] which aims at using physiological measurements to identify psychological stress and provide feedback via virtual 'interreality' to improve personal health. Within this project, work has been published on the potential of virtual environments as a stressor (Pallavicini et al., 2013), behavioral measurements to identify stress (Giakoumis et al., 2011) and the potential of virtual environments to treat psychological stress disorders (Wiederhold & Riva, 2012). This research focuses mainly on treatment of stress and stress related disorders. On the other hand, a project named 'Better decisions under high pressure' targets more the decision making under stress. Their research includes computational models of decision making under stress (Cohen et al., 2012) and predicting performance in stressful situations (Cohen et al., 2015). Within the project STRESS, both coping with extreme negative emotions, such as stress, and decision making while experiencing these emotions is investigated.

While this thesis mostly focuses on emotion regulation, other research within the project STRESS ventures out to developing models pertaining to decision making. Bosse & Provoost (2014) for example describe a model on aggression de-escalation. This model consists of two parts, one describing the aggressor and the other the de-escalator. The two models interact using both verbal and non-verbal behavior, where the de-escalator can take certain actions

[7] http://www.interstress.eu (accessed 29-7-2015).

in order to calm the aggressor down. By running simulations of those models, it is possible to investigate various aggression de-escalation techniques. Those models are re-used in Bosse & Provoost (2015) to produce realistic aggressive behavior, using simulations of those models to drive the actions of virtual agents. Additionally an feedback module has been implemented that uses a decision tree based on those models to analyze the performance of a trainee, identify causes of mistakes and provide relevant feedback. By combining these models with the work presented in this thesis, all aspects of the STRESS project as presented in Section 1.2.1 (p.2) are covered.

1.4 Thesis type and outline

The work presented in the remainder of this thesis is a collection of various articles (cumulative thesis). Most have been published elsewhere and are reprints of refereed papers, with a few exceptions. Chapter 2 has currently been submitted for publication and is based on a number of other publications, while Chapter 9 is included as an extended version of the published paper. Furthermore, the only other changes made have been for consistency in style and formatting, with the exception of Chapter 5 which has been slightly rewritten as well. As each chapter consists of an independently written piece, there will be some overlap between sections as certain aspects had to be explained in multiple papers. Even so, this also entails that there is no need to read all the chapters or even adhere to the order they are presented in. However, there is a logical structure underlying this thesis which is explained below.

The thesis is divided in two parts, based on the nature of the research involved. The first part, titled 'Evoking and measuring negative emotions' covers mostly psychological experiments performed to better understand the interplay between virtual stimuli, the (negative) emotions they evoke and how to measure these effects. The second part details models of among others emotional processes and methods in which they can be used for virtual training. Both the contents of this second part, 'Using computational models in virtual training', and the first part are explained in more detail below. Table 1.1 gives an indication of my individual contributions within each chapter. The final chapter of this thesis covers the discussion, Chapter 11 (p.201).

1.4.1 Evoking and measuring negative emotions

The first part contains four chapters related to evoking and measuring negative emotions. In Chapter 2 (p.31), various stimuli to evoke negate emotions are explored. Using scary video clips, difficult computer games, and unfair evaluations during an emotion recognition task, a stress response is induced in participants which is being measured using both heart rate and skin conductance. Moreover, these different stimuli and their psychological and physiological effects are compared as well. Thereafter, Chapter 3 (p.55), details the results that were obtained in the same experiment using video by analyzing brain waves measured with a consumer-grade EEG device.

The last three chapters of this part have a slightly broader context and are not solely about evoking and measuring negative emotions. Chapter 4 (p.67) investigates the differences in the psychological and physiological response on aggression triggered by a virtual human compared to the response triggered by a real human. The next chapter of this part, Chapter 5 (p.89), studies the short-term and long-term effects of training emotion regulation techniques. Here, pictures are used to evoke negative emotions and three groups of participants were asked to rate these images on their emotional experience, twice on one day and again six months later, while two groups were given a training using those images after rating the images for the first time. The final chapter, Chapter 6 (p.107), covers a four week long evaluation of an implemented virtual training in the domain of public transport on its potential to evoke negative emotions and improve a trainee's aggression de-escalation skills.

1.4.2 Using computational models in virtual training

The second part of this thesis contains four chapters relating to the use of computational models for virtual training. Each of these models relates to different components of the architecture used for the project STRESS as shown in Figure 1.1 (p.5). Chapter 7 (p.125) starts with detailing a model of emotion regulation, including a number of simulation runs, a mathematical analysis and a preliminary validation, which can be used for the 'affective model' of that architecture. Continuing from here, Chapter 8 (p.145) discusses how simulation of such models can be used as a tool during the first stages of developing a virtual training. As part of this chapter, both an analysis model (usable for the 'affective model' as well) and a support model are described (pertaining to the 'feedback determination module'). The next chapter, Chapter 9 (p.167), is another example of a computational model and illustrates a different usage for virtual training, in this case to shape the behavior of a virtual agent. As such, this method of using computational models is an example of how they can be used to shape the 'virtual environment'. Finally, Chapter 10 (p.183) describes an approach to implement adaptivity in a virtual training based on specific learning goals for aggression de-escalation training, relevant for the 'scenario development module'. The relations between these chapters and the project STRESS will be discussed further in the final chapter.

Chapter	Contributions
Chapter 2	Implemented each experiment & explored relevant literature. Co-supervised students performing & analyzing experiments. Wrote a substantial part of corresponding papers. Compared the three experiments & wrote the actual chapter.
Chapter 3	Explored relevant literature & investigated relevant hardware. Analyzed EEG measurements & wrote the article.
Chapter 4	Involved in defining the experimental setup. Explored relevant literature & implemented software. Operated the Faceshift motion capture technology. Co-supervised two students conducting the experiments. Performed part of the statistical analysis. Wrote a substantial part of the article.
Chapter 5	Involved marginally in defining the experimental setup. Explored relevant literature & implemented software. Conducted all experiments together with a co-author. Performed part of the statistical analysis. Wrote a substantial part of the article.
Chapter 6	Involved in defining the experimental setup and learning goals. Operated the Faceshift motion capture technology; Implemented part of the training environment; Conducted part of the experiments; Performed the statistical analysis; Wrote a substantial part of the article.
Chapter 7	Involved in defining the model & explored relevant literature. Used the model to replicate empirical data. Wrote a substantial part of the article.
Chapter 8	Involved in modeling & performed the formal analysis. Wrote a substantial part of the article.
Chapter 9	Individual work & main author of the article.
Chapter 10	Co-supervised student implementing the software. Involved in designing the algorithm. Performed the preliminary evaluation. Wrote a substantial part of the article.

Table 1.1: Individual contributions in each chapter

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