Let me change your mind…
Frontal brain activity in a virtual T-maze

Let me change your mind…

Frontale Hirnaktivierung in einem virtuellen T-Labyrinth

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submitted by

Johannes Rodrigues

from

Heidenheim an der Brenz

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Submitted on: …………………………………………………………..……..

Office stamp

Members of the *Promotionskomitee*:

Chairperson: **Professor Dr. Paul Pauli**

Primary Supervisor: **Professor Dr. Johannes Hewig**

Supervisor (Second): **Professor Dr. Andreas Mühlberger**

Supervisor (Third): **Professor Dr. Erhard Wischmeyer**

Supervisor (Fourth): **Professor Dr. Stefan Lautenbacher**

Date of Public Defence: ……………………………………………….…………

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Für alle, die mich durch mein Leben bisher begleitet haben und diejenigen, die es verlassen haben. Ihr habt mir viel gegeben.

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Abbreviations

ACC	anterior cingulate cortex
Ag/AgCl	silver/ silver chloride
AICC	corrected Akaike information criterion
ANOVA	Analysis of Variance
ARES	Action Regulating Emotion Systems
AVCOVA	Analysis of Covariance
BAIS	Barratt impulsiveness scale
BAS	behavioral activation system
BIS	behavioral inhibition system
cm	centimeters
crit	critical
CSD	current source density
DSM	Diagnostic and Statistical Manual of Mental Disorders
ECG	electrocardiogram
EEG	electroencephalogram
FFFS	fight flight freezing system
FFS	fight flight system
FFT	Fast-Fourier-Transformation
FKK	Fragebogen zu Kompetenz und Kontrollüberzeugungen
Hz	Hertz
ICA	independent component analysis
m	mean
MDD	major depressive disorder
ms	milliseconds
µS	micro Siemens
PANAS	positive and negative affect schedule

SAM	Self-Assessment Manikin
SCL	skin conductance level
SCR	skin conductance response
SD	standard deviation
SE	standard error
sec	second
STAI	State-Trait Anxiety Inventory
STAXI	State-Trait-Anger-Expression-Inventory
VR	virtual reality
VVIQ	Vividness of Visual Imagery Questionnaire

Abstract

Frontal asymmetry, a construct invented by Richard Davidson, linking positive and negative valence as well as approach and withdrawal motivation to lateralized frontal brain activation has been investigated for over thirty years. The frontal activation patterns described as relevant were measured via alpha-band frequency activity (8-13 Hz) as a measurement of deactivation in electroencephalography (EEG) for homologous electrode pairs, especially for the electrode position F4/ F3 to account for the frontal relative lateralized brain activation.

Three different theories about frontal activation patterns linked to motivational states were investigated in two studies. The valence theory of Davidson (1984; 1998a; 1998b) and its extension to the motivational direction theory by Harmon-Jones and Allen (1998) refers to the approach motivation with relative left frontal brain activity (indicated by relative right frontal alpha activity) and to withdrawal motivation with relative right frontal brain activation (indicated by relative left frontal alpha activity). The second theory proposed by Hewig and colleagues (2004; 2005; 2006) integrates the findings of Davidson and Harmon – Jones and Allen with the reinforcement sensitivity theory of Jeffrey A. Gray (1982, 1991). Hewig sees the lateralized frontal approach system and withdrawal system proposed by Davidson as subsystems of the behavioral activation system proposed by Gray and bilateral frontal activation as a biological marker for the behavioral activation system. The third theory investigated in the present studies is the theory from Wacker and colleagues (2003; 2008; 2010) where the frontal asymmetrical brain activation patterns are linked to the revised reinforcement sensitivity theory of Gray and McNaughton (2000). Here, right frontal brain activity (indicated by lower relative right frontal alpha activity) accounts for conflict, behavioral inhibition and activity of the revised behavioral inhibition system, while left frontal brain activation (indicated by lower relative left frontal alpha activity) stands for active behavior and the activity of the revised behavioral activation system as well as the activation of the revised flight fight freezing system. In order to investigate these three theories, a virtual reality T-maze paradigm was introduced to evoke motivational states in the participants, offering the opportunity to measure frontal brain activation patterns via EEG and behavior simultaneously in the first study. In the second study the virtual reality paradigm was additionally compared to mental imagery and a movie paradigm, two well-known state inducing paradigms in the research field of frontal asymmetry.

In the two studies, there was confirming evidence for the theory of Hewig and colleages (2004; 2005; 2006), showing higher bilateral frontal activation for active behavior and lateralized frontal activation patterns for approach (left frontal brain activation) and avoidance (right frontal brain activation) behavior. Additionally a limitation for the capability model of anterior brain asymmetry proposed by Coan and colleagues (2006), where the frontal asymmetry should be dependent on the relevant traits driving the frontal asymmetry pattern if a relevant situation occurs, could be found. As the very intense virtual reality paradigm did not lead to a difference of frontal brain activation patterns compared to the mental imagery paradigm or the movie paradigm for the traits of the participants, the trait dependency of the frontal asymmetry in a relevant situation might not be given, if the intensity of the situation exceeds a certain level. Nevertheless there was an influence of the traits in the virtual reality T-maze paradigm, because the shown behavior in the maze was trait-dependent.

The implications of the findings are multifarious, leading from possible objective personality testing via diversification of the virtual reality paradigm to even clinical implications for depression treatments based on changes in the lateralized frontal brain activation patterns for changes in the motivational aspects, but also for changes in bilateral frontal brain activation when it comes to the drive and preparedness for action in patients. Finally, with the limitation of the capability model, additional variance in the different findings about frontal asymmetry can be explained by taking the intensity of a state manipulation into account.

Zusammenfassung

Frontal Asymmetrie, ein Konstrukt, erfunden von Richard Davidson, das positive und negative Valenz sowie Annäherungsmotivation und Vermeidungsmotivation mit lateralisierter Frontalhirnaktivierung verbindet, wird seit mehr als dreißig Jahren untersucht. Die frontalen Aktivierungsmuster, die als relevant beschrieben wurden, wurden über Alpha-Frequenzband Aktivität (8-13 Hz) im Elektroenzephalogramm (EEG) als Maß für die Deaktivierung für die homologe Elektrodenpaare, insbesondere an der Elektrodenposition F4 / F3 gemessen, um die relative frontale lateralisierte Hirnaktivierung zu messen.

In der vorliegenden Arbeit wurden drei verschiedene Theorien über frontale Aktivierungsmuster, die mit motivationalen Zuständen verbunden sind, in zwei Studien untersucht. Die „valence theory" von Davidson (1984; 1998a; 1998b) und ihre Erweiterung zur „motivational direction theory" von Harmon Jones und Allen (1998) verbindet Annäherungsmotivation mit relativer linksseitiger frontalen Hirnaktivität (durch relative rechtsfrontale Alpha-Aktivität angezeigt) und Rückzugsmotivation mit relativer rechtsfrontaler Hirnaktivierung (durch relative linksfrontale Alpha-Aktivität angezeigt). Die zweite Theorie von Hewig und Kollegen (2004; 2005; 2006) integriert die Ergebnisse von Davidson und Harmon - Jones und Allen mit der „reinforcement sensitvity theory" von Jeffrey A. Gray (1982, 1991). Hewig sieht das lateralisierte frontale „approach system" (Annäherungsverhalten, links frontal), und das „withdrawal system" (Rückzugsverhalten, rechts frontal) von Davidson als Subsysteme des „behavioral activation system" von Gray und bilaterale frontale Aktivierung als biologische Marker für das „behavioral activation system" und aktives Verhalten. Die dritte Theorie, die in den vorliegenden Studien untersucht wird, ist die Theorie von Wacker und Kollegen (2003; 2008; 2010), bei der die frontalen asymmetrischen Gehirnaktivierungsmuster der „revidierten reinforcement sensitvity theory" von Gray und McNaughton (2000) zugeordnet werden. Hier steht die rechte frontale Hirnaktivität (ermittelt durch geringere relative rechten frontalen Alpha-Aktivität) für Konflikte, Verhaltenshemmung und die Aktivität des „revised behavioral inhibition system", während links frontale Hirnaktivierung (ermittelt durch niedrigere relative links frontal Alpha-Aktivität) für aktives Verhalten und die Aktivität des

„revised behavioral activation system“ sowie die Aktivierung des „revised fight flight freezing system“ steht. Um diese drei Theorien zu untersuchen, wurde eine virtuelles T-Labyrinth Paradigma in der ersten Studie eingeführt, um motivationale Zustände bei den Teilnehmern zu induzieren und die Möglichkeit zu erhalten, frontale Hirnaktivierungsmuster im EEG und Verhalten gleichzeitig zu messen. In der zweiten Studie wurde das virtuelle Realität Paradigma zusätzlich im Vergleich zu einem mentalen Vorstellungsparadigma und einem Film-Paradigma, zwei bekannten Paradigmen für die Induktion von motivationalen Zuständen im Bereich der Forschung der frontalen Asymmetrie, eingesetzt.

In den beiden Studien konnte die Theorie von Hewig und colleages (2004; 2005; 2006) belegt werden, da höhere bilaterale frontale Aktivierung für aktives Verhalten und lateralisierte frontale Aktivierungsmuster für Annäherung (linksfrontale Hirnaktivierung) und Vermeidung (rechtsfrontale Hirnaktivierung) gefunden wurde. Zusätzlich wurde eine Limitation des „capability models of anterior frontal asymmetry“ von Coan und Kollegen (2006), nach der die frontale Asymmetrie von relevanten Persönlichkeitsmerkmalen in den entsprechend der Eigenschaft relevanten Situationen beeinflusst werden sollte, gefunden. Da das sehr intensive virtuelle Realität Paradigma im Gegensatz zu den mentalen Vorstellungen und dem Film Paradigma keine Abhängigkeit der frontalen Gehirnaktivierungsmustern in den entsprechenden Situationen von den Persönlichkeitseigenschaften zeigte, kann diese Abhängigkeit der frontalen Asymmetrie von der Persönlichkeit nicht gefunden werden, wenn die Intensität der Situation einen bestimmten Wert überschreitet. Dennoch gab es einen Einfluss der Persönlichkeitseigenschaften in dem virtuellen T-Labyrinth, denn das beobachtbare Verhalten im Labyrinth war persönlichkeitsabhängig.

Die praktische Bedeutung dieser Erkenntnisse sind vielfältig und reichen von möglichen objektiven Persönlichkeitstests durch eine Erweiterung des virtuellen Realität Paradigmas bis hin zu klinischen Implikationen für die Behandlung depressiver Patienten, basierend auf der Veränderungen der lateralisierten Frontalhirnaktivierungsmustern um motivationale Aspekte zu verändern, oder aber der für Änderungen bilateraler frontale Gehirnaktivierung, um den Antrieb und die Handlungsbereitschaft bei Patienten zu verändern. Schließlich kann mittels der Limitierung des

„capability models“ zusätzliche Variation in den verschiedenen Befunden zur frontalen Asymmetrie erklärt werden, indem man die Intensität der Zustandsmanipulation berücksichtigt.

1 Introduction

> “BUT THE THOUGHT IS ONE THING, THE DEED IS ANOTHER, AND ANOTHER YET IS THE IMAGE OF THE DEED. THE WHEEL OF CAUSALITY DOES NOT ROLL BETWEEN THEM.” (NIETZSCHE, 1883-1885/1999, PP. 45–46)

Is it the same to think about shooting someone, seeing a film where someone is shot or actually simulating to shoot someone, for example in an ego shooter computer game ? From the perspective of Nietzsche as mentioned above, these different activities do not have a strong causal relation to each other and as the frequently arising debate about banishing ego shooters does normally not include movie violence or violence present in novels or other media, also the mass media seems to distinguish between these categories of activity. But as the situations are perceived in a different way viewed from above, one might ask which situation has the greater impact on the person performing it and which activity is experienced in higher intensity compared to the others. Also, the really important question would be, whether the difference if one is able to show behavior or not is a driving force of the intensity of the situation (Bülthoff & Veen, 1999) and whether one would be able to make the same prediction about the human behavior without having a behavioral option at hand, because, in this example, if one chooses not to shoot someone in the ego shooter computer game, this is a totally different information than reactions to movies or other non-active media can provide and that can only be extracted by looking at the actual behavior of the person. As people are very interested in predicting human behavior, in this example if one will be shooting someone else, a mere imaginative exposure to such a situation or a movie about this situation and the hypothetical reaction or the ability to think oneself into this situation may not offer a sufficient clue about the actual behavioral tendencies present in the person.

Many approaches have been taken to explain human behavior and many different disciplines of human sciences and nature sciences try to contribute to a successful and valid forecast of it. As philosophy may provide a theoretical and more explanatory framework, psychology, biology and biochemistry try to go for valid predictions of the human behavior as well as explanatory theories. Alongside in the cooperation of these three disciplines, the neurosciences and later also the affective neurosciences (Davidson & Sutton, 1995) arose, linking the functional brain activities to affective states and traits. However, these differences in behavior, linked to differences in the brain activity or the architecture of the brain were often not detected in humans originally, but they were postulated on the basis of animal experiments (e.g. Davidson, 1984; Gray, 1982; Gray & McNaughton, 1996; Gray & McNaughton, 2000). In the behavioral sciences, the classical and operant conditioning experiments with animals, where rats and other rodents were put into mazes with different possible behavioral options and reinforcements, were often used to determine the different reactions to brain lesions in the rodents (e.g. Davidson, 1984; Gray, 1982; Gray & McNaughton, 1996; Gray & McNaughton, 2000). The results from such animal studies led to hypotheses of differences in human behavior, based on structural and functional brain differences of the human brain. To test these hypotheses, many experiments were conducted. As also different research fields and research goals were involved in the research process, different findings could finally be integrated to evaluate the theories of the animal experiments. In the clinical field for instance, lesion patients were investigated (see Wittchen, 2006, pp. 228–231), while in personality psychology, different paradigms and resting state measurements were invented and used to measure the differences of the brain activity and the possible underlying trait (see e.g. Table 11 and Coan & Allen, 2004 for frontal asymmetry). But here, the relation between the brain activity and the behavior got lost, as one focused very much on the brain activation patterns which were hard to measure when active behavior is shown because of movement artifacts (e.g. Reis, Pedro M R, Hebenstreit, Gabsteiger, Tscharner, & Lochmann, 2014) , and the behavior was not measured or of any consequence in the paradigms (see e.g. Table 11 for frontal asymmetry).

But the technical advancements in virtual reality lend us the opportunity of letting a person experience a virtual environment in which the body is kept still while the character performs movements via a movement device like a joystick without walking around in the real world. Thus one does not only have the opportunity to rely on the animal experiments concerning the behavior of a human, one can also generate an virtual environment, where the participants may act and behave, while they are still under controlled conditions and not moving in the real world at all. Finally one can also forge a bridge from the rodent maze experiments to human behavior, as one can also develop human virtual mazes with motivational cues and events that can be triggered and reinforced in different ways. In the present work, a virtual T-maze was developed and used to investigate a frontal brain activation pattern measured with the electroencephalogram (EEG) and it was compared to other paradigms used to induce motivational tendencies without providing active behavioral options and their linked frontal brain activation patterns.

The following section introduces three theories of frontal brain activation patterns linked to different motivational states, as well as the theoretical background of the different paradigms and physiological measurements used in the two studies of the present work. Then, the two studies conducted are presented and their results are discussed. Finally, the results of both studies are integrated into a final discussion, concluding remarks for future research and a conclusion. The conclusion integrates the findings concerning the prediction of the three different theories about frontal activation patterns with motivational tendencies and active behavior, the relation of personality traits in relevant situations dependent on their intensity with frontal activation patterns and the influence of the trait on the observed behavior, if a behavioral option is available.

2 Theoretical background

2.1 Frontal Asymmetry

Intensive research has been conducted over the last 30 years to find the physiological basis for emotional and motivational processes. This research field, which was called “affective neuroscience” by Davidson and Sutton (1995) took lots of effort to investigate the frontal asymmetry that was originally formulated by Davidson (Davidson, 1984, 1998a, 1998b). The concept, that arises from the measurement of the electroencephalogram (EEG) on anterior sites, defines the relative left or right frontal brain activity by measuring the alpha frequency band (for details see chapter 2.5.1) of homologous electrode pairs. The alpha activity is hereby used as measure of cortical deactivation (Davidson, 1984), and an index can be derived from the difference of the alpha activity on the electrode pairs in order to see the relative left or relative right frontal activation of the brain (e.g. Coan & Allen, 2003; Davidson, 1984).

In his early work, Davidson sums up three important points about the new concept of frontal asymmetry, the hemispheric specialization of affective value processing (Davidson, 1984). The first point is about the distinction of the different functions of hemisphere, and that one hemisphere is not likely to be specialized wholly to the processing of a certain type of information. Instead, it is more plausible that the frontal regions are more related to affective behavior and posterior asymmetries are more related to cognitive function (Davidson, 1984). The second point is that the asymmetry, if solely considered at the whole hemispherical level and not split into different areas like the frontal, parietal and occipital area, may in fact be in opposite directions for the mentioned areas and therefore result in an artificial even state of the whole hemispheres, while there is actually a functional asymmetry involved (Davidson, 1984). The third point is about a possible reciprocal interaction between the anterior and posterior activations, also stressing the importance of concentrating on defined regions in the hemisphere and not the hemisphere as a whole (Davidson, 1984). These three claims that are made are backed up by many pieces of evidence by other researchers, starting with animal experiments, where lesions lead to the conclusion of a hemispheric representation of affective behavior in rats, with the left frontal hemisphere being linked to more open-field activity and positive affective behavior, while more right frontal hemisphere activity is linked to mouse killing and the prolonging of taste aversions and therefore with negative affective behavior in rats. Also primate studies, that stress the findings of functional asymmetries, are mentioned although most evidence for an affective driven asymmetry is gathered by rodent studies and bird studies. After pointing out the importance of the lateralization of the brain in animals, Davidson (1984) describes also the concept of lateralization of the brain activity in humans. Having mentioned an extensive body of literature concerning the functional differences of the hemispheres concerning memory and perception, Davidson speculates that there might also be a hemispherical difference in the regulation of affective behavior in humans (Davidson, 1984). This claim is supported by the evidence provided for brain asymmetries in affective processes in clinical populations, where left frontal hemispheric lesions are linked to negative affect, as well as depression is linked to greater relative right frontal brain activity. In non-clinical population, there is a processing advantage for positive stimuli in the right visual field and a processing advantage for negative stimuli in the left visual field. They are stressing the same hemispheric asymmetry as the clinical experiments, along with the same asymmetrical frontal brain activity that could be seen to positive and negative stimuli (Davidson, 1984). Finally, Davidson (1984) discusses the data gathered from infants and newborns showing more left frontal brain activation to positive stimulation (smiles and laughter) and more right frontal brain activation to negative stimulation (frowning and crying, citric acid).

Concluding from all this evidence, Davidson postulated his concept of anterior asymmetry and emotion, with two basic behavioral systems, responsible for emotion and motivation. The two systems are an approach system and a withdrawal system. The approach system (Davidson, 1984, 1998a) was associated with approach motivation and positive affect, as well as higher activity in the left dorsolateral prefrontal cortex. The withdrawal system (Davidson, 1984, 1998a) was associated with withdrawal motivation, negative affect and a higher activation in right dorsolateral prefrontal cortex. In this model, the asymmetrical activation of the prefrontal cortex can be used as a predictor of differences in emotional valence (pleasant / unpleasant) and motivational tendencies (approach /

avoidance), with the right frontal brain associated with withdrawal and negative valence and the left frontal brain for positive valence and approach.

2.1.1 Reinforcement sensitivity theory.

Having created a valence and a motivational direction model of frontal asymmetry, it soon was linked to two other motivational constructs dealing with motivational states and behavior, the behavioral activation system (BAS, see Harmon-Jones & Allen, 1997, Sutton & Davidson, 1997) and the behavioral inhibition system (BIS, see Sutton & Davidson, 1997). These two constructs BAS and BIS are part of the reinforcement sensitivity theory, invented by Jeffrey A. Gray (Gray, 1982, 1991; Gray & McNaughton, 1996). This model postulated three systems in the original version, regulating the emotional and motivational behavior.

The behavioral approach system (Gray & McNaughton, 1996), also named behavioral activation system (Carver & White, 1994; Fowles, 1980), is connected to the concept of reinforcement, as it reacts to positive reinforcements and negative reinforcements and is linked to approach motivation and active withdrawal motivation. The brain areas associated by Gray to this system are defined predominantly by two different motor systems (Gray, Feldon, Rawlins, J. N. P., Hemsley, & Smith, 1991; Gray & McNaughton, 1996). The first motor system includes the caudate system, being associated with the ventral anterior and ventrolateral thalamic nuclei, the caudate-putamen (dorsal striatum), the dorsal pallidum and the substantia nigra, hence the basal ganglia on the level of brain structures, as well as with the neurotransmitters glutamate, gamma-aminobutyric acid and dopamine (Gray & McNaughton, 1996). The second motor system linked to the BAS is the accumbens motor system, with the associated brain structures limbic cortex (including the prefrontal and cingulate cortex), the dorsomedial thalamic nucleus, the ventral striatum (nucleus accumbens), the ventral pallidum, the dopaminergic nucleus A10 and the ventral tegmental area. Again, the neurotransmitters here are glutamate, gamma-aminobutyric acid and dopamine (Gray & McNaughton, 1996). These two motor systems are connected with each other and with the interplay of these two systems with the prefrontal cortex, the sensorimotor cortex, the subicula system, the amygdala and the septo-hippocampal system, motor activity and movements are initiated and executed (Gray & McNaughton, 1996).

But this septo-hippocampal system plays a key role for the behavioral inhibition system (Gray & McNaughton, 1996), that was in the original version of the theory a partly antagonizing system to BAS. The BIS reacts to conditioned punishment and not reinforcement, as well as to novel stimuli and congenital fear stimuli, leading to a state of inhibition or passive avoidance. The neural basis of this system are the septo-hippocampal system, the neocortical inputs to this system from the entorhinal area and the prefrontal cortex as well as the ascending noradrenergic, cholinergic and serotonergic inputs to this septo-hippocampal system (Gray & McNaughton, 1996). Also the dopaminergic ascending input to the prefrontal cortex, the noradrenergic innervation of the hypothalamus and the descending noradrenergic fibres of the locus coeruleus make the neural basis of the BIS (Gray & McNaughton, 1996). The septo-hippocampal system is formed by the entorhinal cortex, the dentate gyrus, the subicular area, the medial and lateral septal areas, the Papez circuit, the mammillary bodies, the anteroventral thalamus and the cingulate cortex (Gray & McNaughton, 1996). With the interplay of the entorhinal area and the ascending noradrenergic projections with the septo-hippocampal system, the BIS is not only able to predict the next sensory event and check whether there is a mismatch between the prediction of the event and actual event or whether the event is aversive, but also the importance of a stimuli can be communicated to the system and therefore a more cautious checking and orienting reaction can be initiated (Gray & McNaughton, 1996).

The last system in the reinforcement sensitivity theory is the flight fight system (FFS), reacting to unconditioned aversive stimuli with an unconditioned escape (flight behavior) or defensive aggression (fight behavior) if the option to escape is no longer available. The neural underpinnings of this system are nuclei in the central periaqueductal gray, components in the medial hypothalamus and the amygdala (Gray & McNaughton, 1996). This system can also be inhibited by the BIS and its behavioral outcomes have been associated with anger for defensive aggression and panic for the unconditioned escape.

2.1.2 Frontal asymmetry and reinforcement sensitivity theory.

In order to link this reinforcement sensitivity theory of Gray (Gray, 1982, 1991; Gray & McNaughton, 1996) to the frontal asymmetry proposed by Davidson (1984; 1998a; 1998b), Davidson and colleagues could show empirical evidence for a positive correlation of BAS manifestation in trait questionnaires and left frontal brain activation during resting EEG (a measurement of EEG where the participant is instructed to do nothing but open and close his/her eyes for one minute and remain calm for a minimum of 4 or better at least 8 minutes, see Hagemann, 2004), as well as a positive correlation of trait BIS measured with questionnaires and right frontal brain activation during resting EEG (e.g. Sutton & Davidson; 1997, Shackman, McMenamin, Maxwell, Greischar, & Davidson, 2009, but see also Coan & Allen, 2003; Harmon-Jones & Allen, 1997 for only evidence for BAS). Therefore, the authors suggest that left frontal brain activity is associated with approach motivation (BAS) and right frontal brain activity is associated with passive avoidance motivation (BIS) as well as with active withdrawal motivation as an extension of the already proposed motivational direction theory of Davidson (1984; 1998a; 1998b). Hence the authors integrate the theory of Gray (Gray, 1982, 1991; Gray & McNaughton, 1996) into the theory of Davidson (1984; 1998a; 1998b), by proposing that the BAS is identical with the approach system and the BIS is identical with the withdrawal system.

2.1.3 Motivational direction theory.

Additionally, the notion that emotional valence is a necessary component of frontal asymmetry could be debilitated, e.g. by Harmon – Jones and Allen (1998). In this work, in which they are investigating anger, as well as positive and negative affect on a trait level, the only relation of the resting brain alpha asymmetry in anterior regions could be found to anger. As anger is a motivational state, having a negative valence but a motivational approach aspect and having a left frontal cortical activation pattern shown in relation to that trait, the imperative role of the valence could be neglected and the importance of the role of the motivational direction for the frontal alpha asymmetry was stressed.

Similar however different findings were reported by Hewig and colleagues, questioning the motivational direction model concerning the emotion anger as a whole being associated with a left sided anterior brain activation (Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2004). In their study, they found a positive correlation between the trait "Anger-Out", meaning the expression of anger towards the environment or others, and relative left frontal brain activity, especially when measured with current density reference, while a general association between the anger out and the left sided frontal brain activation was not found (Hewig et al., 2004).

Therefore, the question whether the motivational direction model is the driving force behind the frontal asymmetry was also questioned, because this model only accounts for the motivational indication of an emotion as a whole and not for the different motivational states that can arise from it like withdrawal in some anger contexts as well as the more common approach linked to anger (see also below: Wacker, Heldmann, & Stemmler, 2003). But from this study of Hewig and colleagues (2004), also an alternative perspective on frontal brain activation patterns arose.

2.1.4 Behavioral activation system and bilateral frontal activation.

Referring to the original reinforcement sensitivity theory of Gray (Gray, 1982, 1991; Gray & McNaughton, 1996), Hewig and colleagues found evidence that active behavioral motivation and behavior (BAS) is linked to bilateral frontal brain activity, but the approach motivation is linked to left frontal brain activation and the withdrawal motivation is linked to right frontal brain activation (Hewig et al., 2004, 2005, 2006).

In their first study (Hewig et al., 2004), the authors investigated additionally to the trait anger mentioned above the trait BAS and the aggregated resting EEG alpha activity from 3 different measurement occasions. Deriving from that data, a bilateral frontal activation was associated with higher trait BAS scores, while neither BIS nor BAS showed a correlation with an asymmetrical frontal alpha activation score. Also in a later study (Hewig et al., 2006), the authors measured BIS and BAS and correlated this trait measurement with the aggregated resting data of 4 measurement occasions per person, again finding only the bilateral frontal alpha activity (less frontal brain activity) being negatively correlated with the BAS and no asymmetrical frontal alpha activity corresponding to neither BIS nor BAS.

It turned out that not only during resting state a correlation between the bilateral frontal brain activation and the trait BAS could be found, but also during a no-go-task (Hewig, Hagemann, Seifert, Naumann et al., 2005). Here, Hewig and colleagues provided the participants with a cue to positive or negative reinforcement or no reinforcement at all during the trials. After that, a go or no-go signal was given. During the cueing period, there was stronger bilateral frontal brain activation the stronger the trait BAS of the participants, if a reinforcement was cued, anyway of the valence and the linked approach or avoidance motivation. This relationship was not present when no reinforcement was cued at all. Also, no asymmetrical frontal brain activation pattern was detected during the cuing period in relation to the traits.

Putting together the evidence gathered in these studies, Hewig (Hewig, Hagemann, Seifert, Naumann et al., 2005, 2006) proposed a model of bilateral frontal brain activity corresponding to the BAS and seeing the motivational directions proposed by Davidson (1984; 1998a; 1998b) and clarified by Harmon-Jones and Allen (1998) as subsystems of the BAS on the motivational level. Hence he postulated that the BAS can account for approach and withdrawal motivation. This finding was present in anterior alpha activation during resting EEG as well as during tasks induced frontal alpha activation patterns.

2.1.5 Revised reinforcement sensitivity theory.

But the reinforcement sensitivity theory of Gray (Gray, 1982, 1991; Gray & McNaughton, 1996), that was one important part of this theoretical link between the frontal asymmetry and the BAS, was criticized in many studies (e.g. Pickering et al., 1997) and finally revised to correct for the new evidence that was brought up (Gray & McNaughton, 2000). The revision includes the same three different systems, regulating the emotional and motivational behavior, but the systems were revised concerning their functions for behavior, while their neural underpinnings remained the same.

The concept of the BAS underwent the smallest modification and was revised to be linked more specific to the approach motivation, reacting now to conditioned and unconditioned reward, as well as to relief and safety signals, if a conditioned or unconditioned punishment ends (Gray & McNaughton, 2000).

The flight fight system (FFS) was renamed into flight fight freezing system (FFFS) and covers all reactions to aversive stimuli, regardless whether they are conditioned or unconditioned stimuli. Hence the revised FFFS reacts to conditioned and unconditioned punishments as well as threats and frustration, which arise if a reward is no longer provided. Also, the shown behavioral responses, the defensive aggression and unconditioned escape were complemented by the flight behavior per se and the freezing behavior. Being independent from predatory aggression, the revised FFFS covers the motivational processes in context of active avoidance, passive avoidance, withdrawal and defensive aggression (Gray & McNaughton, 2000). The resulting behavioral response of the revised FFFS is dependent on the distance that is between the organism and the stimulus provoking the response of the revised FFFS, the opportunity to show fleeing behavior as well as from the intensity of the stimulus. If the stimulus is far or low in intensity, no behavior will be initiated. If the stimulus is in middle range and has moderate intensity, the flight responses are executed if a flight is available, being constituted by active avoidance and withdrawal (Gray & McNaughton, 2000). If the stimulus is in middle range and with middle intensity, then the freezing behavior is executed if no flight is available, thus being a form of passive avoidance (Gray & McNaughton, 2000). However, if the stimulus is near and the organism has no chance to escape any more, the defensive aggression is executed leading to a defensive fighting behavior, followed by an immediate non-directed flight if a chance to escape is available (Gray & McNaughton, 2000). In humans, this activation of the revised FFFS system is associated with panic behavior (Gray & McNaughton, 2000).

The modifications made for the BIS were greatest, for it was changed into a conflict monitor system, inhibiting the two other systems (revised BAS, revised FFFS) if they are both active at the same time and shifting the attention to the stimuli that is causing this double activation (Gray & McNaughton, 2000). Additionally the environment is scanned to detect possible threats and the memory is checked for additional information about this situation. On the emotional level, anxiety is elicited and the induced behavior is therefore dominated by caution and scanning the environment for threats (Gray & McNaughton, 2000). Following this revision of the BIS, the revised BIS has recently been linked to conflict theory (Botvinick, 2007; Botvinick, Braver, Barch, Carter, & Cohen, 2001; Leue, Lange, & Beauducel, 2012) and conflict monitoring. In this theory the anterior cingulate cortex (ACC) serves to monitor for conflicts in information processing (Botvinick, 2007) and therefore the revised BIS can be associated with midfrontal theta activity, as this is a signal in EEG that can be associated with ACC activity (Cohen, 2008; van de Vijver, Ridderinkhof, & Cohen, 2011). This link from the revised BIS to conflict theory questions the possible neural underpinnings of the revised BIS being solely an activation of the septo-hippocampal system, because midfrontal theta is not exactly mirroring the hippocampal theta activity, although this might be an artifact of different phase locking of the midfrontal theta activity and the hippocampal theta activity (Mitchell, McNaughton, Flanagan, & Kirk, 2008).

2.1.6 Revised behavioral inhibition system and lateralized frontal activation.

In order to account for this revised reinforcement sensitivity theory (Gray & McNaughton, 2000) and to link this new concept to the phenomenon of anterior alpha asymmetry, Wacker and colleagues suggested that left frontal brain activity is associated with all kind of behavioral activation in the sense of the revised BAS and the revised FFFS, but right frontal brain activity is linked to behavioral conflicts and behavioral inhibition and hence associated with the revised BIS (Wacker, Chavanon, Leue, & Stemmler, 2008, 2010; Wacker et al., 2003). In all of their studies, the authors do not refer to resting EEG alpha asymmetry, but only to task induced alpha asymmetry.

In their first study, Wacker and colleagues used imaginary scripts of soccer scenarios provided for male soccer players to induce motivational states and emotions (Wacker et al., 2003). The imaginary scripts were designed in a fashion that a protagonist experienced a situation concerning a soccer game and different scripts were made. The different emotional and motivational states that were targeted were anger-approach, anger-withdrawal, fear-approach, fear-withdrawal and a neutral condition. The different scripts were not only intended to evoke the different emotions and motivational aspects, but also the implicit theory was made about the induction of approach-avoidance conflicts if the valence of a situation is highly negative and one is to approach nevertheless according to the script (Wacker et al., 2003). All scripts were presented in a between design together with a training and a baseline script. After the exclusion of about one fourth of the participants showing not the correct intended signs of the emotional states, the alpha asymmetry that was measured in a one minute period after experiencing the scripts on frontal sites was used to compute the frontal asymmetry index. For the frontal brain activation patterns, more relative left sided frontal brain activation was found for the anger scripts and the approach scripts compared to the control condition as well as for the anger conditions compared to the fear conditions (Wacker et al., 2003). However, as the authors combined the frontal asymmetry in the different groups with the reported valence of the scripts by the participants, they found that the higher the negative valence and an approach script was shown, the more relative right sided frontal brain activation could be detected (Wacker et al., 2003). Similar findings were obtained for less negative valence and a withdrawal behavior described in the imaginary scripts (Wacker et al., 2003).

In a second study, Wacker and colleagues (2008) used again imaginary scripts to induce different emotional and motivational states, this time not related to sports but to an assault by some rowdies. Here the goal was to compare flight or fight responses with the behavioral inhibition that should arise from a conflict as proposed by the revised reinforcement sensitivity theory (Gray & McNaughton, 2000) and link these concepts to frontal brain activation patterns. The setting for the participants remained the same as the imagery scripts were presented in a between design and all participants experienced a training script with someone jogging around, a neutral script and one experimental script, which could be either a control condition, where no rowdies were present, a (revised) BIS targeting script, where the protagonist experiences a freezing state when assaulted by the rowdies, or a (revised) FFFS script, were the protagonist starts to run away from the rowdies when assaulted (for more details see Wacker et al., 2008). As in the previous described study, the measurement period where frontal asymmetry was assessed was also after experiencing the imagery scripts with one minute duration. Additionally, high and low (revised) BIS trait groups were used via preselection to ensure a difference in the (revised) BIS reactivity for different groups of participants, as well as self-report measures of the (revised) BIS; (revised) BAS, (revised) FFFS, the pounding of the heart and the vividness of the imagination (Wacker et al., 2008). The authors found more relative right sided frontal brain activation after the (revised) BIS oriented scripts, compared to the control condition and the (revised) FFFS condition. Also they found a positive relation between the self-report the perceived activation of the (revised) FFFS and the (revised) BAS to the experimental scripts and relative left anterior brain activity, as well as a positive relation of the pounding heart to the relative right sided frontal brain activation (Wacker et al., 2008). Using the (revised) BIS trait measurements combined with the ratings of the perception of the scripts, the author also revealed that high trait BIS participants who rated their script more in (revised) FFFS manner showed a more left frontal brain activation pattern than those high (revised) BIS trait participants who experienced their script more in a (revised) BIS manner.

In yet another study, Wacker and colleagues (2010) used a go/no-go task to back up their findings of the two studies mentioned above. In this study, participants were classified accounting for high and low (revised) BIS / BAS and had to perform a go/no-go task with the two reaction patterns keypress and releasing the key. Beside similar findings than Hewig and colleagues (2005) for bilateral frontal activity during go-trials being moderated by trait BAS, the authors found for high trait (revised) BIS participants a relatively more left sided frontal activity for the keypress in go trials vs. the release of the key , while the in no-go trials, the pattern was inversed, meaning more relative right sided frontal activity for the inhibited keypress (Wacker et al., 2010).

Integrating their evidence, the authors suggest that anterior asymmetry is a biological marker linked to the revised reinforcement sensitivity theory model of Gray (Gray & McNaughton, 2000), where the revised BIS is sensible for conflicts between the two other systems revised BAS and revised FFFS (Wacker et al., 2008, 2010; Wacker et al., 2003). Right frontal brain activation hereby stands for an activation of the revised BIS and represents the conflict and the linked inhibition of the other systems. The revised BAS and the revised FFFS are both linked to the left anterior brain activity, being the two systems that lead to behavior and not representing conflict and inhibition (Wacker et al., 2008, 2010; Wacker et al., 2003).

2.1.7 Summing up the three models of anterior brain activation patterns.

Summing up the different models about the frontal asymmetry, the linked model of reinforcement sensitivity (Gray, 1982, 1991; Gray et al., 1991; Gray & McNaughton, 1996) as well as the revised reinforcement sensitivity model (Gray & McNaughton, 2000), there are three positions.

First, Davidson and colleagues (Shackman et al., 2009; Sutton & Davidson, 1997) argue that left frontal brain activity is linked with approach motivation and approach behavior, while right frontal brain activation is connected to behavioral inhibition, passive avoidance and withdrawal behavior (see Figure 1 left part). Therefore, from this point of view, one has to link the BAS to the left frontal side and the BIS of the reinforcement sensitivity theory (Gray, 1982, 1991; Gray et al., 1991; Gray & McNaughton, 1996) to the right frontal side of the brain.

Second, Hewig and colleagues (Hewig et al., 2004, 2005, 2006) argue that left frontal brain activity is linked to approach motivation and right frontal brain activation is linked to withdrawal motivation, but these two motivations are part of a general behavioral activation system (BAS) that is linked to bilateral frontal brain activation (see Figure 1 middle part).

Finally, Wacker and colleagues (Wacker et al., 2008, 2010; Wacker et al., 2003) suggest that left frontal brain activation is linked to active behavioral motivation (revised BAS and revised FFFS), while right frontal brain activation is linked to passive behavioral motivation or conflict (revised BIS, see also Figure 1 right part). This model of anterior activation patterns also targets the revision of the reinforcement sensitivity theory (Gray & McNaughton, 2000) in contrast to the other models.

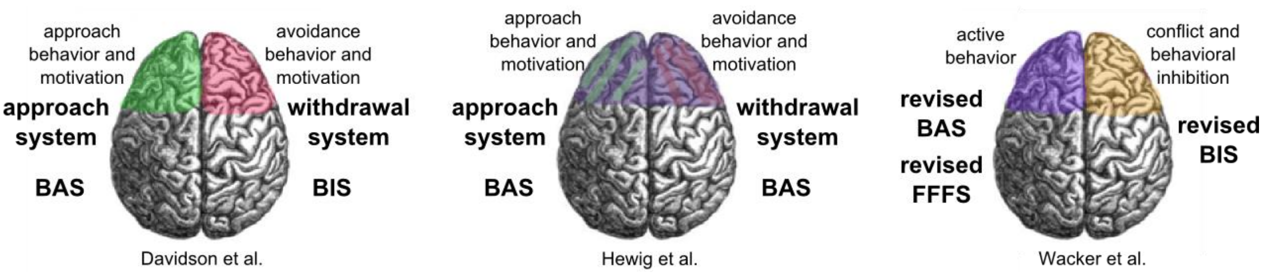

Figure 1: Graphical representation of the three different theories about the frontal brain activation and the motivational aspects of approach, avoidance and conflict, as well as approach or avoidance behavior and behavioral inhibition.

2.1.8 State based approaches on frontal asymmetry and capability model of frontal asymmetry.

The frontal brain activation patterns were investigated with electroencephalography (EEG) on basis of the activity of the alpha frequency band (8-13 Hz) being a marker for deactivation (Davidson, Ekman, Saron, Senulis, & Friesen, 1990). Two major approaches were used in the investigation of the frontal asymmetry, one being a trait based approach, where a stable dispositional asymmetrical frontal activation pattern in the EEG during resting state was assessed and correlated with personality traits (e.g. Coan & Allen, 2003, Harmon-Jones & Allen, 1998, Hewig et al., 2004, Jones, Field, & Davalos, 2000, for a review see Coan & Allen, 2004) or illnesses (for reviews see Thibodeau, Jorgensen, & Kim, 2006 and Field & Diego, 2008). This line of research was the basis of the impact of frontal asymmetry on the medical sector, where it was identified as a risk factor for depression (Allen, Urry, Hitt, & Coan, 2004; Thibodeau et al., 2006) and anxiety disorders (Thibodeau et al., 2006). Hence, frontal asymmetry grew to be considered as an important role for the mental health and the question arose, whether there is the possibility to change frontal brain activation patterns in order to change the risk for illnesses. But this, yet temporally limited, change of frontal asymmetry was already present in another research approach to anterior brain asymmetry in EEG.

This other approach on anterior brain asymmetry was the state based approach, where one tried to induce a certain state of emotion and motivation by different induction methods and thereby also inducing a specific state of frontal asymmetry. Stressing the importance of this state based approach, Coan, Allen, and McKnight (2006) proposed the capability model of individual differences in frontal EEG asymmetry. In this model, the trait based approach is linked to the state based approach, because the authors question the validity of measuring the frontal asymmetry during resting state, where no relevant stimuli in terms of approach or withdrawal are present, and linking the resulting frontal asymmetry to approach or withdrawal tendencies on the trait level (Coan et al., 2006). The solution proposed by the authors is to measure the frontal asymmetry during emotionally salient events in order to assess the individual capabilities for approach and withdrawal responses, and therefore the trait dispositions for approach and avoidance. Hence they suggest to use a combination of trait measurements and the state based approach on anterior EEG asymmetry, in order to get a measurement of the traits in a situation that is relevant for the trait, and therefore a trait activation model is proposed as a reason for the many different findings that arose from the original trait based approach, measuring resting state EEG and linking the results to traits (Coan et al., 2006). Following this idea, one has to create relevant situations in experimental settings to evoke motivational responses for approach and withdrawal, respectively the relevant underlying constructs proposedly driving the anterior brain asymmetry measured with EEG, that were already provided by the state based approach on frontal asymmetry.

Among these methods that were used to induce motivational states and emotions were instructed facial expressions (Coan, Allen, & Harmon-Jones, 2001), pictures of facial expressions (Davidson, Schaffer, & Saron, 1985), pictures with emotional and/or arousing content (e.g. Huster, Stevens, Gerlach, & Rist, 2009), videos with emotional and/or arousing content (e.g. Davidson et al., 1990), reaction time paradigms, in some cases with modified or bogus feedback (e.g. no-go-paradigm: Hewig, Hagemann, Seifert, Naumann et al., 2005, stroop paradigm: Avram, Balteş, Miclea, & Miu, 2010, 2-back-paradigm: Fairclough & Roberts, 2011, simple incentive paradigm: Miller & Tomarken, 2001), startle paradigms (e.g. Nelson et al., 2013) gambling tasks like slot machines (e.g. Nelson, Shankman, & Proudfit, 2014) , social tasks (e.g. cyberball game: Peterson, Gravens, & Harmon-Jones, 2011, shock task with bogus partners: Peterson, Shackman, & Harmon-Jones, 2008), music (e.g. Hernandez-Reif, Diego, & Field, 2006,), emotional sounds like laughter and screaming (e.g. Meyers & Smith, 1986), imagery script tasks (e.g. Wacker et al., 2003), pleasant and unpleasant odor (e.g. Kline, Blackhart, Woodward, Williams, and Schwartz (2000), biofeedback (Allen, Harmon-Jones, & Cavender, 2001), physical exercise (e.g. Petruzzello & Landers, 1994, Petruzzello, Hall, & Ekkekakis, 2001, Ohmatsu et al., 2014), exposure to light (Allen, Iacono, Depue, & Arbisi, 1993), manipulations of feelings of guilt (Amodio, Devine, & Harmon-Jones, 2007), cognitive restructuring (Deldin & Chiu, 2005), painful stimulation with and without analgesia hypnosis (Pascalis & Perrone, 1996), simulated driving task (Fairclough & Spiridon, 2012), sleep deprivation (Ferreira et al., 2006) and even during sleep with negative stimuli (Flo et al., 2011). Also the impact of drugs like cigarettes on frontal asymmetry were assessed (Gilbert, Meliska, Welser, & Estes, 1994), as well as several rather specific mood inducing stimuli and tasks for infants, like stranger approach paradigms in newborn or infants (e.g. Fox & Davidson, 1988) as well as specific paradigms to provide pain for newborns (e.g. Norman et al., 2008). For a more detailed overview of the induction of motivations and emotions in context of frontal asymmetry as a dependent variable, see Table 11 in appendix section.

One major problem of many state based approaches used to investigate frontal asymmetry is the lack of the opportunity to show behavior. As the original theory of Davidson (1984; 1998a; 1998b), its diversification by Harmon – Jones and Allen (1998) as well as its extension by Hewig and colleagues (2004; 2005; 2006) is dealing with approach and avoidance motivation, or further with behavioral activation, these concepts are clearly easier to investigate if there is the possibility to actually show that kind of behavior. For that purpose, I tried to provide the participants in this dissertation project with the opportunity to show measurable behavior while having their frontal asymmetry being measured without the problem of movement artifacts in EEG (e.g. Reis, Pedro M R et al., 2014). Following the example of Fairclough and Spiridon (2012), who used a virtual driving simulator task to measure frontal asymmetry during anger in this driving simulation, virtual reality was used to induce the motivational state, in order to provide a free movement for the participants without having to deal with the movement artifacts normally linked to free movements in a room. A desktop virtual reality was chosen and a free movement task via joystick in a virtual environment provided in order to minimize the movement artifacts, because in Powerwall or virtual cave experiments, the participants have to move around nevertheless and therefore many movement artifacts are to be expected.

Seeing the virtual reality as an induction method for a relevant situation in sense of the capability model (Coan et al., 2006), some additional opportunities of trait and state influences are added by the active behavior that can be executed. The active behavior should be intensifying the relevance of the situation (see Bülthoff & Veen, 1999) and the shown behavior should also be influenced by relevant traits (see e.g. Rodrigues, Ulrich, & Hewig, 2015 for altruism and behavior in dictator games). A theoretical model of the frontal activation pattern dependent on the trait, the trait activation and the role of behavioral options in the relevant situation can be seen in Figure 2.

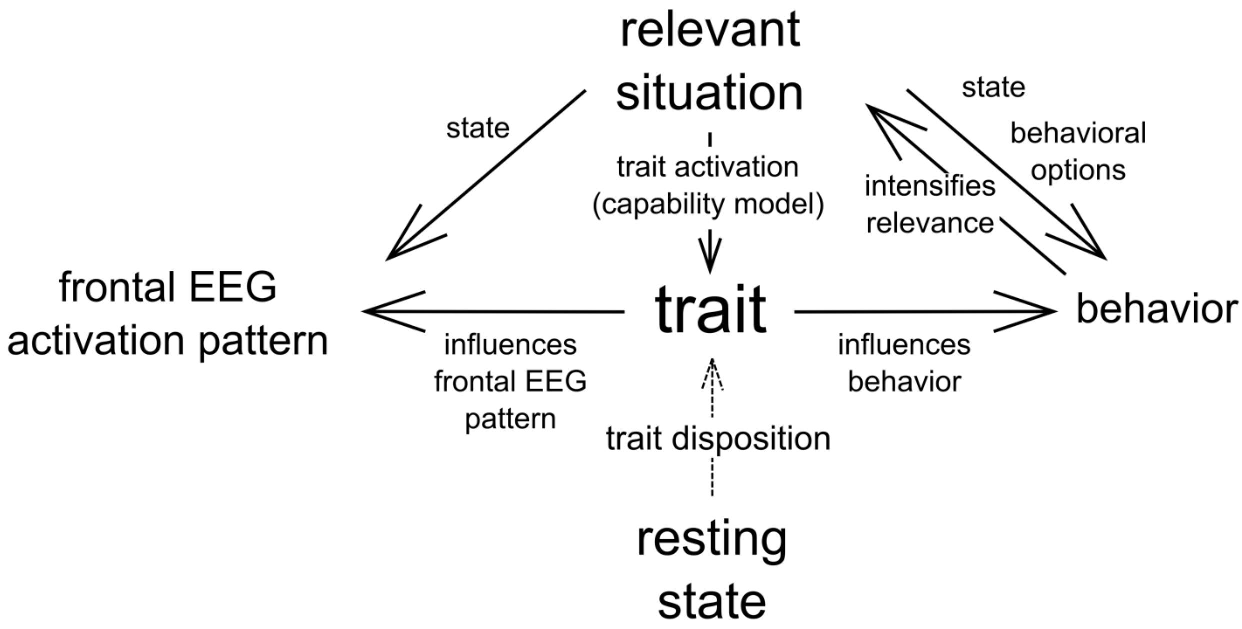

Figure 2: Theoretical relation of frontal activation patterns, trait and the situation of measurement. The situation of measurement is depicted in the middle on the top and on the bottom. The behavioral option of the relevant situation provides additional influence for the trait and intensifies the relevance of the situation.

2.2 Simulation and virtual reality

Over the last few years, the virtual reality (VR) was established as new methodological approach in psychological research (Sanchez-Vives & Slater, 2005; Tarr & Warren, 2002). Since advanced hardware and software components were available along with better graphical implementations, the opportunity to do research with virtual reality systems became more fashionable and the amenities of the virtual reality paradigms could be used for many situations.

The logical principle underlying virtual reality is the idea of simulation. As many situations are too dangerous to be experienced in a real life environment (e.g. driving under the influence of alcohol or other drugs, see Breckenridge & Dodd, 1991), the simulation provides an opportunity to expose the subject to the critical situation in a realistic manner without the danger of the real life situation. This can be achieved by creating a virtual environment in which the participant can experience the situation and interact with the environment. Additionally, the situation can be repeated many times in contrast to many real life situations like car accidents or dangerous driving situations in traffic. Also, it is possible to have a better control over the stimuli that are used in the situations as in real life, so there can even be a specific manipulation of certain features of e.g. fear stimuli, in order to get a more pronounced fear response or even a better psychological treatment in exposure therapy (Mühlberger, Sperber, Wieser, & Pauli, 2008).

Two important parameters of the experience in the virtual reality are “immersion” and “presence”. Immersion tells about the identification with the virtual avatar and the technical implementation of the virtual reality (Bülthoff & Veen, 1999; McMahan, 2003). The higher the immersion, the more identification with the avatar is present, the real world is experienced in a diminished way and instead the virtual reality dominates the sensory experience (Bülthoff & Veen, 1999; McMahan, 2003). The second parameter, presence, describes the sensation that one is a part of the virtual world provided by the virtual reality. The higher the presence, the more one experiences oneself as a part of the virtual reality (Bülthoff & Veen, 1999). Virtual reality was used in many context in psychological research, like traffic psychology (Kemeny & Panerai, 2003) in order to investigate the driving behavior and determine possible influences on it, clinical psychology for exposure therapy (Mühlberger et al., 2008), cognitive psychology (Bülthoff & Veen, 1999), assessing the memory and performance of tasks in a virtual environment, organizational psychology as virtual assessment tools (Negut, Matu, Sava, & David, 2016) or educational psychology to simulate virtual classrooms (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014).

The more complex simulations in virtual reality often target up to four different sensual modalities (e.g. equilibrioception via acceleration platforms (Kemeny & Panerai, 2003), tactile sense (Lacrama & Fera, 2009), optical and acoustic stimuli (Kemeny & Panerai, 2003) or olfactory or gustatory stimuli (Hoffman, Hollander, Schroder, Rousseau, & Furness, 1998). But it is not always advisable to go for the highest complexity in virtual reality research (see Robertson, Card, & Mackinlay, 1993), especially if the technical complexity of the virtual reality may interact solely on the technical level with other measurement in the paradigm, for instance if an acceleration platform would be used together with EEG recordings and therefore lead to massive movement artifacts in EEG. A more simple form of the virtual reality is the desktop virtual reality (Lacrama & Fera, 2009), where, like in computer games, only visual and auditory stimuli are used to constitute the virtual environment. The advantages of this very simple form of virtual reality over other forms of VR is, that besides the lower technical prerequisites, one has to deal with fewer cases of simulator sickness (Sharples, Cobb, Moody, & Wilson, 2008), a special case of motion sickness that can be seen in virtual reality and which polysymptomatic appearance can be best categorized with symptom groups such as nausea, oculomotor disruption and disorientation (Nichols & Patel, 2002). Hence in this study, a desktop virtual reality was used to induce motivation and emotions and therefore also frontal asymmetry, giving participants the opportunity to react to stimuli with behavior in the virtual environment and having an EEG recorded as well.

Also, two classical induction methods for motivation and emotions in the context of frontal asymmetry were used to test whether the differences that were found in the studies that led to the three specific theories about frontal asymmetry mentioned above are due to the induction methods that were used in the paradigms. Hence, the induction method of films with emotional contexts (Allen et al., 2001; Davidson et al., 1990; Ekman, Davidson, & Friesen, 1990; Feng et al., 2012; Jones, Field, Fox, Davalos, & Gomez, 2010; Tomarken, Davidson, & Henriques, 1990) were chosen for the classical theory of Davidson (1984; 1998a; 1998b) and a mental imagery paradigm with the original files of the study of Wacker and collegues (2008) was used to account for the theory of Wacker and colleagues (2008; 2010; 2003).

2.3 Mental imagery

The research of mental imagery has a long tradition in psychological research in the broadest sense, especially because since the very roots of this kind of research can be found long before psychology arose as a scientific field. Aristotle tells us of the *phantasia*, the imagery as a residual effect of perception that can also occur without perception (Eisler & Roretz, 1930). Stoics and Epicureans widen this concept and discriminate between *phantasia* and *phantasma*, the latter describing the illusion or the phantasmagoria (Eisler & Roretz, 1930). Willhelm Wundt, being one of the first experimentally working and empirical research oriented psychologists defines fantasy, fancy and imagination as a crucial part of imagery. Imagery is hereby defined as thinking in perceptual single imaginations, meaning thinking in pictures and images. The mental imagery is an imagination, being made by apperceptive synthesis (Eisler & Roretz, 1930). Therefore Wundt, as Aristotle before him, sees the experience of a stimulus as a necessary predecessor and causing imagination as well as mental imagery.

Since 1943 the question of physiological correlates of mental imagery arose (Golla, Hutton, & Walter, 1943) and the EEG could be used to identify such correlates. In the 1950s and 1960s the discussion was lead about the role of alpha frequency and mental imagery, finding that an absence of alpha activity in the occipital cortex during an mental imagery task, presumably occurring due to an higher activation of the vision related brain areas leads to a more vivid imagination (Slater, 1960). This finding was also used to validate questionnaires about the vividness of mental imagery like the Vividness of Visual Imagery Questionnaire (VVIQ(2), Marks & Isaac, 1995). Additional finding over the last twenty years broadened the knowledge about physiological correlates of mental imagery. For instance there was the finding by Bartolomeo (2002), showing that also temporal regions are activated during mental imagery being related to higher processing aspects and perceptions like color and shape of an object. Also several research groups could find evidence for higher event related components in EEG for stimuli that just exist in one´s imagination compared to real stimuli. Ganis and Schendan (2008) found a more pronounced N170, while Qui and colleagues (2007) found a higher N520. Both research groups interpret their findings as evidence for the higher aspect of “top-down” activation in imaginary stimuli compared to the more “bottom-up” triggered activation of the brain areas of the real stimuli. Therefore, the imaginary stimuli are more moderated by internal control processes than external stimuli. Libby and colleagues (2011) could contribute to the literature about imagery and imagination by showing the influence of the perspective taken during the imagination task. If a scene should be experienced in a vivid way, people tend to take the role of the first person protagonist in their imaginations, while a third person perspective is taken when a statement about the relevance of a certain event or situation for someone has to be made (Libby & Eibach, 2011). In the research about frontal asymmetry, imagery scripts were used by many groups (e.g. Heller, Nitschke, Etienne, & Miller, 1997; Wacker et al., 2008, see also Table 11 in appendix section) in order to evoke emotions or motivational states in participants. Therefore the imagery scripts were presented auditory to the participants, to ensure no confounding with eye movements of the reading procedure.

In the present study, a modified version of the experimental paradigm of Wacker and colleagues (2008) was used, where the participants experience different motivational states and emotions in first person perspective (see also Wacker et al., 2003) in order to provide a strong induction of motivation and emotion.

2.4 Emotional film sequences

Movies and cinema arose from technical acquisitions like the laterna magica, which was invented in the 17th century as a simple projection device used for many presentation topics like ghost-shows, sights, catastrophes or discoveries (Stöber, 2003). Also predecessors of the movies and cinema were "looking boxes" and "Panorama", one often showing even pornographic pictures in private auditions, the other being more open to public and more focused on landscape and scenes (Stöber, 2003). With the technical advancement in the 19th century, the film began to rise to its nature of the "moving pictures" in 1832/33 as the interchangeable pictures were invented as "stroboscopic discs" and further improved to the "picture rounds" in 1857 (Stöber, 2003). As the celluloid was discovered as a carrier for the single pictures in 1888 and the electrical light was invented (by Heinrich Goebel in 1854 and Thomas A. Edison in 1879), technical capabilities were ready for the movies to arise (Stöber, 2003). Since in the early 20th century cinemas appeared all over Europe and the western world, the movies started to be an important economical (Stöber, 2003) but yet also psychological factor in human life, providing people with the gratification of experiencing emotions and feelings (Bartsch, 2012) as well as with the possibility of self-escape and even self-development (Tesser, Millar, & Wu, 1988). Besides the general benefit from experiencing emotions, the psychological interest in the emotions arising from watching films or movies has been very diverse and with considerable tradition, especially since the induction of mood via films or film sequences has been one of the most successful induction methods for mood and emotion induction (Westermann, Spies, Stahl, & Hesse, 1996).

So, also in the research about frontal asymmetry, one common method for the induction of emotions and motivational states was using films with emotional content (see also Table 11 in appendix section). There were quite different approaches to the content of the film sequence that should be used. One attempt was to use videos of facial expressions (Davidson et al., 1990; Ekman et al., 1990) or videos of the emotional state of infants presented to their mothers (Killeen & Teti, 2012), another approach was to show emotionally relevant film excerpts and scenes of movies (e.g. Hofmann, 2007; Schellberg, Besthorn, Klos, & Gasser, 1990). A validated film set for the purpose of inducing emotions and mood were provided by Hewig and colleagues (Hewig, Hagemann, Seifert, Gollwitzer et al., 2005) and these movies were used to induce the motivations and emotions in this classical approach to frontal asymmetry as a marker for emotional and motivational changes and states.

2.5 Electroencephalogram

The electroencephalogram (EEG) and its application to the human head was invented by Hans Berger in 1929 (Berger, 1929), making use of previously discovered electrical reactions and signals from animal brains by Caton (Caton, 1875). In the beginning of the EEG it was measured via needle electrodes from the surface of the scull under the periosteum or directly from the dura of the brain (Berger, 1934). Today, the EEG is just extracted from the scalp with electrodes simply put on its surface and the summed electrical activity of the neurons and their excitatory postsynaptic potentials and dipoles are measured (see Luck, 2005 and Figure 3). Because of the dampening nature of the scull and the dura of the brain, a signal amplifier has to be used in order to get a sufficient signal from the brain activity. To also separate this brain activity from other electrical measurements and background noise like muscle activity and eye-movements, a differential amplification is used, where an active electrode is put on every position one is interested in and also a reference electrode (also on the scalp) and one ground electrode (somewhere on the body) is provided and the difference of the reference electrode and the ground electrode is subtracted from the difference of the active electrode to the ground electrode (Luck, 2005). The resulting signal can be interpreted in different ways.

2.5.1 Frequency analysis.

One approach is the analysis of frequencies, which was already suggested by Berger (1929), although he was relying only on the visual inspection of the raw signal. The frequency analysis can be done by different transformations from the raw EEG signal. The most commonly used transformations are the “Fast-Fourier-Transformation” (FFT) and the “Morlet Wavelet Analysis” (Wavelets) (see Cohen, 2014 for examples of algorithms for both approaches and targeted specifications). Independent of the actual algorithm and transformation that is used, the logical rational is to analyze the raw data in respect to the power of the different frequency bands that constitute the raw signal (see Cohen, 2014). In more detail, the frequency analysis fits different signals with different frequencies to the raw signal and tries to recreate the raw signal with an overlay of the defined frequency bands. Depending on the transformation, the signal that is used to create the raw signal segment is either a sinus curve (for FFT) or a “Mexican Hat-Function” (for Wavelets) (see Cohen, 2014). The different frequency bands that can be extracted are normally grouped into five different frequency bands (Hennig & Netter, 2005) that are often divided further for functional reasons:

- delta-frequency band: 1 – 3 Hz
- theta-frequency band: 4 - 7 Hz
- alpha-frequency band: 8 – 13 Hz
- beta-frequency band: 13 - 30 Hz
- gamma-frequency band: 40 Hz and higher

The different frequency bands are associated with different functional processes and properties. The frequency band that was relevant for the present studies is the alpha band, which is associated with neuronal synchronizing and therefore for a deactivation of the cells (Hennig & Netter, 2005). With the measurement of the frontal alpha activity lateralized and related to the contralateral electrode, an index of lateral frontal activity can be made (Davidson, 1984, 1998a, 1998b). This index of the predominance of the left or right frontal brain is called frontal asymmetry. Over a long period of research, one formula to measure frontal asymmetry has been developed and is nowadays used as frontal asymmetry index. It is the formula ln(right electrode)-ln(left electrode) (see Coan & Allen, 2004). This index is normally taken for the electrode position F4/F3 (see Coan & Allen, 2004), although in early work, Davidson found the differences for the anterior asymmetry for specific emotions rather in central areas of the brain on the positions C4/C3 than in anterior regions (e.g. Davidson et al., 1990).

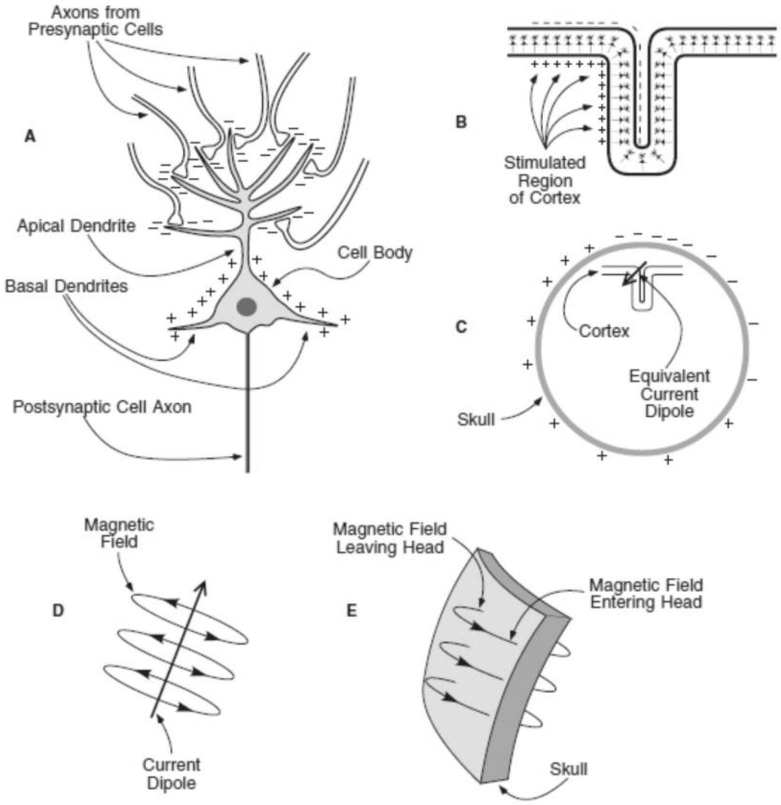

Figure 3: Principles of ERP generation. (A) Schematic pyramidal cell during neurotransmission, (B) folded sheet of cortex containing many pyramidal cells. When a region of this sheet is stimulated, the dipoles from the individual neurons summate. (C) The summated dipoles from the individual neurons can be approximated by a single equivalent current dipole, shown here as an arrow. The position and orientation of this dipole determine the distribution of positive and. negative voltages recorded at the surface of the head. (D) Example of a current dipole with a magnetic field traveling around it. (E) Example of the magnetic field generated by a dipole that lies just inside the surface of the skull. Extracted from Luck, 2005, p. 30.

2.6 Validation of the paradigms

To validate the different conditions that were used in the different paradigms we collected subjective ratings at the end of the paradigm for all conditions as well as skin conductance (Darrow, 1927), respectively the skin conductance response (SCR, Lykken, 1971) for the VR – paradigm of the first and the second study and the skin conductance level (SCL, Lykken, 1971) for the imagery paradigm and the emotional film sequences paradigm of the second study. Also, the heart period of the participants during the paradigms were measured.

2.6.1 Skin conductance.

Skin conductance is a very well established measurement of the activity of sweat glands (Darrow, 1927), that was discovered and used over 120 Years ago by Vigouroux and colleagues in 1879 (see Dawson, Schell, Filion, & Berntson, 2007, Neumann & Blanton, 1970), and its functional link to the sweat gland was first proposed by Tarchanoff in 1890 (see Dawson et al., 2007, Neumann & Blanton, 1970). Being considered as an measurement of arousal right in the beginning by Féré in 1892 (see Neumann & Blanton, 1970), the skin conductance was argued to be an indicator for emotions by Peterson in 1907 (see Neumann & Blanton, 1970) but as the reactions to emotions are not specific, the skin conductance is still considered as a measurement of arousal (Dawson et al., 2007; Roessler, Burch, & Childers, 1966; Woodworth & Schlosberg, 1954).

The skin conductance level (SCL, Lykken, 1971) "(…) describes the overall conductivity of the skin over longer time intervals, typically ranging from tens of seconds to tens of minutes." (Figner & Murphy, 2011, p. 169). This means that only long and mostly steady changes can be detected with this kind of measurement, being therefore ideal for resting state tasks and long time periods. In the present studies, the SCL was used to quantify the arousal of the participants in the imagery paradigm as well as during the emotional film sequence paradigm because of their structure with only one single trial per condition and the long intervals of imagination.

The skin conductance response (SCR, Lykken, 1971) is "(…) a discrete and short fluctuation in skin conductance that lasts several seconds and usually follows a characteristic pattern of an initial, relatively steep rise, a short peak, and then a relatively slower return to baseline" (Figner & Murphy, 2011, p. 169). As the VR paradigm did not have a long time period and just one trial, but had many trials with rather short and defined stimulus onsets and cue onsets, the SCR was used to quantify arousal in the two studies of the VR paradigm instead of the SCL. An example of a SCR can be seen in Figure 4. Summing up the skin conductance measurement, it is a physiological marker of arousal and was used in the present studies to validate the different paradigms in terms of arousal.

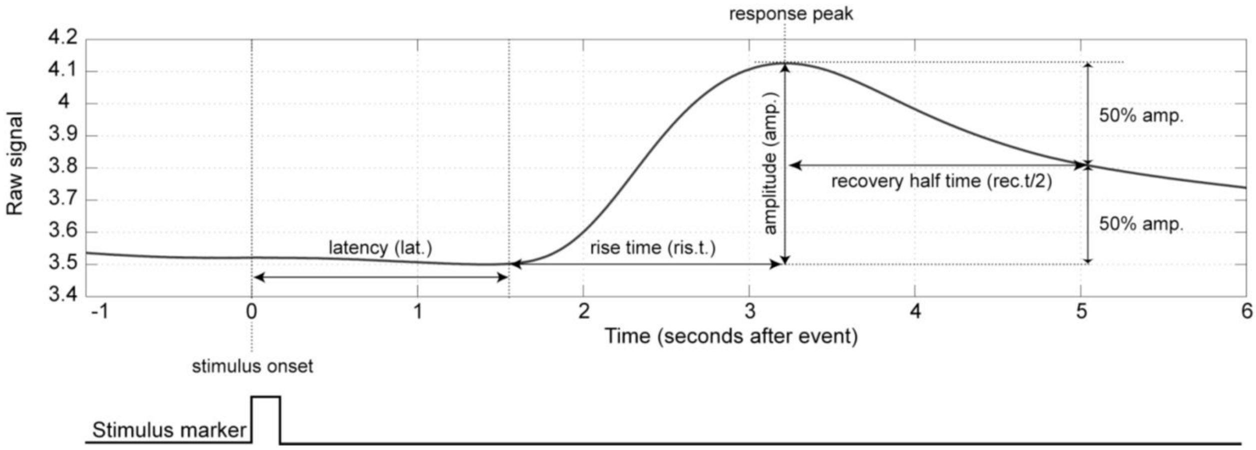

Figure 4: Raw unfiltered skin conductance signal, showing components of an SCR that can be used to quantitatively characterize SCRs. Extracted from Figner & Murphy, 2011, p. 169.

2.6.2 Heart period and heart rate.

The measurement of the heartbeat via electrocardiogram (ECG) is also a method that has been used for a long time in psychophysiology. Being invented in the late 19th century and first recorded by Waller (1887), the signal was quickly described in more detail by Einthoven (1895), already mentioning the PQRST components of the signal (see also Hurst, 1998 and Figure 5).

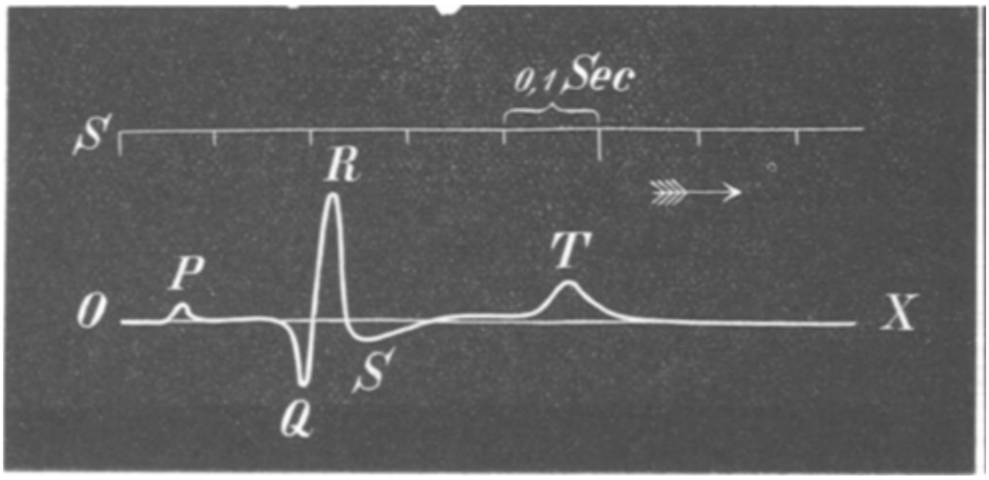

Figure 5: Electrocardiogram showing the PQRST components. Extracted from Einthoven, 1895, p. 107.

Having identified the prominent R-component, a measurement was easily derived by counting the R-spikes in order to get the heart rate or the inter-beat intervals between two beats in milliseconds. The measurement derived from this quantification of the cardiac activity was linked to certain psychophysiological reactions, like the defensive or orienting reaction (Graham & Clifton, 1966; Sokolov, 1963; Turpin, 1986).

The defensive reaction was associated with intense stimuli, peripheral vasoconstriction, cephalic vasodilation, and heart rate acceleration (Sokolov, 1963; Turpin, 1986) with a low latency, meaning a deceleration of the heart period after a longer time period. Also, the response should be mediated by sympathetic reactivity.

The orienting response was characterized by a reaction to low-intensity stimuli, being mediated by parasympathetic dominance and leading to a pattern of peripheral and cephalic vasoconstriction and heart rate deceleration (Graham & Clifton, 1966; Turpin, 1986) without any particular latency. However, this interpretation of the heart period was altered by adding the response pattern of fight/flight behavior (Turpin, 1986) characterized by a higher acceleration in the heart rate compared to the defensive reaction.

But as the heart is a dually innervated organ (Berntson, Cacioppo, & Quigley, 1991; Berntson, Cacioppo, Quigley, & Fabro, 1994) the strict separation of those two systems as well as their associated reactions was altered to the possibility of having also a co-activation or a reciprocally controlled action of both systems being represented in the resulting heart rate. Subsequently, the cardiac defense response was shown to be moderated by both systems (Fernández & Vila, 1989; Quigley & Berntson, 1990; Reyes del Paso, Gustavo A., Godoy, & Vila, 1993) and following a four peak pattern of alternating heart rate acceleration and deceleration starting with an acceleration that is moderated by the parasympathetic system (Quigley & Berntson, 1990; Reyes del Paso, Gustavo A. et al., 1993).

Another theory about the interpretation of the heart rate was given by Lacey (1967), seeing the cardiac deceleration as an index of perceptual processing and sensory intake and the cardiac acceleration as an index of mental processing or even sensory rejection. Fitting for this view, Lang, Greenwald, Bradley, and Hamm (1993) as well as Bradley, Codispoti, Cuthbert, and Lang (2001) found a positive correlation of the first accelerating cardiac component and positive valence compared to negative valence as well as a greater deceleration for negative stimuli (Bradley et al., 2001; Bradley & Lang, 2000), but more important, there was also a smaller positive relation of the first accelerating cardiac component and arousal (Bradley et al., 2001; Lang et al., 1993). In studies about imagery and heart rate, there could also be found the positive link between the arousal and the time window of the first accelerating heart rate component (Cook, Hawk, Davis, & Stevenson, 1991) or the time window for the first accelerating and decelerating heart rate component (van Oywn Witvliet, Charlotte & Vrana, 1995).

In the present studies we provided the heart period as an additional measurement for the paradigms to assess the arousal as well as the valence on a physiological level. Also we were interested in the orienting or defensive responses to certain conditions of the paradigms in order to validate their valence and intensity.

2.6.3 Subjective ratings.

As in other studies about the induction of motivational tendencies, mood and emotions, also subjective ratings were used (Westermann et al., 1996) to determine the mood as well as the emotional and motivational state. Although these ratings are in danger of being contaminated by demand effects (Westermann et al., 1996) and response biases like the order of questions (Strack, Martin, & Schwarz, 1988), the format of the response scales (Presser & Schuman, 1980) and especially of the perceived purpose of the questions (see Strack, 1994), subjective ratings were used alongside with the implicit physiological markers in order to validate the paradigms used to induce emotional and motivational states directly and explicit.

2.7 Hypotheses

2.7.1 Frontal activation.

The hypotheses arising from the three different theories about the frontal activation are divers. All three models about the frontal activation pattern mentioned above propose more relative left frontal brain activation (less left frontal alpha activity) for approach contexts and positive affect, linking the classical BAS (Sutton & Davidson, 1997) and the approach system to the left frontal brain activity in the case of the theory of Davidson (1984; 1998a), the approach system as a subsystem of the classical BAS in the case of the theory of Hewig and colleagues (2004; 2005; 2006) and with the revised BAS and active behavior in the case of Wacker and colleagues (2008; 2010; 2003).

However, for an avoidance contexts without conflict, the model of Wacker and colleagues (2008; 2010; 2003) suggests also more relative left frontal brain activation (less left frontal alpha activity), because the model roots the differences between the hemispheres to a difference in experiencing a conflict between the revised BAS and the revised FFFS system, which activates the revised BIS and therefore the experience of anxiety and behavioral inhibition (see Gray & McNaughton, 2000). As a clear avoidance context does not provide any conflict, the model of Wacker and colleagues (2008; 2010; 2003) suggests a relative left frontal brain activation (less left frontal alpha activity) because the revised BIS is not active in this case. Instead, the revised FFFS would be active and provide the behavioral alternatives of flight, fight or freezing, depending on the relative distance to the stimulus and its intensity (Gray & McNaughton, 2000), respectively a panic reaction in humans. The other two models mentioned above suggest more relative right frontal brain activation (less right frontal alpha activity) in a clear avoidance context, for they linked the activity of the right frontal cortex and with the classical BIS (see Sutton & Davidson, 1997) and the withdrawal system in the case of the theory of Davidson (1984; 1998a), respectively with the withdrawal system as a subsystem of the classical BAS in case of the theory of Hewig and colleagues (2004; 2005; 2006), to execute a withdrawal behavior from the stimulus.

For conflicts, the model of Wacker and colleagues (2008; 2010; 2003) suggest more relative right frontal activation (less right frontal alpha activity) as they link the revised BIS to right frontal activation and therefore the system that functions as a conflict detector between the revised BAS and revised FFFS proposed by Gray & McNaugthon (2000) to this right frontal brain activity. The other two proposed models do not make any particular prediction for the experience of conflict. However, if there arise negative affect from the conflict, all three models would suggest that relative right frontal brain activation should be seen, as this is clearly a state that should be avoided and the withdrawal system of Davidson (1984; 1998a) is linked in both other theory to a left frontal brain activation.

From the theory of Hewig and colleagues (2004; 2005; 2006) there is also the hypothesis of bilateral frontal activation (less frontal bilateral alpha activity) for active behavior per se, as the classical BAS is here seen as a superordinate system including the approach system and the withdrawal system postulated by Davidson (1984; 1998a). The theory of Wacker and colleagues (2008; 2010; 2003) links active behavior to left frontal brain activity, as all behavioral executing systems of the revised reinforcement sensitivity theory are linked to this frontal part of the left hemisphere, the revised BAS as well as the revised FFFS, while the revised BIS is linked to right frontal brain activity (Wacker et al., 2008, 2010; Wacker et al., 2003).

The theory of Davidson (1984; 1998a; 1998b) does not have specific predictions on active behavior, but it links the classical BAS to the left frontal brain activity (Sutton & Davidson, 1997), not integrating the withdrawal system and approach system (Davidson, 1984, 1998a) of the original theory into the classical BAS, but equating the approach system with the classical BAS and the withdrawal system with the classical BIS (see Sutton & Davidson, 1997). However, no prediction for active behavior can be drawn here per se. A summary of the proposed anterior brain activation patterns of the three different models can be seen in Table 1.

Table 1: Frontal brain activation patterns proposed by the three different theories for the relevant systems and behavioral patterns.

	Davidson et al.	Hewig et al.	Wacker et al.
behavior activation system (BAS)	(classical) left hemisphere	(classical) left and right hemisphere	(revised) left hemisphere
behavior inhibition system (BIS)	(classical) right hemisphere	()	(revised) right hemisphere
approach system	left hemisphere	left hemisphere	()
withdrawal system	right hemisphere	right hemisphere	()
approach	left hemisphere	left hemisphere	left hemisphere
withdrawal / avoidance	right hemisphere	right hemisphere	left hemisphere
defensive aggression	right hemisphere	right hemisphere	left hemisphere
active behavior	()	left and right hemisphere	left hemisphere
conflict	()	()	right hemisphere

2.7.1.1 Relevant traits for the frontal activation patterns.

As the frontal activation pattern might be dependent on the traits that are underlying the respective patterns (see capability model of frontal asymmetry, Coan et al., 2006 and chapter 2.1.8), interactions of the relevant traits and the frontal activation patterns are stated. For the model of Wacker and collegues (2008; 2010; 2003), the revised BIS should be relevant for the experience of conflict, for Davidson (1984; 1998a; 1998b) and Harmon-Jones & Allen (1998), the relevant traits are approach motivation (classical BAS) and avoidance motivation (classical BIS) and for Hewig and colleagues

(2004; 2005; 2006) the same traits are relevant. Also Balconi, Falbo and Conte (2012) support this hypothesis that the BAS and BIS are relevant for approach and avoidance motivation.

2.7.1.2 Induction methods.

As the paradigms that are used in study II differ from their scope of active behavior a great deal, differences in the induction of a trait relevant situation are to be expected. The VR paradigm provides active behavior compared to the other induction methods. As the possibility of showing active behavior amplifies the perception of the situation (Bülthoff & Veen, 1999), it is to be expected that the VR paradigm has the strongest induction of the motivational and emotional states and therefore also shows the greatest effect on frontal activation patterns in sense of the capability model proposed by Coan and colleagues (2006). For a graphical illustration of the relation of the trait and the frontal EEG activation pattern, dependent on being measured in a relevant situation or resting state, as well as an active behavior option during the relevant situation that is present in the VR paradigm, see Figure 2

3 Study I

3.1 Methods study I

3.1.1 Participants.

Thirty right handed students (12 male, mean age=24.5 (4 missing data points), range=18 – 32) participated in the study. The participants were paid 20 € or they received course credits for their participation. All students had normal or corrected to normal vision. None of them was color blind.

3.1.2 Paradigm.

The paradigm used in this study is a desktop virtual reality approach, where participants are able to navigate through a virtual T – maze via joystick and experience different events in this maze, partly linked to credits. The duration of one trial is 13 seconds. The participants start each trial in a passage, looking in the direction of the T-arms of the maze. As they move forward, an event is triggered. The events are all indicated by color cues on the wall of the T – arms of the maze in the event cueing period, after the event has been triggered by the participant. After a four second cueing period up to the end of the trial, a specific entity for every trial type can be seen, whereat the entity is only visible if the participant moves in the appropriate direction in the case of a positive entity, respectively its control entity (see below), or keeps the view to the direction were the entity is coming from in case of a negative trial entity, respectively its control entity (see below).

There are six different types of trials: negative events, positive events, control events, approach - avoidance conflicts, approach - approach conflicts and conflict control events. Negative events are trials, where the entity is a monster, chasing the subject and threatening to cause a loss of credits if one cannot escape. To negative events, one must escape by not going into the T-arms of the maze, but by going the starting passage down to the end of the passage, where other passages are accessible. Negative events are cued with a red color cue on the wall with the position of the cue next to the T-arm of the maze from where the monster approaches. Positive events have a sheep as entity, providing the opportunity to raise the credits, if one can reach the sheep in one of the T-arms of the maze before the sheep reached the end of this passage. Positive events are cued with a green color cue on the wall next to the T-maze arm in which the sheep is running away. Control events consisted of trials with jogging male avatars, behaving either like a monster or a sheep, approaching or fleeing the participant. But in contrast to the negative or positive events, the control event does not do any changes to the credits of the participants in any case. Control events are cued with a black color cue on the cue position of the positive or negative events respectively, depending on the behavior of the control entity. The fourth event is an approach – avoidance conflict, consisting of a negative and a positive event at the same time, being also cued the same time, but the negative and the positive event never being in the same T-maze arm. Having to choose whether they want to go for the sheep and get caught by the monster, or whether they want to flee the monster and miss the sheep, the participants have the same expected value in this trial for both behavioral options. The fifth event is an approach – approach conflict, consisting of two positive events, in the right and the left arm of the T-maze simultaneously. Due to the limited trial duration and the sheep fleeing in both arms of the T-maze, one has to choose one of the sheep, because both cannot be reached in one trial. The last event is the control event for the conflicts, consisting of two control events in the right and left arm of the T-maze. In order to strengthen the impact of negative and positive outcomes of the events, harmonic and disharmonic chords are presented via headphones. If one reaches the sheep that was running away, in addition to the raise of credits, a harmonic chord is played. If one does not reach the sheep in time, in addition to the message that the credits remain constant, a disharmonic chord is played. If a monster is present and the participant manages to escape the monster, in addition to the message that the credits remain constant a second different harmonic chord is played. Finally, if a monster is present and the participant is caught by the monster, in addition to the message of the loss of credits a second different disharmonic chord is played.

Each event is repeated 20 times (being a total trial count of 120), in order to get sufficient trials without artifacts in EEG. During each trial, participants are able to behave in any manner they want, allowing to measure behavior and EEG simultaneously to the different events and therefore also link the EEG signal to a behavioral response. At the end of each trial, the participants experience a white fog, beaming them to the starting position once more. Schematic display of the trials and examples for the cueing as well as the entities used in the trials can be seen in Figure 6.

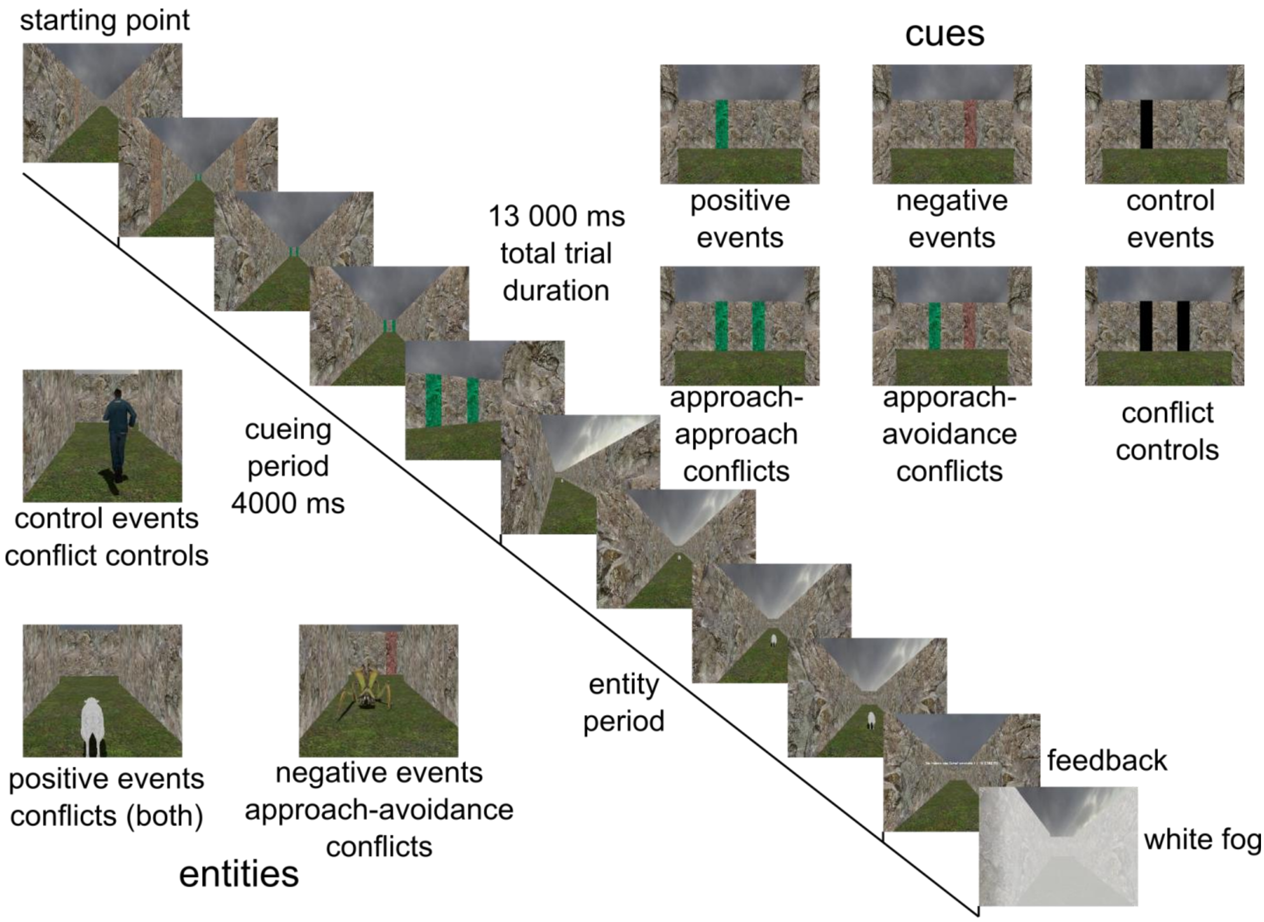

Figure 6: Schematic display of a trial. In the lower left corner examples of the entities used in the paradigm, in the upper right corner examples of the cues used in the trials are shown.

3.1.3 Procedure.

Before coming to the laboratory, the participants filled in a web based questionnaire to assess different relevant traits (see trait measurement section). Also demographical data was collected (gender, age and handedness). The online questionnaire was presented with SoSci Survey (Leiner, 2014) an online questionnaire platform.

In the desktop virtual reality approach, participants were seated in front of a 61 cm (24’’) widescreen monitor in 50 – 60 cm distance and EEG was placed on their head, as well as electrodes for skin conductance on their left hand and electrodes for the heart rate on their collarbones and the left costal arch. Additionally, headphones were placed on the head of the participants in order to provide tones during the paradigm and instructions for the resting EEG period. After that, the participants experienced a resting EEG period consisting of eight minutes with four minutes of closed eyes and four minutes of open eyes in total and a change of open or closed eyes every 60 seconds.

After that they experienced the virtual maze. They were instructed to go into the maze and make as many points as possible. Additionally, they experienced a training phase, where the monster trial (negative event) and the sheep trial (positive event) were introduced and the behavior could be practiced. The training phase did not end until the goal of the trials (being not caught by the monster or catching the sheep respectively) was obtained three times for both of these two training events. Subsequently, the experiment started.

After the experiment, there was a rating of the different events, starting with a brief experience of the relevant event. The participants were told that this event has to be seen as a cue to retrieve the emotions and feeling that were present during the experiment in such trials. Ratings were obtained for every condition and for the movement directions (forward / backward) in general.

3.1.4 Apparatus.

3.1.4.1 EEG.

The EEG was measured by Ag/AgCl-electrodes located in an electrode cap in the following 62 positions: Fp1, Fpz, Fp2, AF7, AF3, AF4, AF8, F11, F9, F7, F3, Fz, F4, F8, F10, F12, FT11, FT9, FT7, FC3, FCz, FC4, FT8, FT10, FT12, T7, C5, C3, C1, C2, C4, C6, T8, TP11, TP9, TP7, CP3, CPz, CP4, TP8, TP10, TP12, P11, P9, P7, P3, Pz, P4, P8, P10, P12, PO11, PO9, PO7, PO3, PO4, PO8, PO10, PO12, Oz, Iz, IIz, and Cz (according to the international 10–10 system). Ground electrode was located on AFz position, the reference electrode was Cz (see Figure 7).

For the elimination or correction of artifacts caused by eye movements, an additional electrode to register eye movements and blinks was put below the left eye. Electrode impedances were kept below 10 kOhm for the EEG. Data were recorded with a sampling rate of 250 Hz and a high-cutoff filter of 80 Hz with BrainVision BrainAmp Standard (Brain Products GmbH, Gilching, Germany) and BrainVision Recorder 1.20 software (Brain Products GmbH). For further computation, MATLAB and EEGLAB toolbox (Delorme & Makeig, 2004) was used. Raw data were filtered with a 0.5 Hz Butterworth high-pass filter and a 70 Hz Butterworth low-pass filter after raw data artifact detection. The segmentation of the data was done from -1 second before the cueing of an event to 5 seconds after the cueing of an event with a baseline form -500 ms to the cue onset. Following the segmenting, jump artifacts were detected and deleted statistically by using a z-value threshold of z =4 for signal and curtosis of the signal, slow drifts were rejected by using trend detection with windowsize =1500 data points, minimum slope =50, minimum $R^2 = 0.3$ and 2 point steps. Additional artifact correction for muscle activity and ocular correction was made with ICA (Makeig, Debener, Onton, & Delorme, 2004), removing manually all components associated with muscular activity or eye movement and blink activity. After that, CSD transformation was applied, using CSD toolbox (Kayser & Tenke, 2006a) and alpha frequency from 8-13 Hz was extracted using morlet wavelets with the eeglab function newtimef using cycle parameters [3 0.5] during 0 to 4 seconds of the cueing period.

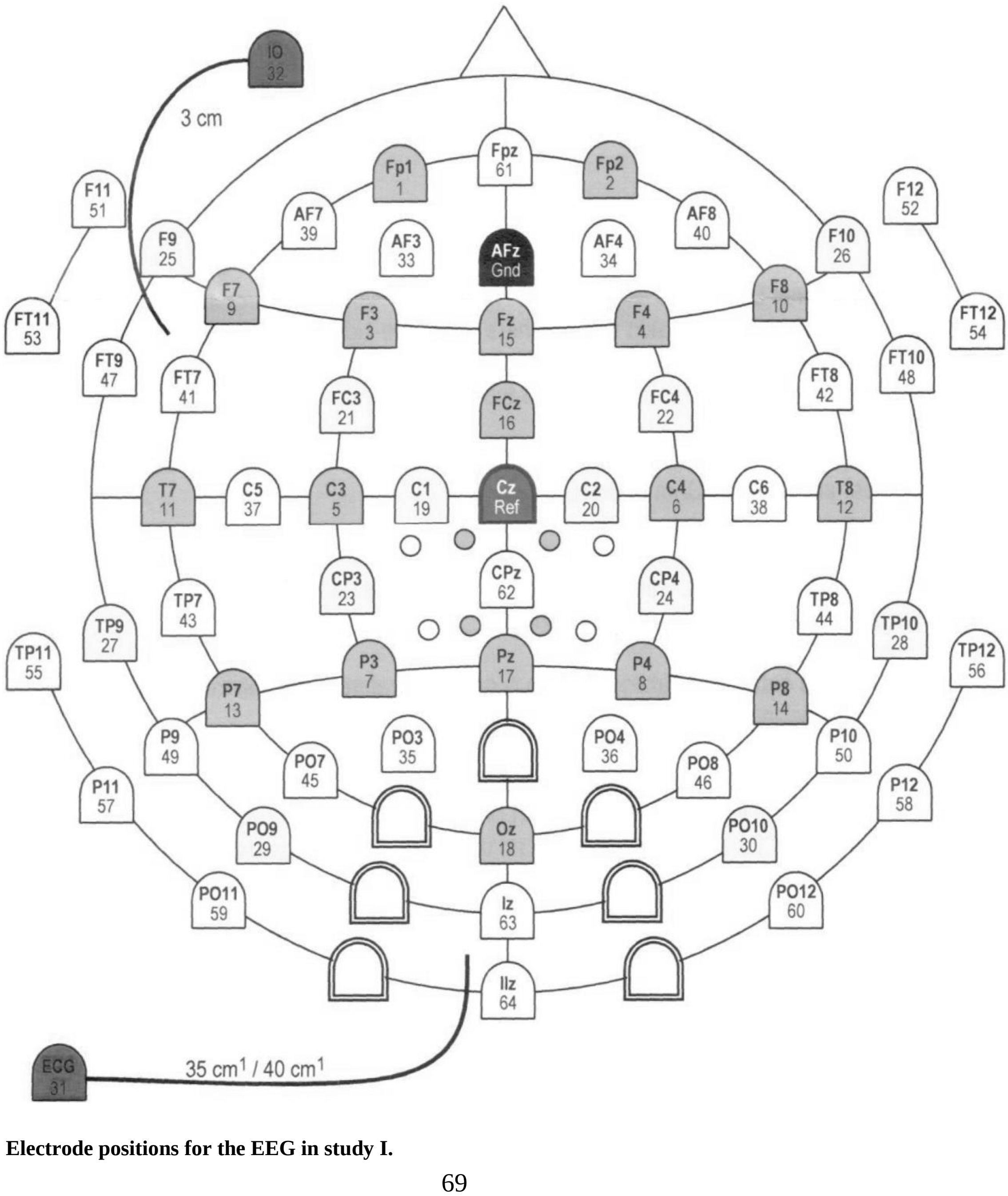

Figure 7: Electrode positions for the EEG in study I.

The selection of wavelets were used to get the opportunity to analyze cross frequency coupling in further analysis that will not be reported here. However, the alpha power was also extracted via Fast Fourier Transformation (FFT), using also the newtimef function from eeglab during the same time window and the resulting ln transformed values correlated with the ln transformed values of the wavelets with r=.97. For further analysis, only the wavelets were included in order to get the opportunity to match results of further analysis like the cross frequency coupling with the results gathered in this study.

3.1.4.2 Heart period.

Heart period and skin conductance were recorded with a sampling rate of 250Hz using a BrainVision BrainAmp ExG amplifier (Brain Products GmbH, Gilching, Germany) and the BrainVision Recorder 1.20 software (Brain Products GmbH). Heart period was measured using three disposable Ag/AgCl electrodes (Covidien Kendall ECG Electrodes H98LG) placed according to a modified Einthoven II lead. The ground electrode was placed below the left collarbone, the negative electrode below the right collarbone and the positive electrode on the left side below the rib cage.

The signal was filtered with a 4 Hz Matlab butterworth highpass filter in order to correct for slow drifts. The time window chosen for analysis was from 0 to 10 seconds after the cueing of the event. Mean inter-beat intervals were extracted for the first 10 beats.

3.1.4.3 Skin conductance.

Skin conductance was measured via two Ag/AgCl electrodes (diameter of contact area between skin and electrode paste: 7 mm, area =38,48^{2}mm) placed on the fingertip of the left index finger and middle finger respectively (see Figner & Murphy, 2011 figure 4). The electrodes were filled with TD-246 Skin Conductance Electrode Paste (0.5 % saline in neutral base, Discount Disposables, St. Albans, Vermont).

The skin conductance signal was filtered with a 2 Hz Matlab butterworth lowpass filter in order to correct for high frequency noise like light or electrical signal noise from the monitor (Figner & Murphy, 2011). The time window for the quantification of the Skin conductance response was made from 1 to 10 seconds after cue onset for every event (Figner & Murphy, 2011; Naqvi & Bechara, 2006). As we were interested in the change of the skin conductance, we took the mean over the whole period of the segment as a baseline in order to lose all tonic changes. We used the quantification of Naqvi and Bechara (2006), taking the area defined by the SCR curve and a sloped line delineated by the intersection of the measurement window and the SCR curve (see also Figner & Murphy, 2011 and Figure 8).

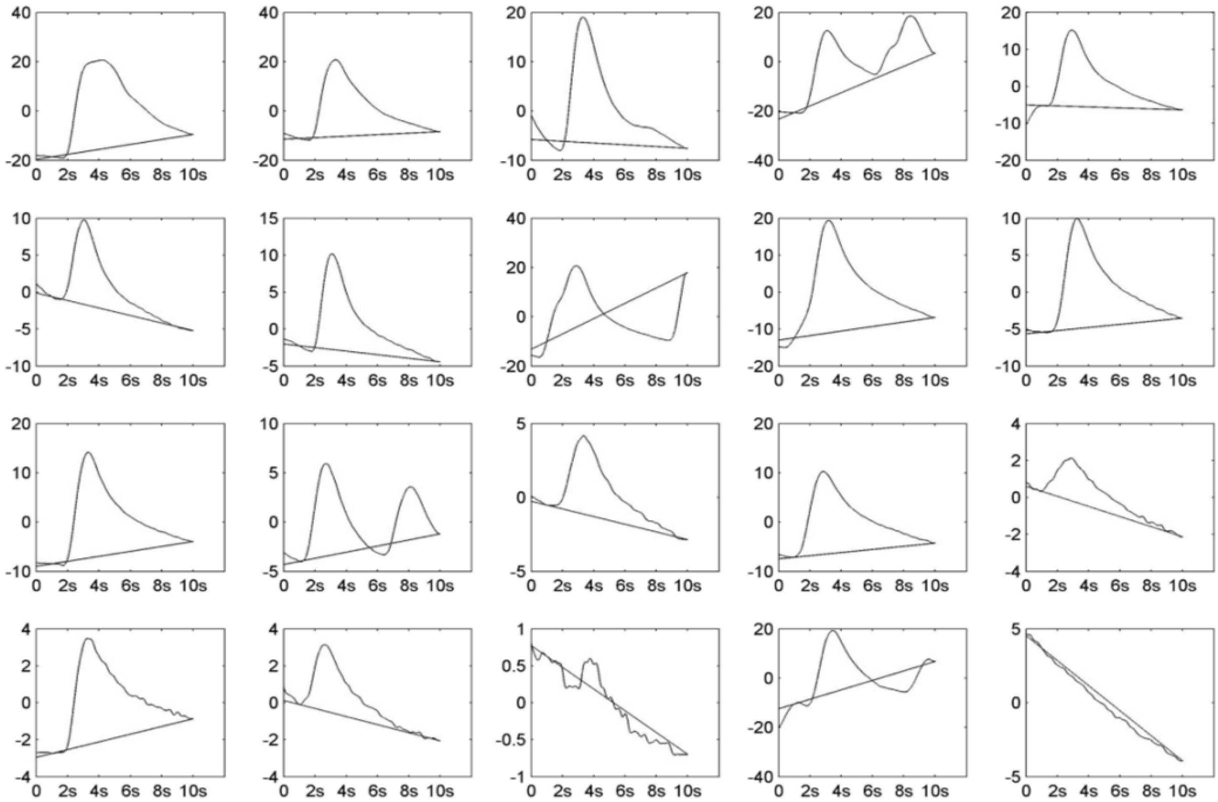

Figure 8: Example for the measurement of the skin conductance response for 20 trials of a subject. On the horizontal axis the seconds after the cueing are depicted, on the vertical axis the skin conductance in µ Siemens is shown.

3.1.5 Frontal activation.

Frontal asymmetry was assessed with the difference from ln(right)-ln(left) electrodes for homologous electrode pairs (Coan & Allen, 2004) in EEG. It was analyzed on the electrode position F4/F3 with a single trial generalized linear mixed model. It was also analyzed for the means of the conditions with a repeated measure ANOVA for the electrode positions Fp2/1, F12/11, F10/9, F8/7, F4/3, AF8/7, AF4/3, C4/3 and P4/3 to get a broader view on the frontal electrodes and also a control for central and parietal activation.

The time window for the extraction of the frontal asymmetry was the first 4 seconds of the cueing period of the event, where the participants could already initiate their movement but did not see the entity of the event. This time window was chosen in order to avoid activation pattern due to differences in visual features of the entities of the events. In the same time window, frontal bilateral activation was analyzed with the formula ln(right)+ln(left) (Hewig et al., 2006) for the homologous electrode pair F4/3 with a single trial generalized linear model and a single trial generalized linear mixed model.

3.1.6 Behavioral measures.

The behavior shown in the paradigm was classified and categorized by tracking the movement of the participant in the virtual reality as well as the movement of the joystick (for an example of the movements of the joystick and the participants in the virtual environment see Figure 9).

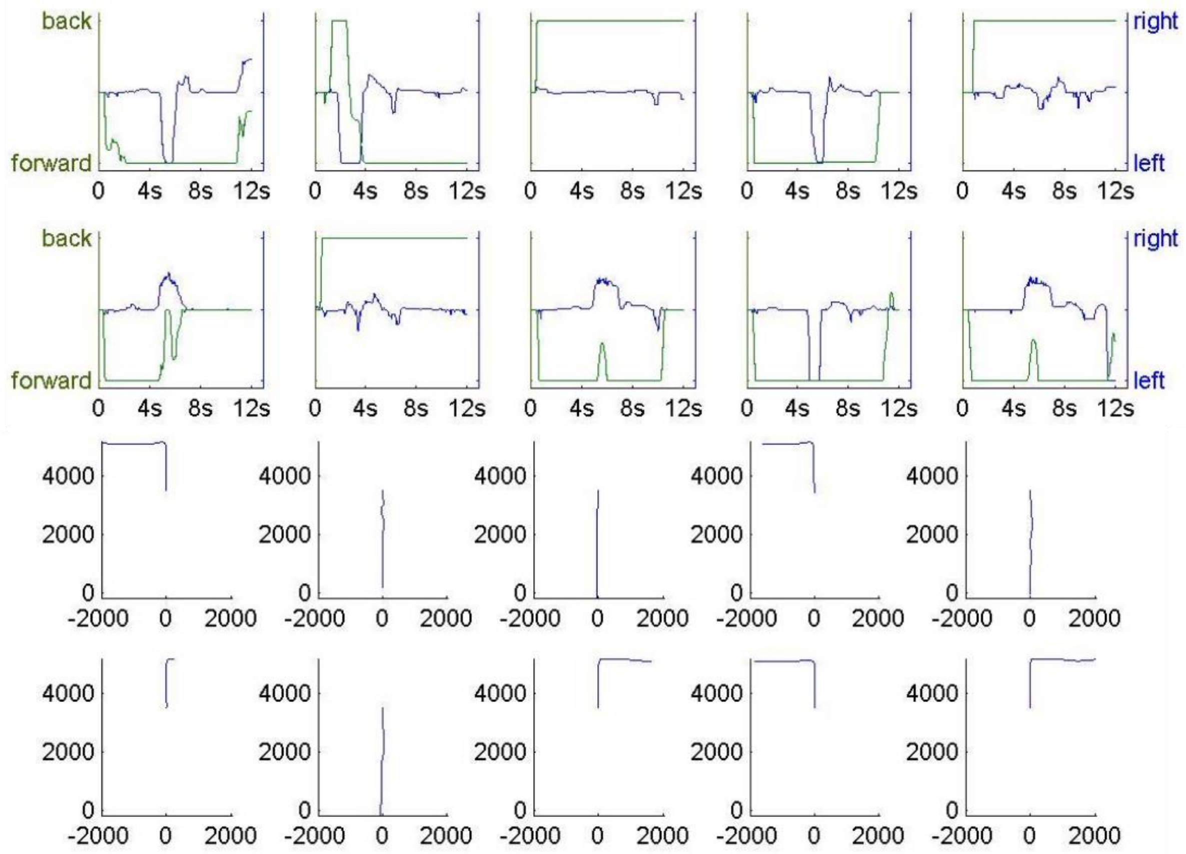

Figure 9: Example of the movement trajectories in the virtual T-maze for 10 trials. On the upper part, the joystick movements are displayed for the first 12 seconds of the trials, on the lower part the corresponding movements in the virtual environment (coordinates) are shown.

Four behavioral categories were chosen: “Fleeing from the stimulus”, “approaching safety from the stimulus”, “reaching out for the stimulus” and “doing nothing”. Other behavior (e.g.

experiencing conflict) had to be excluded, because there were too few trials (0.2 %) to analyze the behavior. "Fleeing from the stimulus" was chosen if the participant went away backwards immediately after triggering the event, without turning and therefore facing the stimulus and/or the wall that cued the event (see Figure 10). "Approaching safety from the stimulus" was chosen, if the participant turned around and went away from the stimulus and/or the wall that cued the event facing the area of safety, where the monster could not reach the participant (see Figure 10). "Reaching out for the stimulus" was chosen, if the participants went toward the stimulus and/or the wall that cued the event, also facing in that direction (see Figure 10). "Doing nothing" was chosen, if the participant did not move at all after triggering the event. This particular behavior was mostly present in control trials and displayed only in few cases of the total behavior (6.5 %). A detailed count of behavior in the different events can be seen in Table 2.

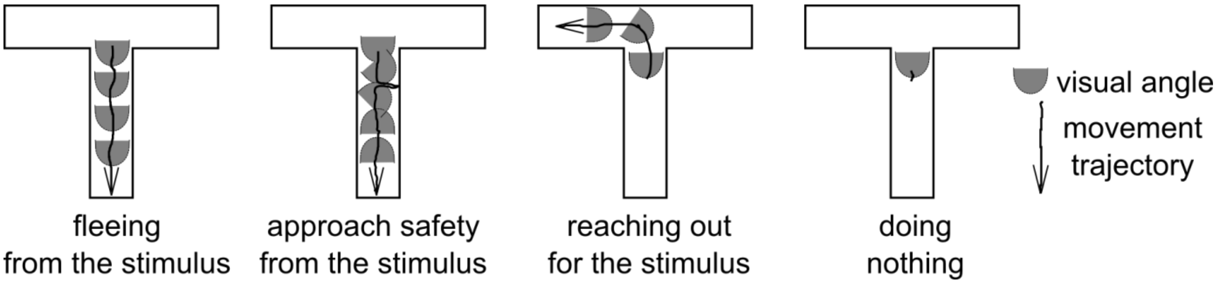

Figure 10: Behavioral categories in the virtual T-maze.

Table 2: Count of shown behavior in the different conditions of the VR paradigm of study I.

	negative events	positive events	approach-approach conflicts	approach-avoidance conflicts	control conflicts	control events
fleeing from the stimulus	239	0	0	102	26	15
approaching safety from the stimulus	347	2	1	127	44	47
reaching out for the stimulus	9	596	598	362	382	384
doing nothing	4	2	1	7	147	151
experiencing conflict	7	0	0	14	7	21

The virtual environment and experimental control was generated by a Source SDK (Valve, Bellevue, Washington, USA) based modification (VrSessionMod 0.5). For data acquisition of the participants' movements and joystick inputs, the VR experimentation software CyberSession CS-Research 5.6 (VTplus, Würzburg, Germany; see also www.cybersession.info for detailed information) was used.

3.1.7 Ratings.

The 23 first participants were provided with 23 questions about the conditions, assessing the concepts of negative emotions, positive emotions, arousal and immersion. Also, the concept of panic as a reaction of the (revised) FFFS was measured and compared to the experience of an uncertainty what to do, in order to provide a distinction between an activation of the (revised) FFFS vs. an activation of the (revised) BIS according to the idea of Wacker and colleagues (Wacker et al., 2008). Hence, a slightly modified form of the question used by Wacker and colleagues (2008) was used in this study. The questions can be seen in Figure 19, Figure 20, Figure 21 and Figure 22. The remaining seven participants were provided with a shortened version of the questions, but only the data of the full questions are provided here.

3.1.8 Trait measurement.

Several traits were assessed with online questionnaires on the SoSci Survey portal (Leiner, 2014). For positive and negative affect, the German version of the positive and negative affect schedule (PANAS Scales, Krohne, Egloff, Kohlmann, & Tausch, 1996; Watson, Clark, & Tellegen, 1988) was used. To assess the Trait anxiety, the German version of the State – Trait anxiety inventory (STAI , Laux, Glanzmann, Schaffner, & Spielberger, 1981) was used. For behavioral activation and behavioral inhibition tendencies, the German version of the BIS-BAS scales (Carver & White, 1994) were used for the whole dimension of the constructs, as well as the ARES scales (Hartig & Moosbrugger, 2003) with the subscales anxiety/nervousness (BIS I), sadness/frustration (BIS II), drive (BAS I) and joy (BAS II) for a better view on the sub-dimensions of behavioral activation and behavioral inhibition.

3.1.9 Statistics.

3.1.9.1 Frontal activation.

The frontal asymmetry was analyzed in two ways. First with the more classical approach, it was entered as the resulting variable of a 9*6*2 repeated measures ANOVA with the within factors electrode position (Fp2/1, F12/11, F10/9, F8/7, F4/3, AF8/7, AF4/3, C4/3, P4/3), condition (negative, positive, control, approach-approach conflict, approach- avoidance conflict, conflict control) and hemisphere (left/right). To further clarify the effects, Bonferroni – Holm adjusted post-hoc t-tests were computed.

Also, a single trial analysis was carried out with a multilevel generalized linear mixed model. At level 1 the predictor was frontal asymmetry on electrode position F4/3, at level 2 predictors were the traits measured in the online questionnaire. The criterion was the resulting behavior in the paradigm as a multicategorial variable with the 3 cases "fleeing from the stimulus", "approaching safety from the stimulus" and "reaching out for the stimulus". The reference category was "fleeing from the stimulus".

The model fit determined with corrected Akaike information criterion (AICC) was best for the model with frontal asymmetry on electrode position F4/3 as fixed level 1 predictor and the random effects frontal asymmetry on electrode position F4/3 (with intercept and uncorrelated covariance matrix type) and with the random effect of trials (without intercept and moving average auto regression covariance matrix type) and no level 2 predictors (see Table 3).

Table 3: Corrected Akaike Information Criterions (AICCs) for general linear mixed models.

Model	Frontal asymmetry	Bilateral activation for behavior	left frontal activation for behavior
Baselinemodel	21946.96	15559.96	15559.96
Model with level 1 predictor	21874.94	15489.07	15543.83
Model with level 1 and level 2 predictor	22019.87	15670.38	15698.60

To test the hypothesis of the bilateral activation for active behavior, a generalized linear model with the predictors bilateral frontal alpha activity, trait behavioral inhibition and the binomial criterion "behavior or doing nothing" was computed for the single trials. The reference category was "doing nothing”. Additionally, a single trial analysis was carried out with a multilevel generalized linear mixed model. At level 1 the predictor was bilateral frontal alpha activity on electrode position F4/3, at level 2 the predictor was trait behavioral inhibition. The criterion was the resulting behavior in the paradigm as a binomial variable with the two cases “behavior”, “doing nothing”. The reference category was “doing nothing”. AICC was best for the model with bilateral frontal alpha activity on electrode position F4/3 as fixed level 1 predictor and the random effects bilateral frontal alpha activity on electrode position F4/3 (with intercept and uncorrelated covariance matrix type) and with the random effect of trials (without intercept and moving average auto regression covariance matrix type) and no level 2 predictors (see Table 3).

In order to test the hypothesis that active behavior leads to left frontal brain activation, a generalized linear model with the predictors frontal alpha asymmetry on electrode position F4/3, trait behavioral inhibition and the binomial criterion “behavior or doing nothing” was computed for the single trials. The reference category was “doing nothing”. Additionally, a single trial analysis was carried out with a multilevel generalized linear mixed model. At level 1 the predictor was bilateral frontal alpha asymmetry on electrode position F4/3, at level 2 the predictor was trait behavioral inhibition. The criterion was the resulting behavior in the paradigm as a binomial variable with the two cases “behavior”, “doing nothing”. The reference category was “doing nothing”. AICC was best for the model with frontal alpha asymmetry on electrode position F4/3 as fixed level 1 predictor and the random effects frontal alpha asymmetry on electrode position F4/3 (with intercept and uncorrelated covariance matrix type) and with the random effect of trials (without intercept and moving average auto regression covariance matrix type) and no level 2 predictors (see Table 3).

3.1.9.2 Skin conductance.

For analysis of the skin conductance for every condition a repeated measure ANOVA was calculated with the within variable condition (negative, positive, control, approach-approach conflict, approach- avoidance conflict, conflict control), followed by a Bonferroni – Holm adjusted t-test comparison. For the ANOVA; Greenhouse-Geisser correction was applied with the correction factor c=.544.

3.1.9.3 Heart period.

For the analysis of the heart inter-beat intervals for every condition a 6*10 repeated measure ANOVA was calculated with the within variables condition (negative, positive, control, approach-approach conflict, approach- avoidance conflict, conflict control) and Heartbeats (1, 2, 3, 4, 5, 6, 7, 8, 9, 10), followed by a Bonferroni – Holm adjusted t-test comparison. Greenhouse-Geisser correction was applied with the correction factor c=.519 for the factor condition, c=.368 for the factor Heartbeat and c=.198 for their interaction.

3.1.9.4 Behavior and traits.

For analysis of the correlation between behavior and traits, median splits of the resulting behavior “fleeing the stimulus” and “approaching safety from the stimulus” were made in the negative condition for the traits, followed by a simple t-test comparison. These median splits were made due to the two clustered distribution of the resulting behavior that made a continuous analysis not fitting for the data. For the approach - avoidance conflict, a correlation was computed between the count of the resulting behavior “reaching out for the stimulus” and the traits. Also correlations of the traits and the count of the behavior “doing nothing” were computed for all conditions in total.

3.1.9.5 Ratings.

For the analysis of the ratings for every condition a 10*4 repeated measure ANOVA was calculated with the within variables condition (negative, negative not finished, positive, positive not finished, control positive, control negative, control approach-approach conflict, control approach-avoidance conflict, approach- avoidance conflict, approach-approach conflict) and question compound (negative emotional, positive emotional, arousal, immersion). Also Bonferroni-Holm adjusted post-hoc t-tests were used to further define the differences in the ratings. For the ANOVA; Greenhouse-Geisser correction was applied with the correction factor c=.432 for the factor condition, c=.688 for the factor question compound and c=.197 for their interaction.

All statistical analyses were carried out with IBM SPSS version 21.

3.2 Results study I

3.2.1 Behavior.

In the negative condition we found an influence of the trait positive affect, leading to more “approaching safety from the stimulus” behavior than “fleeing the stimulus” behavior [$t(28)=-2.58$, $p<.05$, $d=-.95$] (see Figure 11). Also, we found an influence of trait anxiety [$t(28)=2.16$, $p<.05$, $d=.80$] and frustration/sadness [$t(28)=2.39$, $p<.05$, $d=.88$], a sub-dimension of behavioral inhibition. Both traits were leading to less “approaching safety from the stimulus” behavior than “fleeing the stimulus” behavior (see Figure 11 left panels).

For the approach – avoidance conflict, we found a negative correlation between trait anxiety/nervousness, a sub-dimension of behavioral inhibition and “reaching out for the stimulus” behavior [$r=-.418$, $p<.05$] (see Figure 11 middle right panel).

“Doing nothing” behavioral category correlated significantly with trait behavioral inhibition [$r=.425$, $p<.05$] (see Figure 11 right panel).

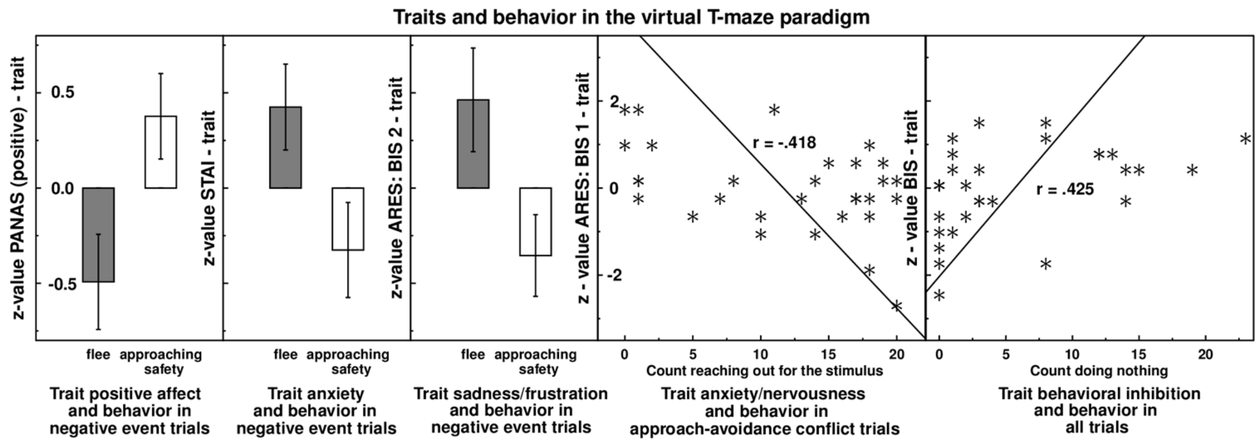

Figure 11: Traits and behavior in negative trials, approach - avoidance conflict trials and in all trials for doing nothing behavioral category. Error-bars represent mean SE of the differences between the conditions.

3.2.2 Frontal asymmetry for different kinds of behavior and conditions.

The generalized linear mixed model with the fixed effect frontal asymmetry on the electrode position F4/3 and the random effects frontal asymmetry on the electrode position F4/3 and trials revealed a significant main effect of frontal asymmetry [$F(2,21)=6.063$, $p<.01$, *semi-partial* $R^2=.37$] for the resulting behavior. The beta weight for “reaching out for the stimulus” showed a significant difference to the reference category [$b=9.2$, $SE=2.74$, $t=3.36$, $p<.01$], indicating a higher likelihood to show the behavior of reaching out to the stimulus if a higher frontal asymmetry is shown (see Figure 12 left panel). The beta weight for "approaching safety from the stimulus" was not significant [*b*=-.3, *SE*=4.15 *t*=.071 *p*>.9].

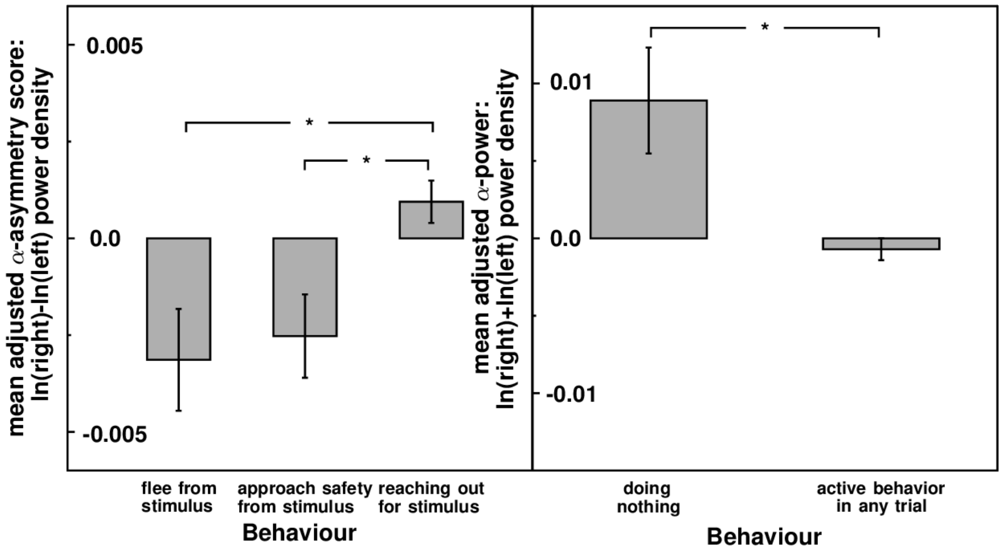

Figure 12: Frontal alpha activity in the single trial analysis: Frontal asymmetry shown at the initialization of the resulting behavior in each trial and frontal alpha activation before initiation of any behavior vs. no behavior at all. Error-bars represent mean SE of the differences between the conditions. *=p<.05

Topographical activation patterns for 10 Hz in the chosen time period from 0 to 4 seconds after the cuing for each behavioral category can be seen in Figure 13. Frequency plots from 3 to 28 Hz for each behavioral category on electrode positions F4 and F3 can be seen in Figure 14.

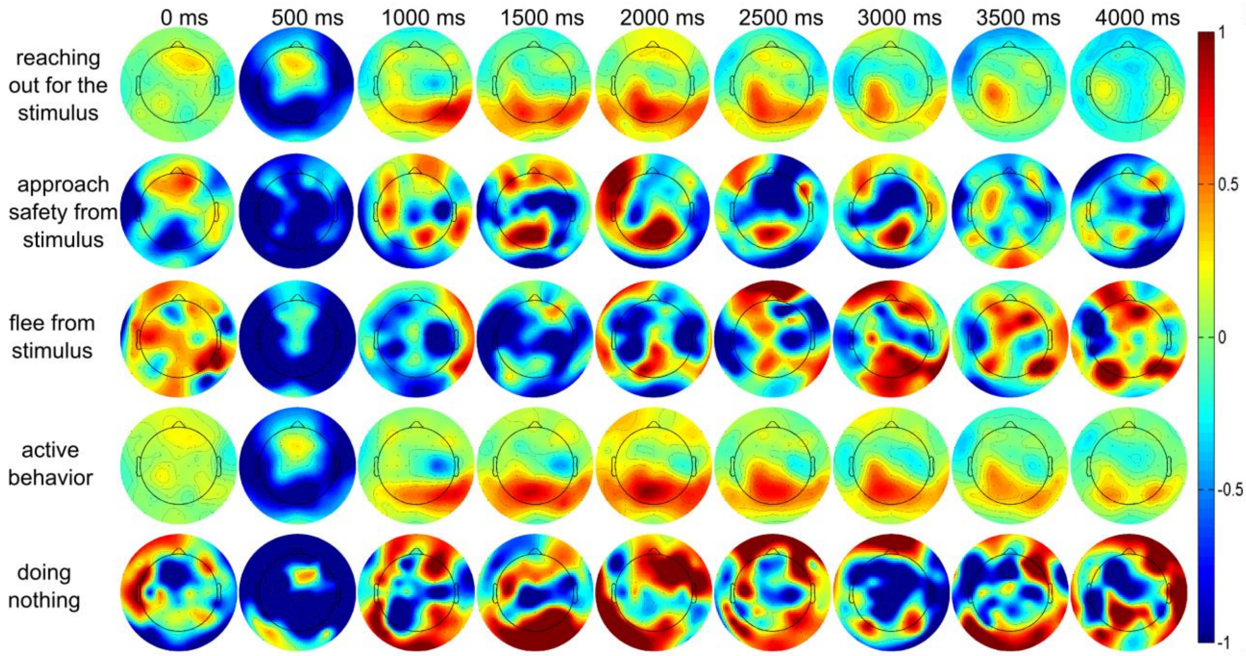

Figure 13: Topographical activation for each behavior in 500 ms steps in the time interval from 0 to 4 seconds after the cueing of the events for 10 Hz.

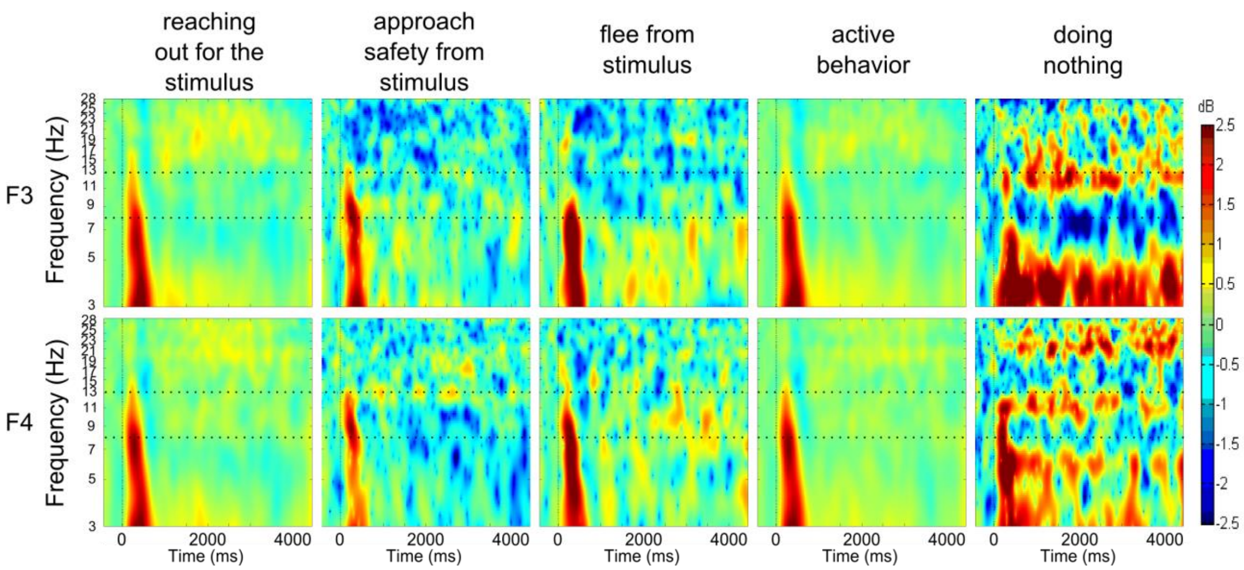

Figure 14: Time-frequency plots of the spectral activation in the time interval from 0 to 4 seconds after the cueing for every behavior from 3 Hz to 28 Hz on the electrode positions F3 and F4. The dotted lines mark the alpha band section from 8 Hz to 13 Hz.

For the repeated measure ANOVA with the within factors electrode position, condition and hemisphere, we found the three way interaction electrode position*condition*hemisphere was significant [$F(40,1080)=1.873$, $p < .05$, $\eta^2 = .07$] (see Figure 15). Post-hoc t-tests revealed more right sided brain activation (more alpha activity on the left side) in the negative event condition compared to all other conditions for the electrode positions F10/9, F8/7, F4/3, AF4/3, and C4/3. Additionally, the control conflict condition showed more left sided brain activation than any other condition on the electrode positions F8/7 and AF4/3. On electrode position C4/3 there was also more left sided brain activation for the approach-approach conflict situation than for every other condition.

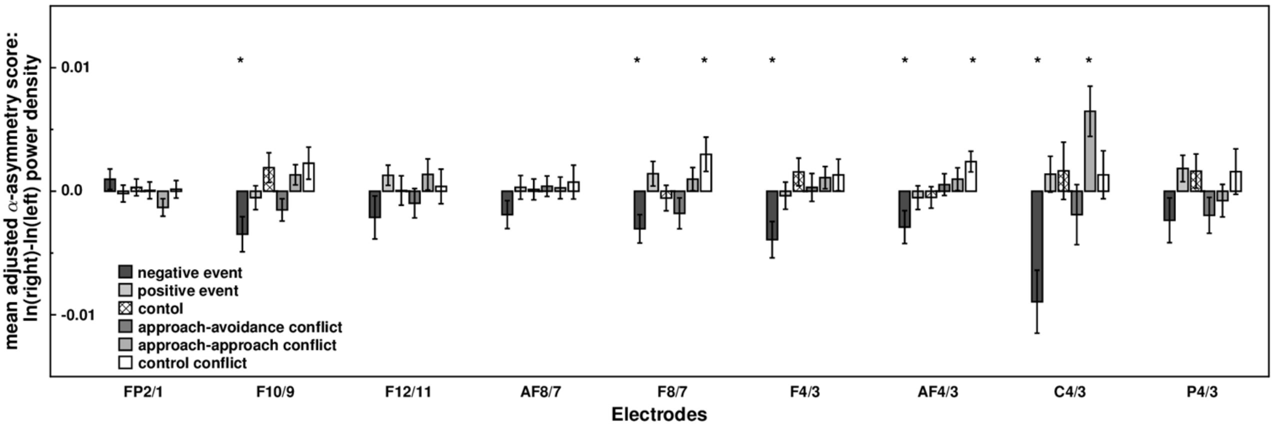

Figure 15: Three way interaction of hemisphere, condition and electrode position. Frontal asymmetry index shows more right sided activation (more left sided alpha activation) if the score is negative. * = significant difference to all other conditions on this electrode position with p<.05.

The two way interaction electrode position*hemisphere [*F*(8,216)=5.904, $p< .01$, η^2=.18] with a general shift in asymmetrical activation to left sided brain activity for the electrodes F4/3, C4/3, P4/3 and more right sided brain activity for the electrodes F10/9, F8/7, and AF8/7 was also significant. Also the condition*hemisphere [*F*(5,135)=5.282, $p< .01$, η^2=.16] was significant. Fitting with the three way interaction, post-hoc t-test revealed more right sided brain activation for the negative event condition than for any other condition. The significant two way interaction electrode position*condition [*F*(40,1080)=8.328, $p< .01$, η^2=.21] revealed that the most pronounced difference of bilateral alpha activation in the conditions was not at frontal electrodes, but at the electrode positions C4/3 and P4/3. The significant main effect of condition [*F*(5,135)=3.453, $p< .05$, η^2=.11] showed different bilateral alpha activation patterns for the different conditions, with the approach- avoidance conflict and the negative event conditions having the most alpha activity and therefore being the most activating conditions and positive and the both control conditions having the most alpha activity and therefore being the least activating conditions. The significant main effect of the electrodes [*F*(8,216)=8.852, $p< .01$, η^2=.23] showed a difference of bilateral alpha activity on each electrode position per se, with more alpha activation in frontal regions than on electrode position C4/3, possibly indicating the motor activity component of the experimental task. All significant effects of the ANOVA can also be seen in Table 4.

Table 4: Significant effects in the ANOVA for the conditions in the VR paradigm in study I.

significant effects	df1	df2	F value	p value	partial η²
electrode position	*8*	*216*	*7.852*	*<.01*	*0.23*
condition	*5*	*135*	*3.453*	*<.05*	*0.11*
*electrode position*condition*	*40*	*1080*	*7.328*	*<.01*	*0.21*
*condition*hemisphere*	*5*	*135*	*5.282*	*<.01*	*0.16*
*position*hemisphere*	*8*	*216*	*5.904*	*<.01*	*0.18*
*electrode position*condition*hemisphere*	*40*	*1080*	*1.873*	*<.05*	*0.07*

Topographical activation patterns for 10 Hz in the chosen time period from 0 to 4 seconds after the cuing for each condition can be seen in Figure 16. Frequency plots from 3 to 28 Hz for each condition on electrode positions F4 and F3 can be seen in Figure 17.

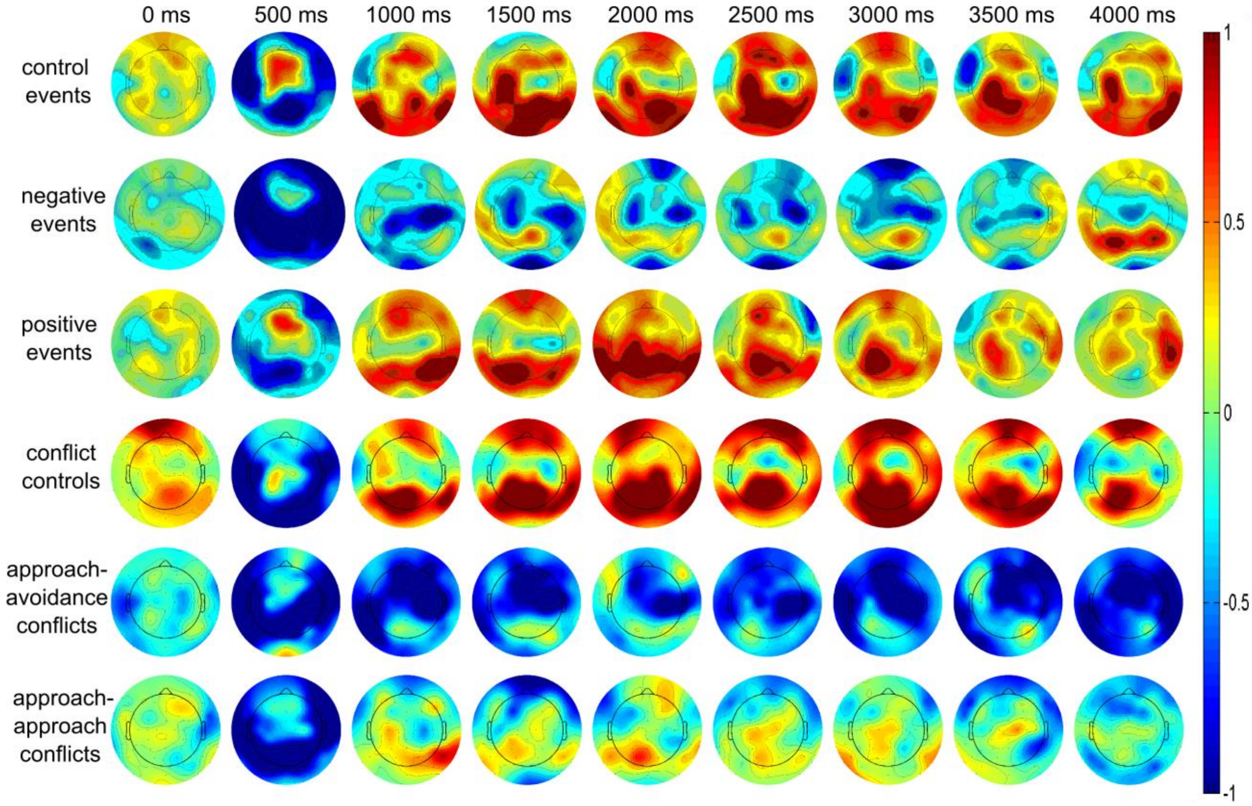

Figure 16: Topographical activation for each condition in 500 ms steps in the time interval from 0 to 4 seconds after the cueing of the events for 10 Hz.

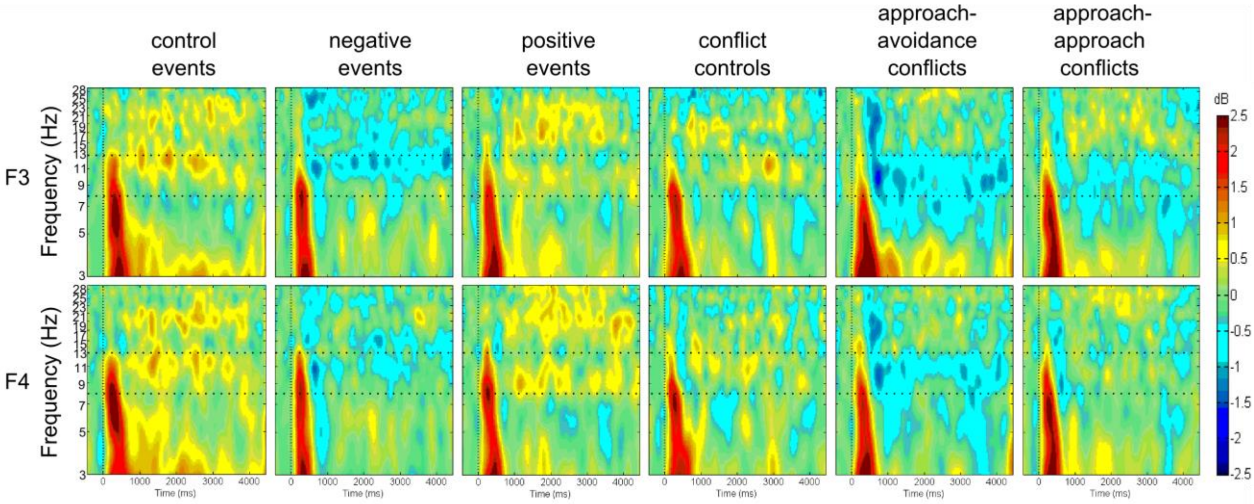

Figure 17: Time-frequency plots of the spectral activation in the time interval from 0 to 4 seconds after the cueing for every condition from 3 Hz to 28 Hz on the electrode positions F3 and F4. The dotted lines mark the alpha band section from 8 Hz to 13 Hz.

3.2.3 Bilateral frontal activation for active behavior.

The generalized linear model with the predictors bilateral frontal alpha activity, trait behavioral inhibition and the binomial criterion “behavior or doing nothing” led to a significant effect for both predictors trait behavioral inhibition [b=-1.66, SD=.24, $Wald\ X^2$=49.63, p<.01] (see also

Figure 11 right panel) and bilateral frontal alpha activity [*b*=-7.28, *SD*=2.31, *Wald* X^2=9.93, *p*<.01] (see Figure 12 right panel), with both predictors leading to a higher chance to show no behavior at all.

However, the generalized linear mixed model with the fixed level 1 predictor bilateral frontal alpha activity and the random effects bilateral frontal alpha activity on electrode position F4/3 as well as the random effect of trials did not show a significant fixed effect for the bilateral frontal activation [*F*(1,14)=.37, *p*=.56] for the classification of the behavior.

3.2.4 Frontal asymmetry for active behavior.

The generalized linear model with the predictors frontal asymmetry on electrode position F4/3, trait behavioral inhibition and the binomial criterion "behavior or doing nothing" led to a significant effect for trait behavioral inhibition [*b*=-1.66, *SD*=.24, *Wald* X^2=49.63, *p*<.01] leading to a higher chance to show no behavior at all (see also Figure 11 right panel). But the predictor frontal asymmetry was not significant [*b*=-2.78, *SD*=3.73, *Wald* X^2=.56, *p*=.46]. For the generalized linear mixed model, the fixed effect of frontal asymmetry was also not significant [*F*(1,2606)=.625, *p*=.429].

3.2.5 Ratings.

The repeated measure ANOVA for the ratings led to a significant effect for the conditions [*F*(9,198)=13.946, *p*<.01, *partial* η^2=.39, *c*=.432], the question compounds [*F*(4,66)=78.013, *p*<.01, *partial* η^2=.78, *c*=.668] and the interaction of the conditions and question compounds [*F*(27,594)=10.644, *p*<.01, *partial* η^2=.326, *c*=.197].

The post hoc t-test for the main effect of the question compounds revealed that highest ratings were obtained for positive emotions (*m*=4.940, *SD*=1.178) [*t*s(22)>2.469, *p*s<.022], followed by the arousal ratings (*m*=4.218, *SD*=.946) [*t*s(22)>11.210, *p*s<.001], immersion (*m*=2.240, *SD*=.440) and negative emotions (*m*=1.973, *SD*=.653) with the lowest ratings [*t*s(22)>9.980, *p*s<.001].

The post hoc t-test for the main effect of the conditions revealed that the ratings were higher for all events (negative events *m*=3.759, *SD*=.526, negative events not finished: *m*=3.632, *SD*=.679, positive events: *m*=3.665, *SD*=.550, positive events not finished: *m*=3.317, *SD*=.643) and conflicts (approach-avoidance conflicts: *m*=3.638, *SD*=.854, approach-approach conflicts: *m*=3.671, *SD*=.636) than for the control conditions (control approach-avoidance conflicts: *m*=2.889, *SD*=.706, control positive events: *m*=2.938, *SD*=.739, control approach-approach conflicts: *m*=2.943, *SD*=.662 control negative events: *m*=2.965, *SD*=.706) [*t*s(22)>2.209, *p*s<.038].

The post hoc t-tests for the interaction of the conditions and the question compounds revealed that for the negative emotions, the negative events (*m*=3.130, *SD*=1.590), the approach-avoidance conflicts (*m*=3.099, *SD*=1.942) and the not finished negative events (*m*=2.814, *SD*=1.436) were highest in the ratings [*t*s(22)>3.828, *p*s<.001]. The positive events (*m*=1.286, *SD*=.474) were lowest in the negative emotion ratings [*t*s(22)>2.307, *p*s<.038] The other conditions had an intermediate rating for negative emotions (positive events not finished: *m*=1.509, *SD*=.406, control positive events: *m*=1.497, *SD*=.520, control negative events: *m*=1.615, *SD*=.687, approach-approach conflicts: *m*=1.540, *SD*=.677, control approach-approach conflicts: *m*=1.634, *SD*=.819, control approach-avoidance conflicts: *m*=1.603, *SD*=.818) (see Figure 18).

For the positive emotions ratings, the positive events (*m*=6.652, *SD*=1.473) and the approach-approach conflicts (*m*=6.217, *SD*=1.708) were highest [*t*s(22)>2.463, *p*s<.022]. All other conditions did not differ significantly from each other (negative events: *m*=4.989, *SD*=1.609, negative events not finished: *m*=4.848, *SD*=1.465, positive events not finished: *m*=5.109, *SD*=1.810, control positive events: *m*=4.435, *SD*=1.993, control negative events: *m*=4.250, *SD*=1.697, approach-avoidance conflicts: *m*=4.467, *SD*=1.525, control approach-approach conflicts *m*=4.337, *SD*=1.841, control approach-avoidance conflicts: *m*=4.054, *SD*=1.724) (see Figure 18).

For the arousal ratings, there were higher ratings for all events (negative events not finished: *m*=4.765 *SD*=1.387, negative events: *m*=4.748, *SD*=1.335, positive events: *m*=4.530, *SD*=1.081, positive events not finished: *m*=4.496, *SD*=1.060) and conflict conditions (approach-approach conflicts: *m*=4.539 *SD*=1.406, approach-avoidance conflicts: *m*=4.844, *SD*=1.422) compared to the control conditions (control approach-approach conflicts: *m*=3.417 *SD*=.815, control positive events: *m*=3.496, *SD*=1.053, control approach-avoidance conflicts: *m*=3.609, *SD*=1.205, control negative events: *m*=3.739, *SD*=1.309) [*t*s(22)>2.872, *p*s<.01] (see Figure 18).

For the immersion ratings, a general differences in the ratings could not be detected as in the other rating scales, but the approach-approach conflict (*m*=2.385, *SD*=.629) and its control condition (*m*=2.385, *SD*=.634) were more immersive than the not finished negative events (*m*=2.099, *SD*=.463), the not finished positive events (*m*=2.385, *SD*=.629) and the approach-avoidance conflicts (*m*=2.143, *SD*=.515) [*ts*(22)>2.150, *ps*<.05]. All other conditions did not differ significantly (negative events: *m*=2.168, *SD*=.436, positive events: *m*=2.193, *SD*=.576, control negative events: *m*=2.255, *SD*=.617, control approach-avoidance conflicts: *m*=2.292, *SD*=.628, control positive events: *m*=2.323, *SD*=.581) (see Figure 18).

In Figure 19, Figure 20, Figure 21 and Figure 22, every question of the compounds is shown separately in order to provide a more detailed view on the four categories. Also, in Figure 19, one can see that the negative event is neither significantly different from the approach-avoidance conflict for the uncertainty what to do [*t*(22)=1.023, *p*=.318] nor for the panic reaction to the stimulus [*t*(22)=1.42, *p*=.170].

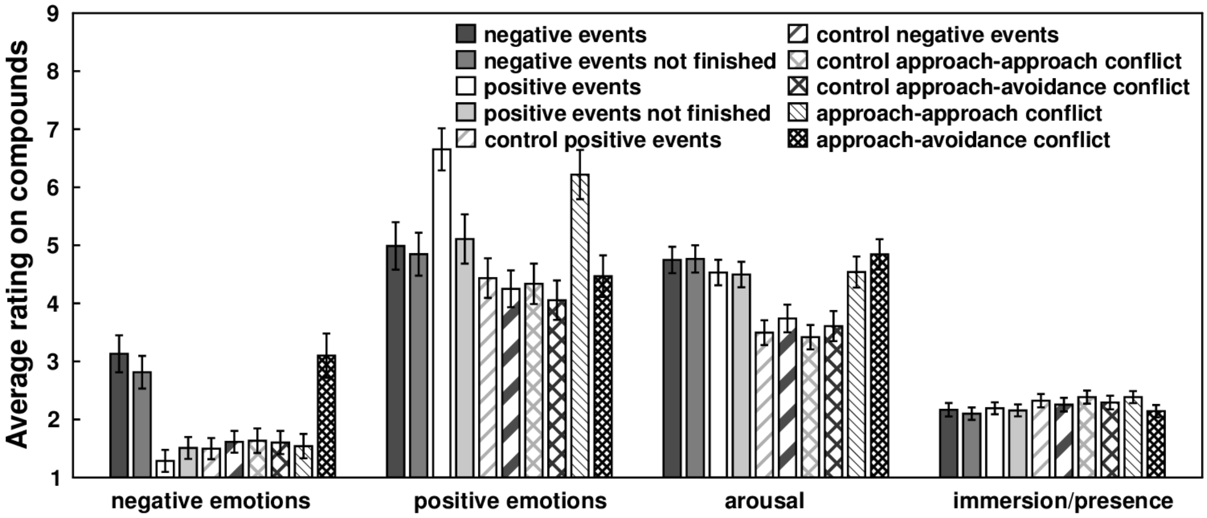

Figure 18: Ratings for the compounds negative emotions, positive emotions, arousal and immersion/presence for the participants. Error-bars represent mean SE of the differences between the conditions.

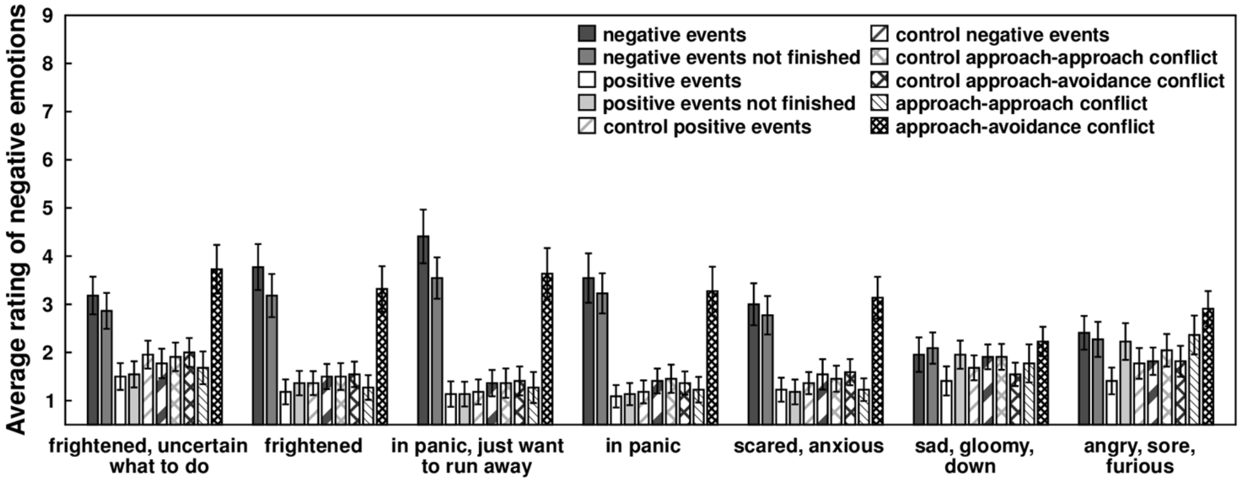

Figure 19: Ratings for every question of the compound negative emotions. Error-bars represent mean SE of the differences between the conditions.

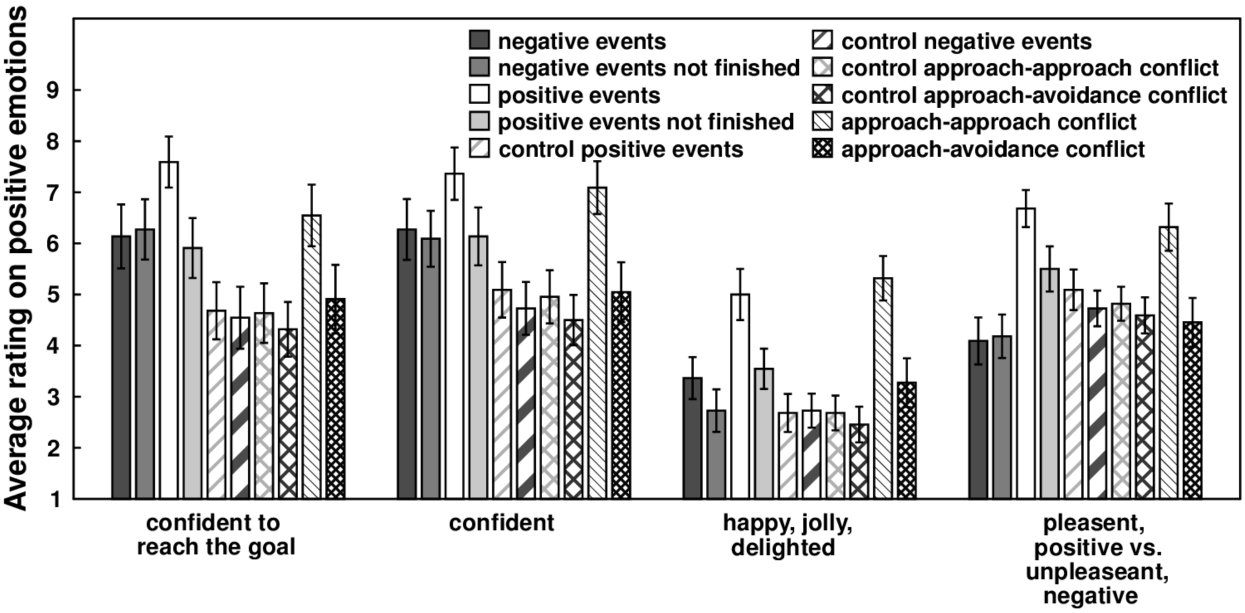

Figure 20: Ratings for every question of the compound positive emotions. Error-bars represent mean SE of the differences between the conditions.

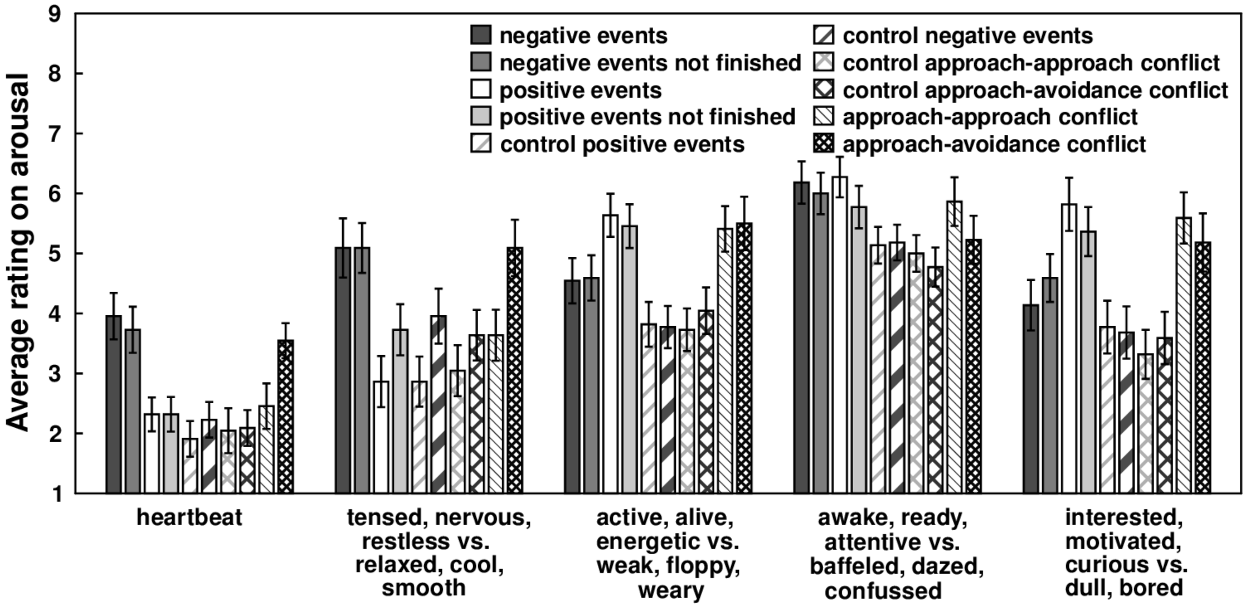

Figure 21: Ratings for every question of the compound arousal. Error-bars represent mean SE of the differences between the conditions.

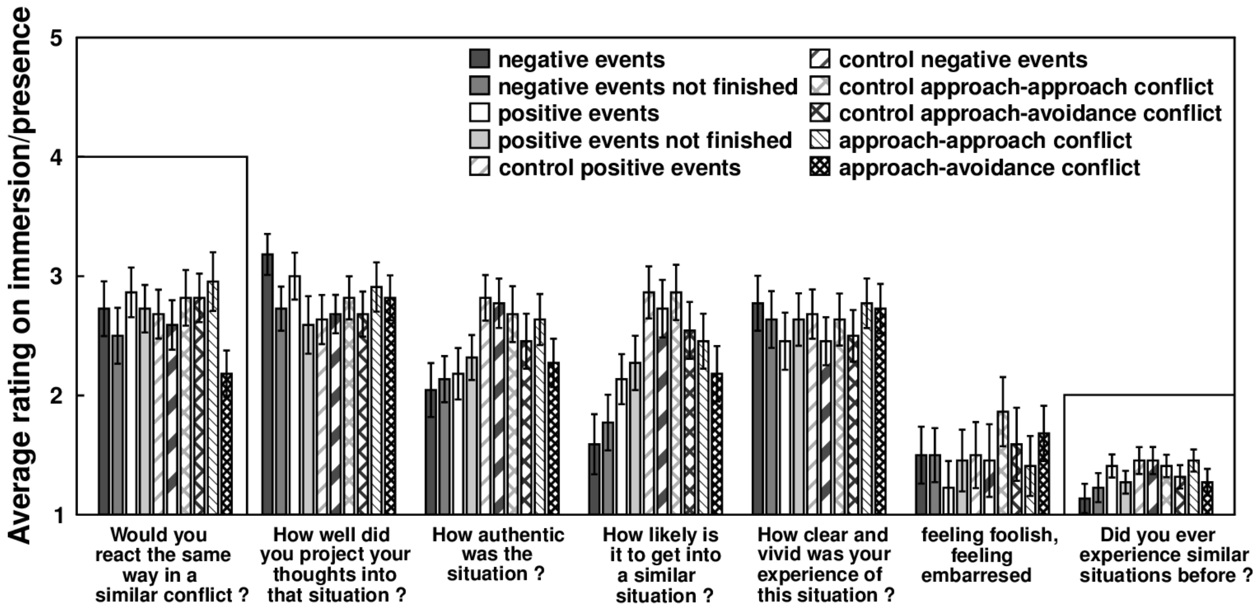

Figure 22: Ratings for every question of the compound immersion/presence. Error-bars represent mean SE of the differences between the conditions.

3.2.6 Skin conductance.

The repeated measure ANOVA for the skin conductance lead to a significant effect for the conditions [$F(5,145)=3.197$, $p<.05$, *partial* $\eta^2=.10$, $c=.544$]. The post hoc t-test revealed that the negative condition ($m=4.657$ µS/sec, $SD=7.430$ µS/sec) showed higher skin conductance than all other conditions [$ts(29)>2.225$, $ps<.04$] except for the approach-approach conflict ($m=2.848$ µS/sec, $SD=4.121$ µS/sec), were this effect is only marginally significant [$t(29)=1.986$, $p=.057$]. Also, the approach – approach conflicts showed significant higher skin conductance [$t(29)=-2.153$, $p<.05$] than the simple control conditions (*m*=1.097 µS/sec, *SD*=4.170 µS/sec) if not corrected for multiple comparison. All other conditions had intermediate skin conductance responses and were not significantly different from each other (positive events: *m*=2.422 µS/sec, *SD*=4.445 µS/sec, approach-avoidance conflicts: *m*=1.621 µS/sec, *SD*=8.515 µS/sec, conflict controls: *m*=1.171 µS/sec, *SD*=3.926 µS/sec). The skin conductance for all conditions can be seen in Figure 23.

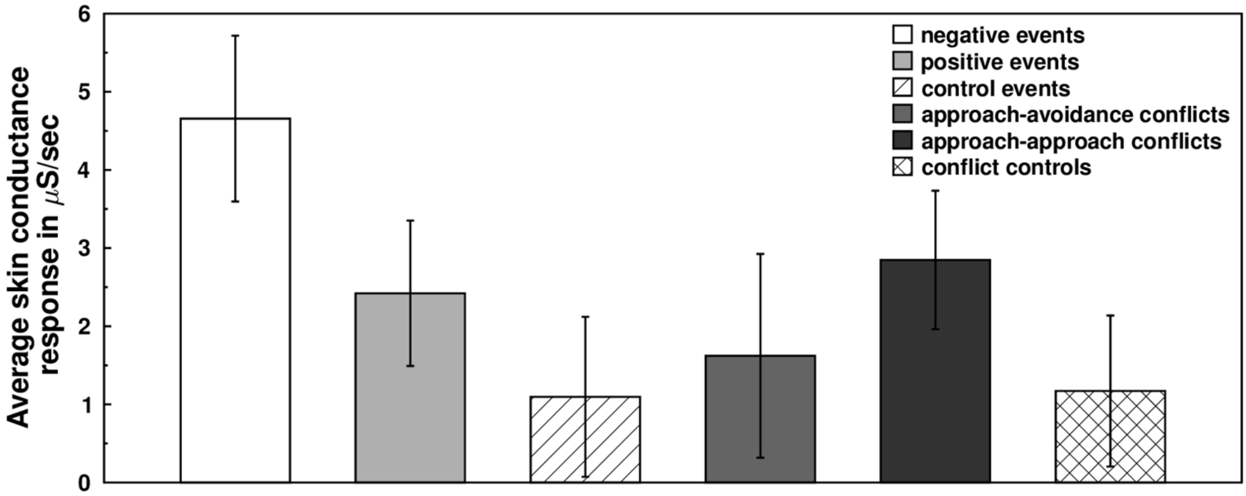

Figure 23: Skin conductance for every condition. Errorbars represent mean SE of the differences between the conditions.

3.2.7 Heart period.

The repeated measure ANOVA for the heart inter-beat intervals lead to a significant effect for the Heartbeats [$F(9,261)=14.20$, $p<.001$, *partial* $\eta^2=.33$] and the interaction of the conditions and Heartbeats [$F(45,1305)=2.76$, $p<.001$, *partial* $\eta^2=.09$].

The post hoc t-test for the Heartbeats revealed that the lowest inter-beat intervals are at the third heartbeat [*t*s(29)>2.191, *p*s<.04], followed by the second and fourth heartbeat [*t*s(29)>2.816, *p*s<.01] compared to the other heartbeats. For the interaction of the heartbeats and the conditions there were differences between the negative events and the approach – avoidance conflicts on the second and third heartbeat [*t*s(29)>2.729, *p*s<.011] with the approach - approach conflict having larger Inter-beat intervals (see Figure 24). On the fourth heartbeat, the inter-beat intervals of the approach - approach conflicts were also larger than the conflict controls and the negative events as well [*t*s(29)>2.508, *p*s<.018] (see Figure 24). On the fifth heartbeat, the approach-approach conflicts had higher inter-beat intervals than all other conditions [*t*s(29)>2.16, *p*s<.04] (see Figure 24). For the sixth heartbeat, that pattern preserves with the exception of control events and the positive events [*t*s(29)>2.100, *p*s<.045]. Also the negative events had shorter inter-beat intervals than the positive events [*t*(29)=2.066, *p*<.05], if not corrected for multiple comparison (see Figure 24). On the seventh heartbeat, the difference between the negative events and the approach – avoidance conflict stays significant [*t*(29)=2.514, *p*<.05], again if not corrected for multiple comparison, with the negative events having smaller inter-beat intervals than the approach –avoidance conflicts (see Figure 24). On the tenth heartbeat, the negative events had significant larger inter-beat intervals than all other conditions [*t*s(29)>2.246, *p*s<.032] with the exception of the marginal difference to the approach – approach conflicts, showing the same direction [*t*(29)=2.026, *p*=.052]. Additionally there was a difference between the positive events and the approach –approach conflicts, leading to higher inter-beat intervals for the approach –approach conflict trials (see Figure 24).

Detailed values for every heartbeat and condition can be seen in Figure 24 and Table 5.

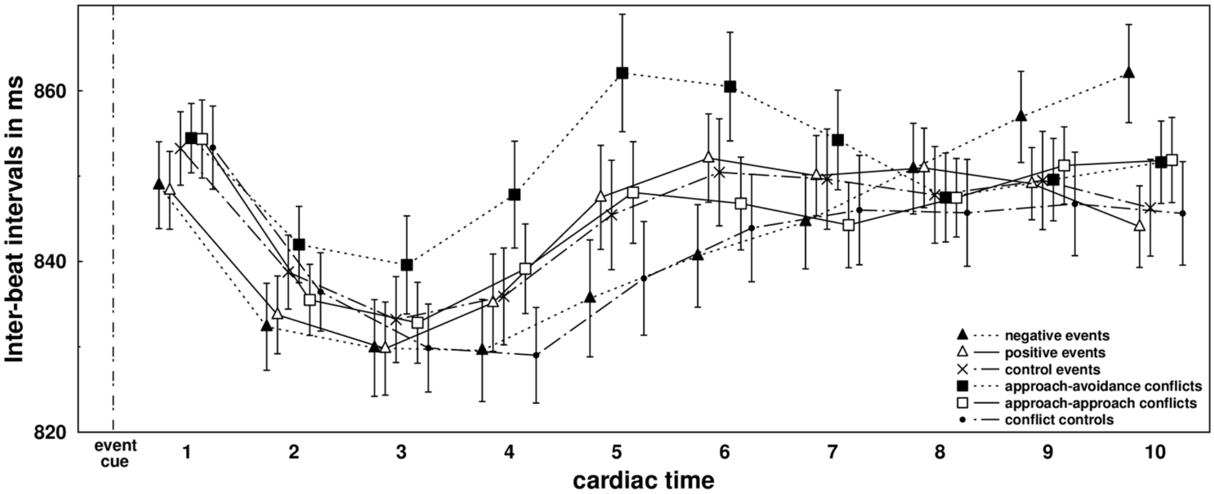

Figure 24: Heart period in ms for every event. Error-bars represent mean SE of the differences between the conditions.

Table 5: Heart period: Inter-beat intervals for the different events in ms.

Heartbeat	Mean	SD	negative events	SD	positive events	SD	control events	SD	approach-avoidance conflicts	SD	approach-approach conflicts	SD	conflict controls	SD
Heartbeat 1	852	99	849	94	848	99	853	102	854	99	854	103	853	104
Heartbeat 2	836	90	832	89	834	90	839	92	842	91	836	92	836	94
Heartbeat 3	833	91	830	91	830	95	833	91	840	96	833	92	830	95
Heartbeat 4	836	96	830	94	835	99	836	94	848	102	839	102	829	97
Heartbeat 5	846	98	836	95	848	99	845	97	862	105	848	103	838	102
Heartbeat 6	849	95	841	94	852	96	850	100	860	98	847	95	844	99
Heartbeat 7	848	93	845	96	850	93	850	98	854	93	844	94	846	94
Heartbeat 8	848	94	851	99	851	93	848	99	847	91	847	98	846	97
Heartbeat 9	851	98	857	101	849	98	849	101	850	99	851	99	847	98
Heartbeat 10	850	97	862	102	844	94	846	102	852	101	852	96	846	100

3.3 Discussion study I

In this study, frontal alpha activation was assessed during movement via joystick in a virtual T-maze in order to provide participants with the opportunity to show active behavior while an EEG is recorded and motivational states and emotions are induced.

3.3.1 Validation of the paradigm.

Subjective impressions of the conditions of the paradigm were compared, alongside with physiological measures of arousal and valence via heartrate and skin conductance. For the subjective ratings, all conditions but the conflict conditions fulfilled the goal they were designed for, as the positive condition was rated more positive than its´ negative or neutral counterpart (see Figure 18). Also the negative conditions did lead to more negative emotions than all other conditions but the approach-avoidance conflict provided in the paradigm (see Figure 18).

However, the experience of the conflict trials was not as clearly as intended, for the approach-avoidance conflict did only score high on negative emotions and not high on positive emotions. Additionally the approach-approach conflict did only score high on the positive emotions and low on negative emotions, indicating for both conflict trials that a conflict might not be perceived in the intensity that was intended or maybe even not perceived at all (see Figure 18). Also, the intended difference of experiencing the approach-avoidance conflict as a conflict in the ratings could not be supported, for there was no significant difference in the perception of uncertainty what to do, compared to the negative events, and also no difference in the intensity of panic reactions to the stimulus for these two conditions. If the conflict was experienced on a subjective level, one would expect more uncertainty what to do for the conflict condition being rooted in the orienting response initiated by the (revised) BIS (see Gray & McNaughton, 2000; Wacker et al., 2008), and a higher degree of panic reaction to the negative events being a result of a higher (revised) FFFS activation (see Gray & McNaughton, 2000; Wacker et al., 2008).

The arousal was rated higher for events containing the monster or the sheep entity, indicating that the arousal is higher if an actual change in credits is at stake (see Figure 18). Therefore the salience was successfully induced to the positive and negative trials as well as to the conflict trials.

The immersion/presence was a bit higher for the control conditions than for the events containing fictive stimuli like the monster or the sheep for that matter, indicating the more common associations with other humans walking around than being chased by monsters or finding oneself chasing a sheep for some reason (see Figure 18).

On the physiological level, the skin conductance was highest for the negative events confirming the arousal ratings of being highest when a monster entity is present and a loss of credits is about to be expected if one is not successful in avoiding the monster (see Figure 23). Therefore this arousal seems to be anxiety or fear of loss related, as it is not present for the approach-avoidance conflicts, where a monster entity is shown but also a sheep is present and a loss from the monster can be compensated by still getting the sheep.

For the change in the heart inter-beat intervals, the approach-avoidance conflicts show a lower initial decrease around the third fourth and fifth heartbeat (see Figure 24), indicting a reaction to negative valued stimuli already shown by Bradley (Bradley & Lang, 2007). This lowering of the beats per minute, corresponding to an increase of the inter-beat intervals in the time window of three seconds after onset, confirms the high negative emotional ratings already given of these conflict trials. Also for the increase of the heart inter-beat intervals for the negative condition on the tenths heartbeat, a defensive reaction as proposed by Sokolov (1963) and Turpin (1986) is present, showing the reaction to a stimulus with negative valence (see Figure 24). Thus the skin conductance confirms the subjective arousal ratings, as well as the heart period confirms the arousal and the valence ratings found in the paradigm. It hereby provides evidence that the paradigm was able to adequately induce positive and negative emotions as well as arousal.

Summing up the validation of the paradigm concerning the induction of emotions and motivation, it was able to successfully induced positive and negative emotions and motivation. This was confirmed by the subjective ratings of the different emotions and the arousal, concerning the different conditions. Also, the implicit measurements via peripheral physiology confirmed that picture. However, one exception was the approach-approach conflict condition that could not be validated by explicit or implicit measurements inducing any kind of conflict. Therefore this condition may not be fitting for further use in other variants of the virtual T-maze paradigm.

3.3.2 Frontal activation and behavior in the paradigm.

For the observed behavior in the maze, there was a difference of the frontal asymmetry at the beginning of the cueing period and movement initiation for different resulting behavioral patterns. Fitting with the argumentation of Davidson (1984; 1998a; 1998b) and Harmon-Jones & Allen (1998) , there was more left frontal brain activation (more relative right frontal alpha activity) for the behavioral pattern of “approaching the stimulus” than for the reference category “fleeing from the stimulus” (see Figure 12). This suggests that frontal asymmetry is influencing the resulting behavior even at the initiation of the behavior and therefore showing its motivational aspect for the following behavior. As there was no statistical difference in frontal asymmetry in the two different behavioral patterns of “fleeing from the stimulus” and “approaching safety from the stimulus”, the shown behavior seems to be in the same behavioral category concerning the frontal asymmetry.

If one takes into account the frontal asymmetry on the different events, one is to discover that the negative event, where most of these two behavioral categories were shown, displays the highest right frontal brain activation of all event conditions (see Figure 15).

As the traits of the participants did influence the shown behavior in this negative trial condition (see Figure 11), participants showed more right frontal brain activation in the motivational state of trying to avoid the negative event, while the traits of positive affect, anxiety and sadness/frustration explain the difference of the actual execution of the behavior. The participants with more trait positive affect preferred to avoid the negative event with some sort of goal related approach behavior toward the “safety zone” where the stimulus was not able to reach them, while the generally more anxious and sad or frustrated participants were more concerned with the certain avoidance of the negative consequences in this condition, being indicated by the simpler and quicker directly backward moving behavioral pattern.

Hence, the frontal asymmetry shows the general motivation to behavior, while the actual execution of the behavior does not simply depend on the frontal asymmetry but is also influenced by relevant traits of the participants. The nature of the relation of frontal asymmetry and the traits for the resulting behavior of the negative trial is different for each relevant trait. As suggested by Iacobucci (2012), mediator analysis was carried out for trait positive affect, trait anxiety and trait sadness/frustration for the predictor frontal asymmetry and the binomial criterion of the behavior during a negative trial with the categories “fleeing from the stimulus” and “approaching safety from the stimulus”. Trait sadness/frustration is a significant mediator of the frontal asymmetry on the shown behavior [$z_{Mediation}$=1.72, p<.05], while trait anxiety only happens to be a marginally significant mediator of the frontal asymmetry [$z_{Mediation}$=1.59, p=.06]. Trait positive affect shows no mediating influence at all [$z_{Mediation}$=0.76, p=.22] and therefore having a direct influence on the chosen behavior.

Remarkably, the relation of the frontal asymmetry and the relevant situation that is proposed by the capability model (Coan et al. 2006) could not be found in this study. All results for frontal asymmetry patterns were independent from the level 2 trait interactions in this VR – paradigm to induce a relevant situation for trait activation. As the influence of the traits on the frontal EEG activation patterns could not be seen in this paradigm per se, the intensity of the induction of the relevant situation might be that high, that the trait activation is no longer the driving force behind the frontal activation patterns, but the state that is induced by the very strong induction method. For that matter, the intensity of the relevant situation might act as a “constraint” (see trait activation theory, Tett & Burnett, 2003), dampening the influence of the trait on the frontal asymmetry pattern. This dampening effect is due to the overly strong motivational induction for every participant, independent of their capability of the relevant motivational direction.

Additionally, this study provides evidence for the theory of Hewig and colleagues (2004; 2005; 2006), assigning frontal asymmetry to the role of a biological substrate of motivational processes and another system, arguably the behavioral activation system being the biological substrate of actual behavior and bilaterally frontally distributed. In our study, we find a higher bilateral frontal alpha activation (less frontal brain activity) during trials where the participants did not show any behavior at all (see Figure 12, right panel). Also the behavioral category of “doing nothing” during a trial was correlated with the behavioral inhibition system (r=.425, see Figure 11). Given the behavioral activation system initiates behavior, the lower bilateral frontal alpha activation and therefore more frontal brain activity for any shown behavior may be an indicator of the behavioral activation system being distributed bilateral in frontal areas (Hewig et al., 2006).

Combined with the findings about frontal asymmetry in this study, the theory of Hewig and colleagues (2004; 2005; 2006) gets additional evidence in seeing the motivational aspects of behavior being partly displayed in frontal asymmetry, but if active behavior is shown, a bilateral frontal activation can be recognized as a measurable substrate of the behavioral activation system. Remarkably, the findings about the bilateral frontal activation did only show up in the fixed effect single trial model and not in the random effect model of the single trials. Here the few trials and their appearance limited to the control conditions have a great influence on the random effects. Thus it was not possible to get a converging model with a fitting random effect structure and therefore the random effect could not be modelled adequately.

The theory of Wacker and colleagues (2008; 2010; 2003), where left frontal brain activation stands for all active behavior and right frontal brain activation occurs while experiencing a conflict and behavioral inhibition as the conflict activates both behavioral systems, the (revised) BAS and the (revised) FFFS, could not be supported in this study, for there was no left frontal activation for the active behavior compared to the participants doing nothing. Hence, this lateralization that was proposed for active behavior could not be found. Of course, one major limitation of this finding is the lack of success to induce conflict behavior for the participants in the conflict conditions, in order to assess the theory of Wacker and colleagues about the frontal asymmetry being driven by conflict rather than by approach and avoidance behavior. Unfortunately, the conflict behavior could only be seen in very few trials of some participants at the beginning of the experiment in the approach – avoidance conflict condition on the behavioral level. Often the participants seem to have a default behavior that is influenced by traits like anxiety and nervousness in conflict situations (see Figure 11). Therefore participants often do not experience the behavioral inhibition caused by the conflict of the revised BAS and revised FFFS in this event category of the paradigm of the present study. Also, the approach-approach conflict condition was not perceived as a conflict at all (see Figure 18) and led to the same resulting behavior as just the positive event condition.

The possible solution to this problem, the combination of the paradigm used by Wacker and colleagues (2008) and the paradigm of the study I was done in study II in order to evoke conflict with the first paradigm and see the execution of behavior in the latter. Also a movie paradigm was added to provide another good established paradigm used to induce motivations and emotions, respectively also frontal asymmetry. Additionally, the virtual T-maze paradigm was modified in order to shorten it and to exclude the approach-approach conflict trials that have not been successfully inducing the motivational state of conflict, but have only been seen as a hyper-positive event. Hence study II was designed to confirm the findings of study I and to further clarify the findings already present concerning the three different theories about frontal asymmetry and frontal activation discussed above in order to provide a reasonable basis of evidence to decide over predictive value of the theories.

4 Study II

4.1 Methods study II

4.1.1 Participants.

56 right handed students (28 male, mean age=24.2, SD=3.3 range=18 – 30) participated in the study. The participants were paid 36 € or they received course credits for their participation. All students had normal or corrected to normal vision. Three participants (two males) had to be excluded from the study due to quitting the study before attending all three sessions of the study. One male participant had to be excluded from all physiological data due to technical problem during two recording sessions. But as the ratings of the participant were available, they were included in the analysis of the ratings. Another male participant had to be excluded from the analysis of the VR paradigm because of color blindness.

The final sample consisted of 53 participants for the ratings and 52 participants for the physiological data (except for the VR paradigm with 51 participants).

4.1.2 Paradigms.

4.1.2.1 VR paradigm.

The paradigm used in this study is similar to the paradigm used in study I. It is also a desktop virtual reality approach, where participants are able to navigate through a virtual T – maze via joystick and experience different events in this maze, partly linked to credits and cued by color bars at the walls of the T-maze. The duration of one trial is also 13 seconds.

One difference is the starting position of the participant. While in study I the participants had to move forward in order to trigger the events, here the participants start every trial on the trigger of the event, leading to an immediate start of the event when the trial starts. The remaining properties are similar to study I, with the exception of the types of trials. In this paradigm there are only five different types of trials compared to the six types of trials in study I: negative events, positive events, control events, approach - avoidance conflicts and conflict control events, dropping the approach - approach conflicts. All remaining events are identical to the events of study I. Each event is repeated 20 times (being a total trial count of 100), in order to get sufficient trials without artifacts in EEG. During each trial, participants are able to behave in any manner they want, allowing to measure behavior and EEG simultaneously to the different events and link the behavioral responses to the EEG signal. At the end of each trial, the participants experience a white fog, beaming them to the starting position once more. Schematic display of the trials and examples for the cueing as well as the entities used in the trials can be seen in Figure 25.

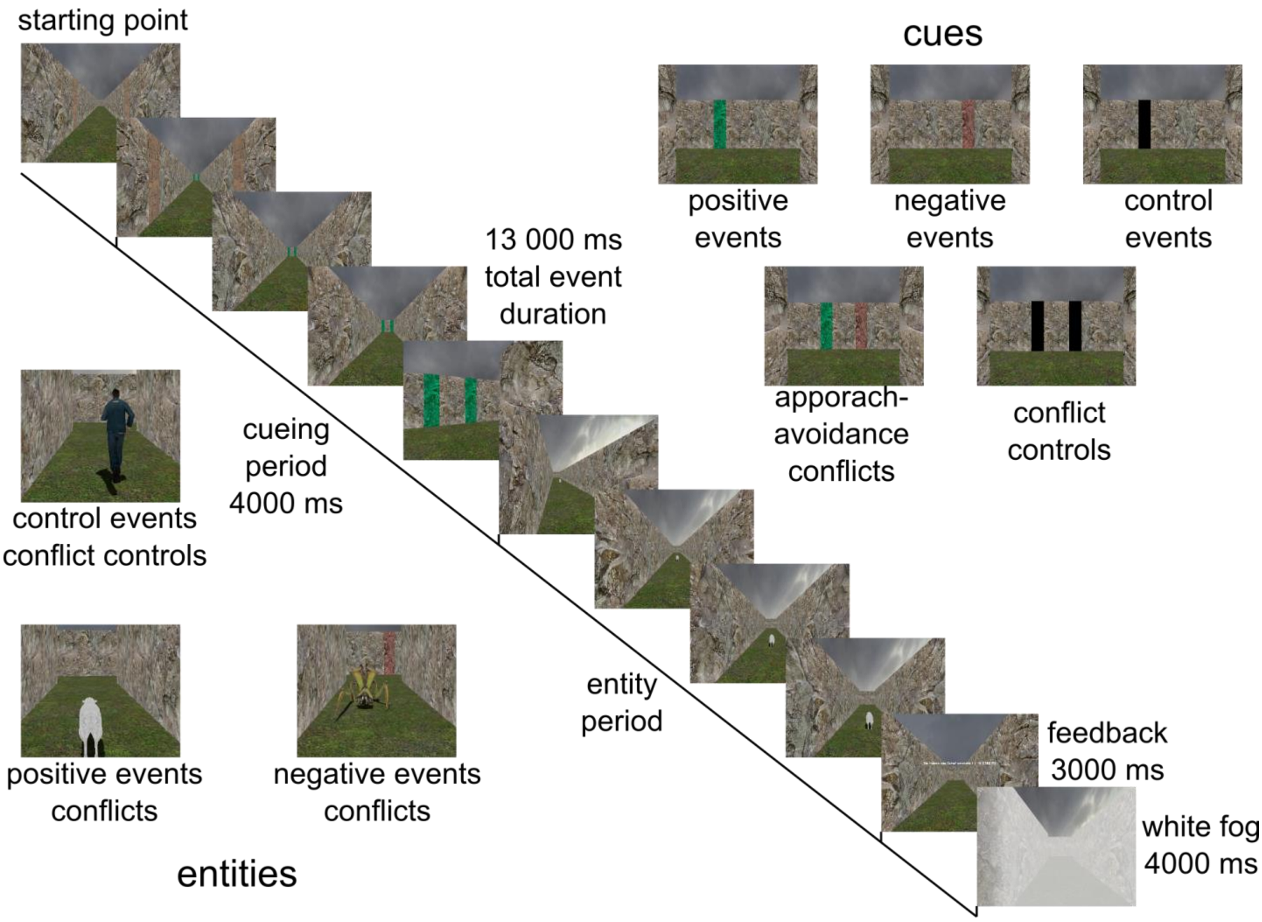

Figure 25: Schematic display of a trial in the VR paradigm. In the lower left corner examples of the entities used in the VR paradigm, in the upper right corner examples of the cues used in the trials are shown.

4.1.2.2 Movie paradigm.

The movie paradigm consists of three film sequences, one neutral film, one negative emotional film and one positive emotional film. All movies that are used were evaluated in advance by Hewig and colleagues (Hewig, Hagemann, Seifert, Gollwitzer et al., 2005). The neutral movie sequence is the neutral sequence "*Crimes and Misdemeanors"* (Hewig, Hagemann, Seifert, Gollwitzer et al., 2005) having a total duration of 63 seconds and showing two man walking around and talking to each other. The negative emotional film is the fear film sequence *"Halloween"* (Hewig, Hagemann, Seifert, Gollwitzer et al., 2005) with a total duration of 208 seconds, showing a female protagonist walking slowly up some stairs, opening the door of a room and seeing a dead person lying on the bed as well as one dead person in the cupboard. After that, a man with a hockey mask appears out of the shadows and attacks the woman with a knife and chases her down the stairs and through the house. The positive emotional film is the amusement film sequence *"An Officer and a Gentleman"* (Hewig, Hagemann, Seifert, Gollwitzer et al., 2005), having a total duration of 111 seconds. The film sequence shows an officer of the US-marines walking into a factory with many, mostly female workers being surprised and curiously following his path. After arriving behind a young female worker, he steps closely to her and starts kissing her. She replies the kisses and she is lifted of the ground by him and carried away from the factory.

Before every film sequence, the participants are told that they will be viewing a short film sequence and that they should try to immerse themselves into the protagonist of the film sequence and try to experience the feeling the protagonist experiences. Also, they are told that after the film sequence, there will be a short period, where they should try to re-experience the feeling the protagonist showed during the film sequence. Additionally, they are told that there is a short interval before the film where they should relax and keep their eyes open. The period before and the period after the film sequences have durations of 60 seconds each. During the period after the movie, the frontal asymmetry is measured, while the 60 second period before the movie sequence is used as a baseline. Immediately after the period of frontal asymmetry measurement, the participants are asked about the film sequence and the immersion period after the film sequence, in respect of presence / immersion, positive and negative emotions, arousal and experience of conflict.

The order of the film sequences are randomized for the negative and positive emotional film sequences, with the neutral film sequence being always the first one. Schematic display of one trial is shown in Figure 26.

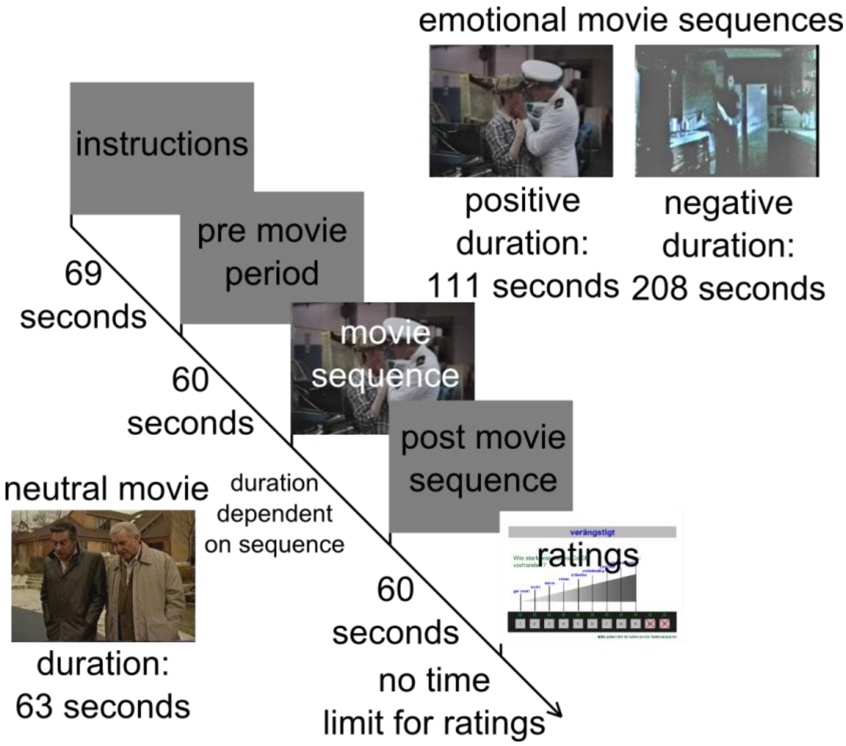

Figure 26: Schematic display of a trial in the movie paradigm. In the lower left corner is an example screenshot from the neutral movie, in the upper right corner example screenshots of the emotional movie sequences.

4.1.2.3 Mental imagery paradigm.

The mental imagery paradigm consists of four different auditory mental imagery scripts, all formulated in first person perspective and presented to the participants via headphones. The fourth script has two different endings that are presented to different participants. All scripts were previously used by Wacker and colleagues (Wacker et al., 2008) for their study about frontal asymmetry leading to their theory of the frontal lateralization of the active behavior vs. the behavioral inhibition being caused by the experience of conflict. The first script that is presented to the participants is a practice script, where the participants hear about a jogging session of a first person protagonist and the bodily sensations that arise during this jogging session. The duration of the script is 108 seconds and it is only used to give the participants an impression of the task they have to do and is not included in the analysis. Additionally, the participants are asked after the script about their bodily sensations and their well-being during the script in order to reinforce the strong immersion in the scripts. The second script is the neutral script that was used in the study by Wacker and colleagues (2008). The script is about a snowy evening, where the protagonist wanders around, sees the snow slowly fall and some cars drive by. Later, a bus arrives and the protagonist helps a woman to get out of the bus with her baby buggy.

After that, the protagonist slides along on an icy surface. This script was used as a baseline script by Wacker and colleagues (2008). The third script that is used is the control script that was used by Wacker and colleagues (2008). The script is about the protagonist having to leave a friends´ apartment due to some unfinished business and walking to the bus stop. At the bus stop, the protagonist observes some people standing there and few moments later, the protagonist enters the bus together with the persons standing at the bus stop. This script is used as the control condition in this paradigm, although the script was not used in a within design with the fourth script in the original study (Wacker et al., 2008). The fourth script that is used in this experiment is the negative emotional script, being the flight-fight-freezing (FFFS) and behavioral inhibition (BIS) script used by Wacker and colleagues (2008). This script is about the protagonist leaving a friends´ apartment due to some unfinished business and in order to catch the last bus. On the way to the bus stop the protagonist, who is already late for the bus is stopped by a few drunken rowdies who attempt to attack. In the BIS version of the script, the protagonist starts sweating, hears the own heart pounding and is rooted to the spot. In the FFFS version of the script, the protagonist is hit by a beer can and hears the own heart pounding, turns around and runs away. A detailed display of the BIS, FFFS and control script will be provided in appendix section and is also available in the original work by Wacker and colleagues (2008).

Before every script, the participants are instructed to immerse themselves into the story that is told and try to feel the feelings that the protagonist is experiencing. Also, they are told that after the script, there will be a short period, where they should try to re-experience the feeling especially during the end of the script. Additionally, they are told that there is a short interval before the script where they should relax and free their minds from any thought. The period before and the period after the film sequences have durations of 60 seconds each. During the period after the scripts, the frontal asymmetry is measured, while the pre-script period was used as a baseline. Immediately after the period of frontal asymmetry measurement, the participants are asked about the script and the period after the script, where they should feel and re-experience especially the end of the scripts, in respect of presence / immersion, positive and negative emotions, arousal and experience of conflict.

The order of the scripts is randomized for the control and negative script, with the training script being always the first one and the neutral script being always the second one, so the control and negative scripts are on the script position three and four in randomized order. Additionally, the negative script has two different endings (BIS vs. FFFS ending) that are presented in a between subject order pseudo-randomly to the participants in order to get both script equally often on every position. In contrast to the original study of Wacker and colleagues (2008), the control script is not presented in a between design with the BIS and FFFS script, but presented in a within design, leading to four scripts that are experienced by every participant. Schematic display of one trial is shown in Figure 27.

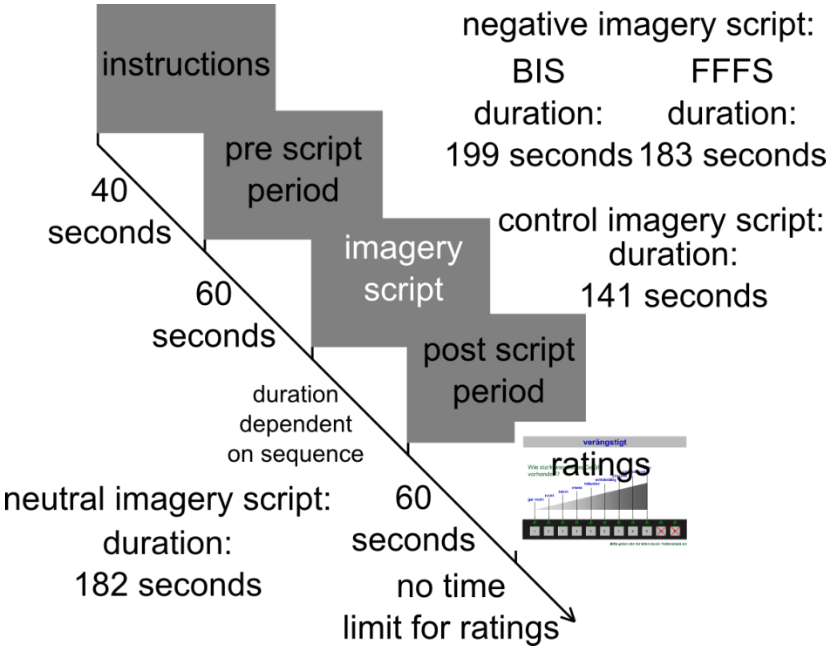

Figure 27: Schematic display of a trial in the mental imagery paradigm. In the lower left corner and the upper right corner the script duration of the different scripts are displayed.

4.1.3 Procedure.

Before coming to the laboratory, the participants filled in a web based questionnaire to assess relevant traits (see trait measurement section). Also demographical data was collected (gender, age and handedness). The online questionnaire was presented with SoSci Survey (Leiner, 2014), an online questionnaire platform.

All experimental sessions were randomized in their order to avoid systematic sequence effects of the paradigms. On the first session, the participants filled in a questionnaire after the arrival at the laboratory (see trait measurement section).

At the beginning of every session, an information material about the session and an informed consent was given to the participants, as well as the SAM scales (Bradley & Lang, 1994 and see state measurement section), in order to assess the state of the participants. Then the participants were seated in front of a 61 cm (24’’) widescreen monitor in 50 – 60 cm distance and EEG was placed on their head, as well as electrodes for skin conductance on their left hand and electrodes for the heart rate on their collarbones and the left costal arch. Additionally, headphones were placed on the head of the participants in order to provide tones during the paradigms and instructions for the resting EEG period.

Following this preparations the participants were assessed once more with the SAM scales (Bradley & Lang, 1994 and see state measurement section) in order to get eventual changes in their states.

After that the participants experienced a resting EEG period, consisting of eight minutes with four minutes of closed eyes and four minutes of open eyes in total and a change of open or closed eyes every 60 seconds in the movie paradigm and the VR paradigm. In the mental imagery paradigm, the resting period consisted of 12 minutes of closed eyes resting. The reason for this difference in the resting EEG periods between the paradigms is that the original study of Wacker and colleagues (2008) used this kind of resting EEG period, but a resting period with closed eyes only would not be appropriate for paradigms with open eyes and visual activity.

After the resting EEG period, the participants experienced the paradigm of the session. At the end of the session - after the paradigm - one final SAM scale (Bradley & Lang, 1994 and see state measurement section) was given to the participants in order to see the changes in the state made by the paradigm. Then, the participants were freed of the apparatus and given the compensation of the session. At the end of the last session, an explanation of the purpose of the study was also given to the participants.

4.1.3.1 VR paradigm.

The participants experienced the virtual maze. They were instructed to go into the maze and make as many points as possible. Additionally, they experienced a training phase, where the monster trial (negative event) and the sheep trial (positive event) were introduced and the behavior could be practiced. The training phase did not end until the goal of the trials (being not caught by the monster respectively catching the sheep) was obtained three times for both of these two training events.

After that, the experiment started. After the experiment, there was a rating of the different events in respect of presence / immersion, positive and negative emotions, arousal and experience of conflict, starting with a brief experience of the event. The participants were told that this present event has to be seen as a cue to retrieve the emotions and feeling that were present during the experiment in such trials. Ratings were obtained for every condition and for the movement directions (forward / backward) in general.

4.1.3.2 Movie paradigm.

The participants experienced the movie paradigm. They were instructed to see the different film sequences and immerse themselves into the protagonist of the sequence and feel the feeling of the protagonist. After every sequence, they were asked to rate their experience in respect of presence / immersion, positive and negative emotions, arousal and experience of conflict, before the next trial started.

4.1.3.3 Mental imagery paradigm.

The participants experienced the mental imagery paradigm. They were instructed to hear the scripts and try to immerse themselves into the protagonist of the scripts and feel the feeling of the protagonist. Then, in a training script, they learned to be aware of their bodily sensations to the imagery script by being asked about them afterwards. After the training script, the experimental scripts started. After every script, they were asked about their experience in respect of presence / immersion, positive and negative emotions, arousal and experience of conflict, before the next trial started.

4.1.4 Apparatus.

4.1.4.1 EEG recording.

The EEG was measured by Ag/AgCl-electrodes located in an electrode cap in the following 32 positions: Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, Fz, Pz, FC1, FC2, CP1, CP2, FC5, FC6, F9, F10, TP9, TP10, PO9, PO10, FCz, and Cz (according to the international

10–10 system). Ground electrode was located on AFz position, the reference electrode was Cz (see Figure 28).

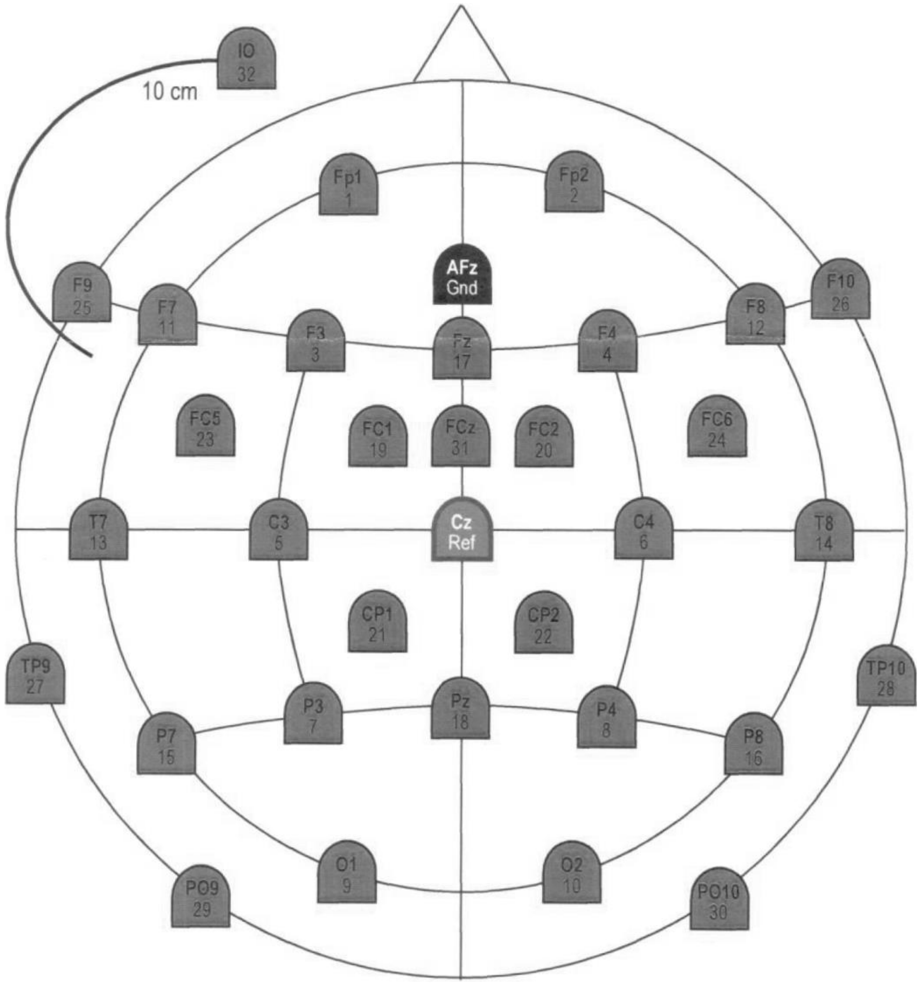

Figure 28: Electrode positions for the EEG in study II.

All online filters, the sampling rate, the electrode impedance, offline filters and procedures to correct for artifacts and analyze the data were identical to study I.

4.1.4.1.1 VR paradigm.

The segmentation of the data for the VR paradigm was done as in study I from -1 second before the cueing of an event to 5 seconds after the cueing of an event with a baseline form -500 ms to the cue onset. Following the segmenting, jump artifacts were detected and deleted statistically by using a z-value threshold of z=4 for signal and curtosis of the signal, slow drifts were rejected by using trend detection with windowsize=1500 data points, minimum slope=50, minimum R^2=0.3 and 2 point steps. Additional artifact correction for muscle activity and ocular correction was made with ICA (Makeig et al., 2004), removing manually all components associated with muscular activity or eye movement and blink activity. After that, CSD transformation was applied, using CSD toolbox (Kayser & Tenke, 2006a, 2006b) and alpha frequency from 8-13 Hz was extracted using morlet wavelets with the eeglab function newtimef using cycle parameters [3 0.5] during 0 to 4 seconds of the cueing period.

Wavelets were used for the same reasons as in study I. Likewise in study I, power values were also extracted via FFT in the same time window and the correlation between the ln transformed power values of FFT and the wavelets was r=.98.

4.1.4.1.2 Movie paradigm.

The segmentation of the data for the movie paradigm was done for the 60 second period after the film sequences, where the participants were told to immerse themselves into the protagonist of the movie and re-experience the situation shown in the movie once more. Also as a baseline, the 60 seconds before every film sequence was taken. The data segments were further divided into overlapping data segments of -1 to 5 seconds that were taken every two seconds and a baseline from -500 ms to 0. Following the segmenting, the same corrections as for the other paradigms were used with jump artifacts statistically being detected and deleted by using a z-value threshold of z=4 for signal and curtosis of the signal, slow drifts were rejected by using trend detection with windowsize=1500 data points, minimum slope=50, minimum R^2=0.3 and 2 point steps. Additional artifact correction for muscle activity and ocular correction was made with ICA (Makeig et al., 2004), removing manually all components associated with muscular activity or eye movement and blink activity. After that, CSD transformation was applied, using CSD toolbox (Kayser & Tenke, 2006a, 2006b) and alpha frequency from 8-13 Hz was extracted using morlet wavelets with the eeglab function newtimef using cycle parameters [3 0.5] during 0 to 4 seconds of the segments.

4.1.4.1.3 Mental imagery paradigm.

The segmentation for the mental imagery paradigm was done for the 60 second period after the imagery scripts, where the participants were told to immerse themselves into the protagonist of the script and re-experience the situation told in the script once more. Also as a baseline, the 60 seconds before every imagery script was taken. The data segments were further divided into overlapping data segments of -1 to 5 seconds that were taken every two seconds and a baseline from -500 ms to 0. Following the segmenting, the same corrections as for the other paradigms were used with jump artifacts statistically being detected and deleted by using a z-value threshold of z=4 for signal and curtosis of the signal, slow drifts were rejected by using trend detection with windowsize=1500 data points, minimum slope=50, minimum R^2=0.3 and 2 point steps. Additional artifact correction for muscle activity and ocular correction was made with ICA (Makeig et al., 2004), removing manually all components associated with muscular activity or eye movement and blink activity. After that, CSD transformation was applied, using CSD toolbox (Kayser & Tenke, 2006a, 2006b) and alpha frequency from 8-13 Hz was extracted using morlet wavelets with the eeglab function newtimef using cycle parameters [3 0.5] during 0 to 4 seconds of the segments.

4.1.4.1.4 Resting period.

The segmentation for the resting period was done for the whole resting period (8 minutes before the VR paradigm and the movie paradigm, 12 minutes before the mental imagery paradigm). The data was segmented into overlapping data segments of -1 to 5 seconds that were taken every two seconds and a baseline from -500 ms to 0. Following the segmenting, the same corrections as for the other paradigms were used with jump artifacts statistically being detected and deleted by using a z-value threshold of z=4 for signal and curtosis of the signal, slow drifts were rejected by using trend detection with windowsize=1500 data points, minimum slope=50, minimum R^2=0.3 and 2 point steps. Additional artifact correction for muscle activity and ocular correction was made with ICA (Makeig et al., 2004), removing manually all components associated with muscular activity or eye movement and blink activity. After that, CSD transformation was applied, using CSD toolbox (Kayser & Tenke, 2006a, 2006b) and alpha frequency from 8-13 Hz was extracted using morlet wavelets with the eeglab function newtimef using cycle parameters [3 0.5] during 0 to 4 seconds of the segments.

4.1.4.2 Heart period.

The heart period measurement devices, the sampling rates and the filter that were applied were the same as in study I.

4.1.4.2.1 VR paradigm.

The time window chosen for analysis was from 0 to 10 seconds after the cueing of the event. Mean inter-beat intervals were extracted for the first 10 beats.

4.1.4.2.2 Movie paradigm.

The time window chosen for analysis was from 0 to 10 seconds after the movie paradigm had finished and the participants received the instruction to re-experience the feelings of the protagonist. Mean inter-beat intervals were extracted for the first 10 beats.

4.1.4.2.3 Mental imagery paradigm.

The time window chosen for analysis was from 0 to 10 seconds after the movie paradigm had finished and the participants received the instruction to re-experience the feelings of the protagonist. Mean inter-beat intervals were extracted for the first 10 beats.

4.1.4.3 Skin conductance recording.

The skin conductance measurement devices, the sampling rates and the filter that were applied were the same as in study I.

4.1.4.3.1 VR paradigm.

The time window for the quantification of the Skin conductance response was made from 1 to 10 seconds after cue onset for every event in the VR paradigm as in study I (Figner & Murphy, 2011; Naqvi & Bechara, 2006). Also the same baseline period as in study I and the quantification of Naqvi and Bechara (2006) from study I was used, taking the area defined by the SCR curve and a sloped line delineated by the intersection of the measurement window and the SCR curve (see also Figner & Murphy, 2011 and Figure 8).

4.1.4.3.2 Movie paradigm.

For the SCL in the movie paradigm, two different time windows were used, one being the same time window of the frontal asymmetry ranging from 0 to 60 seconds after the end of the film sequences, where the participants were told to immerse oneself into the protagonist of the film once more. The second time window was during the viewing of the film sequences. The baseline for the

SCL was provided from a 60 second period before the film sequences, where the participants were told to relax.

4.1.4.3.3 Mental imagery paradigm.

For the SCL in the mental imagery paradigm, also two time windows were used, one being the time window of the frontal asymmetry measurement, being from 0 to 60 seconds after the end of the mental imagery scripts, where the participants were told to immerse oneself into the protagonist of the script and re-experience the feeling of the protagonist once more. The baseline for the SCL was provided from a 60 second period before the imagery scripts, where the participants were told to relax and free their minds from any thought.

4.1.5 Frontal activation.

Frontal asymmetry was assessed with the difference from ln(right)-ln(left) electrodes for homologous electrode pairs (Coan & Allen, 2004) in EEG. Frontal bilateral activation was analyzed with the formula ln(right)+ln(left) (Hewig et al., 2006) for the homologous electrode pair F4/3.

4.1.5.1 VR paradigm.

Frontal asymmetry was assessed on the electrode position F4/F3 with a single trial generalized linear mixed model for the VR paradigm. The time window for the extraction of the frontal asymmetry was the first 4 seconds of the cueing period of the event for the VR paradigm, where the participants could already initiate their movement but did not see the entity of the event. This time window was chosen in order to avoid activation pattern due to differences in visual features of the entities of the events. In the same time window, frontal bilateral activation was analyzed with the formula ln(right)+ln(left) (Hewig et al., 2006) for the homologous electrode pair F4/3 with a single trial generalized linear model and a single trial generalized linear mixed model.

4.1.5.2 Movie paradigm.

For the movie paradigm, frontal asymmetry was assessed with split-plot ANCOVAs for the electrode position F4/3 in the different movie conditions. The time window for the frontal asymmetry was the 60 seconds period after the film sequence, where the participants should re-experience the feelings of the protagonist. For the same time period, the bilateral frontal activation was analyzed with split-plot ANCOVAs for the electrode position F4/3. The baseline period for the frontal asymmetry period was the 60 seconds period before the films started and the participants were told to relax.

4.1.5.3 Mental imagery scripts.

For the mental imagery paradigm, frontal asymmetry was assessed with split-plot ANCOVAs for the electrode position F4/3 in the different mental imagery conditions. The time window for the frontal asymmetry was the 60 second period after the scripts, where the participants should re-experience the feelings of the protagonist. For the same time period, the bilateral frontal activation was analyzed with split-plot ANCOVAs for the electrode position F4/3. The baseline period for the frontal asymmetry period was the 60 seconds period before the mental imagery scripts started and the participants were told to relax.

4.1.5.4 Resting period.

For the resting period, the mean frontal asymmetry and mean bilateral frontal alpha activity on electrode position F4/3 over the three resting periods was correlated with the traits. Also, a reliability analysis was made for the frontal asymmetry and bilateral frontal activation in order to see the stability of the resting measurement and therefore the trait part of the measured values.

4.1.6 Behavioral measures in the VR paradigm.

The behavior shown in the paradigm was classified and categorized by tracking the movement of the participant in the virtual reality as well as the movement of the joystick. As in study I, four behavioral categories were chosen: “Fleeing from the stimulus” (11.46%), “approaching safety from the stimulus” (22.57%), “reaching out for the stimulus” (55.76%) and “doing nothing” (8.32%). Other behavior (e.g. experiencing conflict) had to be excluded, because there were too few trials (1.89 %) to analyze the behavior. All resulting behavioral categories for the different conditions in the VR paradigm are shown in Table 6. The categorization of the behavior was identical to the categories in study I. (see Figure 10)

Table 6: Count of shown behavior in the different conditions of the VR paradigm.

	negative events	positive events	approach-avoidance conflicts	control conflicts	control events
fleeing from the stimulus	295	0	189	58	52
approaching safety from the stimulus	687	2	381	50	50
reaching out for the stimulus	10	1012	411	721	736
doing nothing	27	6	31	188	179
experiencing conflict	7	0	49	21	21

4.1.7 Ratings.

The participants were provided with 25 questions about the conditions and paradigms, assessing the concepts of negative emotions, positive emotions, arousal, immersion/presence (Bülthoff & Veen, 1999) and experience of conflict. Also, the concept of panic as a reaction of the (revised) FFFS was measured and compared to the experience of an uncertainty what to do, in order to provide a distinction between the an activation of the (revised) FFFS vs. an activation of the (revised) BIS according to the idea of Wacker and colleagues (Wacker et al., 2008). Hence, a slightly modified form of the question used by Wacker and colleagues (2008) was used in this study. The ratings of 53 participants who experienced every condition and paradigm were included in the analysis of the ratings. The questions can be seen in Table 10, Figure 48, Figure 49, Figure 50, Figure 51 and Figure 52.

4.1.8 Trait measurement.

Several traits were assessed via online questionnaires hosted with the SoSci Survey online-questionnaire-portal (Leiner, 2014).

For positive and negative affect, the German version of the trait version of the Positive And Negative Affect Schedule (PANAS Scales, Krohne et al., 1996; Watson et al., 1988) was used.

To assess the trait anxiety, the German version of the State - Trait Anxiety Inventory (STAI , Laux et al., 1981) was used.

For behavioral activation and behavioral inhibition tendencies sensu the classical theory of the reinforcement sensitivity (Gray, 1982, 1991; Gray & McNaughton, 1996), the German version of the BIS-BAS scales (Carver & White, 1994) were used for the whole dimension of the constructs, as well as the ARES scales (Hartig & Moosbrugger, 2003) with the subscales anxiety/nervousness (BIS I), sadness/frustration (BIS II), drive (BAS I) and joy (BAS II) for a better view on the sub-dimensions of behavioral activation and behavioral inhibition.

Also targeting the construct of behavioral inhibition and behavioral activation, but their revised versions (Gray & McNaughton, 2000) along with the flight-fight-freezing system, a German version of the Jackson-5 questionnaire (Jackson, 2009) with the subscales BIS, BAS, flight, fight and freezing, was used, providing a subscale for every aspect of the revised reward sensitivity theory (Gray & McNaughton, 2000).

For the assessment of depression, the German version of the Beck depression inventory (Schmitt et al., 2003) was used.

In order to measure impulsiveness, the German short version of the Barratt Impulsiveness Scale (BAIS, Meule, Vögele, & Kübler, 2011) was used. This questionnaire also provided subscales, the non-planning (BAIS:Non-planning), the motor impulsiveness (BAIS:Motor-activity) and the impulsive attention (BAIS:Attention).

Anger was measured with German version of the State- Trait – Anger – Expression – Inventory (STAXI, Schwenkmezger & Hodapp, 1991; Spielberger, 1988) and for the vividness of imagery, the German version of the Vividness of Visual Imagery Questionnaire version (VVIQ, Marks, 1973) was used.

On the first session of the laboratory experiment, the questionnaire about competence and the locus of control (FKK, Krampen, 1991) with the subscales self-concept (SK), internality (I), social externality (P), fatalistic externality (C), self-efficacy (SKI), externality (PC) and internality vs. externality (SKI-PC) was given to the participants.

4.1.9 State measurement.

In order to measure changes in the states of the participants during the experimental sessions, the Self-Assessment Manikin test (SAM, Bradley & Lang, 1994) with the scales valence, arousal and dominance were given to the participants three times. Due to misconception of the instructions, the arousal and dominance ratings of one participant are not present in the data and are therefore not included in the analysis.

4.1.10 Statistics.

4.1.10.1 Frontal activation.

4.1.10.1.1 VR paradigm.

The frontal asymmetry was analyzed in two ways. First, with the more classical approach, it was entered as the resulting variable of a 6*5*2 repeated measures ANOVA with the within factors electrode position (Fp2/1, F4/3, F8/7, F10/9, C4/3, P4/3), condition (negative, positive, control, approach- avoidance conflict, conflict control) and hemisphere (left/right). Bonferroni – Holm adjusted post hoc t-tests were used to further define the differences in frontal activation patterns. Greenhouse-Geisser correction was applied with the correction factor c=.716 for the within-factor condition, c=.633 for the within-factor electrode position, c=.473 for their interaction, c=.772 for the interaction hemisphere*condition, c=.641 for the interaction of hemisphere*electrode position and c=.533 for the threefold interaction of condition*hemisphere*electrode position.

Also, a single trial analysis was carried out with a multilevel generalized linear mixed model. At level 1 the predictor was frontal asymmetry on electrode position F4/3, at level 2 predictors were the traits measured in the online questionnaire. The criterion was the resulting behavior in the paradigm as a multicategorial variable with the 3 cases "fleeing from the stimulus", "approaching safety from the stimulus" and "reaching out for the stimulus". The reference category was "approaching safety from the stimulus".

The model fit determined with corrected Akaike criterion (AICC) was best for the model with frontal asymmetry on electrode position F4/3 as fixed level 1 predictor and the random effects frontal asymmetry on electrode position F4/3 (with intercept and uncorrelated covariance matrix type) and no level 2 predictors (see Table 7).

Table 7: Corrected Akaike Information Criterions (AICCs) for general linear mixed models.

model	frontal asymmetry	bilateral activation for behavior	left frontal activation for behavior
baselinemodel	34523.90	2081.8	2081.8
model with level 1 predictor	34511.25	2076.4	2075.6
best model with level 1 and level 2 predictor	34954.15	2077.0	2077.4

To test the hypothesis of the bilateral activation for active behavior, a single trial analysis was carried out with a multilevel generalized linear mixed model. At level 1 the predictor was bilateral frontal alpha activity on electrode position F4/3, at level 2 the predictor were relevant traits like behavioral inhibition, self-efficacy and self-concept. The criterion was the resulting behavior in the paradigm as a binomial variable with the 2 cases “active behavior”, “doing nothing”. The reference category was “active behavior”. AICC was best for the model with bilateral frontal alpha activity on electrode position F4/3 as fixed level 1 predictor and only the random intercept and no level 2 predictors (see Table 3).

In order to test the hypothesis that active behavior leads to left frontal brain activation, a single trial analysis was carried out with a multilevel generalized linear mixed model. At level 1 the predictor was bilateral frontal alpha asymmetry on electrode position F4/3, at level 2 the predictor were relevant traits like behavioral inhibition, self-efficacy and self-concept. The criterion was the resulting behavior in the paradigm as a binomial variable with the 2 cases “active behavior”, “doing nothing”. The reference category was “active behavior”. AICC was best for the model with frontal alpha asymmetry on electrode position F4/3 as fixed level 1 predictor and only the random intercepts and no level 2 predictors (see Table 3).

To further explore the differences and maybe the driving condition behind the frontal activation detected in the VR paradigm, a principal component analysis with varimax rotation was made over all trials for all participants and all conditions, with participant centered power values on each electrode. The parallel analysis criterion of Horn (1965) was used to determine the amount of components and it revealed 9 components (see Figure 29). The resulting components were analyzed in respect of differentiation of the conditions with a 9*5 within ANOVA with the factors condition (negative, positive, control, approach- avoidance conflict, conflict control) and component (1, 2, 3, 4, 5, 6, 7, 8, 9). To clarify the relation of the conditions of the paradigm to the different components, separate within ANOVAs were made for every component. The ANOVAs included the within factor condition (negative, positive, control, approach- avoidance conflict, conflict control) for each component. Greenhouse-Geisser correction was applied with the correction factors *c*=.739 for the first component, *c*=.806 for the second component, *c*=.839 for the third component, *c*=.779 for the fourth component, *c*=.781 for the fifth components, *c*=.773 for the sixth component, *c*=.657 for the seventh component, *c*=681 for the eighth component and *c*=.899 for the ninth component. For the ANOVA including the components and the conditions, Greenhouse-Geisser correction was applied with the correction factor *c*=.772 for the condition and *c*=.318 for the interaction of condition*component. Bonferroni – Holm adjusted post hoc t-tests were applied to the significant ANOVAs in order to clarify the influence of the conditions on the components.

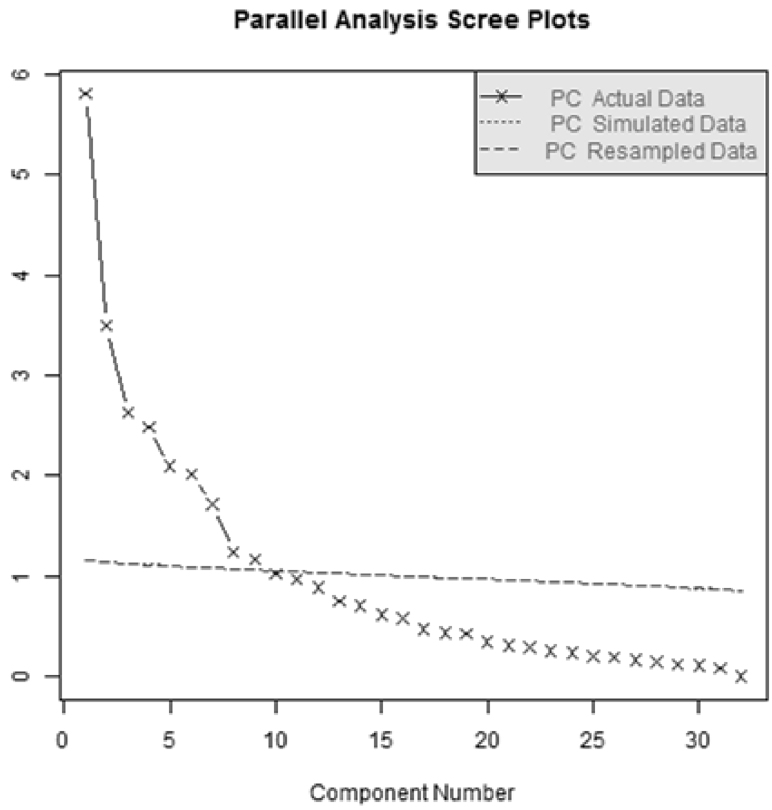

Figure 29: Eigenvalues and simulated eigenvalues of the principal component analysis over all trials of the VR paradigm for all participants and all conditions, with participant centered power values for each electrode.

4.1.10.1.2 Movie paradigm.

Frontal asymmetry on the electrode position F4/3 was analyzed as the resulting variable of 3*2 split-plot ANCOVAs with the within factor condition (neutral film, negative film, positive film), the between factor order (positive movie last, negative movie last) and the traits as covariate for every trait measurement (PANAS positive, PANAS negative, BIS-BAS:BIS, BIS-BAS:BAS, ARES:BIS1, ARES:BIS2, ARES:BAS1, ARES:BAS2, Jackson5:BAS, Jackson5:BIS, Jackson5:Fight, Jackson5:Flight, Jackson5:Freezing, STAI, STAXI, BDI, VVIQ, BAIS, BAIS:Motor-activity, BAIS:Non-planning, BAIS:Attention). As there were no significant main effects in the ANCOVAS for the condition or the order, the interactions of the conditions and the traits were further analyzed. For the two significant trait*condition interactions, regressions were computed for every condition in order to clarify the relation of the traits and the conditions.

Also, bilateral frontal alpha activation on the electrode position F4/3 was analyzed as the resulting variable of repeated measures ANCOVAs with the within factor condition (neutral film, negative film, positive film), the between factor order (positive movie last, negative movie last) and the traits as covariate for every trait measurement (PANAS positive, PANAS negative, BIS-BAS:BIS, BIS-BAS:BAS, ARES:BIS1, ARES:BIS2, ARES:BAS1, ARES:BAS2, Jackson5:BAS, Jackson5:BIS, Jackson5:Fight, Jackson5:Flight, Jackson5:Freezing, STAI, STAXI, BDI, VVIQ, BAIS, BAIS:Motor-activity, BAIS:Non-planning, BAIS:Attention). As there were no significant main effects in the ANCOVAS for the condition and no significant interaction with the traits, the analysis was not carried out further.

4.1.10.1.3 Mental imagery paradigm.

Frontal asymmetry on the electrode position F4/3 was analyzed as the resulting variable of 3*2*2 split-plot ANCOVAs with the within factor condition (neutral script, control script, negative script), the between factors negative script manifestation (BIS imagery script, FFFS imagery script) and order (negative script last, control script last) and the traits as covariate for every trait measurement (PANAS positive, PANAS negative, BIS-BAS:BIS, BIS-BAS:BAS, ARES:BIS1, ARES:BIS2, ARES:BAS1, ARES:BAS2, Jackson5:BAS, Jackson5:BIS, Jackson5:Fight, Jackson5:Flight, Jackson5:Freezing, STAI, STAXI, BDI, VVIQ, BAIS, BAIS:Motor-activity, BAIS:Non-planing, BAIS:Attention). As there were no significant main effects in the ANCOVAS for the condition, the order or the negative script manifestation and no significant interactions with the traits, following the example of Wacker and colleagues (2008) a differentiation concerning the subjective experience of the imagery script was added, using the difference score of the subjective questions about feeling uncertain what to do in this situation (conflict) and the feeling to just want to run away and experiencing panic (FFFS), with negative values indicating a higher experience of conflict. This index of conflict experience was added as an additional covariate to the ANCOVAS.

Also, bilateral frontal alpha activation on the electrode position F4/3 was analyzed as the resulting variable of 3*2*2 split-plot ANCOVAs with the within factor condition (neutral film, negative film, positive film), the between factors negative script manifestation (BIS imagery script, FFFS imagery script) and order (negative script last, control script last) and the traits as covariate for every trait measurement (PANAS positive, PANAS negative, BIS-BAS:BIS, BIS-BAS:BAS, ARES:BIS1, ARES:BIS2, ARES:BAS1, ARES:BAS2, Jackson5:BAS, Jackson5:BIS, Jackson5:Fight, Jackson5:Flight, Jackson5:Freezing, STAI, STAXI, BDI, VVIQ, BAIS, BAIS:Motor-activity, BAIS:Non-planing, BAIS:Attention). As there were no significant main effects in the ANCOVAS for the condition, the negative script manifestation or the order, the interactions of the conditions and the traits were further analyzed. For the significant trait*condition interaction, regressions were computed for every condition in order to clarify the relation of the trait and the conditions.

4.1.10.1.4 Resting period.

For the analysis of the reliability of the frontal asymmetry over the three resting periods, intra-class correlation and Cronbach´s α were computed for the frontal asymmetry and the bilateral frontal alpha activity on electrode position F4/3. The Cronbach´s α was computed within the measurement occasion as a consistency index for every one minute. To further explore the low inter-relation of the different times of measurements for the resting state EEG, two ANOVAs with the factors gender (male/female) and measurement time (resting1 / resting2 / resting3) respectively following paradigm (movie / mental imagery / VR) was computed. Subsequently, Bonferroni adjusted t-tests were computed for the significant interaction.

For the correlation of the traits and the frontal activation, pearson correlation was computed for every trait and the frontal asymmetry, respectively bilateral frontal alpha activity.

4.1.10.2 Skin conductance.

4.1.10.2.1 VR paradigm.

The skin conductance of the virtual T-maze paradigm was analyzed in respect of SCR for every condition with a within ANOVA with the variable condition (negative events, positive events, control negative events, control positive events, approach- avoidance conflict, control approach-avoidance conflict). Post hoc t-tests were used to further define the differences of the SCR. For the ANOVA, Greenhouse – Geisser correction was applied with the correction factor c=.373.

4.1.10.2.2 Movie paradigm.

The skin conductance for the movie paradigm was analyzed in respect of the SCL for every condition with two 3*2 split-plot ANOVA with the within variable condition (neutral movie, positive movie, negative movie) and the between subject variable order (positive movie last, negative movie last). The first ANOVA was made for the period of frontal asymmetry analyzation starting immediately after the end of the film sequence with duration of 60 seconds. The second ANOVA was conducted for the film sequence viewing period in order to check the direct response to the movie stimuli.

4.1.10.2.3 Mental imagery paradigm.

The skin conductance for the mental imagery paradigm was analyzed in respect of the SCL for every condition with a 3*2*2 split-plot ANOVA with the within variable condition (neutral script, control script, negative script) and the between variables negative script manifestation (BIS imagery script, FFFS imagery script) and order (negative script last, control script last). Post hoc t-tests were used to further define the significant differences of the SCL.

4.1.10.3 Heart period.

4.1.10.3.1 VR paradigm.

For the analysis of the heart inter-beat intervals in for every condition, a 5*10 repeated measure ANOVA was calculated with the within variables condition (negative events, positive events, control events, approach- avoidance conflict, conflict control) and Heartbeats (1, 2, 3, 4, 5, 6, 7, 8, 9, 10), followed by a simple t-test comparison. Greenhouse-Geisser correction was applied with the correction factor c=.601 for the factor condition, c=.382 for the factor Heartbeat and c=.253 for their interaction.

4.1.10.3.2 Movie paradigm.

For the analysis of the heart inter-beat intervals in for every condition, a 3*10*2 split-plot ANOVA was calculated with the within variables variable condition (neutral movie, positive movie, negative movie) and Heartbeats (1, 2, 3, 4, 5, 6, 7, 8, 9, 10), as well as the between variable order (positive movie last, negative movie last). Greenhouse-Geisser correction was applied with the correction factor c=.352 for the factor Heartbeat and c=.427 for the interaction of the factors heartbeat and condition.

4.1.10.3.3 Mental imagery paradigm.

For the analysis of the heart inter-beat intervals in for every condition, a 3*10*2*2 split-plot ANOVA was calculated with the within variables condition (neutral script, control script, negative script) and Heartbeats (1, 2, 3, 4, 5, 6, 7, 8, 9, 10), as well as the between variables negative script manifestation (BIS imagery script, FFFS imagery script) and order (negative script last, control script last). Greenhouse-Geisser correction was applied with the correction factor c=.696 for the factor condition, c=.55 for the factor Heartbeat and c=.454 for their interaction.

4.1.10.4 Behavior and traits.

For analysis of the correlation between behavior and traits pearson correlation was computed for every behavioral condition and the traits.

4.1.10.5 Ratings.

For the analysis of the ratings for every condition, a 12*5*2 split-plot ANOVA was calculated with the within variables condition (VR negative events, VR positive events, VR control negative events, VR control positive events, VR approach- avoidance conflict, VR control approach- avoidance conflict, movie neutral, movie negative, movie positive, imagery neutral, imagery control, imagery negative) and question compound (negative emotional, positive emotional, arousal, immersion, conflict) and the between variable negative imagination script (FFFS,BIS). Also post hoc t-tests were used to further define the differences in the ratings. For the ANOVA; Greenhouse-Geisser correction was applied with the correction factor c=.578 for the within-factor condition, c=.471 for the within-factor question compound and c=.203 for their interaction.

4.1.10.6 State measurement.

For the SAM questionnaire there were computed three 3*3 repeated measurement ANOVAS, one ANOVA for each scale of the SAM questionnaire. The two within variables included were time (before EEG-application, after EEG-application, after paradigm) and paradigm manifestation (VR paradigm, movie paradigm, mental imagery paradigm). Greenhouse-Geisser correction was applied with the correction factor c=.801 for the within-factor time and c=.700 for the interaction of time*paradigm manifestation for the valence ratings. For the arousal ratings, Greenhouse-Geisser correction was applied only for the interaction of time*paradigm manifestation with c=.791 and for the dominance ratings, the Greenhouse-Geisser correction was applied with the correction factor c=.733 for the within-factor time and c=.698 for the interaction of time*paradigm manifestation.

All statistical analysis was carried out with IBM SPSS version 21, except for the binomial generalized linear mixed models and the principal component analysis, which were computed with the statistic software R (R Core Team, 2016) using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) with the procedure “glmer” and the “psych” package (Revelle, 2015).

4.2 Results study II:

4.2.1 Frontal activation.

4.2.1.1 Virtual T-maze paradigm.

4.2.1.1.1 Frontal asymmetry for different kinds of behavior and conditions.

The generalized linear mixed model with the fixed effect frontal asymmetry on the electrode position F4/3 and the random effects frontal asymmetry on the electrode position F4/3 revealed a significant main effect of frontal asymmetry [F(2,33)=8.19, p<.01, *semi-partial* R^2=.33] for the resulting behavior. The beta weight for “reaching out for the stimulus” showed a significant difference to the reference category [b=6.99, SE=1.73, t=4.04, p<.01], indicating a higher likelihood to show the behavior of reaching out to the stimulus if a higher frontal asymmetry is shown (see Figure 30 left panel). The beta weight for “fleeing from the stimulus” was not significant [b=-2.23, SE=3.22 t=.69 p>.5].

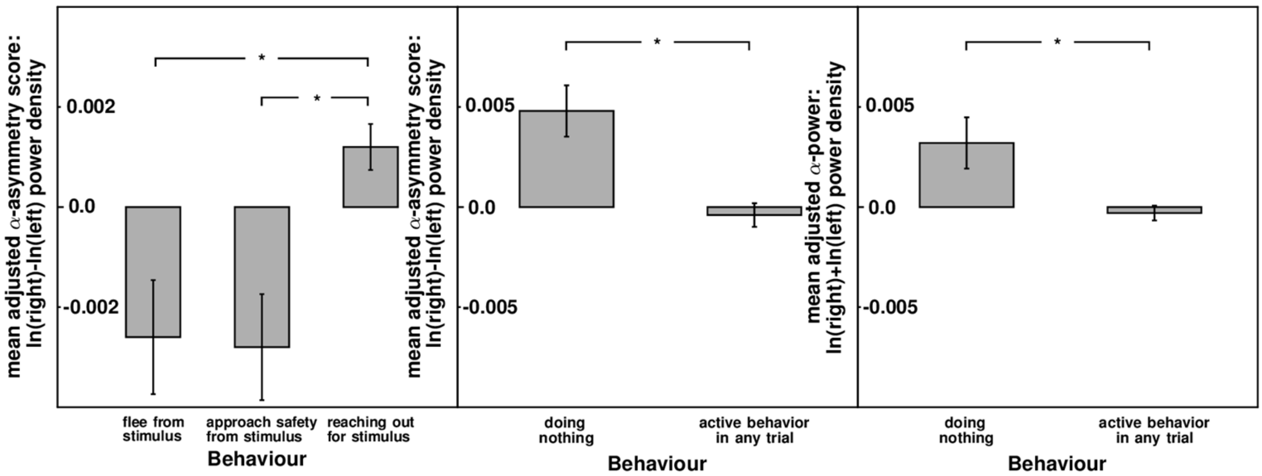

Figure 30: Frontal alpha activity in the single trial analysis: Frontal asymmetry shown at the initialization of the resulting behavior in each trial, frontal asymmetry and frontal alpha activation before initiation of any behavior vs. no behavior at all. Error-bars represent mean SE of the conditions. *=p<.05

Topographical activation patterns for 10 Hz in the chosen time period from 0 to 4 seconds after the cuing for each behavioral category can be seen in Figure 31. Frequency plots from 3 to 28 Hz for each behavioral category on electrode positions F4 and F3 can be seen in Figure 32.

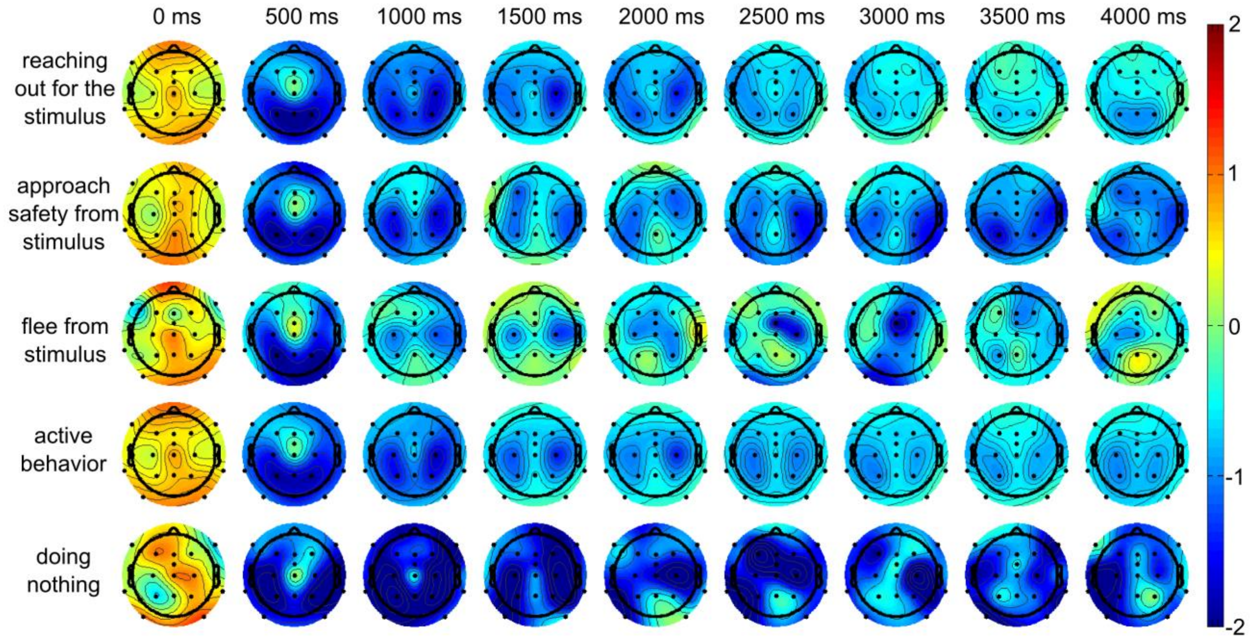

Figure 31: Topographical activation for each behavior in 500 ms steps in the time interval from 0 to 4 seconds after the cueing of the events for 10 Hz.

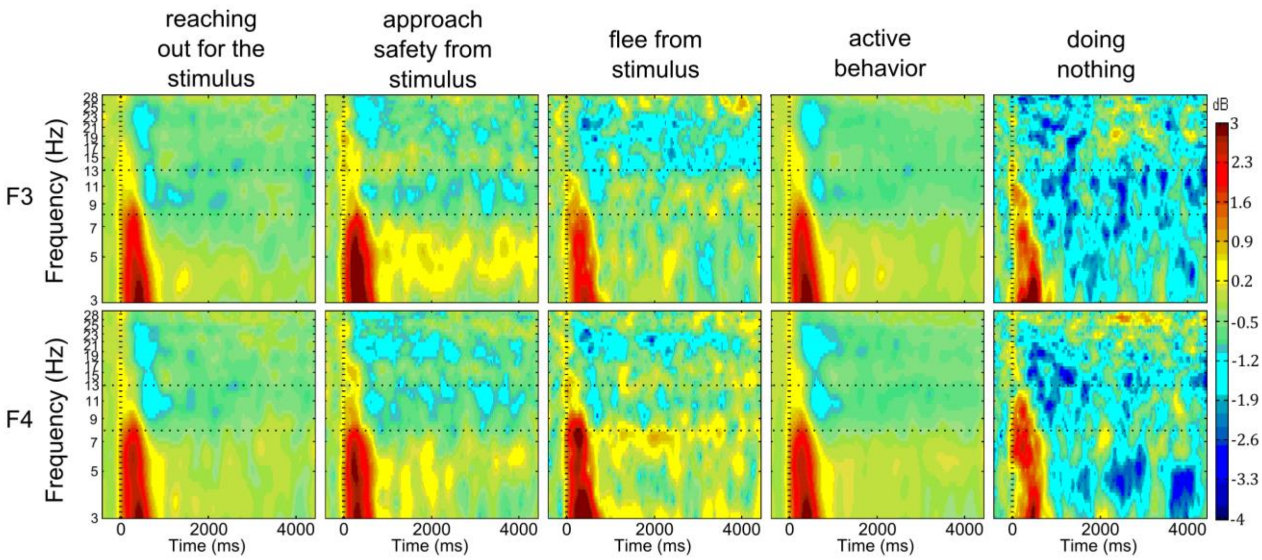

Figure 32: Time-frequency plots of the spectral activation in the time interval from 0 to 4 seconds after the cueing for every behavior from 3 Hz to 28 Hz on the electrode positions F3 and F4. The dotted lines mark the alpha band section from 8 Hz to 13 Hz.

For the repeated measure ANOVA with the within factors electrode position, condition and hemisphere, we found the three way interaction electrode position*condition*hemisphere was significant [$F(20,1000)=2.184$, $p<.05$, *partial* $\eta^2=.042$, $c=.533$] (see Figure 33).

Post hoc t-tests revealed more right sided brain activation (less alpha activity on the right side) in the negative event condition and the approach-avoidance conflicts compared to all other conditions for the electrode positions F4, C4 and P4 [$ts(50)>2.248$, $ps<.05$] . This pattern was also present for the approach-avoidance conflicts on the electrode position Fp2 and F10 [$ts(50)>2.037$, $ps<.05$], with the exception of the control condition [*t*s(50)<.975, *p*s<.33]. The conflict control condition showed highest alpha activity on all electrode positions and on both hemispheres [*t*s(50)>2.522, *p*s<.05] with the exception of the electrode positions F3, F7 and F9, where the was no significant difference to the negative condition [*t*s(50)<1.923, *p*s > .06]. For the left hemisphere, the approach-avoidance conflict had the lowest alpha activity (and therefore highest activation) for the electrode positions C3 and P3 [*t*s(50)>2.242, *p*s<.05], with the control condition being not significantly different on the position P3 [*t*(50)=1.563, *p*=.12]. To further clarify the threefold interaction, frontal asymmetry scores for every electrode position and condition were compared (see also Figure 33). For electrode position Fp2/1, no significant effects were found. For electrode position F4/3, the negative events had the most negative frontal asymmetry score, indicating relative right sided brain activation [*t*s(50)>2.468, *p*<.05], followed by the approach-avoidance conflicts [*t*s(50)>2.386, *p*< .05]. For electrode position F8/7, the same pattern arose for the negative events [*t*s(50)>2.468, *p*< .05] and the approach-avoidance conflicts [*t*s(50)>2.770, *p*<.01] with these two conditions being not significantly different from each other [*t*(50)=1.043, *p*=.30]. On electrode position F10/9 there was the same pattern as before with the negative condition and approach-avoidance conflict condition having the highest right sided activation [*t*s(50)>2.467, *p*<.05], with the exception of the conflict control condition which was only marginally significant from the negative events [*t*(50)=1.876, *p*=.07]. For the electrode position C4/3 the overall pattern with the negative condition showing the highest relative right side activity was repeated [*t*s(50)>2.881, *p*<.01], followed by the approach-avoidance conflicts [*t*s(50)>2.077, *p*<.05]. On the electrode position P4/3 this pattern repeated itself once more with the negative condition showing the highest right side activity [*t*s(50)>2.714, *p*<.01], followed by the approach-avoidance conflicts [*t*s(50)>2.145, *p*<.05] with the exception to the positive events [*t*(50)=.593, *p*=.56].

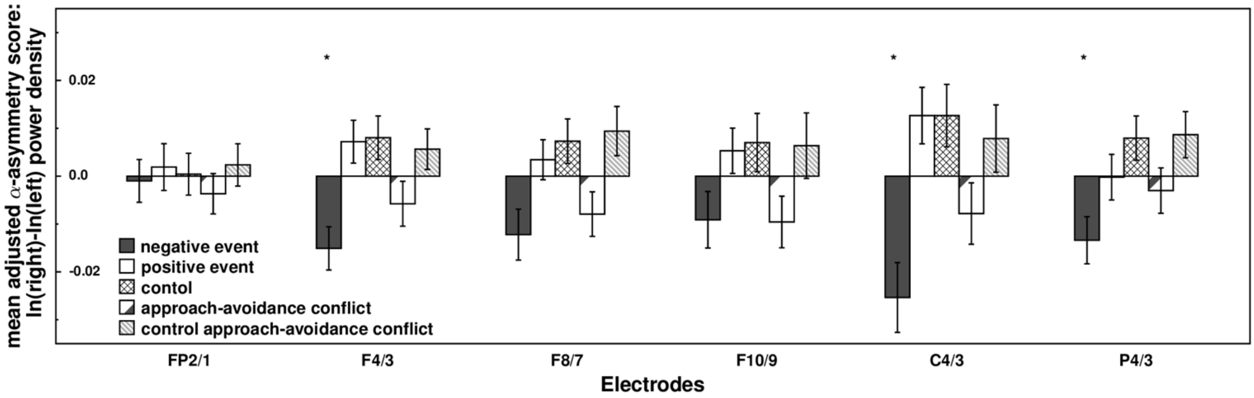

Figure 33: Three way interaction of hemisphere, condition and electrode position. Frontal asymmetry index shows more right sided activation (more left sided alpha activation) if the score is negative. Error-bars represent mean SE of the differences between the conditions. * = significant difference to all other conditions on this electrode position with p<.05.

The two way interaction electrode position*hemisphere [F(5,250)= 8.464, p<.01, *partial* η^2=15, c=.641] with a general shift in asymmetrical activation to left sided brain activity (more right sided alpha activity) for the electrodes F4/3 and C4/3[ts(50)>2.321, ps<.05] and more right sided brain activity for the electrodes F8/7 and F10/9 [ts(50)>2.293, ps<.05] was also significant.

Also the condition*hemisphere [F(4,200)=24.589, p<.01, *partial* η^2=33, c=.772] was significant. Fitting with the three way interaction, post hoc t-test revealed more right sided brain activation (less right sided alpha activity) for the negative events and the approach-avoidance conflict condition [ts(50)>2.221, ps<.05] with the exception of the control event condition being not significantly different from the negative events [t(50)=1.133, p=.26]. Also fitting with the threefold interaction, the control approach-avoidance conflict had the highest alpha activity for both hemispheres [ts(50)>2.963, ps<.01].

The significant two way interaction electrode position*condition [F(20,1000)= 8.473, p<.01, *partial* η^2=15, c=.473] revealed that on every electrode position, fitting with the threefold interaction, the control approach-avoidance conflict condition had the highest alpha activity [ts(50)>2.368, ps<.05]. For the electrodes Fp2/1, the approach-avoidance conflicts had lowest alpha activity [ts(50)>2.009, ps<.05] with the exception of the control condition being not significantly different from the approach-avoidance conflicts [t(50)=.647, p=.52]. On the electrode positions F8/7 and F10/9 the control events and the approach-avoidance conflicts showed the least alpha activity [ts(50)>2.123, ps<.05], with the exception of the positive events being not significantly different from the approach-avoidance conflicts [$t(50)<1.542$, $p>.129$]. For the electrodes C4/3 the negative events and the approach-avoidance conflicts showed the least alpha activity [$ts(50)>2.858$, $ps< .01$] as well as for the electrode position P4/3 [$ts(50)>2.467$, $ps<.05$] with the exception of the control events being not significantly different from the negative events [$t(50)=1.110$, $p=.27$]. All significant effects of the ANOVA can also be seen in Table 8.

Table 8: Significant effects in the ANOVA for the conditions in the VR paradigm in study II

significant effects	df1	df2	F value	p value	partial η²
*electrode position*condition*	*20*	*1000*	*8.473*	*<.01*	*0.15*
*condition*hemisphere*	*4*	*200*	*24.589*	*<.01*	*0.33*
*position*hemisphere*	*5*	*250*	*8.464*	*<.01*	*0.15*
*electrode position*condition*hemisphere*	*20*	*1000*	*2.184*	*<.05*	*0.42*

Topographical activation patterns for 10 Hz in the chosen time period from 0 to 4 seconds after the cuing for each condition can be seen in Figure 34. Frequency plots from 3 to 28 Hz for each condition on electrode positions F4 and F3 can be seen in Figure 35.

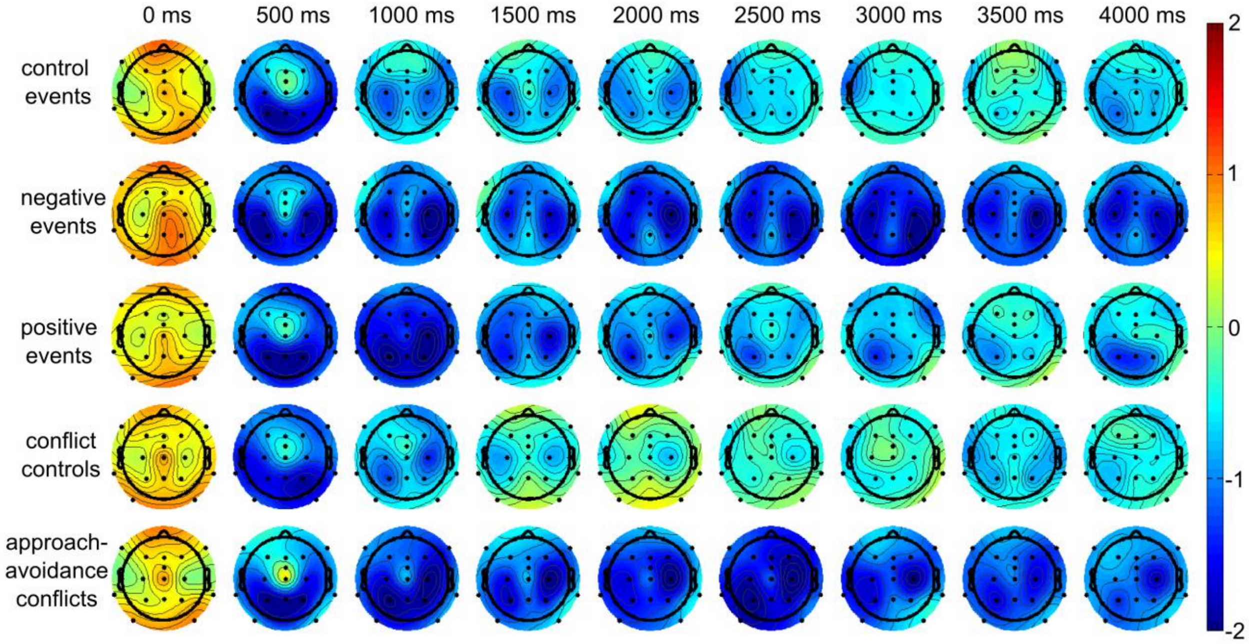

Figure 34: Topographical activation for each condition in 500 ms steps in the time interval from 0 to 4 seconds after the cueing of the events for 10 Hz.

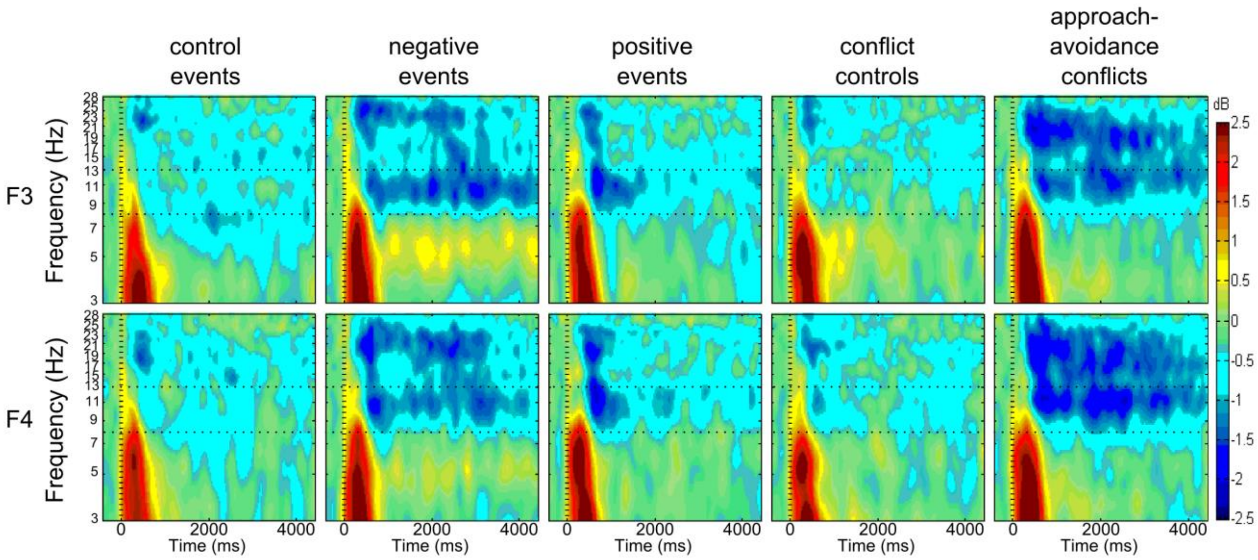

Figure 35: Time-frequency plots of the spectral activation in the time interval from 0 to 4 seconds after the cueing for every condition from 3 Hz to 28 Hz on the electrode positions F3 and F4. The dotted lines mark the alpha band section from 8 Hz to 13 Hz.

4.2.1.1.2 Bilateral frontal activation for active behavior.

The generalized linear mixed model with the fixed level 1 predictor bilateral frontal alpha activity, the random intercept and the binomial criterion “behavior or doing nothing” led to a significant effect for bilateral frontal alpha activity [*b*=4.30, *SD*=1.54, *z*=2.787, *p*<.01] (see Figure 30 right panel), with the predictors leading to a higher chance to show no behavior at all.

4.2.1.1.3 Frontal asymmetry for active behavior.

The generalized linear mixed model with the fixed level 1 predictor frontal asymmetry, the random intercept and the binomial criterion “behavior or doing nothing” led to a significant effect for frontal asymmetry [*b*=7.1789, *SD*=2.47, *z*=2.912, *p*<.01] leading to a higher chance to show no behavior at all if the value of the asymmetry index is more positive, meaning a higher relative left sided activation (see Figure 30 middle panel).

4.2.1.1.4 Principal component analysis of the activation patterns.

The principal component analysis led to the factor structure shown in Table 9. The within ANOVA including the components and the conditions led to a significant effect for condition [$F(4,200)=22.353$, $p<.01$, *partial* $\eta^2=.31$, $c=.772$] with the negative condition and the approach-avoidance conflict having more negative factor loadings than the other conditions (ps<.01) and to a significant interaction of component*condition [$F(32,1600)=10.293$, $p<.01$, *partial* $\eta^2=.17$, $c=.318$].

The within ANOVAs to clarify this interaction for every component with the different condition as within factor led to significant differences for the component 1 [$F(4,200)=5.629$, $p<.01$, *partial* $\eta^2=.10$, $c=.739$], component 3 [$F(4,200)=11.782$, $p<.01$, *partial* $\eta^2=.19$, $c=.839$], component 5 [F(4,200)=18.008, $p<.01$, *partial* $\eta^2=.27$, $c=.781$], component 7 [$F(4,200)=21.595$, $p<.01$, *partial* $\eta^2=.30$, $c=.657$], component 8 [$F(4,200)=13.262$, $p<.01$, *partial* $\eta^2=.21$, $c=.681$] and component 9 [$F(4,200)=4.074$, $p<.01$, *partial* $\eta^2=.08$, $c=.899$].

Post hoc t-test revealed for every but the ninth component that the negative events and the approach-avoidance conflicts had either more negative loadings (for components 3, 5 and 7, [$ts(50)>3.459$, $ps<.01$]) or more positive loading than the other conditions (for components 1 and 8 [$ts(50)>2.019$, $ps<.05$], with the exception of the control condition being not significantly different from these two conditions for the first component [$ts(50)<1.335$, $ps>.19$]). Also, for the components 1, 5 and 7 the negative event condition had more negative loading than the approach-avoidance conflict [$ts(50)>2.022$, $ps<.05$] and for the component 8 the negative events had more positive loadings than the approach-avoidance conflicts [$ts(50)>2.741$, $ps<.01$]. For the fifth component, positive events showed less positive loadings than the remaining conditions [$ts(50)>2.159$, $ps<.05$], for the seventh component the control events had less positive loadings than the control conflicts [$t(50)=2.608$, $p<.05$]. For the ninth component, the control conflict condition had higher factor loadings than the other conditions [$ts(50)>2.808$, $ps<.01$] but the positive events [$ts(50)=1.503$, $p=.14$].

The component 5 loads highly on the classical electrode position for frontal asymmetry (F3 $r=.633$, F4 $r=.7$) and if on looks at the topographical distribution, the component seem to drive the frontal activation pattern of the bilateral frontal activation (see Figure 36).

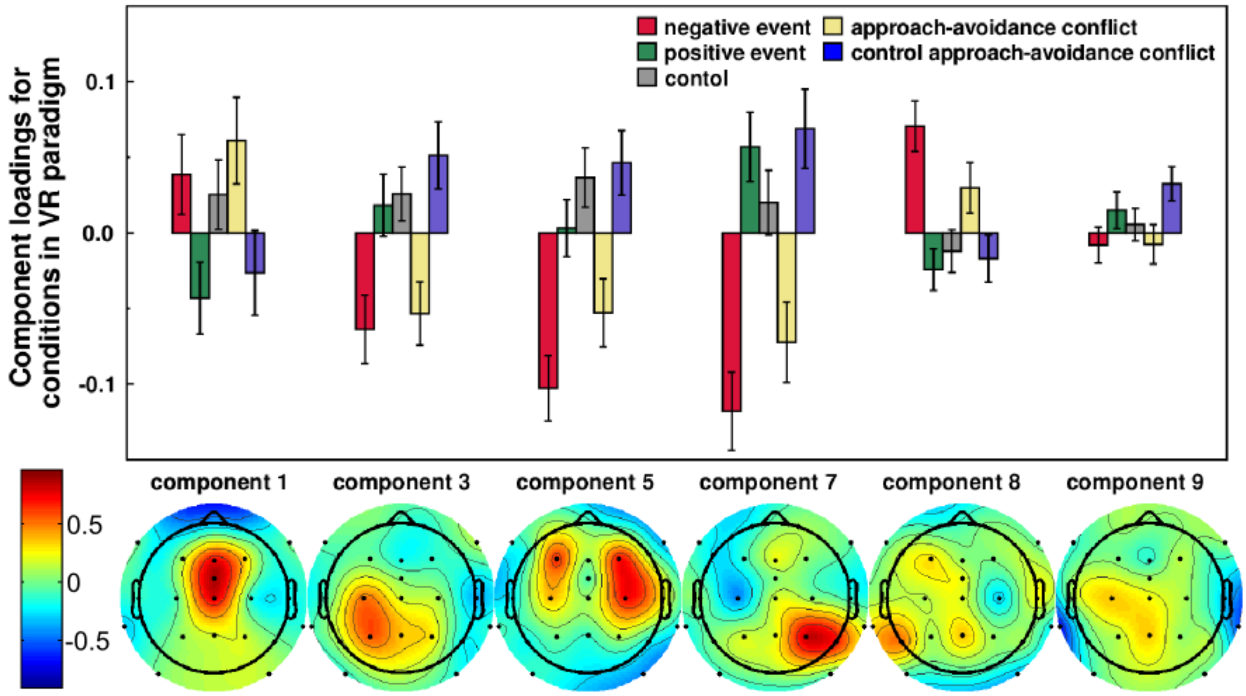

Figure 36: Component loadings and topographical plot for the components that differ in respect of the conditions of the VR paradigm.

This component is primarily driven by the difference between the negative event condition compared to all other conditions [*ts*(50)>2.502, *ps*<.05], but also the approach-avoidance conflicts showed a more negative loading than the remaining conditions [*ts*(50)>2.480, *ps*<.05], followed by the positive events [*ts*(50)>2.159, *ps*<.05], having less positive loadings than the two control conditions.

Table 9: Rotated factor loadings of the principal component analysis on every electrode position.

electrode position	component 1	component 2	component 3	component 4	component 5	component 6	component 7	component 8	component 9
Fp1	-.369	.723	-.010	-.113	.131	.097	-.188	-.125	.080
Fp2	-.330	.680	-.161	-.126	-.101	.281	.083	.027	.019
F9	-.019	.378	-.049	-.680	-.153	.108	-.137	-.064	-.134
F7	-.229	-.172	-.077	-.748	-.140	.068	-.271	.158	-.032
F3	.122	.114	-.014	.020	.633	-.067	-.125	.292	.003
Fz	.739	-.005	-.181	-.234	.043	.073	.205	.059	-.134
F4	.307	.025	-.125	-.090	.700	.328	.039	.016	.124
F8	-.143	.065	-.076	-.119	.039	.796	-.022	.129	-.082
F10	-.011	.272	.117	-.134	-.361	.668	-.056	-.046	.050
FC5	-.228	-.043	-.081	-.469	-.026	-.307	-.490	.173	.452
FC1	.814	-.130	.175	.058	.012	-.103	-.090	.003	.072
FCz	.857	-.086	.030	.178	-.063	-.061	.025	.212	.087
FC2	.802	-.048	.203	.060	.108	-.049	.103	-.054	.042
FC6	-.086	.021	-.572	.095	.334	.029	.082	.173	.426
T7	-.115	-.746	-.076	.016	-.217	-.065	.029	.104	.109
C3	-.060	-.257	.495	-.143	.368	-.093	-.420	.118	.349
Cz	.772	-.009	.157	.146	.075	.095	.163	.186	.237
C4	-.131	.108	.096	.143	.706	-.137	.032	-.278	.076
T8	-.209	-.300	-.354	.061	.267	-.144	-.131	.235	-.301
TP9	-.301	.072	-.098	.005	-.094	-.004	-.171	.312	-.682
CP1	.198	.131	.814	.022	.102	-.042	.057	.192	.092
CP2	.441	.082	.466	.002	-.011	-.004	.500	.061	-.008
TP10	-.137	-.082	-.125	-.088	-.219	-.545	.168	-.214	-.537
P7	-.095	-.214	.131	.545	-.186	.086	.030	.495	-.064
P3	.072	-.217	.564	.295	-.007	.334	.178	.081	.125
Pz	.183	.453	.359	.192	-.113	-.235	.196	.353	.340
P4	.167	.043	.275	.036	.117	-.144	.807	.061	.058
P8	.017	-.229	-.204	.184	-.194	.030	.686	.075	.103
PO9	.011	-.064	-.134	.545	-.115	-.372	-.119	-.083	-.085
PO10	.118	-.428	-.166	.280	-.430	.283	-.028	-.326	-.023
O1	-.353	.044	.016	.273	-.134	-.357	-.190	-.607	-.116
O2	-.207	.087	-.123	.028	-.078	-.082	-.021	-.851	.095

4.2.1.2 Movie paradigm.

4.2.1.2.1 Frontal asymmetry.

The ANCOVA with the frontal asymmetry as resulting variable and the conditions and order as factors, as well as the trait sadness/frustration (ARES:BIS2) as covariate lead to a significant interaction of the covariate with the conditions [$F(2,98)=5.18$, $p<.01$, *partial* $\eta^2=.10$].

The regressions with the trait sadness/frustration as predictor and the frontal asymmetry on the electrode position F4/3 for every condition lead to a significant negative predictor for the negative film [$b=-.384$, $t(51)=2.937$, $p<.01$, $R^2=.15$] and to no significant prediction for the positive film [$b=.043$, $t(50)=.304$, $p=.762$] and the neutral film condition [$b=.154$, $t(50)=1.09$, $p=.281$] (see Figure 37). For both, the positive and the neutral film condition, frontal asymmetry values were corrected for outliers (z-value > 3.29) as it is suggested by Tabachnick and Fidell (2007, p. 73).

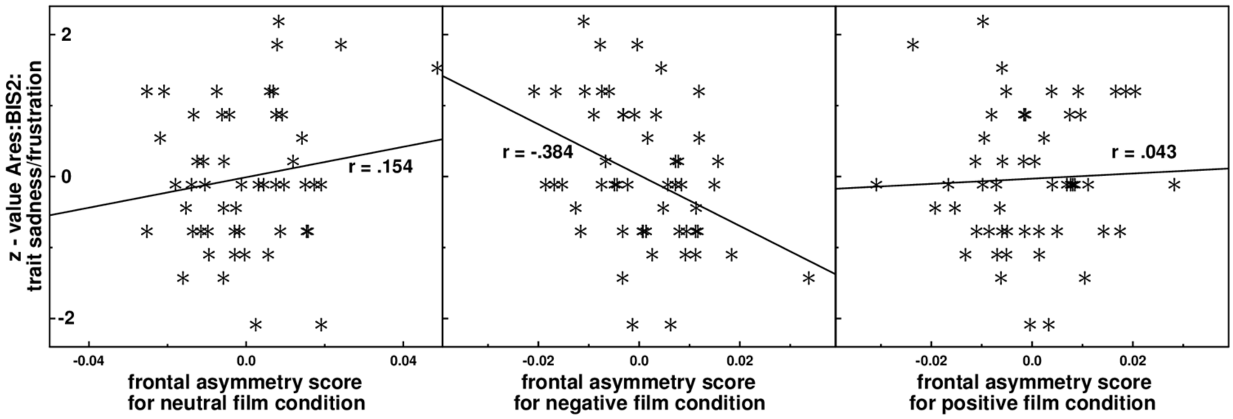

Figure 37: Correlations of frontal asymmetry score for the different conditions of the movie paradigm with the z-transformed trait sadness/frustration score, measured with the ARES-scales.

The ANCOVA with the frontal asymmetry as resulting variable and the conditions and order as factors, as well as the trait impulsive attention (BAIS:Attention) as covariate lead to a significant interaction of the covariate with the conditions [$F(2,98)=3.756$ $p<.05$, *partial* $\eta^2=.07$].

The regressions with the trait impulsive attention as predictor and the frontal asymmetry on the electrode position F4/3 for every condition lead to a significant predictor for the negative film [$b=-.340$, $t(51)=2.553$, $p<.05$, $R^2=.12$] and to no significant prediction for the positive film [$b=.050$, $t(50)=.349$, $p=.729$] and the neutral film condition [$b=-.137$, $t(50)=.965$, $p=.339$] (see Figure 38).

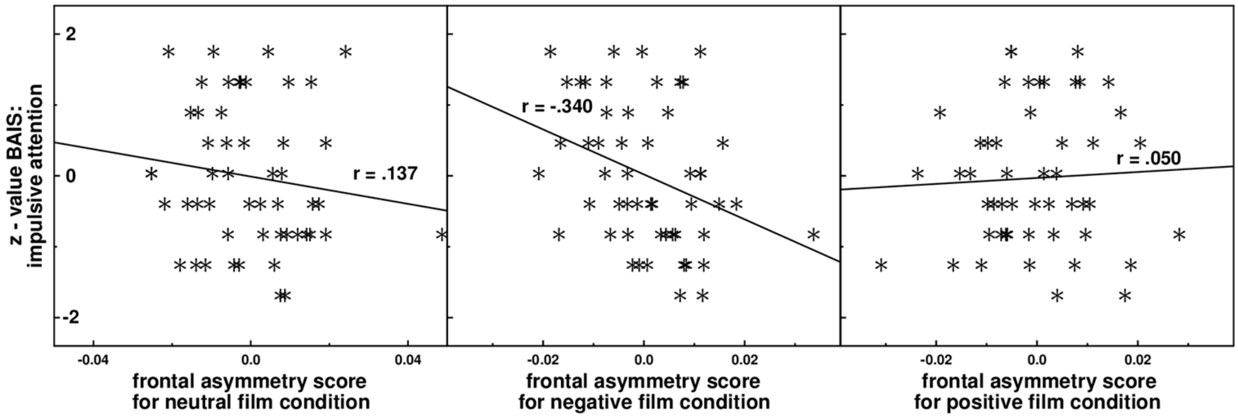

Figure 38: Correlations of frontal asymmetry score for the different conditions of the movie paradigm with the z-transformed impulsive attention score, measured with the Barrett impulsiveness scales.

However, as these significant interactions are derived from a series of ANCOVAS, the results should be considered with caution especially for the impulsive attention, because the critical Bonferroni corrected *p*-value for multiple comparisons was not reached: p_{crit}=.0018,

$p_{sadness/frustration}$=.007,

$p_{impulsive\ attention}$=.027.

4.2.1.2.2 Bilateral frontal activation.

For the bilateral frontal activation, no significant main effect of the conditions [*Fs*(2, 98)<2.396, *ps*>.10] or interaction of the traits with the conditions could be detected in the ANCOVAS [*Fs*(2, 98)<2.278, *ps*>.11] with the conditions and order as factors and the traits as covariate.

4.2.1.3 Mental imagery paradigm.

4.2.1.3.1 Frontal asymmetry.

For the frontal asymmetry, no significant main effect of the conditions [*Fs*(2, 98)<.696, *ps*>.50] or interaction of the traits with the conditions could be detected in the ANCOVAS [*Fs*(2, 94)<2.127, *p* >.13] with the conditions, order and negative script manifestations as factors and the traits as covariate. As executed by Wacker and colleagues, an additional analysis of the subgroups that experienced the scripts more in a (revised) BIS way or a (revised) FFFS way was performed by computing an index of the BIS/FFFS experience of the script based on the two rating questions about the uncertainty what to do and the experience of panic and the feeling to just want to run away (see Wacker et al. 2008). This difference index, subtracting the experience of conflict from the panic, showing negative values for the experience of conflict was added as additional covariate to the ANCOVAS, and still no significant main effects [*Fs*(2, 94)<.597, *ps*>.55] or interactions [*Fs*(2, 92)<2.177, *ps*>.12] could be detected.

4.2.1.3.2 Bilateral frontal activation.

The ANCOVA with the bilateral frontal activation as resulting variable and the conditions, order and negative script manifestation as factors, as well as the trait impulsive non planning behavior (BAIS:Non-planing) as covariate lead to a significant interaction of the covariate with the conditions [$F(2,98)=8.125$, $p<.01$, *partial* $\eta^2=.13$]. This result was significant even under the multiple comparison adjusted p-value of $p_{crit}=.0018$.

The regressions with the trait impulsive non planning behavior as predictor and the bilateral frontal alpha activation on the electrode position F4/3 for every condition lead to a significant positive prediction for the negative scripts [$b=.421$, $t(51)=3.283$, $p<.01$], a significant negative predictor for the neutral script [$b=-.307$, $t(51)=2.283$, $p<.05$, $R^2=.09$] and no significant predictor for the control imagery script [$b=-.013$, $t(51)=-.093$, $p=.926$] (see Figure 39).

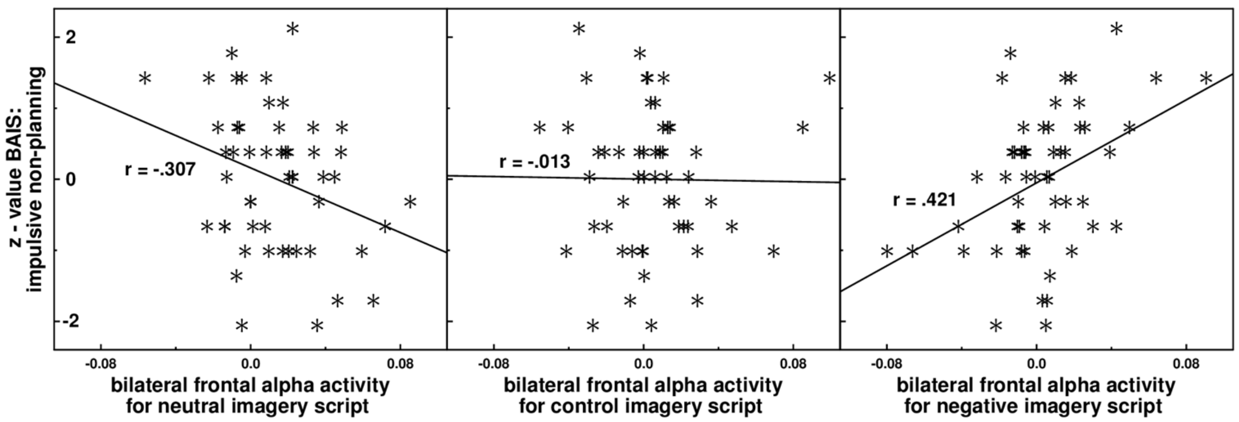

Figure 39: Correlations of bilateral frontal alpha activity for the different conditions of the mental imagery paradigm with the z-transformed impulsive non-planning score, measured with the Barrett impulsiveness scales.

4.2.1.4 Resting period.

4.2.1.4.1 Frontal asymmetry.

4.2.1.4.1.1 Reliability.

Cronbach´s α for the frontal asymmetry on the electrode position F4/3 was α=.990 for the resting state in the VR-paradigm, α=.986 for the resting stat in the movie paradigm and α=.998 for the resting state EEG in the mental imagery paradigm.

However, intraclass correlation of the frontal asymmetry was r=.239, being not significantly different from 0 [F(51,104)=1.315, p=12]. The ANOVA to determine differences concerning gender and the measurement time did not yield to any significant main effect for measurement time [F(2,98)=1.134, p=.33] or gender [F(1,49)=.920, p=.34] nor their interaction [F(2,98)=1.098, p=.34], but the ANOVA with for the paradigm and gender led to a significant interaction of the paradigm and the gender
[F(2,98)=4.013, p<.05], with still no significant main effects for the paradigm [F(2,98)=.166, p=.85] or gender [F(1,49)=.920, p=.34]. The Bonferroni adjusted post hoc t-test led to a higher right sided frontal activation in males during the resting state before the movie paradigm than in females [t(49)=2.965, p<.01].

Following this difference, intraclass correlation of the frontal asymmetry was again computed for each gender separately. For male it was r=.298, for female it was r=.361, but still it was not significant from 0 [F(23,46)=1.425, p=.15 for male and F(26,52)=1.566, p=.08 for female].

4.2.1.4.1.2 Correlation with traits.

The only significant correlation with the traits was present for the impulsive attention (BAIS:Attention) showing a negative correlation r=-.285 p=. 04. However, if the Bonferroni correction for multiple testing is applied, the correlation is not significant anymore, for the critical p-value drops to p_{crit}=.0018.

4.2.1.4.2 Bilateral frontal activation.

4.2.1.4.2.1 Reliability.

Cronbach´s *α* for the bilateral frontal alpha activity on the electrode position F4/3 was *α*=.977 for the resting state in the VR-paradigm, *α*=.982 for the resting stat in the movie paradigm and *α*=.999 for the resting state EEG in the mental imagery paradigm. Intraclass correlation of the bilateral frontal alpha activity was *r*=.898, being significantly different from 0 [*F*(51, 104)=9.758, *p*<.01].

4.2.1.4.2.2 Correlation with traits.

For bilateral frontal alpha activity during the resting period, there were no significant correlations with any trait (all *p*>.12).

4.2.2 Skin conductance.

4.2.2.1 Virtual T-maze paradigm.

The repeated measure ANOVA for the skin conductance lead to a significant effect for the conditions [*F*(5,250)=6.190, *p*<.01, *partial* η^2=.11, *c*=.373].

The post hoc t-test revealed that the negative event condition (*m*=4.734 µS/sec, *SD*=8.624 µS/sec) and the approach-avoidance condition (*m*=5.158 µS/sec, *SD*=11.142 µS/sec) showed higher skin conductance than all other conditions (control positive events: *m*=2.301 µS/sec, *SD*=5.444 µS/sec, positive events: *m*=2.248 µS/sec, *SD*=4.101 µS/sec, control negative events: *m*=2.168 µS/sec, *SD*=4.115 µS/sec, control approach-avoidance conflicts *m*=2.022 µS/sec, *SD*=4.240 µS/sec) [*ts*(50)>2.379, *ps*<.03]. The skin conductance for all conditions can be seen in Figure 40.

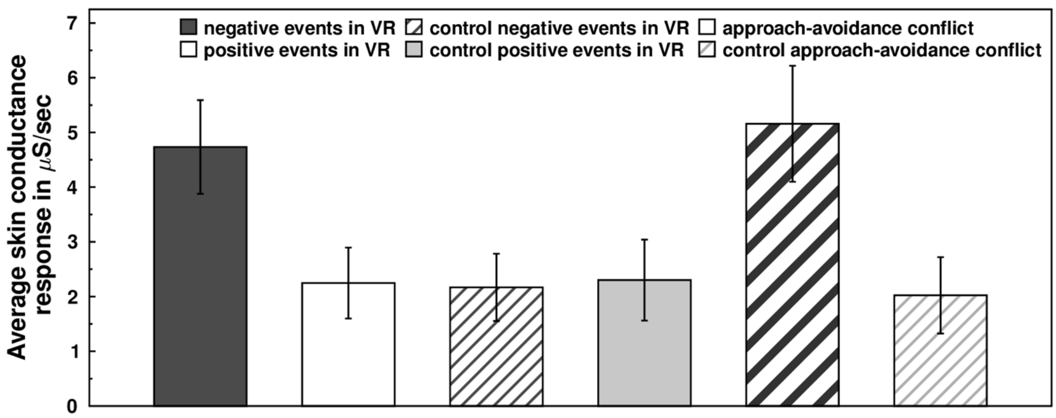

Figure 40: Skin conductance for every condition in the VR paradigm in study II. Error-bars represent mean SE of the differences between the conditions.

4.2.2.2 *Movie paradigm.*

The repeated measure ANOVA for the movie paradigm for the time period of frontal asymmetry measurement did neither yield a significant effect for the condition [$F(2,100)=.212$, $p=.809$] nor for order [$F(1,50)=.769$, $p=.385$] or their interaction [$F(2,100)=.104$, $p=.901$].

Also, did the repeated measure ANOVA for the movie paradigm during the film sequence not lead to a significant effect of the SCL for condition [$F(2,100)=.018$, $p=.982$], order [$F(1,50)=.001$, $p=.982$] and their interaction [$F(2,100)=.207$, $p=.814$].

4.2.2.3 *Mental imagery paradigm.*

The repeated measure ANOVA for the mental imagery paradigm for the time period of the frontal asymmetry led to a significant effect for the SCL for the condition [$F(2,96)=5.258$, $p<.01$, *partial* $\eta^2=.099$]. The negative script manifestation [$F(1,48)=1.192$, $p=.280$], the order [$F(1,48)=3.131$, $p=.083$] their interaction [$F(1,48)=1.598$, $p=.212$], the interaction of condition and the negative script manifestation [$F(2,96)=.946$, $p=.392$], the interaction of condition and order [$F(2,96)=.071$, $p=.931$] and the threefold interaction [$F(2,96)=.108$, $p=.898$] were not significant.

Post hoc t-tests revealed that the SCL was significantly higher for the negative script ($m=.705$ µS, $SD=3.225$ µS) and the neutral script ($m=.066$ µS, $SD=2.726$ µS) than for the control script ($m=-1.238$ µS, $SD=3.116$ µS) [$ts(51)>2.281$, $ps < .03$] (see Figure 41).

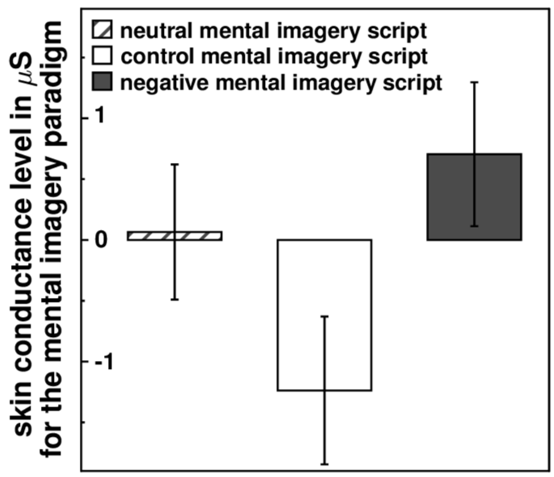

Figure 41: Skin conductance level for the different conditions of the mental imagery paradigm in µ Siemens.

For the imagery script period, the repeated measure ANOVA did not show a significant effect for the SCL for the condition [$F(2,96)=1.728$, $p=.183$]. The negative script manifestation [$F(1,48)=1.296$, $p=.261$], the order [$F(1,48)=1.950$, $p=.169$] their interaction [$F(1,48)=1.534$, $p=.222$], the interaction of condition and the negative script manifestation [$F(2,96)=.478$, $p=.622$], the interaction of condition and order [$F(2,96)=.499$, $p=.609$] and the threefold interaction [$F(2,96)=.826$, $p=.441$] were not significant.

4.2.3 Heart period.

4.2.3.1 VR paradigm.

The repeated measure ANOVA for the heart inter-beat intervals leads to a significant effect for the Heartbeats [$F(9,459)=25.905$, $p<.001$, *partial* $\eta^2=.34$], the conditions [$F(4,204)=2.822$, $p<.05$, *partial* $\eta^2=.05$] and the interaction of the conditions and Heartbeats [$F(36,1836)=3.79$, $p<.001$, *partial* $\eta^2=.07$]. The post hoc t-test for the Heartbeats revealed that the lowest inter-beat intervals are at the third and second heartbeat [$ts(51)>2.017$, $ps<.05$], followed by the fourth heartbeat [$ts(51)>6.546$, $ps<.01$] with the exception of the first heartbeat [$t(51)=1.752$, $p=.09$]. The next highest inter beat interval was present for the first heartbeat [$ts(51)>2.258$, $ps<.03$], with the exception of only marginal differences to the fifth and eighth heartbeat [$ts(51)>1.839$, $ps<.07$]. Also the fifth and eighth heartbeat had significant smaller inter-beat intervals than the sixth and seventh heart [$ts(51)>2.127$, $ps<.04$]. For the conditions, the inter-beat intervals were lowest for the negative events and the positive events [$ts(51)>2.164$, $ps<.04$], with the exception of the control events being not significantly different from the negative events [$t(51)=1.281$, $p=.21$].

For the interaction of the heartbeats and the conditions there were lower inter-beat intervals for the positive events than all other conditions for the second and third heartbeat [$ts(51)>2.053$, $ps<.05$], with the exception of the negative event on the third heartbeat [$t(51)=1.202$, $p=.24$]. For the fifth, the sixth and the seventh heartbeat, the lowest inter-beat intervals were present for the negative events [$ts(51)>2.43$, $ps<.02$] with the exception to the positive events on the seventh heartbeat being not significantly different [$t(51)=.772$, $p=.44$]. The greatest inter-beat intervals for the sixth heartbeat were present for the control approach-avoidance conflicts [$ts(51)>2.159$, $ps<.04$] with the exception of the approach-avoidance conflicts being not significantly different [*t*s(51)=1.571, *p*=.12]. On the eighth heartbeat, the inter-beat intervals were the lowest for the positive events [*t*s(51)>2.62, *p*s<.02], with the exception of the control condition being only marginally different [*t*(51)=1.937, *p*=.06]. On the ninth heartbeat, the highest inter-beat intervals were present for the approach-avoidance conflicts [*t*s(51)>2.325, *p*s<.03] with the exception of its control condition [*t*s(51)>2.04, *p*s<.05]. On the tenth heartbeat, the highest inter-beat intervals were present for the negative events and the approach-avoidance conflict condition [*t*s(51)>2.1, *p*s<.05], with the exception of the control condition being only marginally significant different from the approach-avoidance conflicts [*t*(51)=1.91, *p*=.06]. The interaction is also shown in Figure 42.

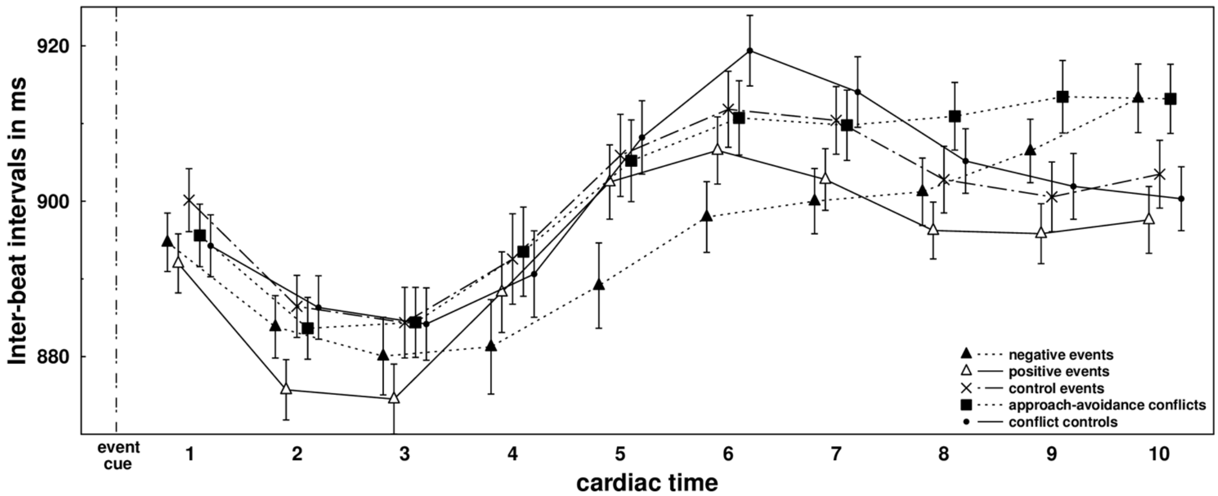

Figure 42: Heart period in ms for every event for 10 cardiac inter-beat intervals in the VR paradigm after the onset of the cueing. Error-bars represent mean SE of the differences between the conditions.

4.2.3.2 Movie paradigm.

The split-plot ANOVA for the heart inter-beat intervals lead to significant effects for the heartbeats [$F(9,450)=9.153$, $p<.001$, *partial* $\eta^2=.16$] and the conditions [$F(2,100)=3.571$, $p<.05$, *partial* $\eta^2=.07$]. The post hoc t-test for the Heartbeats revealed that the lowest inter-beat intervals are first heartbeat [*t*s(51)>2.047, *p*s<.05], followed by the second heartbeat [*t*s(51)>2.27 *p*s<.05] with the exception of the fourth heartbeat [*t*(51)=1.745, *p*=.09]. The next highest inter beat interval was present for the fourth, third and fifth heartbeat [*t*s(51)>2.206, *p*s<.04], with the exception of only marginal differences of the third heartbeat to the sixth and eighth and tenth heartbeat [*t*s(51)>1.734, *p*s<.09] and no significant difference to the ninth heartbeat [*t*s(51)=1.606, *p*=.11]. For the conditions, the inter-beat intervals were lowest for the negative and the positive films [*t*s(51)>2,064 *p*s<.05]. The two main effects can also be seen in Figure 43.

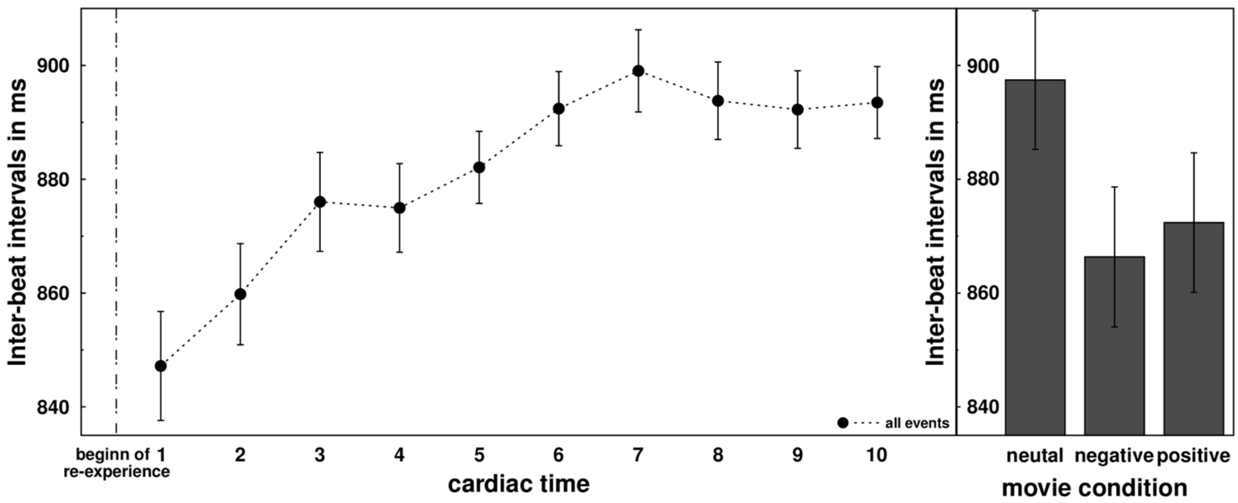

Figure 43: Heart period in ms for 10 cardiac inter-beat intervals in the movie paradigm after the beginning of the re-experience period, together with the heart period for every movie condition. Error-bars represent mean SE of the differences between the conditions.

4.2.3.3 Mental imagery paradigm.

The split-plot ANOVA for the heart inter-beat intervals lead to no significant effect for neither of the factors or the interactions. Neither Heartbeats [*F*(9,432)=1.806, *p*=.11, *c*=.55] the conditions [*F*(2,96)=1.005, *p*=.37, *c*=.696], their interaction [*F*(18,864)=1.222, *p*=.236, *c*=.454], nor the between factors order [*F*(1,48)=1.730, *p*=.20] or negative script manifestation [*F*(1,48)=.123, *p*=.73], their interaction [*F*(1,48)=.265, *p*=.61], or any other interaction of the between factors and the within factors had an influence on the inter-beat intervals (all *p*>.20).

4.2.4 Behavior in the VR paradigm.

The behavior in the VR paradigm was analyzed over all conditions and lead to significant correlations with different traits. “Fleeing from the stimulus” (11.46%), “approaching safety from the stimulus” (22.57%), “reaching out for the stimulus” (55.76%) and “doing nothing” (8.32%).

For the behavior “Fleeing from the stimulus”, which could be seen in all but the positive event conditions and which was predominantly shown in the negative events and approach-avoidance conflicts (see Table 6), there was a significant positive correlation with the self-concept [*r*=.312, *p*<.05] and self-efficacy [*r*=.331, *p*<.05], as well as a negative correlation with trait anger [*r*=--.301, *p*<.05] and the classical behavior inhibition system [*r*=-.333, *p*<.05] (see Figure 44).

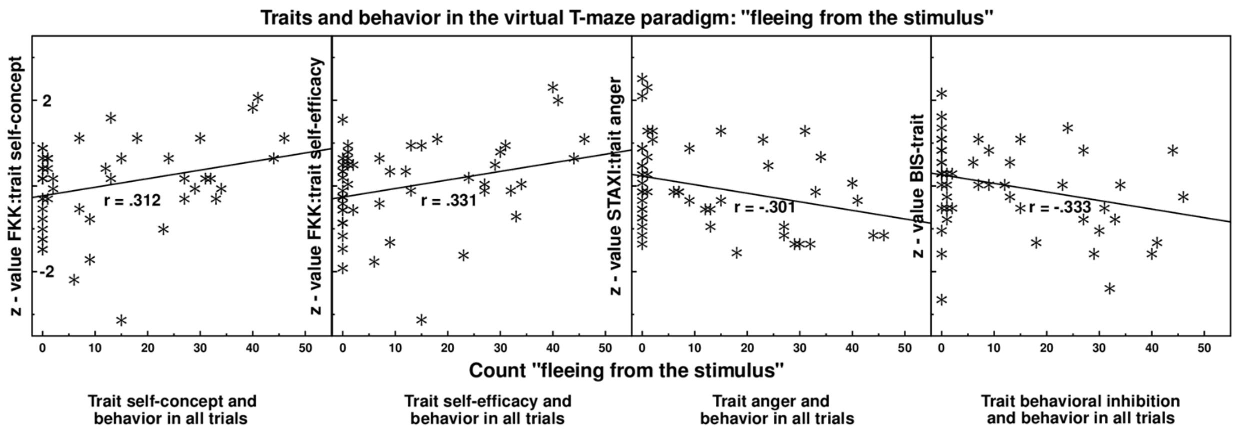

Figure 44: Traits and behavior in all trials for "fleeing from the stimulus" behavioral category in the VR paradigm in study II.

The "approaching safety from the stimulus" behavior which could also be seen in all but the positive event conditions and which was predominantly shown in the negative events and approach-avoidance conflicts (see Table 6) was not significantly correlated with any trait.

The "reaching out for the stimulus" behavioral condition, that could be seen in any condition in the paradigm but which was negligible during the negative condition (see Table 6), was linked to positive correlations with the traits BAS drive [*r*=.316, *p*<.05] and the classical behavior inhibition system [*r*=.312, *p*<.05], as well as negative correlations with the traits self-concept [*r*=-.365, *p*<.01], internality [*r*=-.337, *p*<.05], self-efficacy [*r*=-.415, *p*<.01] and fight [*r*=-.359, *p*<.01] (see Figure 45).

In the "doing nothing" behavioral category, that was seen in every experimental condition but the positive events (see Table 6), one outlier had to be excluded (z-value =3.54 > 3.29, see Tabachnick & Fidell, 2007, p. 73). The remaining correlations between the "doing nothing" behavioral category and the traits were for positive for self-concept [*r*=.304, *p*<.05] and self-efficacy [*r*=.370, *p*<.01] (see Figure 46).

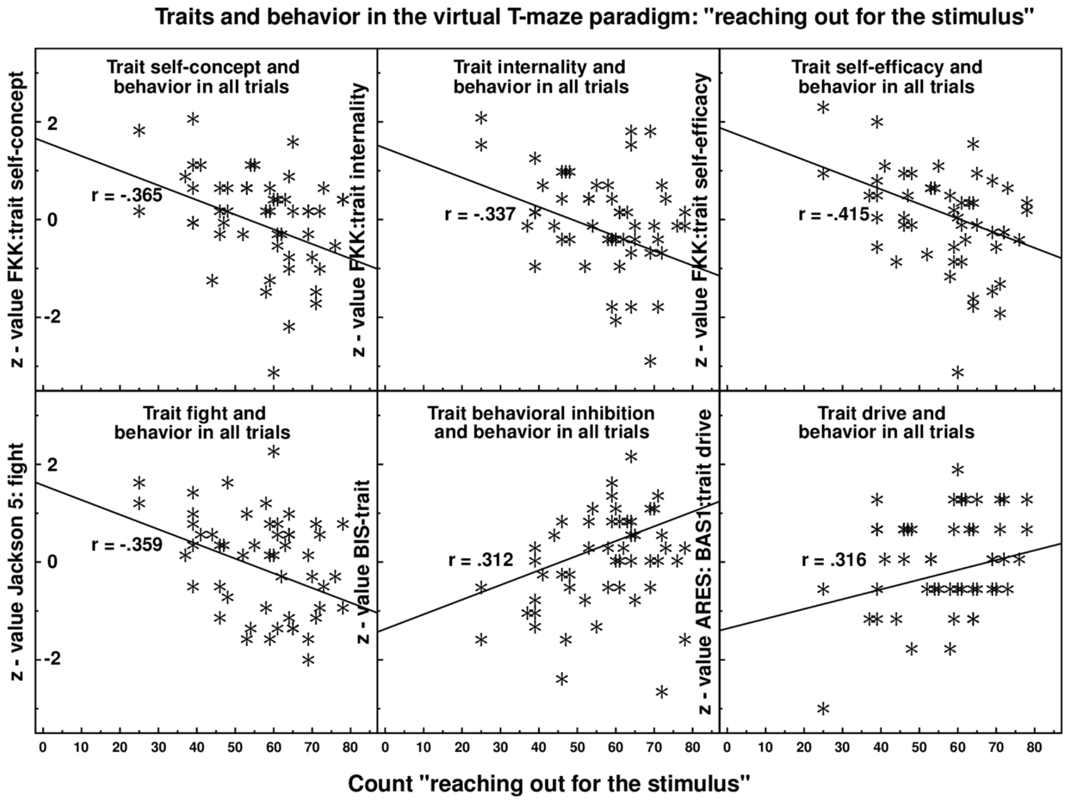

Figure 45: Traits and behavior in all trials for "reaching out for the stimulus" behavioral category in the VR paradigm in study II

However, all correlation between the traits and the shown behavior in the VR paradigm of this study are to be interpreted cautiously, because with the Bonferroni correction for multiple comparison (28 different traits or subtraits), no significant relation is found any more (*p*-value for multiple comparisons: p_{crit}=.0018, $p_{strongest\ trait\ relation}$ =.002).

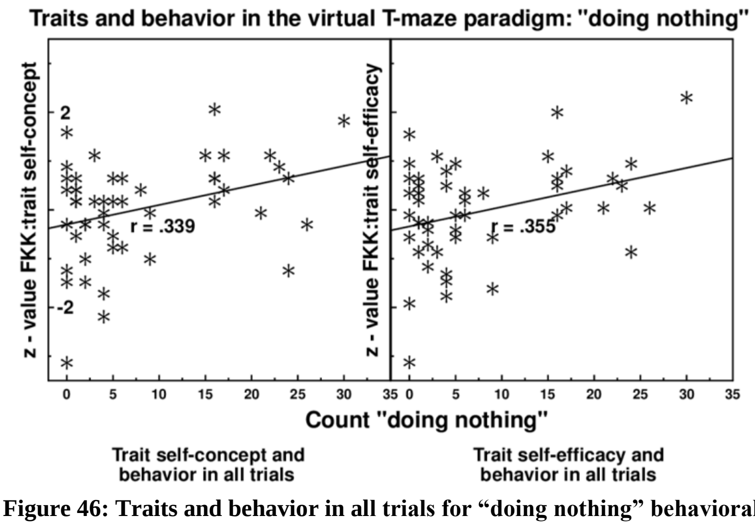

Figure 46: Traits and behavior in all trials for "doing nothing" behavioral category in the VR paradigm in study II.

4.2.5 Ratings.

The repeated measure ANOVA for the ratings led to a significant effect for the conditions [$F(11,561)=41.491$, $p<.01$, *partial* $\eta^2=.449$, $c=.578$], the question compounds [$F(4,204)=193.135$, $p<.01$, *partial* $\eta^2=.791$, $c=.471$], the interaction of the conditions and question compounds [$F(44,2244)=38.813$, $p<.01$, *partial* $\eta^2=.432$, $c=.203$].

The between factor was not significant [$F(1,51)=2.047$, $p=.159$], as well as the interaction of this factor with the condition [$F(11,561)=1.307$, $p=.216$, $c=.578$], the compounds [$F(4,204)=.090$, $p=.904$, $c=.471$] and the interaction of the compounds, the conditions and the between factor [$F(44,2244)=1.62$, $p=.108$, $c=.203$].

The post hoc t-test for the main effect of the question compounds revealed that highest ratings were obtained for positive emotions ($m=5.135$, $SD=.835$) and arousal ($m=5.036$, $SD=.655$) [$ts(52)>6.569$, $ps<.001$], followed by the conflict ratings ($m=3.741$, $SD=1.000$) [$ts(52)>8.192$, $ps<.001$], the immersion ratings ($m=2.616$, $SD=.316$) [$ts(52)>3.809$, $ps<.001$] and negative emotions ($m=2.341$, $SD=.515$) with the lowest ratings [$ts(52)>3.809$, $ps<.001$].

The post hoc t-test for the main effect of the conditions revealed that the ratings were lowest for the control conditions of the VR (control negative events: $m=3.260$, $SD=.540$, control positive events: $m=3.288$, $SD=.524$, control approach-avoidance conflicts: $m=3.294$, $SD=.639$) [$ts(52)>3.056$, $ps<.01$], followed by the neutral movie ($m=3.637$, $SD=.552$) and the positive VR condition ($m=3.568$, $SD=.569$) [$ts(52)>2.048$, $ps<.05$] with the neutral movie condition having no significant difference in the rating to the VR negative condition [$t(52)=.906$, $p=.369$]. The next higher ratings are for the negative events in VR ($m=3.735$, $SD=.624$), the imagery control condition ($m=3.812$, $SD=.401$), the approach-avoidance conflicts in the VR paradigm ($m=3.880$, $SD=.729$), the positive movie condition ($m=3.928$, $SD=.569$) and the imagery neutral condition ($m=3.945$, $SD=.401$) [$ts(52)>2.048$, $ps<.05$], with the negative VR condition having lower ratings then the neutral imagery condition [$ts(52)=2.079$, $ps<.05$]. The next higher ratings were for the negative movie condition ($m=4.302$, $SD=.705$) [$ts(52)>3.405$, $ps<.01$] and the highest ratings were obtained for the negative imagery condition ($m=4.637$, $SD=.548$) [$ts(52)>3.620$, $ps<.01$].

The post hoc t-tests for the interaction of the conditions and the question compounds revealed that for the negative emotions, the negative imagery condition of the imagery paradigm (*m*=5.024, *SD*=1.602) and the negative movie of the film sequence paradigm (*m*=4.941, *SD*=2.322) were highest in the ratings [*t*s(52)>7.035, *p*s<.001], followed by the negative events (*m*=2.844, *SD*=1.183) and the approach avoidance conflicts (*m*=2.660, *SD*=1.309) in the virtual T-maze paradigm [*t*s(52)>3.032, *p*s<.01]. The remaining conditions were all low in negative emotion ratings, with the neutral film sequence (*m*=1.846, *SD*=.798) being a bit higher in negative emotion ratings than the positive events (*m*=1.375, *SD*=.469) and the single control events (control negative events: *m*=1.528, *SD*=.601, control positive events: *m*=1.472, *SD*=.709) in the VR paradigm and the neutral (*m*=1.472, *SD*=.614) and control imagery scripts (*m*=1.447, *SD*=.550) [*t*s(52)>2.444, *p*s<.02]. Also, the positive film sequence (*m*=1.854, *SD*=1.373) was higher in negative emotion rating than the neutral and control imagery scripts and the positive events in the VR paradigm [*t*s(52)>2.005, *p*s<.05] and the control approach avoidance conflicts (*m*=1.625, *SD*=.897) was higher in negative rating than the positive events in VR [*t*(52)=2.107, *p*<.05]. All interactions of the question compounds and the conditions are also shown in Figure 47.

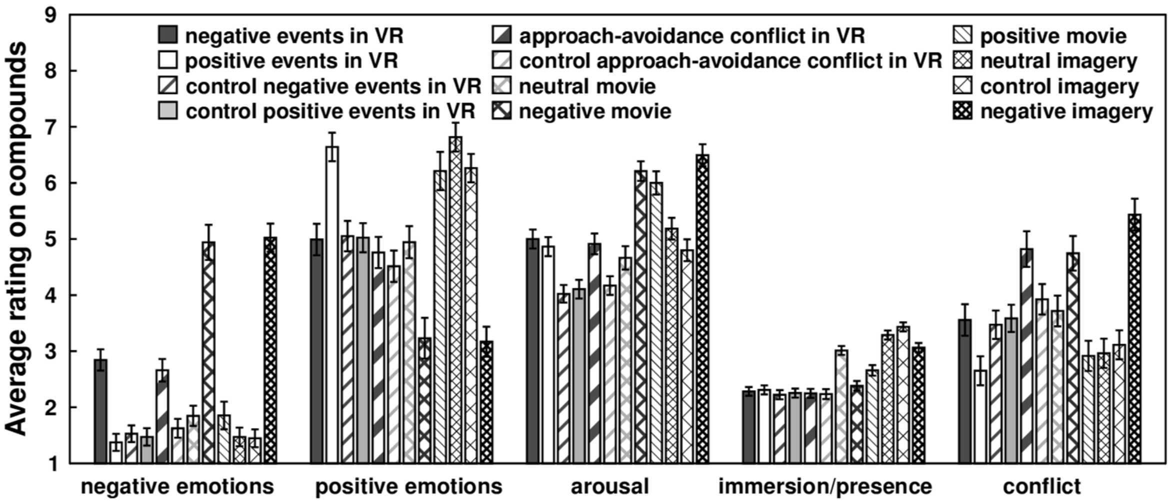

Figure 47: Ratings for negative emotions, positive emotions, arousal, immersion/presence and conflict in study II. Error-bars represent mean SE of the differences between the conditions.

For the positive emotions ratings, the positive events in the VR paradigm (*m*=6.642, *SD*=1.300), the neutral (*m*=6.816, *SD*=1.298) and the control imagery scripts (*m*=6.264, *SD*=1.257) as well as the positive movie (*m*=6.212, *SD*=2.104) had highest ratings [*t*s(52)>3.183, *p*s<.01] with the neutral imagery script being higher in positive ratings than the control imagery script and the positive movie condition [*ts*(52)>2.145, *p*s<.05]. The lowest positive emotion ratings were present for the negative movie condition (*m*=3.231, *SD*=2.138) and the negative imagery conditions (*m*=3.170, *SD*=1.180) [*t*s(52)>3.025, *p*s<.01]. Additionally, there was a lower positive emotional rating for the control approach-avoidance conflicts (*m*=4.514, *SD*=1.918) than for the single control conditions in the VR paradigm (control negative events: *m*=5.052, *SD*=1.850, control positive events: *m*=5.024, *SD*=1.805) [*t*s(52)>3.075, *p*s<.05]. All other conditions were in midrange for the positive ratings, differing not significantly from each other (negative events in VR: *m*=4.990, *SD*=1.669, neutral movie condition: *m*=4.943, *SD*=1.462, approach-avoidance conflicts in VR: *m*=4.759, *SD*=1.597). For graphical illustration see Figure 47.

For the arousal ratings, the positive (*m*=6.000, *SD*=1.177) and the negative movie (*m*=6.211, *SD*=1.136) as well as the negative imagery conditions (*m*=6.494, *SD*=1.043) have the highest rating [*t*s(52)>4.335, *p*s<.001] with the positive movie being less arousing than the negative imagery conditions [*t*(52)=2.743, *p*<.05]. The lowest arousal ratings were present for the control conditions of the VR paradigm (control negative events: *m*=4.023, *SD*=1.071, control positive events: *m*=4.106, *SD*=1.126, control approach-avoidance conflicts: *m*=4.170, *SD*=1.084) [*t*s(52)>2.473, *p*s<.02]. Additionally, there were higher arousal ratings for the neutral imagery script (*m*=5.185, *SD*=1.006) than for the control script (*m*=4.800, *SD*=1.055) and the neutral movie (*m*=4.664, *SD*=1.106) [*ts*(52)>2.174, *ps*<.04]. The remaining conditions in the VR paradigm had moderate arousal ratings not differing from each other (positive events: *m*=4.864, *SD*=1.177, approach-avoidance conflicts: *m*=4.913, *SD*=1.385, negative events: *m*=5.000, *SD*=1.132, see also Figure 47).

The highest immersion and presence ratings were present for the control imagery script (*m*=3.434, *SD*=.355) [*t*s(52)>2.129, *p*s<.05], followed by the neutral imagery script (*m*=3.288, *SD*=.433) [*t*s(52)>2.863, *p*s<.01]. Next highest ratings were present for the negative imagery scripts (*m*=3.062, *SD*=.449) and the neutral movie (*m*=3.013, *SD*=.488) [*t*s(52)>4.696, *p*s<.001], followed by the positive films (*m*=2.658, *SD*=.544) [*t*s(52)>2.879, *p*s<.01]. All other conditions made no difference in respect to immersion and presence (negative movie: *m*=2.383, *SD*=.501, events and conflicts in VR:

positive events: *m*=2.310, *SD*=.573, negative events: *m*=2.283, *SD*=.480, control positive events: *m*=2.253, *SD*=.573, approach-avoidance conflicts: *m*=2.248, *SD*=.577, control approach-avoidance conflicts: *m*=2.235, *SD*=.636, control negative events: *m*=2.224, *SD*=.564). Immersion and presence ratings for the different condition are also displayed in Figure 47.

The conflict was perceived highest in the negative imagery conditions (*m*=5.434, *SD*=1.653), the approach-avoidance conflicts in the VR paradigm (*m*=4.820, *SD*=2.202) and the negative movie condition (*m*=4.745, *SD*=1.844) [*t*s(52)>2.375, *p*s<.03] with the negative imagery conditions having higher conflict ratings than the negative movie condition [*t*(52)=2.442, *p*<.05]. The next highest ratings for conflict were present for the control approach-avoidance conflicts in the VR paradigm (*m*=3.925, *SD*=1.947), the neutral movie condition (*m*=3.717, *SD*=1.433), the control positive events (*m*=3.585, *SD*=1.740), the negative events (*m*=3.557, *SD*=1.772) and the control negative events in the VR paradigm (*m*=3.472, *SD*=1.750) [*t*s(52)>2.158, *p*s<.04] with the exceptions of the control negative events being not significantly different in the conflict ratings from the control imagery condition (*m*=3.113, *SD*=1.350) [*t*(52)=1.406, *p*=.166] and the neutral imagery condition (*m*=2.962, *SD*=1.372) [*t*(52)=1.909, *p*=.062], as well as the control positive condition in the VR paradigm being not significantly different from the control imagery script [*t*(52)=1.901, *p*=.063] and the negative condition in the VR paradigm being not significantly different from the control imagery script [*t*(52)=1.781, *p*=.081]. Additionally, the control approach-avoidance conflict showed significant higher conflict ratings than the control negative condition in the VR paradigm [*t*(52)=2.358, *p*<.05]. The lowest conflict ratings were present for the control imagery condition, the neutral imagery script, the positive movie (*m*=2.915, *SD*=1.477) and the positive events in VR condition (*m*=2.651, *SD*=1.511). All question compounds are displayed in Figure 47 for all experimental conditions.

The means and standard deviations for every question and condition can be seen in Table 10 and Figure 48, Figure 49, Figure 50, Figure 51 and Figure 52. As one can see in Figure 48, the panic reaction to the approach-avoidance conflicts in VR is less than to the negative events in VR [*t*(52)=3.572, *p*<.01]. Also, in the approach-avoidance conflicts in VR as well as in the negative imagery condition, the participants report more uncertainty what to than a feeling of panic in this condition [*ts*(52)>2.708, *ps*<.01].

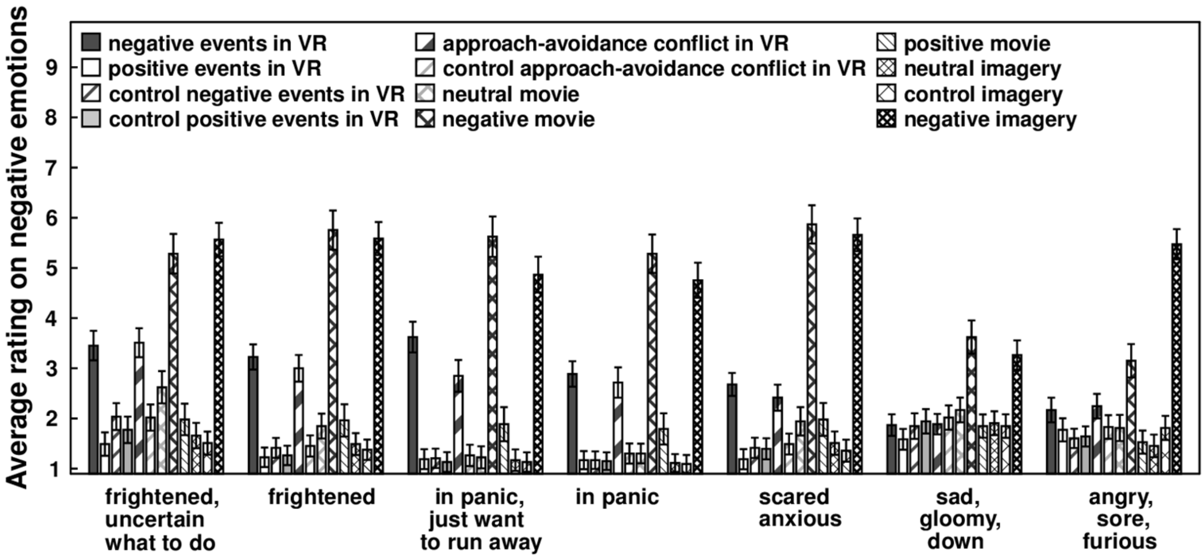

Figure 48: Ratings for every question of the compound negative emotions in study II. Error-bars represent mean SE of the differences between the conditions.

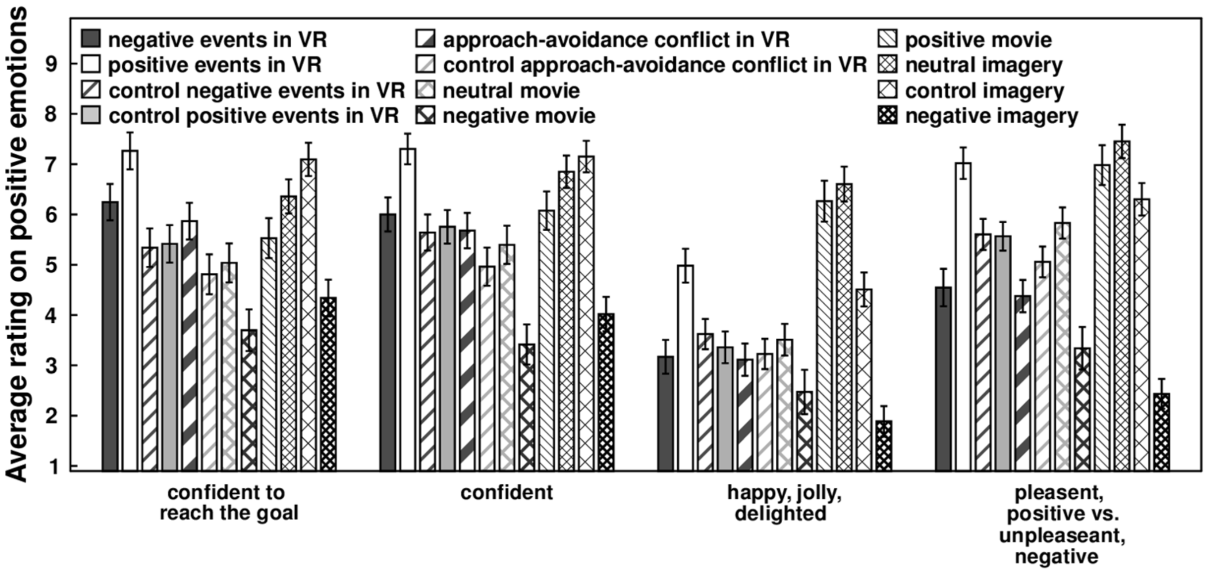

Figure 49: Ratings for every question of the compound positive emotions in study II. Error-bars represent mean SE of the differences between the conditions.

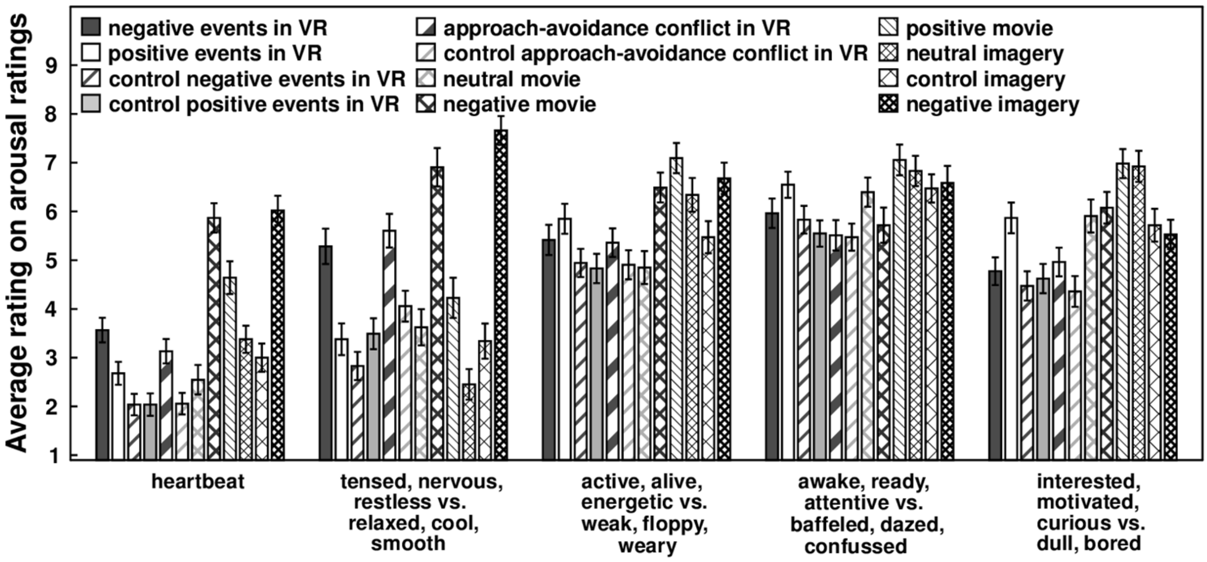

Figure 50: Ratings for every question of the compound arousal in study II. Error-bars represent mean SE of the differences between the conditions.

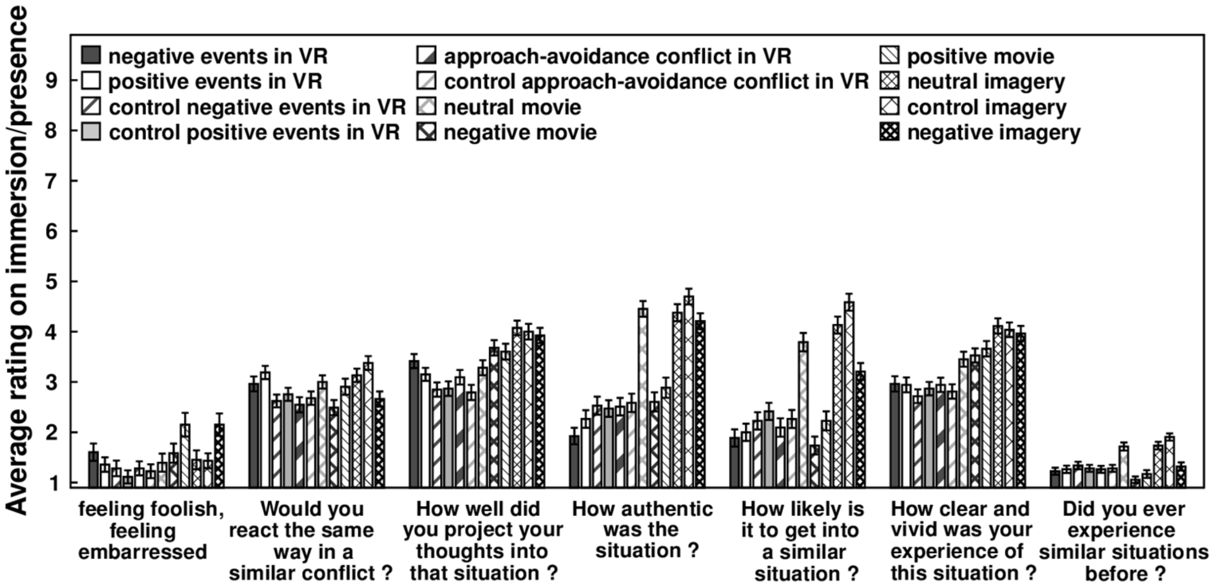

Figure 51: Ratings for every question of the compound immersion/presence in study II. Error-bars represent mean SE of the differences between the conditions.

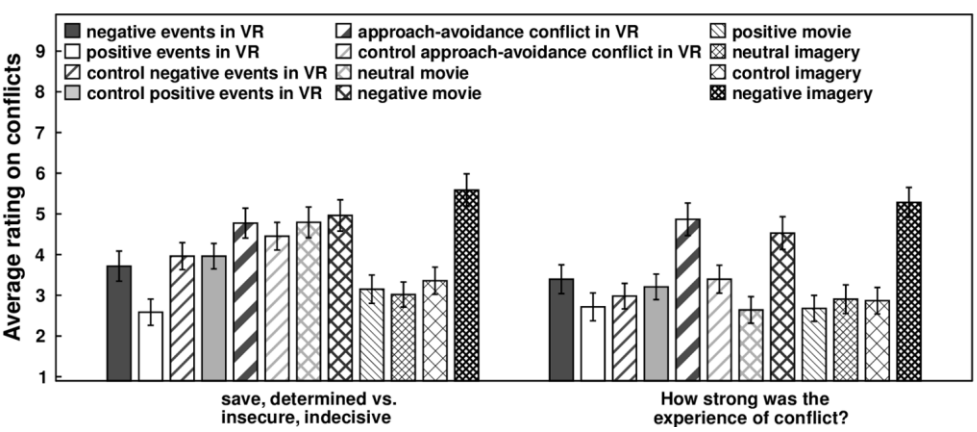

Figure 52: Ratings for every question of the compound conflicts in study II. Error-bars represent mean SE of the differences between the conditions.

Table 10: Mean Ratings (and SD in brackets) for every question for every condition of the different paradigms.

question number	question compound	question:	negative events VR	positive events VR	control negative events VR	control positive events VR	approach-avoidance conflicts VR	control approach-avoidance conflicts VR	neutral movie	negative movie	positive movie	neutral imagery script	control imagery script	negative imagery script
1	negative emotions	frightened, uncertain what to do	3.45 (1.68)	1.49 (0.67)	2.04 (1.49)	1.77 (1.45)	3.51 (1.79)	2.02 (1.53)	2.62 (1.79)	5.28 (2.66)	1.98 (1.63)	1.66 (1.02)	1.51 (0.67)	5.57 (2.02)
2	negative emotions	frightened	3.23 (1.56)	1.23 (0.42)	1.42 (0.72)	1.26 (0.59)	3 (1.72)	1.45 (0.99)	1.85 (1.15)	5.75 (2.85)	1.96 (1.81)	1.49 (0.93)	1.38 (0.69)	5.58 (2.1)
3	negative emotions	in panic, just want to run away	3.62 (2.06)	1.19 (0.48)	1.21 (0.41)	1.13 (0.48)	2.85 (2.12)	1.26 (0.79)	1.23 (0.7)	5.62 (2.94)	1.89 (1.87)	1.17 (0.64)	1.13 (0.39)	4.87 (2.42)
4	negative emotions	in panic	2.89 (1.59)	1.17 (0.47)	1.17 (0.38)	1.15 (0.41)	2.72 (2.01)	1.3 (0.8)	1.3 (0.64)	5.28 (2.81)	1.79 (1.74)	1.11 (0.32)	1.09 (0.35)	4.75 (2.39)
5	positive emotions	confident to reach the goal	6.25 (1.98)	7.26 (1.77)	5.34 (2.68)	5.42 (2.55)	5.87 (2.09)	4.81 (2.79)	5.04 (1.99)	3.7 (2.36)	5.53 (2.54)	6.36 (1.87)	7.09 (1.72)	5.66 (2.1)
6	positive emotions	confident	6 (1.99)	7.3 (1.5)	5.64 (2.59)	5.75 (2.39)	5.68 (2.16)	4.96 (2.71)	5.4 (2.07)	3.42 (2.31)	6.08 (2.33)	6.85 (1.66)	7.15 (1.68)	3.26 (1.83)
7	immersion / presence	feeling foolish, feeling embarrassed	1.6 (0.99)	1.36 (0.79)	1.28 (0.89)	1.11 (0.32)	1.28 (0.53)	1.23 (0.64)	1.4 (1.17)	1.58 (1.25)	2.15 (1.55)	1.45 (1.03)	1.43 (0.82)	5.47 (1.9)
8	negative emotions	scared, anxious	2.68 (1.37)	1.19 (0.52)	1.42 (0.82)	1.4 (1.04)	2.42 (1.66)	1.49 (1.05)	1.94 (1.47)	5.87 (2.77)	1.98 (1.8)	1.51 (1.05)	1.36 (0.68)	4.34 (1.99)
9	negative emotions	sad, gloomy, down	1.87 (1.04)	1.58 (0.95)	1.85 (1.59)	1.94 (1.57)	1.89 (1.12)	2.02 (1.57)	2.17 (1.28)	3.62 (2.3)	1.85 (1.17)	1.91 (1.18)	1.85 (1.31)	4.02 (1.83)
10	positive emotions	happy, jolly, delighted	3.17 (2.13)	4.98 (2.29)	3.62 (2.02)	3.36 (2.01)	3.11 (2.03)	3.23 (1.93)	3.51 (1.71)	2.47 (2.49)	6.26 (2.49)	6.6 (1.82)	4.51 (1.81)	1.89 (1.12)
11	negative emotions	angry, sore, furious	2.17 (1.52)	1.77 (1.34)	1.6 (1.18)	1.64 (1.32)	2.25 (1.6)	1.83 (1.59)	1.81 (1.32)	3.15 (2.2)	1.53 (1.1)	1.45 (0.99)	1.81 (1.48)	2.43 (1.2)
12	arousal	heartbeat	3.57 (1.96)	2.68 (1.64)	2.04 (1.26)	2.04 (1.39)	3.13 (1.9)	2.06 (1.2)	2.55 (1.6)	5.87 (2.02)	4.64 (2.26)	3.38 (1.78)	3 (1.68)	6.02 (1.82)
13	arousal	relaxed, cool, smooth vs. tensed, nervous, restless	5.28 (2.36)	3.38 (1.88)	2.83 (1.54)	3.49 (1.76)	5.6 (2.06)	4.06 (1.9)	3.62 (2.15)	6.91 (2.25)	4.23 (2.59)	2.45 (1.49)	3.34 (1.88)	7.66 (0.83)

question number	question compound	question:	negative events VR	positive events VR	control negative events VR	control positive events VR	approach-avoidance conflicts VR	control approach-avoidance conflicts VR	neutral movie	negative movie	positive movie	neutral imagery script	control imagery script	negative imagery script
14	**arousal**	**weak, floppy, weary vs. active, alive, energetic**	5.42 (2.23)	5.85 (2.2)	4.94 (2.02)	4.83 (2.23)	5.36 (2.04)	4.91 (2.12)	4.85 (1.7)	6.49 (1.48)	7.09 (1.72)	6.34 (1.93)	5.47 (1.96)	6.68 (1.67)
15	**arousal**	**baffled, dazed, confused vs. awake, ready attentive**	5.96 (2.14)	6.55 (1.76)	5.83 (1.88)	5.55 (1.81)	5.51 (2.21)	5.47 (1.94)	6.4 (1.75)	5.72 (2.37)	7.06 (1.73)	6.83 (1.67)	6.47 (1.58)	6.58 (2.13)
16	**positive emotions**	**unpleasant negative vs. pleasant, positive**	4.55 (2.27)	7.02 (1.62)	5.6 (1.93)	5.57 (1.77)	4.38 (1.79)	5.06 (1.94)	5.83 (1.55)	3.34 (2.45)	6.98 (2.29)	7.45 (1.64)	6.3 (1.5)	5.53 (1.35)
17	**arousal**	**dull, bored vs. interested, motivated, curious**	4.77 (1.91)	5.87 (2.35)	4.47 (2.26)	4.62 (2.19)	4.96 (2.16)	4.36 (2.3)	5.91 (1.87)	6.08 (1.67)	6.98 (1.5)	6.92 (1.64)	5.72 (1.94)	2.15 (1.57)
18	**conflict**	**insecure, indecisive vs. save, determined**	3.72 (2.37)	2.58 (1.75)	3.96 (2.1)	3.96 (1.94)	4.77 (2.42)	4.45 (2.22)	4.79 (1.99)	4.96 (2.22)	3.15 (1.94)	3.02 (1.43)	3.36 (1.73)	3.92 (0.76)
19	**conflict**	**experience of conflict**	3.4 (2.09)	2.72 (2.18)	2.98 (2)	3.21 (2.23)	4.87 (2.62)	3.4 (2.26)	2.64 (1.72)	4.53 (2.57)	2.68 (1.76)	2.91 (2.21)	2.87 (1.97)	4.21 (0.69)
20	**immersion / presence**	**reacting the same way in a similar conflict**	2.96 (0.92)	3.19 (0.86)	2.62 (0.86)	2.75 (0.85)	2.55 (1.01)	2.68 (0.89)	3 (0.73)	2.49 (0.89)	2.91 (0.86)	3.13 (0.83)	3.38 (0.66)	3.21 (0.84)
21	**immersion / presence**	**project thoughts into situation**	3.42 (0.93)	3.15 (0.93)	2.85 (0.91)	2.87 (0.98)	3.09 (1.01)	2.79 (1.04)	3.28 (0.91)	3.68 (0.83)	3.6 (0.88)	4.08 (0.68)	4 (0.76)	3.96 (0.65)
22	**immersion / presence**	**authenticity of the situation**	1.92 (0.96)	2.26 (1.16)	2.53 (1.12)	2.47 (1.01)	2.51 (1.14)	2.58 (1.13)	4.45 (0.64)	2.6 (1.12)	2.89 (1.19)	4.38 (0.88)	4.7 (0.5)	1.32 (0.47)
23	**immersion / presence**	**likelihood to get into a similar situation**	1.89 (1.1)	2 (1.16)	2.23 (1.12)	2.42 (1.15)	2.09 (1.21)	2.26 (1.2)	3.79 (1.12)	1.74 (0.79)	2.23 (0.99)	4.13 (0.98)	4.58 (0.69)	5.58 (2.31)
24	**immersion / presence**	**clearness and vividness of the situation**	2.96 (0.94)	2.94 (1.06)	2.72 (0.84)	2.87 (0.86)	2.94 (1.01)	2.81 (1)	3.45 (0.95)	3.53 (0.8)	3.66 (0.88)	4.11 (0.78)	4.04 (0.73)	5.28 (2.19)
25	**immersion / presence**	**experienced a similar situation before**	1.23 (0.42)	1.26 (0.45)	1.34 (0.48)	1.28 (0.45)	1.26 (0.45)	1.28 (0.45)	1.72 (0.45)	1.06 (0.23)	1.17 (0.38)	1.74 (0.45)	1.91 (0.3)	2.66 (0.88)

4.2.6 State measurement.

The ANOVA for the valence scale of the SAM with the within factors time and paradigm manifestation lead to a significant main effect for the paradigm manifestation [$F(2,102)=10.018$, $p<.01$, *partial* $\eta^2=.164$] and for the time [$F(2,102)=21.812$, $p<.01$, *partial* $\eta^2=.30$, $c=.801$]. Also the interaction of the two factors was significant [$F(4,204)=15.303$, $p<.01$, *partial* $\eta^2=.231$, $c=.700$].

Post hoc t-test revealed that the valence rating after the paradigm was significantly less positive than for the other two time points [$ts(51)>4.807$, $ps<.01$] and that the VR paradigm was significantly less positively rated than the other paradigms [$ts(51)>3.685$, $ps<.01$]. Supporting the main effects, the post hoc t-tests for the interaction revealed a significant difference for the valence ratings after the paradigm, being less positive for the VR paradigm [$ts(51)>5.619$, $ps<.01$] (see Figure 53).

For the arousal ratings, the ANOVA lead to no significant main effect for paradigm manifestation [$F(2,100)=.029$, $p=.97$] and time [$F(2,100)=2.257$, $p=.11$]. However, the interaction of these two were significant [$F(4,200)=3.246$, $p<.05$, *partial* $\eta^2=.06$, $c=.791$].

Post hoc t-tests revealed marginal differences for the arousal being higher before the movie paradigm started than before the other paradigms [$ts(50)>1.687$, $ps<.10$] and being lower after the movie paradigm than after the other paradigms [$ts(50)>1.659$, $ps<.10$] (see Figure 53).

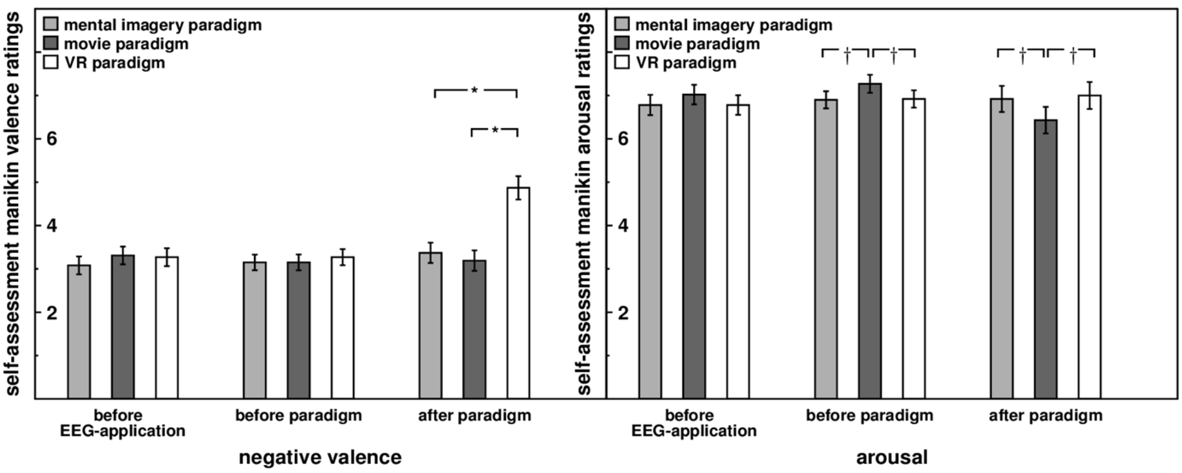

Figure 53: Mean ratings of negative valence and arousal measured with the SAM scales in study II. Error-bars represent mean SE of the differences between the paradigms. *=p<.05, †=p<.10.

For the dominance ratings, neither the main effects of paradigm manifestation [$F(2,100)=.456$, $p=.64$, $c=.733$] or time [$F(2,100)=.395$, $p=.68$] nor their interaction [$F(4,200)=.855$, $p=.49$, $c=.698$] had significant influence on the ratings.

4.3 Discussion study II

The study investigated three different theories about frontal activation and used three different paradigms to investigate the frontal activation patterns on the same participants in order to get a clear differentiation between the different paradigms and to provide some evidence of their advantages and disadvantages.

4.3.1 Validation of the paradigms.

To get access to the advantages and disadvantages of the paradigms, the subjective impressions of the paradigms and their conditions were compared, alongside with physiological measures of arousal and valence via heartrate and skin conductance.

For the subjective ratings, all paradigms and their conditions fulfilled the goal they were designed for, as the positive conditions of each paradigm were rated more positive than their negative or neutral counterpart (Figure 47), as well as all negative conditions did lead to more negative emotions than other conditions provided in the paradigm (Figure 47).

Also, the experience of conflict was also higher in the negative conditions for the mental imagery and in the movie paradigm and in the conflict condition of the VR paradigm than in other conditions (Figure 47). This experience of conflict is also supported by the questions about the uncertainty what to do in comparison to the panic and the feeling to just want to run away, experienced in this situation, because the uncertainty what to do is higher than the panic in the conflict condition of the VR paradigm and the negative conditions of the mental imagery paradigm, where one of the conditions was a (revised) BIS conflict (see Wacker et al. 2008).

The arousal was rated higher for events containing the monster entity for the VR paradigm, which replicates the findings of study I. For the movie paradigm, the arousal was higher for both, the negative and the positive movie and for the mental imagery paradigm, the negative scripts had the highest arousal ratings.

If one compares the ratings between the different paradigms, one might argue that the ratings of the mental imagery paradigm and the movie paradigm tend to be more extreme in general and therefore the experience might be more intense than in the VR paradigm. But this effect might only be due to the time point of the sampling of the ratings, as the ratings were collected directly after the one-shot trial conditions in the movie paradigm and the mental imagery paradigm, whereas the ratings of the conditions of the VR paradigm were gathered after having experienced 100 trials (the complete paradigm) and therefore having seen 20 trials of each condition, arguably providing an habituation effect.

Yet, one can state that the advantage of the movie paradigm and the mental imagery paradigm is the higher immersion/presence that could be seen in the subjective ratings, alongside with the shorter duration of the paradigm itself, which might be the reason for the drop in wellbeing for the VR paradigm compared to the other paradigms after finishing the experimental session, that could be seen in the change of SAM ratings.

On the physiological level however, there is a clear evidence for the VR paradigm leading to strong effects on the arousal, measured via skin conductance and heart rate, while the movie paradigm and the mental imagery paradigm are not that clear in the physiological data confirming the involvement of the participant in the paradigm.

In the VR paradigm the skin conductance was highest for the negative events and the approach-avoidance conflicts, confirming the arousal ratings of being highest when a monster entity is present. For the change in the heart inter-beat intervals, the positive events showed the greatest decrease around the third heartbeat, which is perfectly in line with the finding by Lang (Lang et al., 1993) and Bradley (Bradley et al., 2001; Bradley & Lang, 2000) who could show that for positive pictures and sounds there is an increase of beats per minute, corresponding to a decrease in inter-beat intervals in the time window of three seconds after onset. Also for the increase of the heart inter-beat intervals for the negative condition on the tenths heartbeat, as in study I, a defensive reaction as proposed by Sokolov (1963) and Turpin (1986) is present. Hence the skin conductance confirms the subjective arousal ratings, as well as the heart period confirms the arousal and the valence ratings for the VR paradigm, providing evidence that the paradigm was able to provide adequate induction of positive and negative emotions as well as arousal. For the conflicts, the subjective ratings do provide evidence that the paradigm did also induce the experience of conflict in the participants.

For the movie paradigm, the skin conductance did not lead to a significant difference between the different conditions. Hence, the induction of the different conditions might not be as strong as it was for the other paradigms. But for the heart period there could be seen that the participants showed smaller inter-beat intervals from the beginning of the measurement onwards and also for the emotional films there were lower inter-beat intervals than for the control condition. This suggests that the participants had a higher heart rate during the film sequences, especially if they were with emotional content, and this also leads to the conclusion that the rise in heart rate is due to arousal (Fowles, 1980) and not induced by valence. Thus, for the movie paradigm, the arousal rating could be confirmed by the implicit measure of the heart period, but not the valence ratings. Here, the paradigm seems to have some disadvantages over the VR paradigm, because here it was possible to clearly confirm the ratings with the implicit measures of heart period and skin conductance altogether.

For the mental imagery paradigm, the skin conductance was higher for the neutral and the negative script. While the neutral script was always at the first position of the scripts and therefore the first of the experimental scripts that was experienced, which could also lead to a higher skin conductance level and therefore physiological arousal (Lader, 1964), the negative script was not on a fixed position and therefore the higher skin conductance might also stand for arousal (see Neumann & Blanton, 1970), if being more related to the content of the script. Hence, the arousal ratings of the mental imagery paradigm could be confirmed by the skin conductance, leading to higher arousal for the negative scripts. For the heart rate however, there was no difference present, so the difference in valence reported for the different conditions in the paradigm could not be confirmed. Also, like for the movie paradigm, there is a disadvantage of the mental imagery paradigm over the VR paradigm, because in the VR paradigm it was possible to confirm arousal and valence ratings with implicit measurements.

Summing up the comparisons of the different paradigms and their functionality concerning the induction of emotions and motivation, there seems to be an advantage of the VR paradigm over the movie paradigm and the mental imagery paradigm, because in the VR paradigm one is able to confirm the subjective ratings of the different emotions and the arousal concerning the different conditions with implicit measurements via peripheral physiology. On the other hand, the subjective well-being was lower after the VR paradigm than after the other paradigms, what could be due to the longer duration and thereto related weariness.

4.3.2 Frontal activation in the paradigms.

The frontal activation that could be measured in the paradigms was different for the every paradigm.

In the movie paradigm and in the mental imagery paradigm, the frontal activation that could be seen was not directly related to the conditions of the paradigm, but it was related to the traits that were interacting with the conditions of the paradigm. Thus for the movie paradigm, frontal asymmetry could only be seen, if trait sadness/frustration was considered as moderating variable, leading to more right sided frontal brain activation for negative film sequences than if the trait sadness/frustration was high: This is perfectly in line with the capability model of individual differences on frontal EEG asymmetry (Coan et al., 2006), where a trait has to be activated by a relevant situation in order to measure frontal asymmetry, as well as with the original theory about the frontal asymmetry provided by Davidson (1984; 1998a; 1998b) and its extension by Harmon-Jones and Allen (1998) that would suggest a more right sided frontal brain activation for withdrawal motivation. In this paradigm, the bilateral frontal activation could not be seen at all, maybe indicating the more passive nature of the movie paradigm if one takes into account the theory of Hewig and colleagues (2004; 2005; 2006), that tells us that the bilateral frontal activation is a biological marker for the BAS and therefore for behavioral activation or behavioral approach as it was introduced by Gray (Gray, 1982, 1991; Gray & McNaughton, 1996).

However, for the mental imagery paradigm, there was no frontal asymmetry detected, neither directly related to the different conditions of the paradigm, nor to the interaction of those conditions with the traits that were measured during the study. Still, an interaction of the bilateral frontal activation with the impulsive non-planning behavior could be detected, showing lower bilateral frontal activation for persons that are more impulsive and less planning orientated for the negative script, possibly showing the momentary depletion of possible opportunities for action, that were suggested by the negative scripts, especially by the BIS script ending. For the neutral script, a higher bilateral frontal activation was found for the more impulsive non planning oriented participants, indicating the higher preparedness for action of the impulsive persons. This would be in line with the findings of Matthews and Amelang (1993) concerning the arousal theory proposed by Eysenk for extraversion (Hennig & Netter, 2005; Matthews & Amelang, 1993), that tends to be more compelling for impulsivity than for extraversion (see Matthews & Amelang, 1993). This supports also the view of a trait activation model of frontal activation (see Coan et al., 2006 for frontal asymmetry), where the frontal activation patterns are better measureable if a relevant trait is activated by a relevant situation in the participant.

However, if one considers the VR, the frontal activation can be measured without being influenced by the trait (see Table 7). Here, more right frontal brain activation is present for the experimental conditions negative event and approach-avoidance conflict (see Figure 33), therefore in the trials where a monster entity is present. This fits perfectly to the argumentation about frontal asymmetry that was given by Davidson (1984; 1998a; 1998b) with negative valence being associated with relative right frontal brain activation, and its extension by Harmon –Jones and Allen (1998), seeing motivation as a driving force behind the frontal asymmetry with withdrawal motivation being linked to relative right frontal brain activation. Additionally, all trials with the negative monster entity load in the same direction in the component analysis (see Figure 36), indicating a similar reaction to the negative events and the approach-avoidance conflicts.

But if one takes the shown behavior into account, one can clearly distinguish between these two different theories about valence and motivation, by showing that all behavior associated with withdrawal, that is fleeing the stimulus or approaching the safety from the stimulus does show right frontal activation, while a goal oriented behavior, here the approach of the stimulus, shows a left frontal activation (see Figure 30 left panel). Thus, there is clear evidence for the motivational direction theory from this paradigm concerning the frontal asymmetry. In order to test the theory of Hewig and colleagues (2004; 2005; 2006), where the BAS (Gray, 1982, 1991; Gray et al., 1991; Gray & McNaughton, 1996) is a superior system including the approach system and the withdrawal system proposed by Davidson (1984, 1998a, 1998b) and bilateral frontal brain activation stands for the active behavior, the active behavior, compared to the trials were nothing was done by the participants was tried to be predicted by frontal asymmetry and bilateral frontal activation. Also, the theory from Wacker and colleagues (2008; 2010; 2003), where active behavior is represented as left frontal brain activity versus right frontal brain activity for conflict and inhibition respectively, was reviewed with this statistical analysis. From these statistical models arose the same findings than in study I, where bilateral frontal activation was linked to active behavior, while bilateral frontal deactivation was linked to doing nothing (see Figure 30 right panel). Also, the principal component analysis of the different conditions led to a component for bilateral frontal activation, where the most positive loadings of the component were created by the control conditions, where most of the "doing nothing" behavior was shown (see Figure 36 and Table 6). Hence, it is plausible that the bilateral frontal alpha activity, and therefore the lack of frontal activation, is driven by these conditions and moreover driven by the "doing nothing" behavior which occurred frequently in these conditions. Alongside with this finding, the bilateral activation is more linked to the conditions where more active behavior is shown, as these conditions are negatively linked to the component of bilateral frontal alpha activity and therefore bilateral frontal deactivation (see Figure 36).

Contrary to the model of Wacker and colleagues (2008; 2010; 2003), there was also the finding of right frontal activation for active behavior, which is the opposite direction that would be predicted by this model (see Figure 30 middle panel). This finding cannot be explained by the three proposed models so far and one can only speculate why this finding was occurring. One possible explanation is that the trials were nothing was done are not directly linked to conflict and behavioral inhibition (Gray & McNaughton, 2000) in this case. They may represent some kind of revitalizing self-made break of the participants, and therefore being a refreshing and positive experience. The subjective ratings of the valence after the paradigms, where the negative valence is higher after the VR paradigm than any other paradigm (see Figure 53) are bolstering this interpretation, together with a different similar explanation. As the VR paradigm itself seems to be inducing negative mood in this study and the total count of positive entities have been reduced, the frequent appearance of the very intense negative entity might overshadow the equally often appearance of the positive and control entities. These other entities might generate a contrast effect, being at least not the really negative monster entity, and as the doing nothing did mostly occur in the control trials, the relative left frontal brain activation might just stand for a contrast to the intense negative entities. These two effects could lead to the frontal asymmetry that is found for the "doing nothing" trials, indicating a rather positive, pleasant and desirable state (see Davidson, 1984, 1998a, 1998b). However, one has to admit that the testing of the theory of Wacker and colleagues (2008; 2010; 2003) is only fully appropriate if one is able to induce conflict in the participants. As this is provided on a subjective level (see Figure 47 and Figure 48) but not on link between the behavior and the trait level, because the "doing nothing" behavior was not correlated with behavioral inhibition (Gray & McNaughton, 2000) in this study, it may be the case that the theory of Wacker and colleagues (2008; 2010; 2003) could not be assessed with the VR paradigm here in an intense and appropriate manner.

Hence, from the VR paradigm, the theories about frontal asymmetry from Davidson (1984; 1998a; 1998b), Harmon –Jones and Allen (1998) dealing with the approach and withdrawal motivation as well as the extension provided by Hewig and colleagues (2004; 2005; 2006), accounting for the BAS and the active behavior compared to no behavior at all, can be supported by the data. The theory of Wacker and colleagues (2008, 2010, 2003) can be contradicted in respect of active behavior being lateralized to the left hemisphere, but the conflict that was to be induced did not show up on a behavioral level. On the subjective level to the different trials, it was seen and a right sided frontal brain activation was shown to potential conflict trails, but this right frontal activation could also be explained by the undesirability of the state of conflict and the resulting negative affect (see Davidson, 1984, 1998a, 1998b), as well as with the count of the behavior in this type of trials that favor the different types of withdrawal behavior, that are linked to more right frontal brain activation (see Table 6). Also, the induction of the motivational tendencies seem to be that strong, that independently of the trait level, the state frontal asymmetry is triggered as it was reported by Coan and Allen (2004), instead of the capacity model proposed by the authors together with McKnight (2006). This might be the case because the participants were provided with a desktop virtual reality, giving the opportunity to experience the different conditions in a very intense way (see Bülthoff & Veen, 1999), alongside with tones that even intensify the experience of the positive or negative consequences of the trials (see Hendrix & Barfield, 1996). Also, giving the participants the opportunity to move around and actually do something brings a whole new quality to the experience of a situation intensifying the perception of the situation (Bülthoff & Veen, 1999). Therefore it seems, that the frontal activation patterns are state based, if one uses a really strong induction method for the motivational tendencies and provides the possibility to actually show behavior.

On the other hand, one has to take into account that the time windows that are used in the different paradigms for the analysis of the frontal asymmetry are quite different. In the movie and in the mental imagery paradigm a rather long time window, not immediately linked to the actual stimulus was used, but a time window that was just associated with re-experiencing the feeling evoked by the stimulus. However, the time window chosen in the VR paradigm was directly after the onset of the event cueing. Therefore the frontal asymmetry, being a biological correlate of the motivational state of the participant might be really strong compared to the movie and mental imagery paradigm, where the traits could be the reason to preserve the immediate frontal asymmetry response, also due to a greater capability of reacting in the appropriate manner of the underlying trait (see Coan et al., 2006). Also the repetition of the trials may lead to a more precise estimate of the frontal asymmetry, although there might also be a habituation to the stimuli even dampening the response (Amochaev, Salamy, Alvarez, & Peeke, 1989).

Summing up the frontal activation patterns that have been found in the three different paradigms shows a similar pattern for the movie and mental imagery script paradigms, where the capability model of Coan et al. (2006) may be the adequate model to describe the frontal activation patterns, although the bilateral frontal activation was not part of that model so far. Also, there is support for the frontal asymmetry model from Davidson (1984; 1998a; 1998b) and Harmon –Jones and Allen (1998), from the movie paradigm if one takes into account the trait activation hypothesis of the capability model mentioned above (Coan et al., 2006). For the VR paradigm however, there is clear evidence for the frontal activation patterns being a state based phenomenon (Coan & Allen, 2004), with support for the models of Davidson (1984; 1998a; 1998b), Harmon –Jones and Allen (1998) and ultimately the model of Hewig and colleagues (2004; 2005; 2006) proposing the behavioral activation system (Carver & White, 1994) or behavioral approach system (Gray, 1982, 1991; Gray & McNaughton, 1996) as a superior system including the withdrawal system and approach system proposed by Davidson (1984; 1998a; 1998b), and therefore being correlated with bilateral frontal activation.

Integrating these two findings for the paradigms and the models, depending on the strength of the motivational induction, the frontal activation pattern can be trait- related or rather state-related, being more state-related the stronger the motivational induction is, with left frontal brain activation for approach motivation, right frontal brain activation for withdrawal motivation and bilateral activation in case of active behavior.

4.3.3 Traits and Behavior in the VR paradigm.

The traits played a role for choosing the behavior in the VR paradigm (see Figure 11, Figure 44, Figure 45 and Figure 46). So the conflict condition did often not lead to a conflict, but only to a selection of the behavior that was already defined by the trait preference and only activated by the conflict condition.

Two important traits that had a lot of influence on the behavior that was shown, was the self-concept and the self-efficacy, being related negatively to approach behavior and positively to withdrawal behavior and the “doing nothing” behavior, possibly indicating taking a break from the paradigm. This is very fitting with the natural perception of those concepts being highly expressed in “strong personalities” who are not that dependent on external rewards that could be taken with the higher approach behavior and who are also willing to take their break when they want to do nothing. This relation of the behavior with the traits shows the possible implementation of indirect personality measures by a modified VR paradigm, possibly accounting more for social situations than for simple approach and avoidance goals.

However, one has still to be cautious with interpreting what trait is the driving force behind the selection of the behavior, for due to multiple testing correction, all significant trait behavior relations did not reach statistical significance any more. On the other hand one must admit, that Bonferroni´s correction, which was applied hare, was intended for independent constructs, but there is no appropriate correction for dependent constructs and sub-constructs that could be applied in this case, so the greater relations that show in multiple patterns of behavior might still be valid to interpret. But as an ultimate solution, a replication of the findings in the exact paradigm should be executed, because - compared to the first study - different traits had influence on the chosen behavior, although one must admit, that also the paradigm was slightly modified.

4.3.4 Resting EEG and Traits.

The resting state EEG intra-class correlation for the frontal asymmetry scores of this study was extraordinary bad (see Coan & Allen, 2004, Hagemann, 2004) with r=.239. When corrected for the gender, the intra-class correlation tended to be higher, as it was r=.298 for male it and r=.361 for female participants. But still, the correlations did not reach an expected extend of about r=.6 (see Coan & Allen, 2004, Hagemann, 2004). But the reliability of each single resting state measurement was extraordinary high with the lowest Cronbach´s α =.986.

The reason for the high changes in frontal asymmetry between the different measurements of resting state could be very diverse. One reason could be a special sample being due to the recruiting which was not just from psychology students. Another reason could be different daytimes of the resting EEGs, but in order to avoid that problem, the participants were asked to participate only at the same time-slot, and regularly they did so. Another reason could be a very long time between the different measurements. Yet, all but two participants did not have such a gap in the timings of the experimental sessions. The most plausible explanation for the difference in the resting state EEG measurements is a priming effect of the upcoming paradigm and the expectancy generated by it, because the participants were told about the paradigm they were to experience at the beginning of the measurement session and before the resting state EEG was applied. Following this logic, a difference could be detected for the movie paradigm resting state EEG that was also dependent on the gender, with more left frontal brain activation for female participants compared to male participants, maybe indicating the more positive expectation of the females concerning the movie paradigm. For the other paradigms, no difference was present, and no general effect of the paradigms could be detected. Hence it seems that this gender moderated effect, that was only present for the resting state of the movie paradigm, did drive the decline of the resting state intra-class correlation, although I cannot provide a reasonable explanation why this difference in expectancy should be presumed. So, as I cannot provide a good explanation or reason why the resting data should be that different from each other on a theoretical basis, other state based influences like nervousness, expectancy or other not controllable factors that may change the feelings and motivational defaults of the participants must be the driving force behind the differences of the genders in respect of the resting state EEG before the movie paradigm.

For the correlation with the traits, no robust significant relation to any trait could be detected, what could also be an artifact of the differences between the resting states being overshadowed by uncontrollable states in different ways for each paradigm.

The bilateral frontal activation for the resting periods however was rather well interrelated (r=.898) with also really high values in Cronbach´s α, with the lowest being α =.977. Anyhow, there was no significant relation to a trait noticeable.

The reason for these null-findings could be the relatively small sample size of 52 participants for an analysis of the resting period relation of traits. Also, it would have been better to measure the traits on several occasions in order to also provide a reliability measurement of the trait measurements and get a better estimation of the true values of the traits

5 General discussion

5.1 Frontal activation

In the studies conducted, one goal was to determine the predictive value of the three theories about frontal asymmetry that were made by Davidson (1984; 1998a; 1998b), Harmon –Jones and Allen (1998), Hewig and colleagues (2004; 2005; 2006) and Wacker and colleagues (2008; 2010; 2003). These theories were investigated with a newly developed paradigm that was able to investigate frontal activation patterns via EEG while participants were able to virtually move around in a virtual T-maze via joystick without the problem of movement artifacts that would occur while moving around in reality.

Additionally, the frontal asymmetry was investigated with two well established paradigms in a within design, in order to compare the results of the paradigms without having to account for between subject differences, often masking effects because of the great inter-individual difference in brain activation pattern intensities (Hagemann, 2004 for trait / state variance of frontal asymmetry: 60% / 40%).

The three theories investigated are firstly the theory about motivational direction, proposed by Davidson (1984; 1998a; 1998b) and Harmon –Jones and Allen (1998), with approach motivation being associated with relative left frontal brain activity and withdrawal motivation being linked to relative right frontal brain activity. Secondly, the theory of Hewig and colleagues (2004; 2005; 2006), where the motivational direction theory of Davidson (1984; 1998a; 1998b) and Harmon –Jones and Allen (1998), and the reinforcement sensitivity theory of Gray (1982; 1991; Gray & McNaughton, 1996) are integrated into one theory showing frontal asymmetry to motivational states and bilateral frontal activity, if the BAS as a superior system, incorporating the approach system and withdrawal system proposed by Davidson (1984, 1998a, 1998b), is active. Thirdly, the theory of Wacker and colleagues (2008; 2010; 2003), where right frontal brain activation stands for the activation of the revised BIS (Gray & McNaughton, 2000) and therefore for conflict and behavioral inhibition, as well as left frontal brain activation stands for active behavior of any kind, being initiated by the revised BAS and the revised FFFS (Gray & McNaughton, 2000).

Discussion

The results of both studies suggest that the theory of Hewig and colleagues (2004; 2005; 2006), gets the most supporting evidence. Both studies find effects predicted by the theory of Hewig and colleagues (2004; 2005; 2006) on the motivational level with right frontal brain activation for withdrawal behavior and left frontal brain activation for approach behavior, while the motivational direction theory of Davidson (1984; 1998a; 1998b) and Harmon –Jones and Allen (1998) of course also gets support, being part of the integration by Hewig and colleagues (2004; 2005; 2006). Furthermore the bilateral frontal activation pattern for active behavior suggested by Hewig and colleagues (2004, 2005, 2006) could be found, expressing the bilateral frontal activation for the activation of the BAS.

The theory of Wacker and colleagues (2008; 2010; 2003) had no conclusive confirming evidence in both studies conducted and therefore these studies cannot support this theory. However, there are strong limitations to this finding, because it is questionable whether a conflict situation was sufficiently induced during both studies, because the relation of traits proposed to be linked to conflict and behavioral conflict was not shown in both studies. But as either subjective ratings or physiological indication like the heart inter-beat intervals and skin conductance or even both indicators, direct and indirect validation of the conflict conditions, do confirm that conflict was present in the critical conflict conditions, except the approach-approach conflict in the first study, the results may be quite robust, if not as intense as expected. Additionally, in study II, there was little confirming evidence for the theory of Wacker and colleagues (2008; 2010; 2003), where right frontal brain activation was present to conflict trial in the VR paradigm, but this right frontal activation could rather be explained by the shown withdrawal behavior that was predominantly present in this kind of trial. On the behavioral level, where the “doing nothing” was used as a behavioral conflict indicator, one might argue that the “doing nothing” behavioral category in the VR paradigm is not a reaction to conflict at all, which is quite reasonable, because in study II there can be seen a frontal asymmetry normally linked to positive stimuli and approach, indicating that the “doing nothing” behavior had there a positive connotation. But for a link of active behavior to left frontal brain activity that was proposed by the theory of Wacker and colleagues (2008; 2010; 2003), there is no evidence at all.

Hence, the data do simply support the theory of Hewig and colleagues in both studies (2004; 2005; 2006), where frontal asymmetry shows the motivational states of a person with relative left frontal brain activation for approach motivation and relative right frontal brain activation for withdrawal motivation, while bilateral frontal activation can account for their behavior and the behavioral activation system (Carver & White, 1994) or behavioral approach system (Gray, 1982, 1991; Gray & McNaughton, 1996), being a superordinate system incorporating the withdrawal system and approach system proposed by Davidson (1984, 1998a, 1998b). A summary of the evidence provided by the two studies linked to the theoretical models can be seen in Figure 54.

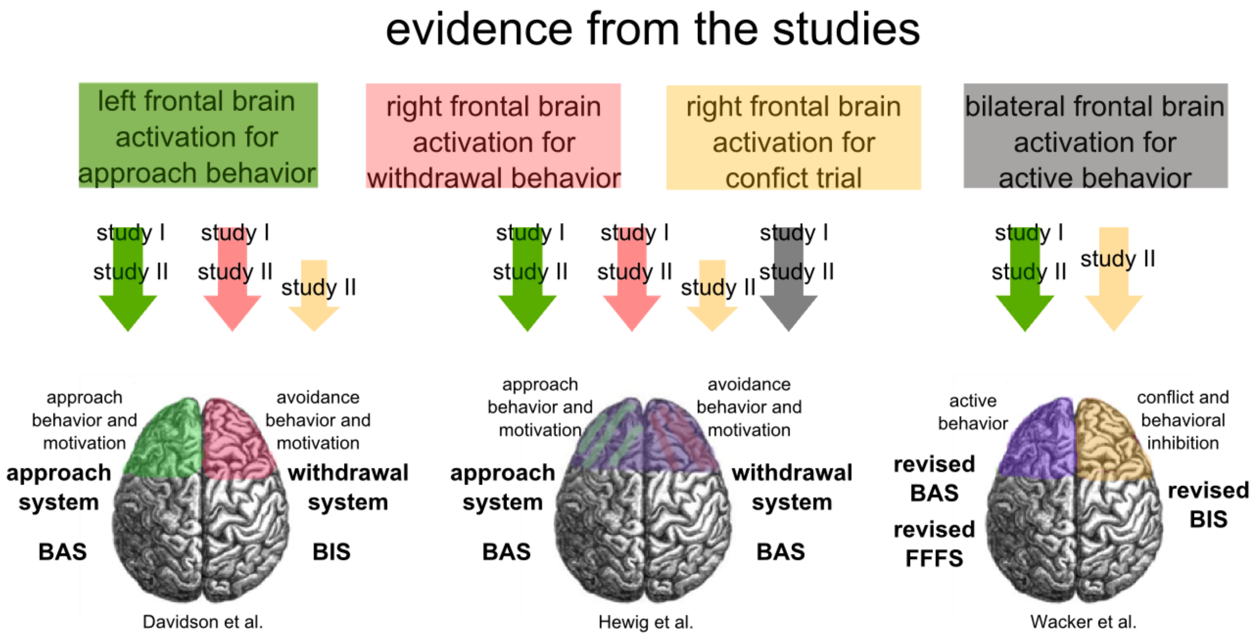

Figure 54: Link of the evidence provided by the two studies to the three different theoretical models. The arrows resemble the findings of the studies, color-coded for different parts of evidence. The smaller arrows indicate an indirect support of the theories, because the theory did not explicitly account for conflict.

These findings could only be achieved by providing the participants with the opportunity to actually show active behavior during the trials in the paradigm alongside with the measurement of frontal activation patterns in EEG. However, the opportunity to show relevant behavior did also affect the intensity of the relevance of the situation (see Bülthoff & Veen, 1999) and alongside with this effect, the capability model (Coan et al., 2006) of the frontal activation patterns was questioned. Following the evidence provided by the two studies, the frontal activation pattern in the VR paradigm was independent of the traits. In study II, in the movie paradigm and the mental imagery paradigm, a trait activation in sense of the capability model (Coan et al., 2006) could be seen, as the classical BIS did lead to a higher relative right frontal brain activation during the negative movie condition and not during the other movie conditions. Alongside with this finding, a higher bilateral frontal brain activation could be seen for an aspect of impulsivity during neutral scripts and lower bilateral frontal brain activation of the same aspect during the negative scripts, indicating the general preparedness for action in impulsive persons and the strong engagement to the script where they could do at least something and were not just idling in their thoughts with low stimulation.

Integrating these findings about the role of the traits, it is plausible, that the intensity of the relevant situation that is provided might change the influence of the trait on the frontal asymmetry pattern, for the most intensive situation, the VR paradigm, was not influenced by the traits and solely the relevant situation did lead to the frontal activation pattern, while in the lesser intense induction methods, the capability model got support. As the intensity of the situation grows, it overcomes a level of trait dependence and the situation becomes relevant for everyone, as everyone might be startled, fleeing or react in a strong manner to a person threatening them with a gun, while a mere picture or mental imagination of this situation might not be that intense for everyone but just the ones that have a strong relevant trait like anxiety. Hence, the intensity of the induction method for the relevant situation accounts for the ratio of trait or state influence on the frontal activation pattern in the relevant situation, with higher state dependence the higher the intensity. However, if the situation provides the opportunity to show some behavior, a trait dependence of the shown behavior can be seen. A summary of the evidence of the two studies and the proposed capability model (Coan et al., 2006) can be seen in Figure 55, integrating the intensity of the situation also into the model as a relevant constraint (see trait activation theory, Tett & Burnett, 2003) for the trait influence.

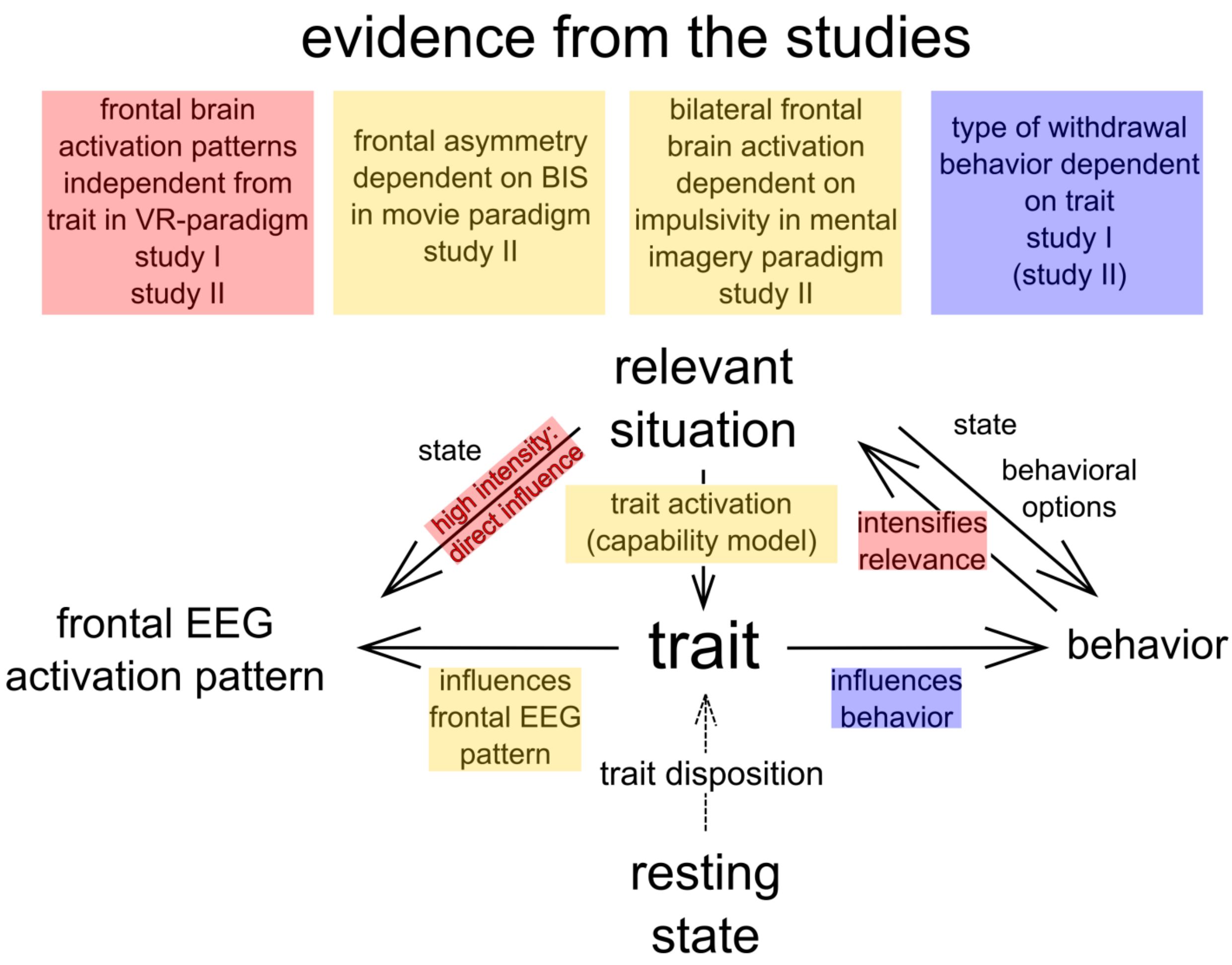

Figure 55: Link of the evidence provided by the two studies to the relation of frontal activation patterns, trait and the situation of measurement. The situation of measurement is depicted in the middle on the top and on the bottom of the lower part of the model. The color-coded evidence found in every study is linked to the theoretical model. The intensity of the relevant situation can lead to a direct influence of the relevant situation and therefore the state, independent from the trait.

The relevance of the findings gathered by the studies is multifarious. The dissociation of the BAS from the motivational components of the stimulus opens the door for independently measuring and even manipulating these two biological correlates with methods like transcranial direct-current stimulation (TDCS) in order to achieve differences in behavior that can be based on both systems, the motivational system as well as the pure drive provided by the BAS. Also, the inter-individual differences in resulting behavior can be targeted more precisely and specifically if these two constructs can be used to assess the differences in the resulting behavior and not only the motivational differences being bound to account for all the variance.

From a clinical perspective, these findings suggest that there could be different ways to take influence on the behavior via active manipulation of the frontal activation in order to modify and shape behavior, maybe as a treatment of depression or anxiety disorders, diseases that are closely linked to right side frontal activation patterns (Thibodeau et al., 2006). For most of the biofeedback oriented approaches to treat depression have simply focused on the motivational aspect of the frontal activation patterns and trying to decrease relative right frontal brain activation (e.g. Allen et al., 2001; Quaedflieg, Conny W. E. M. et al., 2016), while the complex symptom accumulation of depression is often also about lack of drive and activity, or at least about a change in the activity patterns. Accordingly, the Diagnostic and Statistical Manual of Mental Disorders (*DSM-V*, American Psychiatric Association, 2013) states among the 9 symptoms for major depressive disorder (MDD) or depressive episodes from which 5 have to be occurring nearly every day in order to get MDD beside the depressed mood, decreased interest or pleasure, the appetite or weight change, the sleep change, the guilt and worthlessness, the lack of concentration or indecisiveness and suicidality also the change in activity and the fatigue or loss of energy (American Psychiatric Association, 2013). Therefore, one should not only target asymmetrical brain activation patterns, but also try to enhance the bilateral frontal activation in order to provide the patients with an enhancement of the BAS.

This possible approach to cure the symptoms of depression may also be an explanatory approach to the finding that the frontal asymmetry is only a biological risk-marker for depression and is not a biological correlate of depression (Allen et al., 2004), for the motivational disposition may stay the same even after treatment, but the enhanced resources of the patients can lead to a higher drive and urge to actually do something, and therefore a higher activation of the BAS in general and not a lower activation of the specific subsystem. So, the practical implications of the present findings for therapy might be one that is already implemented in mild cases of depression, where the patient is encouraged and reminded of their strengths in order to support an enhanced will to act and being active. However, in severe cases of depression it is often necessary to dampen the drive that is left in the patients, because of a motivational state that leads predominantly to suicidal acts (see also criteria 9 for major depression and depressive episode in *DSM-V*, American Psychiatric Association, 2013). In these severe cases, a change of the cognitive structure that lead only to destructive and self-destructive behavior has to be done before taking the risk of enhancing activation and trigger motivational states that lead to suicidal acts (see Barnhofer et al., 2007). Hence, although there is evidence that asymmetrical frontal activation patterns are linked to motivational states and bilateral activation patterns to the behavioral activation system (Carver & White, 1994) or behavioral approach system (Gray, 1982, 1991; Gray & McNaughton, 1996), the implications that arise from these findings are not necessarily easy and generally to state in severe clinical cases.

In fact, the implications that arise from a differential psychological perspective on these findings are very promising, regarding the possibility to develop a modification of the BAS, incorporating both motivational systems, and also showing the differences in the personality based on different psychophysiological brain activation patterns, as they are coming out of different behavioral decisions made in paradigms were the right decision is less obvious and immediate. The implications on the clinical field however, are not that straight forward as mentioned above, although there are divers implications for clinical treatments as well as explanations for the underlying mechanism of treatments already used in certain therapy concepts for depression.

The other important finding about the intensity of the relevant situation being a constraint (Tett & Burnett, 2003) for the influence of the trait on the frontal asymmetry pattern can account for many differences in the findings about frontal asymmetry patterns that were present in the literature (e.g. Thibodeau et al., 2006). As an extension of the capability model of anterior asymmetry (Coan et al., 2006) it can account for additional variance on the edge of the continuum of the intensity of the relevant situations, where the frontal asymmetry is independent from the trait.

Additionally, the perspective of inducing frontal asymmetry in everyone, independent of the traits, as long as the intensity is strong enough, sheds a different light on the research about frontal asymmetry and personality traits, as well as on clinical treatments of depression, where the frontal asymmetry is targeted. For the research about personality traits, the conclusion must be that the intensity of the paradigm that is used has to be in a range where the intensity does still reflect a capability of the trait, or, maybe as an alternative strategy, the time window of frontal asymmetry should be considerably long, as the capability for relevant traits may preserve the frontal activation pattern. For clinical treatments, like treatments for depression, the finding provides an additional explanation and reason for strategies like cognitive restructuring, reappraisal as it is already present in cognitive therapy and patient resource oriented therapy concepts (Hallis, Cameli, Dionne, & Knäuper, 2016). As patients are reminded of the positive consequences and chances of positive situations as well as of his or her strengths, the negative attribution style, being often present, is tried to be changed. If this change is successful even for a short time period, it may cause a higher intensity for positive situations, crossing the line to a higher intensity and providing the opportunity of being independent of traits that favor depression. In this time interval, the patient may experience a neuronal pattern to approach situations that can provide a new baseline to the neural system for approach situations. On the other hand, treatments like Neurofeedback, transcranial magnetic stimulation and other treatments solely targeting the neural components of frontal asymmetry do also get support by this study, because as their intensity may be really high, they may be able to provide the experience of a normalized frontal asymmetry pattern to approach and avoidance behavior for depressive patients, providing the same new neuronal baseline to approach reactions as the reappraisal and cognitive restructuring. But as the finding of the studies do stress the importance of the intensity - this intensity was already present in a desktop VR paradigm - one might think about implementing virtual therapy concepts (e.g. Mühlberger et al., 2008 for spider phobia), where patients can learn to approach and act in a safe virtual environment, preparing them to act in a non-depressed way.

5.2 Virtual reality paradigms to determine personality

A possible further approach to make use of the findings and the VR paradigm that has already been developed in this study could be a paradigm with situations that are less precise and clear in the value of the outcome of the trials. In such a paradigm, the participants would be more likely to react to the situations in a way they are used to react (compare social desirability bias Nederhof, 1985) and therefore the traits would increase having an influence on the resulting behavior, as they already showed in study I and study II in the chosen behavior even if the results of the behavior are clearly and immediately promoted. Also, the higher arousal arising from this uncertainty or ambiguity of the task may strengthen this effect (Mair, Onos, & Hembrook, 2011).

One possible scenario would be a game-like meta-goal oriented environment, where the participants have to achieve a task or quest and the way they choose to obtain the goal is up to them. Being much like role-playing games, a further approach could be trying to develop a role playing game, where personality traits can be measured via chosen reactions and ways to solve tasks, quests and riddles, as well as keeping track of the physiological basis of the motivational and behavioral related aspects of the decision making. These games would also be valuable in assessing personality and skills via implicit measurement and therefore being less vulnerable to report biases per se. On the other hand one great danger in game-like application of measurement is the absurdity and explicit difference of the game to reality (Huizinga, 1939), which might provoke reactions that one would not show under normal circumstances, like being overly aggressive or even showing an amount of faith and guts that are not present in real life. Therefore, such a paradigm has to be developed and tested very carefully alongside with mindful and meaningful instructions, never breaking the boundary of the simulation of behavior to actual gaming. But if these obstacles are taken, such a paradigm would also be valuable especially for work psychology, giving the opportunity to simulate work-like situations and see the performance of the worker in this simulation, as well as determine possible pitfalls that have to be avoided in the working process.

5.3 Future studies

Many changes can be done to the newly developed VR paradigm in order to account for different problems arising in the studies. In the two studies, a desktop virtual reality was used to provide participants with the opportunity to react to stimuli with behavior, as well as measure their frontal brain activation patterns to the situations in combination to their behavioral choices. The paradigm consisted of positive and negative events, conflicts and control conditions. The behavioral options were free movements, so only approach and avoidance behavior could be shown.

An interesting new approach would be to include other types of events or behavior, like defensive aggression on the behavioral level and uncertainty of an outcome on the cue level, e.g. for the approach-avoidance conflicts. These two modifications could account for the difference of the three proposed models in the case of defensive aggression. Additionally, with the implementation of the uncertainty, one might find the possibility to strengthen the relation of trait and the shown behavior in the paradigm (see e.g. Lynn et al., 2016 for uncertainty in emotional face recognition, dependent on working memory capacity and capacity of facial emotion recognition). Also, because their actions are no longer linked to the same outcome independent of the behavioral choice in the case of an approach-avoidance conflict, the experience of conflict might arise between the two different behavioral options. This experience of conflict could then be moderated by the trait preference for reward and approach or the withdrawal tendencies, as we already saw in the present VR paradigm. A similar effect could be induced with an uncertain cue per se, where the participant does not know what entity will come. Here, the approach and avoidance tendencies should dominate the shown behavior, because no prediction of the successful behavior can be made and the trait can be used as a heuristic for the behavior (see Smith & Mackie, 2007, pp. 249–258).

Furthermore, one can think about providing a paradigm, where each decision is no longer independent of each other, but each decision triggers a different modification of the subsequent trials. If this change and dependence of trials are known to the participant, the trait might also have an even greater influence on the decisions they make and the paradigm is able to offer the possibility to differentiate degrees of personality in the paradigm on a more detailed scale due to adaptive testing and item response characteristics of the situations and the shown behavior (see Bühner, 2006, pp. 300–385 for probabilistic test theory).

As all situations were really artificial with the participant moving through a virtual T-maze, approaching and avoiding positive and negative stimuli, one further step would be to go for more realistic scenarios. Also the stimuli of the paradigm, being a virtual sheep, a jogging person or even a monster were intense, but not realistic. A possible approach would be a confrontation with human avatars in virtual reality, where the situations get their approach and avoidance character by the cue and context of the situation or the actions of the virtual human (e.g. an attacking man or a man offering something good). This additional realism should increase the immersion and hopefully compensate the drop in intensity coming from the less intense stimuli as especially the monster had a very convincing physical and behavioral appearance, maybe also triggering spider phobia (see Figure 6).Another level of change can be provided by changing the platform of the virtual reality to a possibly more immersive medium like VR-displays, power-walls or even cave experiments. But in order to change the platform, the paradigm has to be modified to a slower speed, because the speed did cause some simulator sickness problems in VR-displays, which was also a reason to still use desktop virtual reality.

Combining these two advancements and adding many behavioral options, one can see into the development of an adaptive paradigm with many possibilities to express the trait on behavioral level where the participant might experience a sophisticated way of measuring his or her personality without even knowing it, because every decision he or she makes might account for additional variance concerning the underlying traits of the shown behavior, as it was already mentioned in section 5.2.

On the theoretical level it would be good to further explore the dependencies of the frontal activation patterns from a trial by trial basis, in order to identify also some possible carry over or expectancy effect concerning the frontal asymmetry as well as the dependency of the frontal asymmetry from the intensity of the stimulus. Additionally, it would be good to further study the impact of conflicts on the behavior, because on the behavioral level in the present paradigm, there were hardly any detectable conflicts. Also, if one showed conflict in a first conflict condition trial in the VR paradigm, he or she quickly adapted and chose a strategy (based on the traits) to react in conflict trials, so that there was no longer a detectable conflict on the behavioral level at all. As a conflict on behavioral level is hard to induce with this yet non-adaptive paradigm without manipulating the uncertainty of an event, maybe the changes have to be included in the dependent decision paradigm with human avatars, where some adaptive ambivalent stimuli have to be included in order to evoke real conflict in the participants. If this ambivalent stimulus is always changing, tagging the brink of the actual decision heuristic of the participant, provided in every trial, a conflict should also be induced in other trials than the first one in the conflict condition.

Another approach for studies not concentrating on virtual reality would be the use of mobile EEG devices in real life situations, in order to get the combination of behavior in real life and frontal brain activation patterns. As the technical advances grow in this respect (Kranczioch, Zich, Schierholz, & Sterr, 2014; Stopczynski et al., 2014; Vos & Debener, 2014; Vos, Gandras, & Debener, 2014;

Wascher, Heppner, & Hoffmann, 2014), one might find a reasonable solution in near future that can measure EEG with non-disruptive hardware and software components, offering the possibility to measure real time real life EEG in order to link behavior to brain activation in complex real life situations of approach, avoidance, conflict and ambivalence, as they are part of our daily lives. Also, the relevance of real life situations is much higher than any other simulated or artificial environment can provide, if one thinks of a romantic approach motivation or the approach motivation towards food if one is hungry, for example.

Staying in this context, the augmented reality (e.g. Laine & Suk, 2016 for problem solving games used with elementary school children) could be a good approach, to combine the advancements of virtual reality together with the advancements in mobile EEG devices, to provide realistic behavioral reactions to situations, while the stimuli triggering that behavior are still controlled and standardized. Following the recent development in augmented reality games, “Pokémon Go” managed to enchant over 65 million users within one week of its launch (Serino, Cordrey, McLaughlin, & Milanaik, 2016) and therefore demonstrated the high acceptance for augmented reality in the population. Also, “Pokémon Go” has already be seen as a good way to enhance the physiological fitness in children (Serino et al., 2016) as well as in patients (Anderson, Steele, O'Neill, & Harden, 2016). This “exergaming” (Anderson et al., 2016) stresses the impact of augmented reality on the population, especially concerning the approach motivation to the virtual pocket monsters. Therefore, one should also think about creating scientific applications of augmented reality in combination with mobile EEG devices. One might for instance think about a similar game-like application as “Pokémon Go”, where the participants may run around and catch some little furry virtual creatures, with a strong approach motivation. For the avoidance motivation, one could introduce other virtual creatures that take away all or several virtual creatures that have already been obtained, if they virtually catch the user of the application. Here, a strong avoidance motivation should be present. In such an augmented reality setting, a mobile EEG device could provide very potent data about approach and avoidance motivations or the experience of conflict. Alongside with the many possibilities offered by the augmented reality and the broad acceptance of the population for this new method present especially in games like “Pokémon Go”, one is able to maintain the controllable stimulus as in a laboratory experiment setting, while having the high intensity of a field experiment.

5.4 Conclusion

Summing up the results of the studies, the frontal activation patterns support the theory of Hewig and colleagues (2004; 2005; 2006), where frontal asymmetrical activation patterns account for motivational aspects of approach and avoidance, while bilateral frontal activation is linked to the behavioral activation system (Carver & White, 1994) or behavioral approach system (Gray, 1982, 1991; Gray & McNaughton, 1996) and active behavior.

Also, differences in the used paradigms were detected, concerning the influence of traits on the frontal asymmetry, possibly arising from the strength of the induction of the frontal asymmetry or from the different time periods used in the different paradigms. Here, the more immediate and also more intense experience during the VR paradigm led to the independence of the frontal asymmetry from the traits (see Coan & Allen, 2004), while the other paradigms lead to frontal activation patterns that were dependent on the traits (compare Coan et al., 2006).

These findings stress the importance of seeing frontal asymmetry as a biological construct that can be influenced in many ways by altering motivational aspects. But in order to predict behavior shown by participants, it is not sufficient to only know about their motivation, but one must also know about their tendency to show behavior as well as their behavioral preferences. Hence, it is important to not only look onto frontal asymmetry if one tries to predict behavior, but also on the bilateral frontal activation patterns in order to see whether a behavior is executed or not.

In combination, these two measurements of frontal brain activation can be applied to real life situations in order to predict behavior with the help of the biological markers of approach and avoidance motivation as well as biological markers for the drive to execute active behavior.

In further studies, preferably with mobile EEG and augmented reality, one may explore this predictive value of frontal brain activation patterns for behavior. Therefore, the present studies can also be seen as a first step towards new methods in investigating frontal brain activation patterns. Of course, the paradigm can only be seen as a first step toward augmented reality paradigms, but as for the prediction of behavior, it´s not only about the motivational direction, it´s also about taking the first step and “every step is a first step if it's a step in the right direction” (Pratchett, 2010, p. 329).

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7 Appendix

7.1 Methods of induction of mood, motivational and emotional states in context of frontal asymmetry.

Table 11: Appendix: Methods of induction of mood, motivational and emotional states in context of frontal asymmetry.

Authors of the study and publication year	Induction method used in the study to influence mood / motivational state
Chan, Han & Cheung 2008	music
Hernandez-Reif, Diego & Field 2006	
Jones & Field 1999	
Mikutta, Altorfer, Strik & Koenig 2012	
Schmidt & Trainor 2001	
Trochidis & Bigand 2013	
Vecchiato, Maglione, Scorpecci, Malerba, Marsella, Francesco, Vitiello, Colosimo & Babiloni 2012	
Meyers & Smith 1986	sounds
Meyers & Smith 1987	
Papousek, Freudenthaler & Schulter 2011	
Papousek, Reiser, Weber, Freudenthaler & Schulter 2012	
Allen, Harmon-Jones & Cavender 2001	video
Cole, Zapp, Nelson & Pérez-Edgar 2012	
Davidson, Ekman, Saron, Senulis & Friesen 1990	
Ekman, Davidson & Friesen 1990	
Feng, Forbes, Kovacs, George, Lopez-Duran, Fox & Cohn 2012	
Hofmann 2007	
Jones, Field, Fox, Davalos & Gomez 2001	
Killeen & Teti 2012	
Ohme, Reykowska, Wiener & Choromanska 2010	
Papousek, Reiser, Schulter, Fink, Holmes, Niederstätter, Nagl, Parson & Weiss 2013	
Pickens, Field & Nawrocki 2001	
Rognoni, Galati, Costa & Crini 2008	
Schellberg, Besthorn, Klos & Gasser 1990	
Bowley, Faricy, Hegarty, Johnstone, Smith, Kelly & Rushby 2013	picture
Crabbe, Smith & Dishman 2007	
Davidson, Schaffer & Saron 1985	
Goodman, Rietschel, Lo, Costanzo & Hatfield 2013	
Hietanen, Leppänen, Peltola, Linna-aho & Ruuhiala 2008	

Huster, Stevens, Gerlach & Rist 2009	
Ichebeck, Endrass, Simon & Kathmann 2014	
Kline, Blackhart & William 2007	
Rodriguez, Rey & Alcaniz 2013	
Wiedemann, Pauli, Dengler, Lutzenberger, Birbaumer & Buchkremer 1999	
Zotto, Deiber, Legrand, Gelder & Pegna 2013	
Hietanen, Leppänen, Peltola, Linna-aho & Ruuhiala 2008	**live and picture**
Pönkanen & Hietanen 2012	
Pönkanen, Peltola & Hietanen 2011	
Heller, Nitschke, Etienne & Miller 1997	**narrative / imagery**
Hofmann, Moscovitch, Litz, Kim, Davis & Pizzagalli 2005	
Nietschke, Heller, Etienne & Miller 2004	
Wacker, Chavanon, Leue & Stemmler 2008	
Wacker, Heldmann & Stemmler 2003	
Allen, Harmon-Jones & Cavender 2001	**biofeedback**
Allen, Iacono, Depue & Arbisi 1993	**light**
Passynkova & Volf 2001	
Cole, Zapp, Nelson & Pérez-Edgar 2012	**speech preparation**
Pérez-Edgar, Kujawa, Nelson, Cole & Zapp 2013	
Schmidt, Santesso, Miskovic, Mathewson, McCabe, Antony & Moscovitch 2012	
Peterson, Gravens & Harmon-Jones 2011	**cyber-ball task**
Peterson, Shackman & Harmon-Jones 2008	**aggression shock paradigm**
Verona, Sadeh & Curtin 2009	
Petruzello, Hall & Ekkekakis 2001	**physical activity / exercise**
Petruzzello & Landers 1994	
Petruzzello & Tate 1997	
Vogt, Schneider, Brümmer & Strüder 2010	
Woo, Kim, Kim, Petruzzello & Hatfield 2009	
dePascalis & Perrone 1996	**hypnosis**
Sabourin, Cutcomb, Crawford & Pribram 1990	
Rodriguez, Rey & Alcaniz 2013	**virtual environment**
Fernandez, Hernandez-Reif, Field, Diego, Sanders & Roca 2004	**odor**
Kline, Blackhart, Woodward, Williams & Schwartz 2000	
Sanders, Diego, Fernand, Field, Hernandez-Reif & Roca 2002	
Ferreira, Deslandes, Moraes, Cagy, Basile, Piedade & Ribeiro 2006	**sleep deprivation**
Shankman, Nelson, Sarapas, Robison-Andrew, Campbell, Altman, McGowan, Katz & Gorka 2013	**startle**
Shankman, Nelson, Sarapas, Robison-Andrew, Campbell, Altman, McGowan, Katz & Gorka 2013	**slot-task**

Shankman, Sarapas & Klein 2011	
Fernandez, Blass, Hernandez-Reif, Field, Diego & Sanders 2003	**sucrose**
Fox & Davdison 1986	
Shelley-Tremblay, Ernst & Kline 2009	
Sobotka, Davidson & Senulis 1992	**reward-punishment paradigms**
Coan, Allen & Harmon-Jones 2001	**voluntary facial expression / direct facial action task**
Stewart, Coan, Towers & Allen 2011	
Stewart, Coan, Towers & Allen 2014	
Tops, vanPeer, Wester, Wijers & Korf 2006	**cortisol**
Tops, Wijers, vanStaveren, Bruin, denBoer, Meijman & Korf 2005	
Lopes, Oliveira, Freire, Caldirola, Perna, Bellodi, Valença, Nascimento, Piedade, Ribeiro, Zin & Nardi 2009	**CO2**
Tops & Boksem 2010	**flanker task**
Gilbert, McClernon, Rabinovich, Dibb, Plath, Hiyane, Jensen, Meliska, Estes & Gehlbach 1999	**stress paradigm**
Verona, Sadeh & Curtin 2009	
Werner-Wilson, Lianekhammy, Frey, Parker, Wood, Kimberly, Perry, Blackburn, Smith, Terrana, Pucket & Dalton 2011	
Zinser, Fiore, Davidson, Baker 1999	
Hewig, Hagemann, Seifert, Naumann & Bartussek 2005	**no-go-task**
Wacker, Chavanon, Leue, Stemmler 2010	
Wacker, Mueller, Pizzagalli, Henning & Stemmler 2013	**experimenter attractiveness and dominance**
Gilbert, Meliska, Welser & Estes 1994	**smoking/nicotine**
Jaworska, McIntosh, Villeneuve, Thompson, Fisher, Milin & Knott 2011	
Knott, Bisserbe, Shah, Thompson, Bowers, Blais & Ilivitsky 2013	
Zinser, Fiore, Davidson & Baker 1999	
Amodio, Devine & Harmon-Jones 2007	**guilt manipulation**
Avram, Baltes, Miclea & Miu 2010	**emotional stroop task**
Chan, Han & Cheung 2008	**relaxation techniques / meditation**
Crost, Pauls & Wacker 2008	**private and public context**
Deldin & Chiu 2005	**cognitive restructuring**
Diaz & Bell 2012	**infant tasks: stranger approach / masks / toy spider**
Fox & Davdison 1988	
Jones, Field, Fox, Davalos & Gomez 2001	
Fernandez, Blass, Hernandez-Reif, Field, Diego & Sanders 2003	**infant tasks: strokes negative**
Fairclough & Roberts 2011	**2-back-task**
Fairclough & Spiridon 2012	**simulated driving task**
Flo, Steine, Blagstad, Gronli, Pallesen & Portas	**conditioned fear (shock)**

2011	
Goodman, Rietschel, Lo, Costanzo & Hatfield 2013	
Harmon-Jones, Abramson, Nusslock, Sigelman, Urosevic, Tironie, Alloy & Fearn 2008	**anagram**
Henriques & Davidson 1997	**visuo-spatial tasks**
Henriques & Davidson 1997	**word finding task**
Jones & Field 1999	**massage therapy**
Jones, Field & Davalos 1998	
Kerick, Iso-Ahola & Hatfield 2000	**Shooting task**
Stevens 2007	**transcranial direct magnetic stimulation**
Valiulis, Gerulskis, Dapsys, Vistartaite, Siurkute & Maciulis 2012	

7.2 Imagery Scripts provided by Wacker, Chavanon, Leue & Stemmler 2008 in the appendix section.

7.2.1 (revised) FFFS and (revised) BIS Scripts

You are at the party of a friend who lives on the edge of town. The atmosphere is okay and actually you would like to stay. However, tomorrow you want to get up early because you have to give a talk in class. You have no intention of walking all the way home, so you say good-bye just in time to catch the last bus. The bus stop is only a few minutes away from your friend’s apartment. You have dawdled a little and now need to hurry quite a bit in order not to miss the bus. You walk swiftly through the deserted side streets toward the main street. In a small, dark alley, just before the bus stop, you see the bus coming. If you now speed up some more for the last few meters, you will make it just in time. You start running. Only now you notice a group of three young men standing at the end of the alley. Until now you did not pay any attention to them. But now you realize that they seem to have noticed you. The guys carry beer cans and are obviously intoxicated. They seem to be looking for a fight. You slow down a little. One of them throws an empty beer can in your direction and yells at you: “Hey you, what are you doing, running around here this late at night?” The others hoot. You walk on slowly and hesitatingly. “Oh, damn, the bus will be gone in no time,” you say to yourself. They slowly spread out in a threatening semicircle, blocking the exit of the alley. One flings a cigarette at you and bellows in your direction: “Are you deaf or what?” You stop walking. Tensed silence. Every single one of your muscles is tensed.

7.2.1.1 BIS Version

You start to sweat. “What’s happening here? What do they want from me?” If you don’t start running again immediately, you’ll have to walk all the way home. “Should I simply keep going?” You feel your heart pounding in your head. You simply stand there rooted to the spot.

7.2.1.2 FFFS Version

You hear the bus depart. A beer can flies in your direction and hits your arm. Your respiration accelerates. You feel your heart pounding in your head. You stumble a few steps backward and turn around. You hear them yell from behind: “Hey, he’s trying to run! Go get him!” You run as fast as you can.

7.2.2 Control Script

It’s Sunday afternoon. You have been having lunch at your friends’ place. You would like to stay a little longer, but you need to go home to finish working on the talk you will present in class tomorrow. Your friends’ apartment is located on the edge of town and you have decided to take the bus. The bus stop is a few minutes away from the apartment. You have dawdled a little and now need to hurry quite a bit in order not to miss the bus. You walk swiftly through the deserted side streets toward the main street. In a narrow street just before the bus stop, you see the bus approaching from behind. You start running and turn into the main street, where the bus stop is located. Some people are already waiting at there. You are a little out of breath from running. You look around. You see an elderly woman with an eccentric long red shawl. A small boy stands next to her and plays absentmindedly with a thread hanging from his jacket. There are probably more than 10 people here, waiting to get into the bus. A couple talks excitedly about the latest discounts at the local fashion store. Others stand nearby and just stare at the ground or in the direction of the corner at which the bus should appear any minute now. You look in the same direction and see a man stride around the corner. A moment later the bus also appears at the corner. The old lady pulls the boy in the jacket back from the side of the road and whispers something to him out of earshot. The youngster still plays with the thread completely absentmindedly. The bus arrives at the bus stop and comes to a halt. The doors open. You let a few people enter before you and then follow them and find a vacant seat behind the couple. The bus departs.

7.3 Information for Participants.

7.3.1 Study I.

Probandeninformation

Liebe/r Teilnehmer/in,

das folgende Experiment gliedert sich in mehrere Teile.

Zunächst füllen Sie verschiedene Fragebögen in einer Onlinebefragung aus, sowie einen papierbasierten Fragebogen bezüglich ihrem befinden.

Anschließend wird die Messung des Elektroenzephalogramms (EEG) vorbereitet. Hierfür wird Ihnen eine EEG-Kappe aufgesetzt, deren Elektroden mit leitfähigem Gel gefüllt werden. Dazu wird eine Spritze mit einer Stumpfkanüle benutzt. Durch Verreiben des Gels auf der Kopfhaut wird die Leitfähigkeit zwischen Kopfhaut und Elektrode erhöht. Für Sie entstehen dadurch keine Schmerzen. Das Gel ist nach dem Experiment einfach aus den Haaren auswaschbar. Zudem werden Ihnen eine Elektrode auf den Rücken geklebt, die die Herzrate bestimmt, sowie zwei weitere Elektroden an den Fingerkuppen der linken Hand angebracht, die die Hautleitfähigkeit messen.

Nach dem Anlegen des EEGs werden Sie noch einmal nach ihrem Befinden befragt.

Der danach folgende Hauptteil des Experiments gliedert sich in vier Unterteile, die alle am Computer stattfinden.

Zu Beginn wird ein Ruhe – EEG von Ihnen gemessen, bei dem Sie akustisch dazu aufgefordert werden, die Augen zu schließen (und geschlossen zu lassen), bzw. die Augen zu öffnen (und offen zu lassen). Dieses Ruhe – EEG dauert etwa 8 Minuten.

Danach erleben Sie eine kleine Trainingsphase, in der Sie sich mit der virtuelle Realität auseinander setzen können und die Navigation in der virtuellen Realität üben können, sowie einige Situationen der virtuellen Realität erleben können.

Nach dieser Trainingsphase beginnt das eigentliche Experiment, in dem Sie sich in der virtuellen Realität verschiedenen Situationen ausgesetzt sehen. Dieser Teil des Versuches dauert ca. 66 Minuten.

In einer letzten Phase des Versuches werden Sie noch einmal ein paar Situationen der virtuellen Realität erleben und werden zu dem Erleben der jeweiligen Situation befragt.

Am Ende des Versuches werden Ihnen noch ein paar Fragebogen zum Erleben der virtuellen Realität und dem aktuellen Befinden ausgehändigt.

Falls Sie Fragen haben, wenden Sie sich bitte an den Versuchsleiter.

7.3.2 Study II.

7.3.2.1 Movie paradigm.

Probandeninformation Teiluntersuchung Film

Liebe/r Teilnehmer/in,

das Experiment, an dem Sie teilnehmen gliedert sich in mehrere verschiedene Teiluntersuchungen, von denen Sie heute an der Teiluntersuchung „Film“ teilnehmen.

Die heutige Teiluntersuchung besteht aus mehreren Teilen:

Zunächst füllen Sie ein paar Fragebögen bezüglich Ihres Befindens aus.

Anschließend wird die Messung des Elektroenzephalogramms (EEG), sowie der Hautleitfähigkeit und der Herzrate (EKG) vorbereitet.

Hierfür wird Ihnen eine EEG-Kappe aufgesetzt, deren Elektroden mit leitfähigem Gel gefüllt werden. Dazu wird eine Spritze mit einer Stumpfkanüle benutzt. Durch Verreiben des Gels auf der Kopfhaut wird die Leitfähigkeit zwischen Kopfhaut und Elektrode erhöht. Für Sie entstehen dadurch keine Schmerzen. Das Gel ist nach dem Experiment einfach aus den Haaren auswaschbar. Zudem werden Ihnen an den Schlüsselbeinen und am linken unteren Rippenbogen EKG-Elektroden zur Herzschlagmessung, sowie zwei weitere Elektroden an den Fingerkuppen der linken Hand angebracht, die die Hautleitfähigkeit messen.

Nach dem Anlegen des EEGs, des EKGs und der Hautleitsfähigkeitsmessung werden Sie noch einmal nach ihrem Befinden befragt.

Der danach folgende Hauptteil des Experiments gliedert sich in drei Unterteile, die alle am Computer stattfinden:

Zu Beginn wird ein Ruhe – EEG von Ihnen gemessen, bei dem Sie akustisch dazu aufgefordert werden, die Augen zu schließen (und geschlossen zu lassen), bzw. die Augen zu öffnen (und offen zu lassen). Dieses Ruhe – EEG dauert etwa 10 Minuten.

Danach erleben Sie kurze Filmausschnitte ohne Ton.

Sie werden drei verschiedene Filmausschnitte erleben, und dazu befragt werden.

Vor und nach jedem Filmausschnitt sind jeweils kurze Ruhephasen. Nutzen Sie die Ruhephase vor einem Filmausschnitt bitte dazu, sich möglichst zu entspannen und alle Gedanken und Gefühle aus ihrem Geist zu verbannen. Versuchen Sie dann, während dem Filmausschnitt in die Szene einzutauchen und sie so lebendig wie möglich aus der Sicht des Protagonisten mitzuerleben. Nutzen Sie die Ruhephase nach jedem Filmausschnitt bitte dazu, die eben erlebte Szene noch einmal so lebendig wie möglich gedanklich und emotional nachzuerleben. Dieser Teil des Versuches dauert ca. 25 Minuten.

Am Ende des Versuches werden Ihnen noch ein paar Fragebögen zu dem aktuellen Befinden ausgehändigt.

Falls Sie Fragen haben, wenden Sie sich bitte an den Versuchsleiter.

7.3.2.2 Mental imagery paradigm.

Probandeninformation Teiluntersuchung Vorstellung

Liebe/r Teilnehmer/in,

das Experiment, an dem Sie teilnehmen gliedert sich in mehrere verschiedene Teiluntersuchungen, von denen Sie heute an der Teiluntersuchung „Vorstellung“ teilnehmen.

Die heutige Teiluntersuchung besteht aus mehreren Teilen:

Zunächst füllen Sie ein paar Fragebögen bezüglich Ihres Befindens aus.

Anschließend wird die Messung des Elektroenzephalogramms (EEG), sowie der Hautleitfähigkeit und der Herzrate (EKG) vorbereitet.

Hierfür wird Ihnen eine EEG-Kappe aufgesetzt, deren Elektroden mit leitfähigem Gel gefüllt werden. Dazu wird eine Spritze mit einer Stumpfkanüle benutzt. Durch Verreiben des Gels auf der Kopfhaut wird die Leitfähigkeit zwischen Kopfhaut und Elektrode erhöht. Für Sie entstehen dadurch keine Schmerzen. Das Gel ist nach dem Experiment einfach aus den Haaren auswaschbar. Zudem werden Ihnen an den Schlüsselbeinen und am linken unteren Rippenbogen EKG-Elektroden zur Herzschlagmessung, sowie zwei weitere Elektroden an den Fingerkuppen der linken Hand angebracht, die die Hautleitfähigkeit messen.

Nach dem Anlegen des EEGs, des EKGs und der Hautleitsfähigkeitsmessung werden Sie noch einmal nach ihrem Befinden befragt.

Der danach folgende Hauptteil des Experiments gliedert sich in drei Unterteile, die alle am Computer stattfinden:

Zu Beginn wird ein Ruhe – EEG von Ihnen gemessen, bei dem Sie akustisch dazu aufgefordert werden, die Augen zu schließen (und geschlossen zu lassen), bzw. die Augen zu öffnen (und offen zu lassen). Dieses Ruhe – EEG dauert etwa 10 Minuten.

Danach erleben Sie ein kurzes Trainingsskript, wobei Sie üben können, sich in das dargebotene Szenario hinein zu versetzen und das Szenario in Ihrer Vorstellung lebhaft zu erleben.

Nach dieser Trainingsphase beginnt das eigentliche Experiment, wobei Sie drei verschiedene Vorstellungsszenarien erleben, und dazu befragt werden.

Vor und nach jedem Szenario sind jeweils kurze Ruhephasen. Nutzen Sie die Ruhephase vor einem Szenario bitte dazu, sich möglichst zu entspannen und alle Gedanken und Gefühle aus ihrem Geist zu verbannen. Versuchen Sie dann, in das jeweilige Szenario einzutauchen und es so lebendig wie möglich gedanklich zu erleben. Nutzen Sie die Ruhephase nach jedem Szenario bitte dazu, das eben erlebte Szenario noch einmal so lebendig wie möglich nachzuerleben. Dieser Teil des Versuches dauert ca. 20 Minuten.

Am Ende des Versuches werden Ihnen noch ein paar Fragebögen zu dem aktuellen Befinden ausgehändigt.

Falls Sie Fragen haben, wenden Sie sich bitte an den Versuchsleiter.

7.3.2.3 VR paradigm.

Probandeninformation Teiluntersuchung virtuelle Realität

Liebe/r Teilnehmer/in,

das Experiment, an dem Sie teilnehmen gliedert sich in mehrere verschiedene Teiluntersuchungen, von denen Sie heute an der Teiluntersuchung „virtuelle Realität“ teilnehmen.

Die heutige Teiluntersuchung besteht aus mehreren Teilen:

Zunächst füllen Sie ein paar Fragebögen bezüglich Ihres Befindens aus.

Anschließend wird die Messung des Elektroenzephalogramms (EEG), sowie der Hautleitfähigkeit und der Herzrate (EKG) vorbereitet.

Hierfür wird Ihnen eine EEG-Kappe aufgesetzt, deren Elektroden mit leitfähigem Gel gefüllt werden. Dazu wird eine Spritze mit einer Stumpfkanüle benutzt. Durch Verreiben des Gels auf der Kopfhaut wird die Leitfähigkeit zwischen Kopfhaut und Elektrode erhöht. Für Sie entstehen dadurch keine Schmerzen. Das Gel ist nach dem Experiment einfach aus den Haaren auswaschbar. Zudem werden Ihnen an den Schlüsselbeinen und am linken unteren Rippenbogen EKG-Elektroden zur Herzschlagmessung, sowie zwei weitere Elektroden an den Fingerkuppen der linken Hand angebracht, die die Hautleitfähigkeit messen.

Nach dem Anlegen des EEGs, des EKGs und der Hautleitsfähigkeitsmessung werden Sie noch einmal nach ihrem Befinden befragt.

Der danach folgende Hauptteil des Experiments gliedert sich in vier Unterteile, die alle am Computer stattfinden:

Zu Beginn wird ein Ruhe – EEG von Ihnen gemessen, bei dem Sie akustisch dazu aufgefordert werden, die Augen zu schließen (und geschlossen zu lassen), bzw. die Augen zu öffnen (und offen zu lassen). Dieses Ruhe – EEG dauert etwa 10 Minuten.

Danach erleben Sie eine kleine Trainingsphase, in der Sie sich mit der virtuellen Realität auseinander setzen können und die Navigation in der virtuellen Realität üben können, sowie einige Situationen der virtuellen Realität erleben können.

Nach dieser Trainingsphase beginnt das eigentliche Experiment, in dem Sie sich in der virtuellen Realität verschiedenen Situationen ausgesetzt sehen. Dieser Teil des Versuches dauert ca. 37 Minuten.

In einer letzten Phase des Versuches werden Sie noch einmal ein paar Situationen der virtuellen Realität erleben und zu dem Erleben der jeweiligen Situation befragt werden.

Am Ende des Versuches werden Ihnen noch ein paar Fragebögen zu dem aktuellen Befinden ausgehändigt.

Falls Sie Fragen haben, wenden Sie sich bitte an den Versuchsleiter.

7.4 Written informed consent.

7.4.1 Study I.

Einwilligungserklärung:

Liebe/r Teilnehmer/in,

vielen Dank für Ihr Interesse an dieser Studie zum Thema „Virtuelle Realität“. In dieser Studie soll die Gehirnaktivität während einer simplen Operationalisierung der virtuellen Realität gemessen werden.

Hiermit erkläre ich mich freiwillig bereit, an der Studie zur Untersuchung der virtuellen Realität teilzunehmen. Ich wurde über den Sinn, den Ablauf und die Risiken dieser Studie umfassend aufgeklärt. Ich habe keine weiteren Fragen.

Ich weiß, dass alle von mir erhobenen Daten vertraulich behandelt und nicht an Dritte weitergegeben werden.

Es ist mir bekannt, dass ich die Teilnahme an dieser Studie jederzeit ohne Angabe von Gründen beenden kann, wobei Versuchspersonenstunden anteilig gewährt werden.

Würzburg, den Unterschrift ProbandIn:

Unterschrift Untersuchungsleiter:

7.4.2 Study II.

7.4.2.1 Movie paradigm.

Einwilligungserklärung Teiluntersuchung Film:

Liebe/r Teilnehmer/in,

vielen Dank für Ihr Interesse an dieser Studie zum Thema „Gehirnaktivität“. In dieser Studie soll die Gehirnaktivität während der Darbietung von verschiedenen Filmsequenzen gemessen werden.

Hiermit erkläre ich mich freiwillig bereit, an der Studie zur Untersuchung der Gehirnaktivität während der Darbietung von verschiedenen Filmsequenzen teilzunehmen. Ich wurde über den Sinn, den Ablauf und die Risiken dieser Studie umfassend aufgeklärt. Ich habe keine weiteren Fragen.

Ich weiß, dass alle von mir erhobenen Daten vertraulich behandelt und nicht an Dritte weitergegeben werden.

Es ist mir bekannt, dass ich die Teilnahme an dieser Studie jederzeit ohne Angabe von Gründen beenden kann, wobei Versuchspersonenstunden oder anderweitige Kompensation anteilig gewährt werden.

Würzburg, den Unterschrift ProbandIn:

Unterschrift Untersuchungsleiter:

7.4.2.2 Mental imagery paradigm.

Einwilligungserklärung Teilversuch Vorstellung:

Liebe/r Teilnehmer/in,

vielen Dank für Ihr Interesse an dieser Studie zum Thema „Gehirnaktivität". In dieser Studie soll die Gehirnaktivität während der Vorstellung von verschiedenen Szenarien gemessen werden.

Hiermit erkläre ich mich freiwillig bereit, an der Studie zur Untersuchung der Gehirnaktivität während der Vorstellung von verschiedenen Szenarien teilzunehmen. Ich wurde über den Sinn, den Ablauf und die Risiken dieser Studie umfassend aufgeklärt. Ich habe keine weiteren Fragen.

Ich weiß, dass alle von mir erhobenen Daten vertraulich behandelt und nicht an Dritte weitergegeben werden.

Es ist mir bekannt, dass ich die Teilnahme an dieser Studie jederzeit ohne Angabe von Gründen beenden kann, wobei Versuchspersonenstunden oder anderweitige Kompensation anteilig gewährt werden.

Würzburg, den Unterschrift ProbandIn:

Unterschrift Untersuchungsleiter:

7.4.2.3 VR paradigm.

Einwilligungserklärung Teilversuch virtuelle Realität:

Liebe/r Teilnehmer/in,

vielen Dank für Ihr Interesse an dieser Studie zum Thema „Gehirnaktivität". In dieser Studie soll die Gehirnaktivität während einer simplen Operationalisierung der virtuellen Realität gemessen werden.

Hiermit erkläre ich mich freiwillig bereit, an der Studie zur Untersuchung der Gehirnaktivität während der virtuellen Realität teilzunehmen. Ich wurde über den Sinn, den Ablauf und die Risiken dieser Studie umfassend aufgeklärt. Ich habe keine weiteren Fragen.

Ich weiß, dass alle von mir erhobenen Daten vertraulich behandelt und nicht an Dritte weitergegeben werden.

Es ist mir bekannt, dass ich die Teilnahme an dieser Studie jederzeit ohne Angabe von Gründen beenden kann, wobei Versuchspersonenstunden oder anderweitige Kompensation anteilig gewährt werden.

Würzburg, den   Unterschrift ProbandIn:

Unterschrift Untersuchungsleiter:

8 Publication list

8.1 Articles in peer reviewed journals

Rodrigues, J., Ulrich, N., & Hewig, J. (2015). A neural signature of fairness in altruism: a game of theta? Social neuroscience, 10(2), 192–205. doi:10.1080/17470919.2014.977401

8.2 Conference Contributions & Talks

8.2.1 Talks

Rodrigues (2015, September) Intra- and interindividual prediction of altruistic behavior using multinomial logistic regression and structural equation modelling. Talk given at the 12th meeting of „Fachgruppe Methoden & Evaluation [FGME]“ of the German Society for Psychology (DGPs), Jena, Germany. p.192-205.

8.2.2 Poster presentations

Rodrigues, Müller & Hewig (2016, September). To flee or not to flee: Frontal activation patterns and behavior in a virtual T-maze. Poster presentation at 56th annual meeting of the Society for Psychophysiological Research (SPR), Minneapolis, USA.

Rodrigues, Müller & Hewig (2016, June). To flee or not to flee: Frontal activation patterns and behavior in a virtual T-maze. Poster presented at the 42st conference "Psychologie und Gehirn", Berlin, Germany.

Rodrigues & Hewig (2015, October). *Frontal asymmetry as a predictor of behavior in a virtual T-maze.* Poster presentation at 55th annual meeting of the Society for Psychophysiological Research (SPR), Seattle, USA.

Rodrigues & Hewig (2015, September). *Das „wer“ bestimmt das „wie“: Persönlichkeitskorrelate in Fluchthandlungen auf negative Situationen in einem virtuellen Labyrinth.* Poster presentation at 13th meeting of „Fachgruppe Differentielle Psychologie, Persönlichkeitspsychologie und Psychologische Diagnostik“ of the German Society for Psychology (DGPs), Mainz, Germany.

Rodrigues & Hewig (2015, June). *Frontal asymmetry as a predictor of behavior in a virtual T-maze.* Poster presented at the 41st conference "Psychologie und Gehirn", Frankfurt, Germany.

Rodrigues, Mühlberger & Hewig (2014, September). *From brain to behaviour – inducing frontal asymmetry with virtual reality, preliminary results.* Poster presented at the 54th annual meeting of the Society for Psychophysiological Research, Atlanta, USA.

Rodrigues, Ulrich & Hewig (2014, September). *The sign of altruism? An exploratory study about midfrontal theta activity and altruism in dictator game.* Poster presented at the 54th annual meeting of the Society for Psychophysiological Research, Atlanta, USA.

Rodrigues & Hewig (2014, June). *Lang lebe der Diktator! Eine explorative Studie über Theta – Aktivität und Altruismus im Diktatorspiel.* Poster presented at the 40th conference "Psychologie und Gehirn", Lübeck, Germany.

Rodrigues & Hewig (2013, October). *Physiological correlates of individual differences in mental imagery.* Poster presented at the 53rd annual meeting of the Society for Psychophysiological Research, Florence, Italy

Rodrigues & Hewig (2013) BIS man flieht: Behaviour Inhibition System und visuelle Vorstellung einer Vermeidungssituation. Tagungsband der 39. Tagung Psychologie und Gehirn 2013, p. 62.

8.3 Awards

2015: Poster award (German Society for Psychophysiology and its Application, DGPA).

2014: Neuroscience Research Award (from the Section Neuroscience of the GSLS Würzburg)

9 Curriculum Vitae

PERSONAL INFORMATION:

Name: Johannes Rodrigues

Adress: Pleicherschulgasse 1
97070 Würzburg Germany

Telephone: +49 931/31-81771 (work)
Mobile:
E-mail: johannes.rodrigues@uni-wuerzburg.de (work)

Date of birth: 18.01.1986
Place of birth: Heidenheim an der Brenz (Germany)
Marital status: single

EDUCATION:

general qualification for university entrance: Abitur (A-level equivalent)
Schillergymnasium Heidenheim *September 1996 – June 2005*
(Final Grade: 1.8; 1 down to 6)

Studies: Chemistry/Physics (aborted)
Universität Konstanz *October 2006 – September 2007*

Open University course: Psychology (aborted)
October 2007 – March 2008

Diploma, Psychology
Julius – Maximilians – Universität Würzburg *April 2008 – September 2012*

THESIS: "Helden im Geiste: Visuelle Vorstellung bei Pen & Paper - Rollenspielern"

Specialization: - Differential psychology
- Traffic psychology
(Final Grade: 1.6; 1 down to 6)

TEACHING AND RESEARCH EXPERIENCE SUMMARY:

Tutor: Statistics
Julius – Maximilians – Universität Würzburg
October 2009 - February 2012

On a semester-by-semester basis, my responsibilities included helping problems with quantitative statistics.

Research assistant: "Studentische Hilfskraft", department of psychology III: Cognitive psychology
Julius – Maximilians – Universität Würzburg
November 2008 – July 2012

My responsibilities included programming experiments, designing graphics, developing tutorials for several programs, conducting experiments and in spring 2010 assistant teaching in cognitive psychology.

<u>Research assistant: "Studentische Hilfskraft", department of psychology I: Differential psychology, personality psychology, and psychological diagnostics</u>
Julius – Maximilians – Universität Würzburg
February 2012 – September 2012

My responsibilities included programming experiments, conducting experiments and analyzing data. The data were on physiological (EEG) and behavioral basis.

<u>Research assistant at Julius – Maximilians – Universität Würzburg at department for differential psychology, personality psychology, and psychological diagnostics (teaching and research)</u>
Since November 2012

My teaching experience includes seminars in differential psychology, practical courses in diagnostics and differential psychology on analyzing data and conducting experiments.
My research experience includes designing, programming and conducting experiments, virtual reality experiments and online experiments, analyzing behavioral data including movement trajectories in virtual reality, EEG-data, skin conductance and heart rate- data as well as preparing manuscripts.

Seminars in differential psychology and personality psychology (undergraduate level in psychology):

Journal Club: Biopsychological aspects of differential psychology (summer term 2014, winter terms 2014/15, 2014/15)

Seminar: Alpha activity in EEG as a marker for personality traits (winter terms 2013/14, 2014/15, summer terms 2014, 2015, 2016)

Practical courses (undergraduate level in psychology):

Introduction into empirical and experimental research methods (winter terms 2013/14, 2015/16 summer term 2015)

Tutorial: Diagnostics, test theory and test development (winter terms 2013/14, 2014/15, 2015/16, summer terms 2014, 2015, 2016)

SKILLS:

Language skills:	German (mother tongue)		
	English (advanced)		
	French (basic knowledge)		
Computer skills:	Microsoft Office (Word, Power Point, Excel)		
	SPSS		Brain Vision Analyzer
	GLE		Onyx
Programming Skills:	Matlab	Phython	HTML / HTML 4.0
	R	PHP	Psychophy

Curriculum Vitae

E – Prime Presentation SQL

C++ (basic knowledge) Java (basic knowledge)
SILAB (basic knowledge)

PUBLICATIONS:

Rodrigues, J., Ulrich, N. & Hewig, J.(2015). A neural signature of fairness in altruism: A game of theta ? *Social Neuroscience.* doi:10.1080/17470919.2014.977401.

AWARDS, FELLOWSHIPS & RESEARCH FUNDINGS:

11/2013: Research funding from "Universitätsbund" University of Würzburg for recruiting participants (1000 €)

09/2014: SPR student travel award (1000 $) from society of psychophysiological research (SPR)

11/2014: Neuroscience Research Award (3000 €) from the Section Neuroscience of the Graduate School of Life Science at the University of Würzburg

05/2015 Research funding (1480 €) and travel funding (763€) from faculty of human sciences of the University of Würzburg

06/2015: Poster award (300 €) from German Society for Psychophysiology and its Application, DGPA.

09/2015 SPR Research training fellowship (2000 $) from society of psychophysiological research (SPR)

05/2016 Research funding (3800 €) and travel funding (1404€) from faculty of human sciences of the University of Würzburg

MEMBERSHIP IN PROFESSIONAL ASSOCIATIONS:

since 03/2013 Society for Psychophysiological Research (SPR)

12/2014 - 12/2015 Association for Psychological Science (APS)

SOCIAL COMMITMENT:

Acolyte, Youth Leader, musician
Kirchengemeinde St.Maria Heidenheim *1997 – 2005*

Community Service
Universitätsklinikum Tübingen: Augenklinik *September 2005 – May 2006*

Temporary male nurse
Universitätsklinikum Tübingen: Augenklinik *July 2006 – September 2006*