Neural correlates of decision making in quasi-realistic binary decision situations – an EEG and fMRI study

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1. Abstract

A central aspect of daily life is decision making, often under uncertain and ill-defined conditions. This may be why there is huge and continuously growing scientific interest in human decision making. Research of decision making was dominated by mathematical and economic models at first, which led to abstract problems and decision situations, but recent years have seen a growing trend to orient research towards realistic scenarios. The relatively young branch of Naturalistic Decision Making (NDM) placed analyzing real world decision processes of experts at its very core and emphasizes the importance of recognizing the situation to come to a quick yet reliable decision.

Uncertainty is a constant aspect of decision making and can be defined as a feeling of doubt that delays or impedes the decision.

The aim of this study was to investigate the neural correlates of decision making under certainty and uncertainty in a quasi-realistic setting, that approached the principles of NDM as much as possible in neuroscience. Participants were presented with variations of a simple binary choice. Two types of information from different sources were presented to them: a weather forecast on the probability of rain and a picture of the sky. Based on this information the participants decided whether they would want to take an umbrella with them in a hypothetical context situation. This information varied in its conclusiveness and in its congruency, evoking either certainty or uncertainty in the decision makers, depending on their decision strategies. Each participant undertook the experiment twice; their neural activity was measured once with the EEG and once with fMRI.

To account for said individual decision strategies, uncertain and certain decision making during the experiment was identified for each participant individually. This categorization was based on the congruency of the participants' choices.

Multiple analyses were conducted to investigate the data, namely: statistical analyses of the behavioral data, including visualization and parameterization of decision strategies; a contrast and conjunction analysis of the fMRI data, and an additional analysis of individual voxel based activation; an ERP analysis, and a frequency analysis of the EEG data.

Overall, this study has shown two things. One concerns the neural correlates of decision making: The processing of uncertain and certain decision making seems to have some differences, as addressed in the relevant literature, but seems to be mostly driven by the same fronto-parietal network. The second concerns the nature of quasi-realistic research, which seems to be possible in a laboratory context and offers much needed ecological validity, but requires attention to detail and individual variations. To properly use quasi-realistic designs, the standard procedures of analysis have to be adapted.

During the analysis of the data, a number of limitations of the experimental design became apparent, mostly stemming from an initial underestimation of the participant's individually varying decision strategies. Many possible improvements and alternative approaches to design and analysis could be devised based on these realizations, which may be beneficial to future studies in this general field.

Zusammenfassung

Ein zentraler Aspekt des Alltagslebens ist die Entscheidungsfindung, oft unter unsicheren und vagen Bedingungen. Vielleicht deswegen gibt es ein beachtliches und stets wachsendes wissenschaftliches Interesse an menschlicher Entscheidungsfindung. Die Erforschung von Entscheidungen war anfangs von mathematischen und ökonomischen Modellen dominiert, untersucht mittels abstrakter Aufgaben und Entscheidungssituationen, doch in den letzten Jahren gab es einen wachsenden Trend zu realistischeren Szenarios. Der vergleichsweise junge Zweig des Naturalistic Decision Making (NDM) konzentriert sich auf die Entscheidungsfindung von Experten im realen Leben und betont die Bedeutung von Situationswahrnehmung für schnelle und verlässliche Entscheidungen.
Unsicherheit ist ein konstanter Aspekt von Entscheidungsfindung und kann als Zweifel, der die Entscheidung verzögert oder verhindert, definiert werden.
Das Ziel dieser Studie war die Untersuchung der neuronalen Korrelate sicherer und unsicherer Entscheidungsfindung in einem quasi-realistischen Szenario, welches sich den Prinzipien von NDM soweit wie möglich annäherte. Den Teilnehmenden wurden Variationen einer binären Wahl präsentiert. Es gab zwei Informationsquellen: Eine Wettervorhersage über die Regenwahrscheinlichkeit und ein Bild vom Himmel. Auf Basis dieser Informationen musste über die Mitnahme eines Regenschirmes in einer hypothetischen Kontext-Situation entschieden werden. Die Informationen variierten in ihrer Schlüssigkeit und Kongruenz, was zu Unsicherheit sowie Sicherheit führen konnte, abhängig von den Entscheidungsstrategien der Teilnehmenden. Alle Teilnehmenden absolvierten das Experiment zweimal; die Hirnaktivität wurde einmal mit EEG und einmal mit fMRT gemessen.
Um die individuellen Entscheidungsstrategien zu berücksichtigen, wurden sichere und unsichere Entscheidungen für alle Teilnehmenden einzeln identifiziert. Diese Kategorisierung basierte auf der Kongruenz der Entscheidungen.
Verschiedene Analysen wurden durchgeführt, um die Daten zu untersuchen, und zwar: Statistische Analysen der behavioralen Daten, inklusive einer Visualisierung der Strategien; eine contrast- und conjunction-Analyse der fMRT Daten, und eine zusätzliche Analyse von voxel-basierter Aktivität; eine EKP Analyse und eine Frequenzanalyse der EEG Daten.
Im Gesamten hat diese Studie zwei Dinge gezeigt. Erstens, in Bezug auf die neuronalen Korrelate von Entscheidungsfindung: Das Verarbeiten sicherer und unsicherer Entscheidungen scheint einige Unterschiede zu zeigen, wie sie auch in der entsprechenden Literatur angesprochen werden, basiert aber auf demselben fronto-parietalen Netzwerk. Zweitens, in Bezug auf quasi-realistische Forschung: Solche Forschung scheint im Laborkontext möglich zu sein, und erhöht die ökologische Validität, verlangt aber Detailgenauigkeit und die Beachtung von individueller Variation. Um solche Designs angemessen zu verwenden, müssen die gebräuchlichen Analysen angepasst werden.
Während der Analyse der Daten wurden mehrere limitierende Faktoren des experimentellen Designs offensichtlich, die größtenteils von einer anfänglichen Unterschätzung der individuellen Entscheidungsstrategien herrühren. Viele mögliche Verbesserungen und alternative Ansätze zum Design und der Analyse konnten davon abgeleitet werden, die zukünftigen Studien in diesem Feld zuträglich sein könnten.

2. Introduction

People have to make decisions every day throughout their lives, and the feeling of uncertainty is common for those decisions (Mousavi & Gigerenzer, 2014). Given the omnipresence of this topic it is not surprising that many different scientific disciplines are involved in the research of those decisions and the processes by which they are made (Ernst & Paulus, 2005; Johnson & Busemeyer, 2010).

Scientific research into decision making was, for a long time, focused on abstract situations, uncommon in everyday life. While this revealed important information about partial processes of decision making, there is doubt that the qualitatively different processes taking place in real life decision making can be researched that way (Hammond, 2015). Since the theories of classical decision making seem to have their limits concerning real, everyday life decision making, a novel approach termed Naturalistic Decision Making (NDM) has been established over the last 20 years. The goal of NDM, towards which some progress has been made, is to research how expert decision makers actually make decisions in unstable and complex real life situations (Lipshitz, Klein, Orasanu, & Salas, 2001).

Neuroscience fulfills an important role in decision making research, since it is able to gather evidence for how humans process information and come to decisions. For example, neuroscientific studies could, in certain circumstances, decide which of multiple competing theories about human decision making is more accurate, even when behavioral data is inconclusive. A neuroscientific analysis of NDM could bring about interesting results regarding the complex mental processing of real world decision making.

However, NDM is by definition naturalistic, a basis entirely opposite to the laboratory context of neuroscientific methods. Therefore, a quasi-realistic experimental design would have to be developed, with the goal of bringing the experiment as close to a real life situation as possible.

This thesis describes the efforts to create such a quasi realistic design and use it to investigate the neural process of human decision making during certain and uncertain decisions. The core goals were twofold: First, the feasibility of such an approach was

supposed to be tested and appropriate methods of stimulus design and of data analysis were to be explored. Second, the results were to be used to either validate or broaden the understanding of neural correlates of decision making gained from studies that used a more abstract and unrealistic design.

First the theoretical background will be outlined, defining the important terms and fixing the hypotheses. After that the experimental design and overall structure of the study will be described. The different routes of analysis - behavioral, EEG, and fMRI and their subcategories - will be explained separately. For each the same structure will be followed: First, the data acquisition and statistical analysis will be outlined, followed by the results and a short discussion in light of the hypotheses and of the limitations that were revealed during the course of the work. At the end of each segment, there will be an overall discussion.
Lastly, a successor experiment will be outlined shortly and its results will be discussed in relation to open questions from the main experiment.

3. Theoretical Background

First of all, the concepts of decision making, uncertainty, risk, and ambiguity will be investigated and, for the context of this thesis, defined. This is a necessary first step to avoid confusion resulting from mismatched definitions.

In the following paragraphs the cornerstones of classical decision making theories shall be outlined, in combination with their limitations and criticism of them. After that, NDM will be explained and important aspects of the research into this field will be mentioned.

3.1. Decision Making

Considering the attention decision making receives from many different scientific disciplines (Ernst & Paulus, 2005; Johnson & Busemeyer, 2010) it is not surprising that the definitions of decisions and decision making processes don't always overlap perfectly. Therefore the following paragraphs will attempt to separate the different aspects of human behavior that are summarized as 'decision making' and will define what is understood as decision making in the context of this thesis.

As a first step it should be noted that this thesis focuses on value-based decision making, which can be understood as choosing among options, each of which is associated with a certain value, which could be a reward or a punishment (Rangel, Camerer, & Montague, 2008; Vaidya & Fellows, 2017). Therefore this thesis does not take into consideration the processes of responding with a certain behavior based on a rule (instructed action selection, see Vaidya & Fellows, 2017) or of classification of sensory information (perceptual decision making, see Summerfield & Blangero, 2017), both of which are termed 'decision making' in some instances.

In the second step it is important to note that there are different levels when it comes to the complexity of a decision and its cognitive demand (See fig. 1 for a simplified overview, Jungermann, Pfister, & Fischer, 2010; Volz, Schubotz, & von Cramon, 2006):

(1) On the first level there are routine decisions which are made so often that one merely needs to compare the current situation and its options to previous situations and

previously chosen options. No decision making in the sense of comparing options is required (Volz et al., 2006), only a matching process with low cognitive demand which triggers the automated response if the situations are sufficiently similar (Jungermann et al., 2010).

(2) Decisions of the second level are called stereotypical. They demand a marginally higher attention and cognitive effort than routine decisions and are specific not for a situation but for the set of options (Jungermann et al., 2010). A classic example are consumer decisions (e.g. 'Which of these deserts will I eat?'). The decision on this level is based on a holistic impression of the different options and on simple heuristics that rely on intuition (Volz et al., 2006).

(3) On the third level there are the reflected decisions. In these decisions the decision maker has to actively relate their values to the current situation and its options (Volz et al., 2006), because no routine or stereotypical preferences are available. This creates a higher cognitive demand and the complexity (and often, importance) of such decisions can sometimes lead to the decision maker postponing or entirely aborting the decision (Jungermann et al., 2010).

(4) The fourth and cognitively most demanding type of decision is called constructive decision. Here the options are either not given or ill-defined and the values relevant for the decision are either unclear or have to be newly derived from the decision makers value system (Jungermann et al., 2010). This process of generating new options and choosing one of them also contains lower level processes (Volz et al., 2006) and additional cognitive processes (Jungermann et al., 2010).

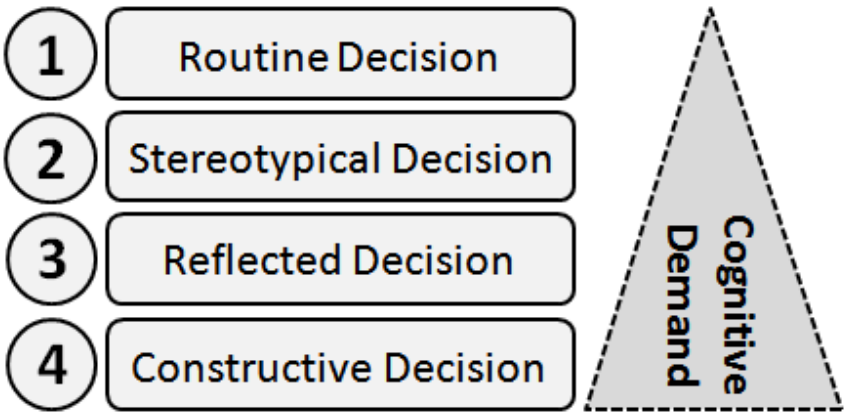

Fig. 1: Abstract overview of the four decision levels.

The question which types of decision making will be the topic of this thesis can only be answered properly after taking into account the theoretical framework. See section 3.5.1 for such considerations.

Lastly, it should be considered that decision making can be separated into different, temporally distinct steps (Ernst & Paulus, 2005). One possible differentiation would be into assessment, execution, and outcome processing. During the assessment, the attributes of the decision situation are perceived, including possible options, and preferences are formed. During execution, one preferred option is chosen and executed. The outcome of that decision will then be perceived and processed (Ernst & Paulus, 2005).

3.2. Dual-Process Theories

It is a widespread idea in psychology that thinking, reasoning, and decision making are based on two distinct processes. Many different variations of the concept exist, united by the common idea that one process (System 1) is fast, reflexive, intuitive, and largely unconscious and the other (System 2) is slow, deliberate, analytic, and conscious (Evans, 2008; Weber & Johnson, 2009). The amount of cognitive demand also differs between the systems; System 1 barely needs any effort while System 2 is more demanding (Croskerry, Petrie, Reilly, & Tait, 2014). Based on that, this theory can be united with the decision levels introduced in the last section: System 1 spans routine and stereotypical decisions while System 2 is responsible for reflected and constructive decisions.

Because of the broad terms this theory is formulated in, it can be applied to explain psychological phenomena in different domains, one of which is judgment and decision making (Alós-Ferrer & Strack, 2014; Evans, 2008; Weber & Johnson, 2009).

Many details of this system are still being debated, like the degree of interaction between the largely independent systems, or whether they work in parallel or sequence, or whether System 2 fulfills a supervisory role over System 1 (Weber & Johnson, 2009).

Another open question is how many additional subsystems may be necessary to sufficiently explain decision making (Weber & Johnson, 2009). On top of that, there is the question regarding the coordination and integration of information from the two (or more) systems before a decision can be acted out (Weber & Johnson, 2009).
Despite the vagueness of many of the theory's details, the concept in general is a useful one for structuring human decision making processes. Following sections will therefore refer to this model where it is applicable.

3.3. Uncertainty, Risk and Ambiguity

When consulting existing literature in the field of decision making, the concepts of uncertainty, risk, and ambiguity appear regularly. However, there are considerable differences between the individual definitions of these aspects of a decision (Lipshitz & Strauss, 1997). To further complicate the issue, similar definitions are used for different concepts (Lipshitz & Strauss, 1997), meaning a given study about risk may have more in common with one about uncertainty than with a second one about risk.

In regard to economic decisions as discussed in theoretical economics, uncertainty and risk were differentiated almost a hundred years ago by Frank Knight in 1921. He defined risk as something quantifiable, like a business venture that has a specific known (smaller than 100%) probability of succeeding, while uncertainty is something not quantifiable, where the decision maker does not know the probabilities of an event occurring or a plan succeeding (Knight, 1921). Therefore uncertainty cannot be overcome by complex algorithms, and should rather be tackled by using heuristics that don’t need exhaustive information (Mousavi & Gigerenzer, 2014).
This definition, however, is not widely used. Risk for example is frequently defined as the (subjective) possibility of loss or injury following a decision, with or without the inclusion of known probabilities (e.g. Brachinger & Weber, 1997; Cazzell, Li, Lin, Patel, & Liu, 2012). The definition of risk also differs systematically between different fields (see Schonberg, Fox, & Poldrack, 2011). Additionally there is the concept of ambiguity, which sometimes overlaps with that of uncertainty as having no clear information about probabilities (Chen et al., 2013; Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005).

Some authors also differentiate between first- and second-order uncertainty; The former describes uncertainty about the outcome of an action and the latter the uncertainty about the accuracy of the first-order uncertainty (Bach, Hulme, Penny, & Dolan, 2011).

In this thesis, the definition of uncertainty proposed by Lipshitz and Strauss (Lipshitz & Strauss, 1997) shall be used. They defined uncertainty as a feeling of doubt in the decision maker, which slows the decision or hinders it completely. This general view has the advantage of being based on the behavior of the decision maker and allowing for many subjective reasons for the uncertainty (Lipshitz & Strauss, 1997). Since the frame of this work is neuropsychological and not economical in nature, a definition of uncertainty that is centered around a person's psychological state during the decision making process seems to be most appropriate.
The concepts of both risk and ambiguity were avoided in this thesis. There were two reasons for that: The first reason was that - based on the most common definitions of risk (potential of loss after a decision with known probabilities) and ambiguity (unclear probabilities) - risk was not present in this study and ambiguity was already covered by the concept of uncertainty. The second reason was to avoid confusion by adding multiple definitions to the already existing mass. Therefore, only uncertainty was used.

3.4. Classical Decision Making

The beginning of research into decision making in the 1950s was coined by the dominance of economical and mathematical approaches. Normative models were created to predict human decisions in specific situations, using axioms and formulas (see Weber & Johnson, 2009). It was assumed that people made (or at least tried to make) optimal decisions based on the value of the possible outcomes and their respective probabilities. As such, the research of decisions could be broken down to a mathematical problem, where the expected value for all options is calculated and the best option with the highest value is selected (Johnson & Busemeyer, 2010).

One model of major importance in the context of decision making under uncertainty and risk was the expected utility model created by Neumann and Morgenstern and extended by Savage (Johnson & Busemeyer, 2010; see Tversky & Kahneman, 1981). The model was supposed to describe rational human choice, based on a set of axioms that reasonable decision makers would want to obey (Kahneman & Tversky, 1979). The utility of each option was defined as the sum of the utility of each possible consequence weighed by the subjective probability of occurrence of that consequence. But probability calculations still bound the subjective probabilities (Johnson & Busemeyer, 2010).

However, Kahneman and Tversky pointed out the model's inability to accurately predict human decisions in some contexts (Kahneman & Tversky, 1979). There are systematic mistakes in the rational judgment of the majority of humans that the expected utility model fails to account for. Many of those stem from a use of the automatic, unconscious System 1 (Croskerry et al., 2014). This system uses heuristics to supply intuitive and fast answers, which are more prone to error in the given contexts (Evans, 2008).

As a consequence to that, the so called prospect theory (Tversky & Kahneman, 1981) was created, to better account for systematic deviations of human decision makers from previous predictions.

This theory is an example of the so called descriptive models, which integrated findings of psychology into the prediction of decisions, making it more accurate for actual human behavior (Johnson & Busemeyer, 2010). Still, even with these alterations, descriptive models represent an adaptation of the normative models after accounting for human peculiarities (Johnson & Busemeyer, 2010).

There exists a multitude of different descriptive models, each with their unique approach of describing human decision making. Some are more capable than others in explaining seemingly paradox human choices, while others simply use a different psychological reasoning while explaining the same empirical data as others (for an extensive review, see Johnson & Busemeyer, 2010).

After the descriptive models came the computational approaches which focused primarily on the cognitive processes of decision rather than on a mathematical description thereof. These include for example the heuristic approaches (based on simple but effective rules of thumb) and the decision field theory (based on accumulation of preferences over time) (Johnson & Busemeyer, 2010).

The field of neuroscience has recently begun to contribute to the debates in decision making research. Using neuroscientific means it was possible to gather empirical data on how humans process the different aspects of a decision situation and how the final decision might be made. That way, neuroscience can sometimes support certain theories of decision making (like the decision field theory from the computational approaches) over others (like normative and descriptive approaches), solving a debate the behavioral data alone could not end (see Johnson & Busemeyer, 2010).

In recent years, criticism of classical decision making theories and research has increased (see Hammond, 2015). The abstract "small worlds", to which decision making research was confined, function differently from the complex and uncertain "large worlds" (Brighton & Gigerenzer, 2012) and require qualitatively different cognitive processes (Hammond, 2015). The situations analyzed were mostly theoretical; optimal choices a human could make only if they had extensive knowledge, statistical prowess and the time to analyze the situation. All these factors are assumed in "small world" approaches (Luan, Schooler, & Gigerenzer, 2011), but are not commonly present in every day decisions (see Falzer, 2004).
Naturalistic Decision Making (NDM) research constitutes an alternative to classical decision making.

3.5. Naturalistic Decision Making

The field of NDM emerged in a conference in 1989 and, as the name implies, is concerned with understanding decisions in naturalistic settings in contrast to a laboratory context (Lipshitz et al., 2001). Instead of trying to find the optimal solution mathematically and explore how and why people deviated from it, NDM-researchers

wanted to understand real life decision strategies used in unstable and vague conditions (Klein, 2008).

Roughly ten years after its inception, Zsambok reflected on the progress that has been made, the prevalent topics that developed in NDM over the years, and the core aspects of NDM research (Zsambok, 1997). Since these four defining core aspects illustrate the focus of NDM well, they shall be outlined here shortly:

1) *A number of requirements for the task and the setting*. Decision making in the field setting differs from that of the laboratory in a number of points, such as ill-defined problems and goals, an uncertain environment in which decisions have consequences and lead to a changed situation that prompts new decisions, the presence of multiple decision makers, and more (Zsambok, 1997).

2) *Experienced individuals are researched*. NDM did not focus on naïve decision makers, unfamiliar with the problem at hand, but rather on people with experience, on experts in a given field (Klein, 2008, 2015).

3) *The goal of NDM-research is uncovering actual decision making processes*. Where classical decision making researched had focused on how people would make decisions if they acted completely rational, NDM tries to shed light on the processes they actually use when making decisions in complex, real life environments (Zsambok, 1997).

4) *Temporally broader focus on decision making processes*. An important step of decision making, that is underrepresented outside of NDM, is the assessment of the situation (Zsambok, 1997). Klein argued that situation awareness is more important for quickly making good decisions than comparing options, since a correct identification of the situation based on experience would lead to a fast and appropriate response (Klein, 2015). This emphasis on situation assessment is captured in the recognition-primed-decision model (RPD, Klein, 2008), one of the most notable models in the field of NDM.

3.5.1. Recognition- Primed- Decision Model

The RPD describes how experts make a decision based on previous experience and action patterns. It was originally created based on interviews with firefighters, expert decision makers in their field and trained in deciding under time pressure and uncertainty (see Lipshitz et al., 2001). The initial findings have been replicated several times, with experts from different fields (Klein, 1998; Lipshitz et al., 2001).

The RPD states that when people encounter a situation repeatedly, patterns are formed. Those patterns contain the important cues for the given type of situation, the goals to work towards, expectancies, and the standard reaction(s) in this context (Klein, 2008). That way, when a situation is encountered, it doesn't have to be analyzed completely. Instead, if it matches a learned pattern, the appropriate reaction can be carried out immediately, which saves a lot of time and enables quick decisions (Klein, 2008).

Nonetheless, the RPD does not rely solely on pattern matching. If the situation is not clear, the decision makers will employ a strategy of mental simulation. A story-building strategy is used to assess what might have happened previous to the current state of the situation (Lipshitz et al., 2001). That way, they will likely be matched to a typical pattern. If the decision makers made an error in the assessment of the situation, they will notice it as soon as one of the expectancies that come with a given pattern is violated by the current situation. That will trigger a reassessment of the situation, either leading to different pattern matching or to gathering of more data (Klein, 1998).

Before executing an option the decision makers can use mental simulation to visualize whether it would work. If it does, the option is executed; if not, adaptations are made or other options apart from the one suggested by the pattern are considered (Klein, 1998). Therefore an expert in a field can usually choose the first option they think would work, instead of having to compare all available options and choosing the optimal one (Klein, 2008).

For a simplified overview of the entire RPD, see figure 2.

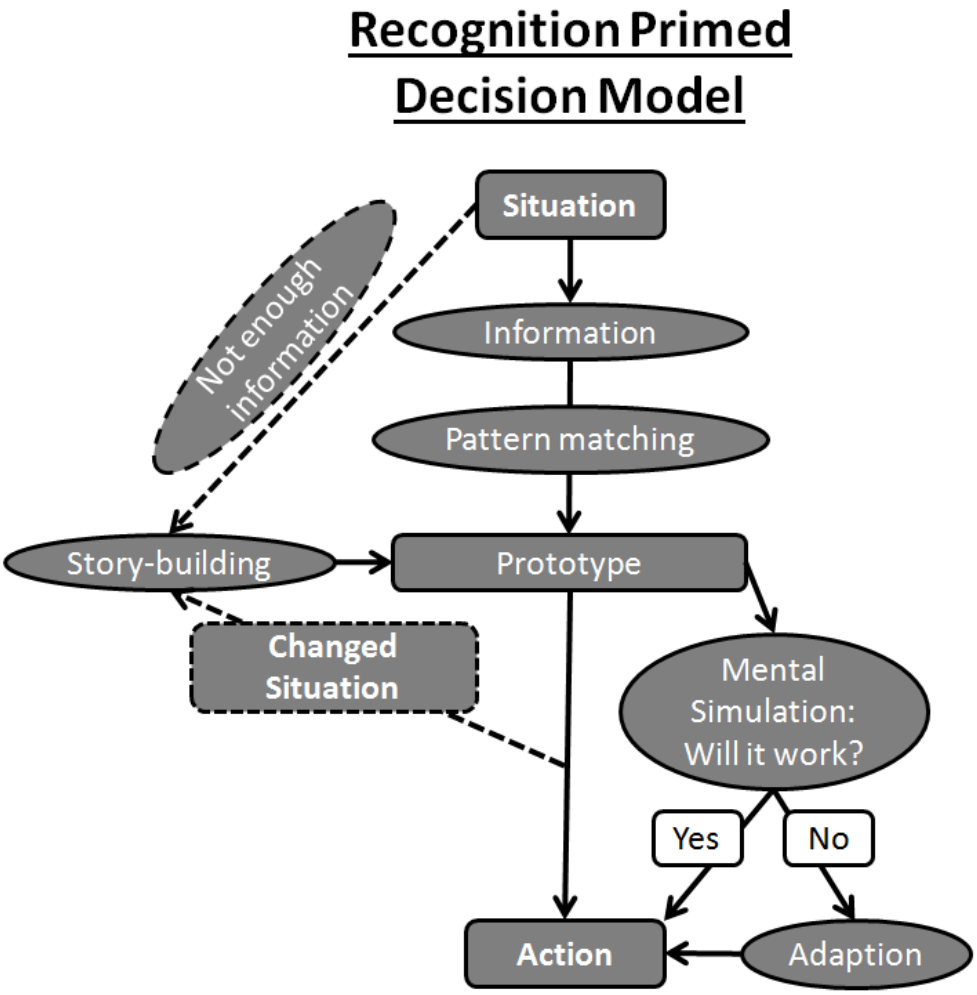

Fig. 2: Abstract overview of the Recognition Primed Decision Model.

The RDP unites intuitive (System 1) and analytic aspects (System 2), the former represented by the pattern matching and the latter by the mental simulation and story-building (Kahneman & Klein, 2009; Klein, 2008). However, these three parts of the model all rely on the expertise of the decision maker (Lipshitz et al., 2001). It is important to note that expertise does not necessarily mean professional expertise. As stated above, repeated exposure to a specific situation and repeated decisions in that situation, connected with feedback, create expertise (Klein, 2008). This concept can apply to every person for ordinary everyday situations, as long as the environment in which the decisions are made fulfills some conditions: It ought to have sufficient regularity and offer valid cues to base the decision on, and there has to be ample opportunity to learn the relevant cues (see Kahneman & Klein, 2009).

There are, of course, limits to the applicability of the model and its single-strategy-approach. The process described by the RPD will likely be used if the decision maker is under time pressure, if they are an expert in the given domain, when the conditions are dynamic and when the goals are unclear (Klein, 1998). On the other hand, the RPD will probably not be used if the decision maker has to justify their choices or has to resolve a conflict between parties, when optimization is the goal of the decision, or when the problem is one of computational complexity (Klein, 1998).

If one assumes the RPD to be accurate, the level of decision making that the decisions considered in this thesis have (see section 3.1) can now be ascertained:
A certain situation which fits an established pattern would be of type 1, a routine decision, because no options have to be compared, it is 'merely' a process of pattern matching. It would be executed by mostly System 1, the fast and automatic processes of decision making.
An uncertain situation which does not fit a pattern could be considered to be of type 3, a reflected decision, since there a no stereotypical preferences available and the cognitive load is likely higher. This analytical and conscious approach would imply the use of System 2. However, it depends on the decision maker and the situation; If an individual does not perceive the differences from established prototypes to be sufficient to warrant a reflected decision, the same processes as stated for certain decision would still apply.

For completeness' sake it shall be mentioned that there are other models similar to the RPD; For example, there is the instance-based learning theory, which has been expressed in a cognitive architecture model ("CogIBLT", Gonzalez, Lerch, & Lebiere, 2003). This model describes similar processes (repeated decisions in a context, connected with feedback, creating intuitive expertise) and comes to similar predictions as the RPD (Thomson, Lebiere, Anderson, & Staszewski, 2015). However, in this thesis only the RPD will be examined closely, as concentrating on one model allows for a more focused discussion of the material.

3.5.2. Naturalistic Decision Making in Neuroscience

Compared to other disciplines like economics or psychology, the research of decision making is relatively young in neuroscience (Vaidya & Fellows, 2017). Additionally, a large number of experiments in the field of cognitive neuroscience use hypothetical situations and unrealistic stimuli (Camerer & Mobbs, 2017). The ideas of naturalistic decision making could therefore have some benefit in this field.

However, transferring the concept of NDM research to neuroscience is coupled with a number of restrictions and limitations. This is mostly due to the constraints of the methods of data acquisition. Field research is impossible when the necessary machines like the EEG and the MR-scanner are complicated and time consuming to set up or are exceedingly huge, respectively. Therefore, neuroscience will not leave the laboratory environment any time soon. Also, the tasks used in neuroscience demand a certain level of abstract structure and repetition, both of which are in contrast to the ideas of NDM. And if the context of the experiment became too complex and ill-defined, as NDM demands, the results would be difficult to connect to specific processes (see Vaidya & Fellows, 2017).
Approaching the cornerstones of NDM research, however, can be possible by utilizing quasi-realistic decision making designs (QDM, e.g. Miedl, Fehr, Herrmann, & Meyer, 2014; Miedl, Fehr, Meyer, & Herrmann, 2010). Realistic stimuli, a context scenario close to a real-life situation, a decision which allows for utilizing experience and expertise; considerations like these can bring a QDM experimental design closer to the requirements of NDM research.

In order to create a link between NDM and neuroscience it may be useful to view results of one discipline in light of the other. The RPD-model for example, which was described above, bears a resemblance to a model describing decision making from the neuroscientific perspective: The 'Perception-Action Cycle' (PA cycle, Fuster, 2004). Fuster drafted this concept as part of a neural network theory which postulated interacting neural networks called 'cognits', each of which is associated with a specific complex mental process. Multiple levels of hierarchy exist within each cognit and are

connected via bottom-up as well as top-down processes. Additionally, cognits have connections between each other, each on comparable levels of hierarchy (Fuster, 2006). Two cognits would be most important in a decision situation: 'perceptual memory' and 'executive memory' (Fuster, 2004). In a decision context, previous experience would be used to structure processing of new information (Fuster, 2017) and the situation would be potentially matched to prototypes of similar situations (see Fehr, Achtziger, Roth, & Strüber, 2014). This largely perceptual and associative process is localized in postcentral areas of the brain. Basic perceptual information is processed in primary cortices, which form the lowest hierarchy level of that cognit (Fuster, 2004, 2006), and then it gradually moves up the hierarchy to individually organized association cortices (Fehr, 2013). After the situation is processed a (subjectively) appropriate response is selected and executed by different hierarchy levels of executive (precentral) brain areas, depending on the hierarchy level the perceptual processing reached (Fuster, 2004). Experience is of central importance in this concept, since it shapes perceptual cognits, which influence future perception, and since it can establish stereotypical actions connected to perceived situations (Fehr, 2012).

In conclusion, it seems that the PA cycle is a fitting model for approaching the field of NDM from a neuroscientific perspective.

3.5.3. Aptitude of weather context for decision making research

As Gigerenzer, Hell and Blank have shown, the context of an experimental design is prominently influencing the way people make decisions (Gigerenzer, Hell, & Blank, 1988), with a design based on real-world experience allowing for more complex decision making. Therefore, if the goal is capturing realistic decisions, the design should use a context people are used to from their everyday lives. Evaluating the weather situation based on forecasts is ideal for this purpose, since people are exposed to weather forecasts daily (Gigerenzer, Hertwig, Van Den Broek, Fasolo, & Katsikopoulos, 2005; Morss, Demuth, & Lazo, 2008).

Additionally, it is exactly this daily exposure to the situation that creates expertise in the individuals by learning patterns of prototypic situations and associated responses (see sections 3.5 and 3.5.1).

Even though weather forecasts - specifically precipitation forecasts - are often communicated as if they were certain, there is an inherent uncertainty in forecast information, which is mostly recognized by the consumers (Morss et al., 2008). Thus this type of information is ideal to both create a realistic context for an experiment and convey a feeling of uncertainty to the participants.

Lastly, Gigerenzer and colleagues found that people tend to take an umbrella with them if there is a probability for rain of (on average) circa 50 percent (Gigerenzer et al., 2005). Accordingly, when it comes to taking an umbrella along, there might be two areas of certainty in the high and low percentages and one area of uncertainty (or lowered certainty), distributed around 50 percent rain probability.

3.6. Neural correlates of decision making and uncertainty

Decision making in general and uncertainty specifically has been discussed in relation to a number of brain areas. Amongst those, the most prominent and most frequently mentioned are three parts of the prefrontal cortex: The dorsolateral prefrontal cortex (DLPFC), the orbitofrontal cortex (OFC) and the anterior cingulate cortex (ACC). The current literature is in quite the disagreement about the exact processes these areas are connected to, seeing as each has been discussed to be responsible for many different processes. However, the ACC seems to be most commonly associated with conflict detection and therefore uncertain situations (see Carter & van Veen, 2007; Ernst & Paulus, 2005), the DLPFC with resolving conflicts and integrating information (Broche-Pérez, Herrera Jiménez, & Omar-Martínez, 2016; Carter & van Veen, 2007), and the OFC with affective stimuli or decisions based on affect (Broche-Pérez et al., 2016; Ernst & Paulus, 2005). On the other hand, the OFC is often related to detecting and processing of uncertainty as well (Blakemore & Robbins, 2012; Mushtaq, Bland, & Schaefer, 2011).

In regard to affective attributes of stimuli or emotional decision situations, the insula also seems to play an important role (Blakemore & Robbins, 2012; Ernst & Paulus, 2005), in addition to the amygdala and medial prefrontal cortex (Ernst & Paulus, 2005). The amygdala has additionally been connected with motivation (Fuster, 2017; Mushtaq et al., 2011), but also uncertainty processing and detecting need of cognitive control,

similar to the ACC (Mushtaq et al., 2011). As for the insula, it has also been found to show increasing activation with increasing uncertainty of a decision (Huettel, Song, & McCarthy, 2005).
Parts of the parietal cortex have also been discussed in relation to aspects of decision making that are important in the present study. There is the posterior parietal cortex, which may play a role in cognitive control (Mushtaq et al., 2011) and risk processing (Blakemore & Robbins, 2012). The right inferior parietal lobule was found to show increased activation with increased uncertainty (Huettel et al., 2005). Additionally, the parietal cortex seems to be important in approximate arithmetic (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999) and probability coding (Ernst et al., 2004; Platt & Glimcher, 1999).

Regarding oscillatory correlates of decision making, increased activity in the delta frequency band (~0.5 to 3.5 Hz) has been discussed most notably (Başar, Başar-Eroğlu, Karakaş, & Schürmann, 1999; Güntekin & Başar, 2016).
Interestingly, the delta band can also be connected to long distance communication between different brain areas, as such non-local processing has been attributed to low-frequency oscillations (Gupta & Chen, 2016). Other authors reported slightly differing results; Fronto-parietal interactions where found to emerge in the theta and alpha range (von Stein & Sarnthein, 2000). Despite this small difference, both papers report the connection of low-frequency oscillation to global processing and cortical integration, and of high-frequency oscillation to local processing.
As such, a connection between decision making processes and a delta synchronization could be attributed to an increased cortical integration during those processes.

In the context of decision making, there also exists a considerable number of studies using ERP analyses of their EEG data to find or substantiate differences caused by external variables, or to investigate feedback processing. Despite of that, very few studies have taken a look at the core process of decision making itself, or at the differences between uncertain and certain decisions. Based on a study by Wang and colleagues (Wang, Zheng, Huang, & Sun, 2015), which tested ambiguity and risk against

each other, both of which would be called uncertainty in the context of this thesis, it can be assumed that the P300 at central and fronto-central electrodes is an important component in uncertainty. However, it is unclear how this compares to certain decisions.

4. Research question and hypotheses

The present study aims to explore the neural correlates of decision making in quasi realistic decision (QDM) situations using ecologically valid stimuli under different degrees of certainty and uncertainty.

As outlined in the theoretical background, most research into decision making and its neural foundations was based on abstract situations and was using stimuli that are alien in everyday life. This is why this study is exploratory in large parts, producing results that future research can test for their reliability by basing new hypotheses on them.

The explorational approaches will be outlined here:

Approach 1: The participants' decision behavior shall be explored, using visualization and numerical parameters.

Approach 2: The differences in neural activation between uncertain and certain decision making shall be explored using fMRI contrast analyses.

> *Approach 2.1*: Both conditions shall be compared to a low-level baseline, and a conjunction analysis shall be employed to find commonly activated regions.
>
> *Approach 2.2*: Additionally to the classic contrast analysis, an analysis of individual voxel density shall be used to find differences the contrast analysis is not sensitive to.

Approach 3: An ERP analysis of EEG data shall be conducted, to find differences in ERPs between uncertain and certain decision making.

Approach 4: A frequency analysis of EEG data shall be conducted, to find differences in relative frequency band power between uncertain and certain decision making, as well as correlations between said power and external variables.

Additionally, based on the existing literature and a behavioral pilot study for the design used in this study (Doehring, 2016), the following basic hypotheses were formulated:

Hypothesis 1: During processing of decisions based on experience (as the "Recognition- Primed Decision Model" addresses) regions of the brain discussed to be connected to perceptual and conceptual-motoric processing are active.

Hypothesis 2: Decisions under uncertainty lead to a higher activity in frontal areas of the brain than during certainty, specifically in areas connected to uncertainty and conflict processing, like the DLPFC or the ACC.

Hypothesis 2.1: This activity is especially expressed in the delta frequency band. Uncertain decision should therefore show a higher relative delta power.

Hypothesis 3: Processing of certain versus uncertain decisions results in different ERPs at fronto-central and central electrodes, mainly in the P300 component. Since little can be said about the nature of this difference, an explorative comparison of uncertain and certain decisions will be conducted.

5. General Methods

The study presented in this thesis was approved by the ethics committee of the University of Bremen and was conducted using both EEG and fMRI, measured on different days with the same participants.

In the following paragraphs, the basic, general methods of the experiment performed for this study will be described. All methods which are specific to either fMRI or EEG data acquisition or to one distinct avenue of analysis will be explained in the corresponding section.

Furthermore, as mentioned in the introduction, each method section of a specific analysis will be directly followed by their respective results and discussion sections. This structure was chosen to increase readability, and because some of the methods were dependant on results of previous analysis steps.

5.1. Participants

30 people participated in this study. One person was excluded from all analyses due to low data quality and problems with compliance. From the fMRI analysis, one additional participant was excluded due to a lack of uncertainty in their behavior and three more due to technical problems influencing the quality of the fMRI scans (n=25 for fMRI). From all EEG analyses six participants were excluded; three due to poor data quality and three due to a lack of uncertainty in their decisions (n=23 for EEG).

All were healthy, female, right handed students aged between 18 and 30 (mean age = 21.3 years, standard deviation (sd) = 3.2 years). All participants were students of the University of Bremen; Therefore, they had a similar level of education.

Each participant received 6 "*Probandenstunden*" after the experiment. In the bachelor of psychology at the University of Bremen, these serve as proof of having participated in an experiment and thus having learned something about its practical procedure. This is an important aspect of the education in psychology. These credits, however, can be earned in any experiment related to psychology. No commitment to this study was necessary.

Before the start of the individual experiments each participant gave their informed consent (see appendix A and B for the written information on fMRI and EEG experiments, and appendix C and D for the respective statements of consent).

5.2. Stimulus Material

The stimulus material was created to ensure a maximum of ecological validity and functionality within the given context. All stimuli were behaviorally validated with a sample of 20 people before the start of this study (Doehring, 2016).

Two different stimulus-types were used: On the one hand, there were pictures that visually represented weather forecasts, depicting the probability of rain in percent for the time specified in the experiment (see figure 3 for examples). This format was chosen because most people prefer precipitation forecasts in percentages (Morss et al., 2008).

The forecast's percentages ranged from 10% to 90%, in steps of 10%. Absolutes (0% or 100%) were intentionally avoided.

Fig. 3: Exemplary forecasts. The percentage represents the probability of rain.

On the other hand, there were pictures of a (more or less cloudy) sky as seen from out of a window (see figure 4 for examples). There were thirty different pictures and the cloudiness, brightness, and likeliness of rain rose slightly from one picture to the next.

Fig. 4: Exemplary sky-pictures.

In the experiment, each trial consisted of one stimulus of each of the two types; Participants had to come to a decision based on both a forecast and a sky-picture. Due to these two sources of information, there exists a wide range of possible combinations with varying degrees of certainty in the information. This possible stimulus space with certain and uncertain areas is visualized in figure 5.

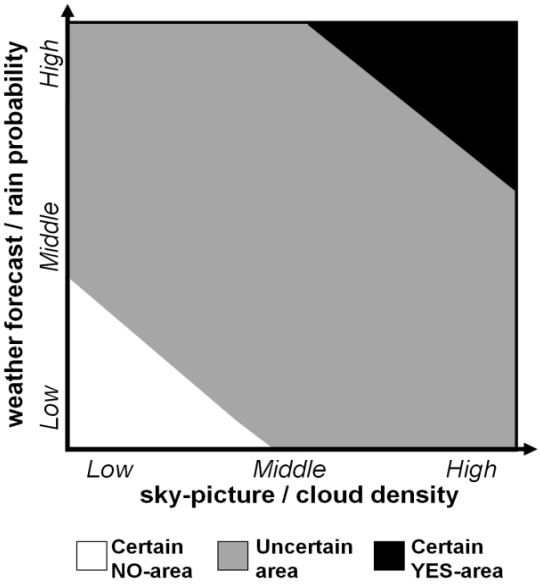

Fig. 5: Visualization of the stimulus space, which holds all possible combinations of both stimulus types, and the resulting distribution of certainty and uncertainty. Note that this is a general overview based on average data from the pilot study; individual distributions of certainty and uncertainty differ notably.

5.3. Task and Procedure

Each participant performed the experiment twice, on two separate days. One time the EEG was used to measure neural activity during the task, the other time the method used was fMRI. The order of measurements was counterbalanced across the participants.

Before the experiment started each participant was informed about the procedure of either EEG or fMRI, depending on what was used on the respective day, and signed a letter of agreement.

On the first day, two short questionnaires were answered by the participant. One contains questions regarding general information and demographics, while the other is specialized to test for compatibility with the MRI procedure. Only if a person was cleared for MRI research were they allowed to participate in the experiment.

After that the participants were introduced to the experimental task. A story was presented to them, which was supposed to create a context for the decisions in the experiment. The story (see appendix F) put the participants into a hypothetical situation in which they could either take an umbrella with them, in case they thought it might rain, or could leave without an umbrella, if they thought it would not rain. They were instructed that in the following experiment variations of this situation would be shown, with different information about likelihood of rain based on the forecast and the sky. They were supposed to decide on the umbrella for each individual situation and based on both sources of information. The relevance they assigned to each source, however, was up to their own judgment.

The experiment itself took about 45 minutes to complete and consisted of two sequences. Both sequences contained 180 trials. The same combinations of stimuli were presented in the first and the second sequence, but in a different order. Therefore, each trial was presented exactly twice.

The trials in both sequences were pseudo-randomized, in a non-stationary probabilistic order (see Friston, 2000). Therefore, the probability of occurrence for trials from a given area of the stimulus space changed throughout the experiment, with intervals of especially high and especially low probability. This measure was supposed to achieve a good signal-to-noise-ratio, as discussed to be present in block-designs, while preventing the participants from developing expectations towards the next trials, which is the benefit of randomized designs (see Fehr et al., 2014).

Fig. 6: Visualization of the trial-structure. The sky-picture was displayed until a decision was made, or for a maximum of 3800ms after 200ms of fade-in.

Each trial had the same structure (see figure 6): First the weather forecast, which was supposed to be presented for 1000ms total, including a fade-in and fade-out that took 200ms each. Then the sky-picture was similarly faded in and was then continuously presented until the participant made a decision or 3800ms passed after the fade-in. The participants were instructed to make the decision based on both stimuli. If they wanted to take an umbrella with them in the presented situation (YES-decision) they pressed “up” on the arrow-keys (middle finger of the right hand). If they did not want to take an umbrella (NO-decision) they pressed left on the arrow-keys (index finger of the right hand). As soon as the decision was made or after the time had passed, the sky-picture was faded out for 200ms and a fixation dot was presented in the middle of the screen for a time randomly jittered between 2600 and 3400ms.

5.4. Additional tests

After completing the experiment, participants answered several short questionnaires. On the first day the d2-Test was performed, (Brickenkamp, 1981) to detect abnormalities in the selective attention and sustained attention of the participants. Only the value labeled 'KL' was used subsequently, which is supposed to reflect the general attention performance. After that test the participants answered the short version of the Neo-Five-Factor Inventory (Neo-FFI, Borkenau & Ostendorf, 2008), which is a short personality test (60 items) that tests five classical scales of personality (neuroticism, extraversion, openness, agreeableness and conscientiousness). This was to later test whether personality traits have an influence on the behavior, the decision strategy or the neuronal correlates of decision making.

On the second day - after all experimental runs were over - the participants evaluated the stimulus material. Both the forecasts and the sky-pictures were evaluated for subjective probability of rain (between 0% and 100%) and whether an umbrella would be taken along or not based solely on that stimulus. The evaluation was done using an in-house evaluation program for the sky-pictures and a paper-pencil questionnaire for the forecasts. Lastly there was a questionnaire developed specifically for this design which contained questions relevant in this context (Additional Questionnaire: RaB-2, see appendix E). The sixth question, regarding the individual understanding of precipitation forecasts, was based on a question used by Morss and colleagues (Morss et al., 2008). The questions labeled "01" and "02" were adapted from the Subjective Numeracy Scale (Fagerlin et al., 2007).

6. Behavioral Analysis

The behavioral analysis was performed using in-house scripts for Matlab R2017a and the free statistical software R (R Development Core Team, 2017).

6.1. Evaluation of the stimulus material

The evaluation of the forecasts and the sky-pictures was checked for conformity of the participant's rating of the stimuli with the expected perception of the stimuli based on the pilot study. Linear regression analyses were used for both stimulus types since a linear rise in expected probability of rain for rising stimulus numbers was expected. Confidence intervals (alpha = 95%) around the mean rating were calculated for each forecast and sky-picture.

6.1.1. Evaluation Results

The evaluation of the stimuli (both FC and SKY) is visualized in figure 7. Depicted are box plots of the assumed probability of rain according to the participant's evaluation for each stimulus.

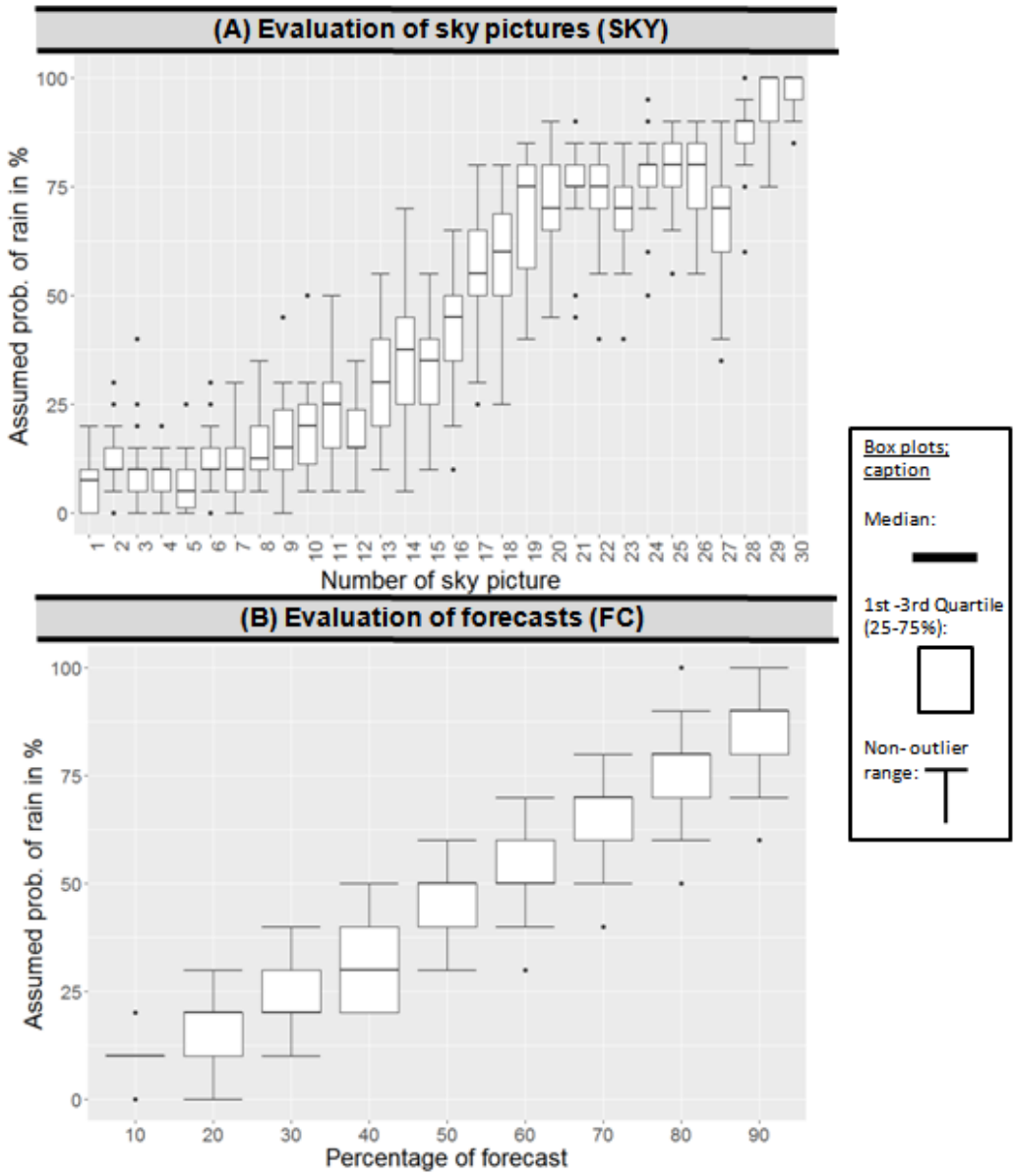

Fig. 7: Box-plots visualizing the evaluation of the stimulus material. (A) shows the evaluation of the sky-pictures and (B) that of the forecast stimuli. On the x-Axis there are the stimuli, rising in number to the right, and on the y-Axis there is the assumed probability of rain according to the participants, in percent. Outliers are denoted with black dots.

The linear regressions for the rating of the rain probability showed a significant result both for SKY ($p < 0.001$, adjusted R-squared = 0.86) and for FC ($p < 0.001$, adjusted R-squared = 0.89).

Table 1 contains the 95% confidence intervals for both the sky-pictures (A) and the forecasts (B).

Table 1: Confidence intervals (alpha = 95%) for the evaluation of the sky-picture [A] and forecast [B] stimuli. 'Mean' is the average perceived probability of rain of the respective stimulus, 'lower' and 'upper bound' are the bounds of the confidence interval.

A

sky-picture	lower bound	Mean	upper bound
1	3.90	6.00	8.10
2	9.87	12.50	15.13
3	6.54	9.50	12.46
4	6.53	8.50	10.47
5	4.96	7.50	10.04
6	8.52	11.33	14.15
7	6.98	9.67	12.35
8	11.49	14.33	17.18
9	13.85	17.17	20.48
10	15.52	18.83	22.15
11	19.39	23.17	26.95
12	15.24	18.00	20.76
13	25.96	30.17	34.37
14	31.66	36.67	41.67
15	28.98	33.50	38.02
16	37.89	42.83	47.78
17	49.68	54.83	59.99
18	52.17	57.17	62.16
19	62.86	67.83	72.80
20	67.41	71.17	74.92
21	71.42	75.50	79.58
22	68.77	72.83	76.90
23	66.53	70.00	73.47
24	72.03	76.33	80.63
25	77.00	79.83	82.67
26	73.71	77.17	80.62
27	63.08	68.00	72.92
28	85.55	88.50	91.45
29	92.79	95.17	97.54
30	95.02	96.67	98.32

B

forecast	lower bound	Mean	upper bound
10	7.37	9.67	11.96
20	13.13	15.67	18.20
30	19.58	23.00	26.42
40	28.51	32.67	36.82
50	40.96	44.00	47.04
60	49.88	53.00	56.12
70	60.71	64.33	67.96
80	70.78	74.67	78.56
90	83.30	87.33	91.37

6.1.2. Evaluation Discussion

The evaluation of the stimulus material was mostly in conformity with the expected perception of the stimuli, as can be inferred from the significant linear regressions. With rising stimulus numbers, indicating rising probabilities of rain, the participants' assumed probability of rain also increased. This is in accordance with the results of the pilot study (Doehring, 2016). Since this stimulus inventory is relatively new and the experiment's validity is based, among other things, on the stimuli's validity, these results are an important basis for all further interpretations.

However, it should be noted that for the sky-pictures the confidence intervals of many stimuli overlap, making a statistical distinction between them difficult. Future studies could take this into consideration, for example by decreasing the amount of sky-pictures and thereby reducing overlap.

The forecasts, on the other hand, do not show any overlap of the confidence intervals.

6.2. Behavioral Signature Plots

In order to analyze the strategies participants used to make decisions in the experiment, a plot termed 'behavioral signature plot' (BSP) was introduced.

The BSPs have the sky-pictures on the x-axis (rising stimulus numbers to the right) and the forecasts on the y-axis (rising percentages upwards). Therefore, all possible trials — each with a combination of forecast and sky-picture — could be found at one coordinate in the plot. At that position, a color code was used to express the behavior of the participants in the given trial: Black stood for two consistent YES decisions in the first and second run, white tiles stood for a consistent NO decisions. Lastly, the tile was colored gray if the decisions were inconsistent (YES in the first and NO in the second run, or the other way around). All positions that corresponded to trials from the experiment were colored based on that system (see figure 8 for an exemplary BSP).

However, not all possible combinations of stimuli were actually shown in a trial of the experiment. Therefore, 90 out of 270 coordinates would be empty. To improve the visualization the BSPs provide, these were interpolated with the mean value of the adjacent trials.

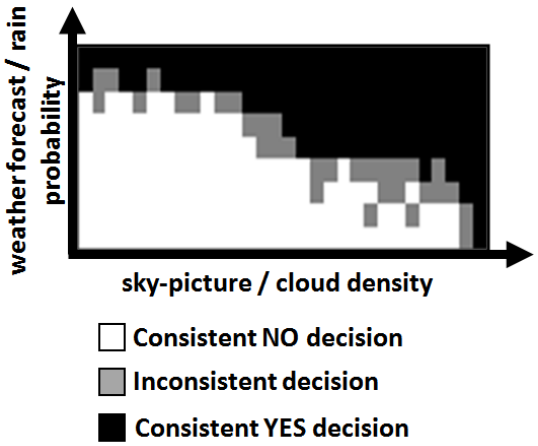

Fig. 8: Exemplary behavioral signature plot.

The distribution of YES answers, NO answers and inconsistent answers as visualized by the BSPs was supposed to facilitate a quick overview of the participant's behavior and their strategy (trust in the forecasts or the sky, general tendency to take the umbrella along or not, etc.).

To check for reliability of the participant's decision strategy between the fMRI and EEG experiment, Cohen's kappa (un-weighted) was calculated for each participant. Then, an average over all participants was calculated.
Kappa was introduced by Cohen in 1960, as a measure of reliability between two raters who categorize subjects into k categories of a nominally scaled variable (Cohen, 1960). In this case, the two experimental measurements represent the two raters, each trial a subject, and the three states the BSP can adapt (2 * YES; YES/NO; 2 * NO) are the categories.

6.2.1. Behavioral Signature Plots Results

BSPs were plotted for both the fMRI experiment and the EEG experiment (see figures 9 and 10 respectively).

The average value for Cohen's kappa was 0.59, with a range from 0.45 to 0.82, apart from one outlier, participant 3, who had a value of kappa = -0.2. The complete table of kappa values can be found in appendix G.

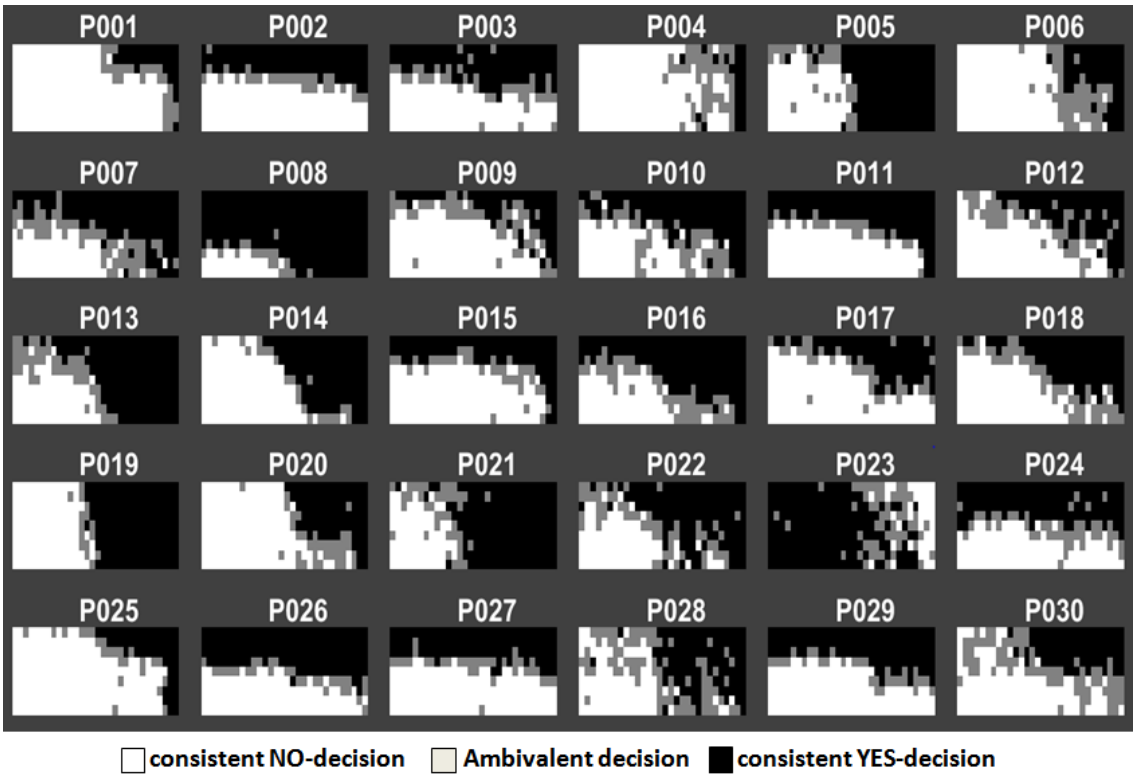

Fig. 9: BSPs for each participant (P0...), based on the data from the fMRI experiment. Participant 23 confused the keys, which is why their BSP seems reversed.

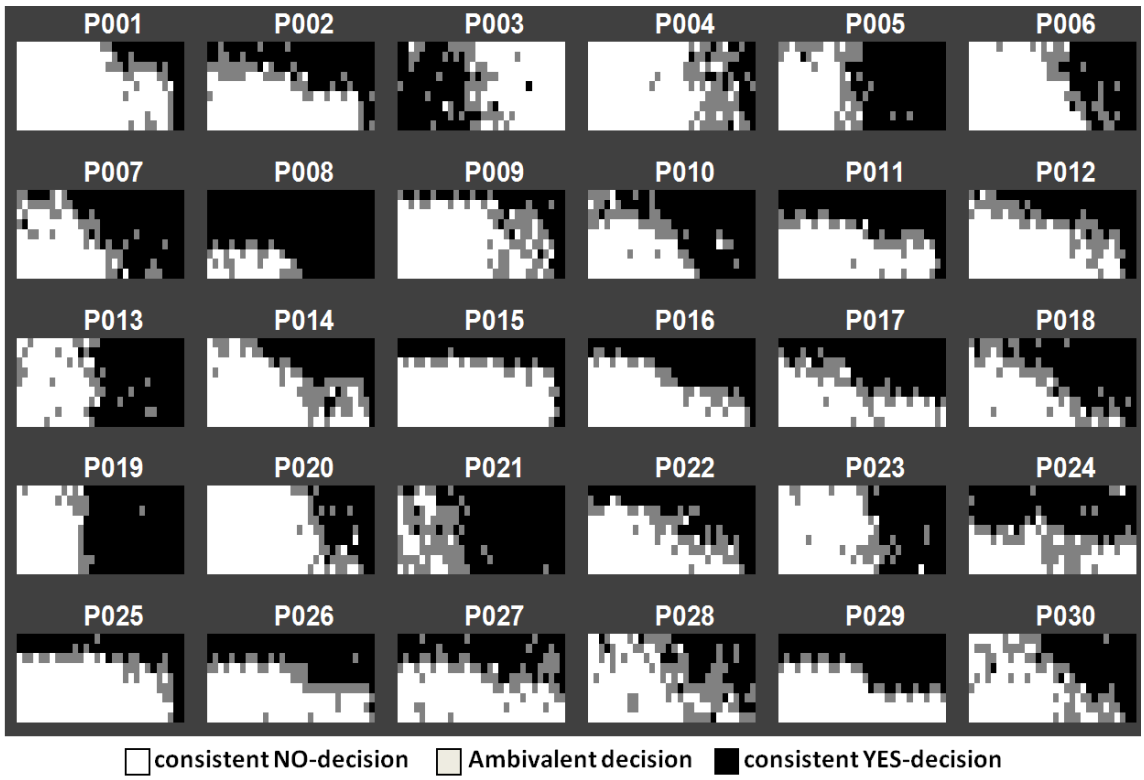

Fig. 10: BSPs for each participant (P0...), based on the data from the EEG experiment. Participant 3 confused the keys, which is why their BSP seems reversed.

6.2.2. Behavioral Signature Plots Discussion

In the BSPs the wide range of different strategies the participants have employed in the experiment becomes apparent.

First there is the general trend towards taking the umbrella along or not, answering with mostly YES (e.g. participant P 008) or mostly NO (e.g. P 001).

Secondly, they also differ in the amount of inconsistent trials, with some showing many (e.g. P 028) and some barely any (e.g. P 029). The reason for that can only be speculated upon, as will be elaborated in section 7.

And lastly, there is the trust in the two sources of information. Some base their decision almost entirely on the information gained from the weather forecast (e.g. P 027) while other use only the sky-picture to make their decision (e.g. P 019). Most participants, however, employ a mixed strategy.

Considering these varying aspects of the participants' strategies, it is no surprise that the displayed strategies differ greatly. Despite the difficulties for analyses that different strategies bring with them, allowing participants to use their own strategies during decision making has to be a part of a QDM design. The fact that the participants did use individual strategies is thus an indicator that the design worked as intended, in this regard.

There are a few participants that, as it becomes obvious in the BPSs, changed their decision strategies between the two experimental measurements (EEG and fMRI). In most cases the changes are only of minor impact. Like for example participant 13 who seems to follow a mixed strategy in the fMRI experiment, relying on the forecast and the sky-picture, but relied solely on the sky in the EEG experiment. Or participant 25, whose strategy does not seem to change much between experiments, but who does take the umbrella along if the forecast is high and the sky bright in the EEG experiment, but not in the fMRI experiment. Even more minor changes concern the exact threshold for taking the umbrella along, or the amount of inconsistently answered trials. Only participant 3 seems to have changed their decision strategy completely between experiments; They followed a forecast-based strategy in the fMRI experiment, and a sky-based strategy in the EEG experiment (during which they

additionally confused the answer keys). This changed strategy is also reflected by the participants kappa value (kappa = -0.2). At present, no explanation is known for this drastic change in behavior, as none was reported in the post-experiment interview.

Overall, however, the participant's behavior was mostly stable between measurements. This is signified by the average kappa of 0.59, which constitutes a moderate agreement (Landis & Koch, 1977).

6.3. Behavioral Indicators: UI, PI, and TI

Based on the participant's responses in the experiment, three new numeric values were calculated to capture the most important aspects of the individual decision strategies.

The first was the Uncertainty Index (UI) which was supposed to represent a measure of uncertainty in the participant's decisions. Since each of the 180 combinations of stimuli was presented once in each sequence, agreement of the decisions in both sequences can be tested. Consistent decisions might indicate certainty, while inconsistent decisions might indicate uncertainty. The UI was calculated as follows:

$$UI = 1 - \left(\frac{Number\ of\ matching\ decisions}{Number\ of\ unique\ trials}\right)$$

Thus, a small UI (close to 0) was assumed to indicate low uncertainty, as many trials' decisions are matching, while a large UI was assumed to indicate differing responses and therefore higher uncertainty. It should be noted that an UI of 0.5 would be on the level of random answers in each trial; so even in uncertain situations a UI of less than 0.5 is desirable.

The second new value was the Preference Index (PI), which represented the tendency to take the umbrella along. It is calculated by taking the number of trials where the decision was in favor of the umbrella (YES) and dividing it by the total number of decisions. Thus, a PI of 1 means the participant always took the umbrella with them. The PI was calculated as follows:

$$PI = \frac{Number\ of\ YES\ decisions}{Total\ number\ of\ decisions}$$

Both the UI and the PI were calculated for each participant as an average across all trials, separately for the EEG and fMRI experiments.

The third numerical parameter was the Trust Index (TI), which was supposed to reflect a single participant's trust in either the forecast, the sky-picture, or both. It has a value range from -1 (complete trust in sky-picture) over 0 (equal trust in both sources of information) to 1 (complete trust in forecast).

The basis of the TI was the observation that trust in one source of information increases the influence of that information on the decision. Therefore, the tendency to take the umbrella along (PI) changes along the axis of that stimulus. The other stimulus type, in which there is no trust, would have roughly the same PI in each stimulus. It follows that the change in PI is an indicator for trust (see figure 11 [A] for visualization).

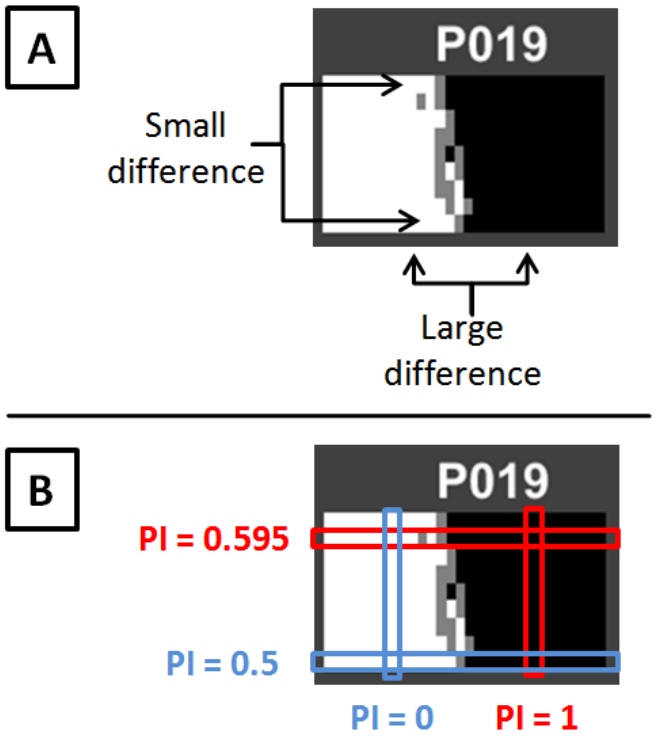

Fig. 11: [A] Visualization of the basis for the TI. This BSP of participant 19 shows a decision behavior based on the sky pictures (x-axis) rather than the forecast (y-axis). As one can see, the amount of decisions to take the umbrella along (black) does not change much along the y-axis; but it does change vastly along the x-axis.
[B] Calculation of the PI for each stimulus. Shown are only the stimuli per condition (FC and SKY) which have the minimum (blue) and the maximum (red) PI values.

The TI was calculated in several steps, which shall be explained with the example of the BSP shown in figure 11:

1) The PI was calculated for each individual stimulus (both for FC and SKY), over all trials in which the stimulus was shown (the respective row or column in the BSP). This results in nine PI values for FC and thirty PI values for SKY (see figure 11 [B]).

2) For both categories, the maximum and minimum PI were identified. For SKY, the maximum was PI = 1, and the minimum was PI = 0. For FC, the maximum was PI = 0.595, and the minimum was PI = 0.5 (see figure 11 [B]).

To reflect the change in PI along the respective axis, the difference between the minimum and maximum PI was calculated for each category.

$$For\ FC:\ 0.595 - 0.5 = 0.095$$
$$For\ SKY:\ 1 - 0 = 1$$

3) In the last step, the PI-differences were related to each other to obtain one value that reflects the relative trust in both sources of information. To achieve that, the difference from SKY (1) was subtracted from the difference from FC (0.095). Then, the result was divided by the sum of both differences to set the value range from -1 to 1.

$$TI = \frac{0.095 - 1}{0.095 + 1} = -0.826$$

The resulting TI was -0.826, which signifies a stronger trust in SKY compared to FC.

Generalized, the calculation of the TI is as follows:

1) PI is calculated for each stimulus.

2) The maximum and minimum PI within each category (FC and SKY) are found and their difference calculated:

$$MaxPI\ of\ FC - MinPI\ of\ FC = Max\ PIdifference\ of\ FC$$
$$MaxPI\ of\ SKY - MinPI\ of\ SKY = Max\ PIdifference\ of\ SKY$$

3) The TI is calculated based on the following formula:

$$TI = \frac{Max\ PIdifference\ of\ FC - Max\ PIdifference\ of\ SKY}{Max\ PIdifference\ of\ FC + Max\ PIdifference\ of\ SKY}$$

All three parameters (UI, PI, TI) were eventually correlated with a number of variables, namely: the mean overall response time (RT), the scales of the Neo-FFI (neuroticism, extraversion, openness, agreeableness and conscientiousness), the d2 (KL-value, which signifies a general concentration level), several items from the additional questionnaire RaB-2 (questions labeled: 2; 4-20) and each other.

Pearson correlation and an alpha of 0.05 were used for all correlations.

This process was done for the data from the EEG and the fMRI experiments separately.

6.3.1. Behavioral Indicators Results

Table 2 shows the PI, the UI and the TI for each participant and for both the EEG- and the fMRI- experiment separately, while the correlations between those parameters and external variables are shown in table 3.

Table 2: Preference Index, Uncertainty Index, and Trust Index for each participant and for the fMRI and EEG experiment respectively. The value range of the PI and UI is from 0 (never take the umbrella along/ no inconsistency) to 1 (always take the umbrella along/ absolute inconsistency). The possible values of the TI range from -1 (complete trust in sky-picture) over 0 (equal trust in both sources of information) to 1 (complete trust in forecast).

participant	PI fMRI	PI EEG	UI fMRI	UI EEG	TI fMRI	TI EEG
1	0.17	0.21	0.09	0.09	-0.40	-0.41
2	0.41	0.44	0.08	0.13	0.43	0.04
3	0.46	0.44	0.13	0.17	0.34	-0.58
4	0.18	0.23	0.17	0.18	-0.72	-0.61
5	0.59	0.58	0.10	0.15	-0.52	-0.68
6	0.31	0.38	0.17	0.12	-0.56	-0.58
7	0.59	0.57	0.21	0.16	0.01	-0.29
8	0.84	0.85	0.04	0.04	0.06	0.20
9	0.34	0.32	0.16	0.14	0.01	-0.09
10	0.53	0.58	0.16	0.14	-0.05	-0.33
11	0.47	0.49	0.06	0.09	0.14	0.11
12	0.40	0.41	0.14	0.16	-0.13	-0.10
13	0.63	0.56	0.16	0.13	-0.29	-0.64
14	0.47	0.41	0.08	0.16	-0.25	-0.15
15	0.39	0.33	0.09	0.03	-0.01	0.07
16	0.60	0.48	0.17	0.09	0.00	0.05
17	0.37	0.52	0.10	0.12	0.15	0.08
18	0.45	0.53	0.16	0.17	-0.09	-0.19
19	0.55	0.61	0.04	0.07	-0.79	-0.83
20	0.36	0.30	0.12	0.11	-0.46	-0.53
21	0.66	0.76	0.14	0.22	-0.57	-0.56
22	0.57	0.49	0.17	0.14	-0.16	0.03
23	0.75	0.44	0.17	0.12	-0.54	-0.71
24	0.51	0.55	0.14	0.17	0.36	0.22
25	0.24	0.36	0.07	0.09	-0.28	0.05
26	0.54	0.48	0.08	0.10	0.17	0.20
27	0.43	0.43	0.09	0.11	0.29	0.36
28	0.50	0.41	0.29	0.27	-0.35	-0.29
29	0.45	0.49	0.06	0.01	0.36	0.41
30	0.40	0.45	0.24	0.21	-0.08	-0.33

Table 3: Correlations of behavioral parameters from the fMRI and EEG experiment and other variables of interest. Pearson's correlation coefficient is listed if the correlation was significant at the level 0.05; if not, it is marked as n.s. (not significant). Significant positive correlations are highlighted in blue, negative correlations are highlighted in red. For the content of the RaB-2 questions, see appendix E (additional questionnaire).

	UI		PI		TI	
	EEG	fMRT	EEG	fMRT	EEG	fMRT
Response Time	n.s.	n.s.	-0.39	n.s.	n.s.	n.s.
Neo: Neuroticism	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Openness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Agreeableness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscientiousness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2-Test: KL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Forecast-Trust; general	n.s.	n.s.	n.s.	n.s.	0.5	0.71
Forecast-Trust; 1 day	n.s.	n.s.	n.s.	n.s.	n.s.	0.45
Forecast-Trust; 2 days	n.s.	n.s.	n.s.	n.s.	n.s.	0.44
Forecast-Trust; 3 days	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 4	n.s.	n.s.	-0.37	n.s.	n.s.	-0.62
RaB-2: Question 5	n.s.	n.s.	n.s.	n.s.	n.s.	0.59
RaB-2: Question 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 7	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 9	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 10	n.s.	n.s.	n.s.	n.s.	n.s.	0.37
RaB-2: Question 11	n.s.	n.s.	n.s.	n.s.	0.53	0.66
RaB-2: Question 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 14	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 16	n.s.	n.s.	0.39	0.42	0.47	n.s.
RaB-2: Question 17	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 18	n.s.	n.s.	n.s.	-0.45	n.s.	n.s.
RaB-2: Question 19	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB-2: Question 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UI	/	/	n.s.	n.s.	-0.4	n.s.
PI	n.s.	n.s.	/	/	n.s.	n.s.
TI	-0.4	n.s.	n.s.	n.s.	/	/

6.3.2. Behavioral Indicators Discussion

The three behavioral parameters represent an attempt at capturing the three main aspects of a participant's strategy as discussed above: the general tendency to answer with YES or NO, the amount of inconsistent decisions, and the trust in the two sources of information. This was done in order to, eventually, classify different types of decision makers. The sample was not large enough to actually form these groups and analyze them in a meaningful way, but this approach might be useful for future studies.

The parameter for the first aspect would be the PI, reflecting the general tendency to answer with YES or NO. The PI was found to correlate negatively with the response times (at least in the data from the EEG experiment) with a strength of r= -0.39, indicating that participants who take the umbrella along more often also take longer to make their decisions. Questions 4 and 18 from the additional questionnaire both correlate negatively with the PI (albeit only in one of the two experiments). Both questions concern intuitive decision making, signifying that people who decide intuitively also take the umbrella along with them less.

The parameter for the second aspect of strategy would be the UI, reflecting the relative amount of inconsistent decisions between two runs. The UI was found to only correlate with the TI, negatively with a strength of r= -0.4 (in the EEG experiment). This is according to expectations, since a rising TI corresponds to higher trust in the forecast; and since the forecast presents a more precise information than the sky-picture, it makes sense for the UI to decrease when the TI increases. Because no other significant correlations were found, it is difficult to associate this parameter with any other behavior the participants have shown.

The parameter for the third aspect would be the TI, capturing the trust in, or the reliance upon, both sources of information. The TI correlated positively with the general trust in the forecast (in both experiments) and with the trust in the forecast one and two days into the future (in the fMRI experiment). Since the TI becomes positive when a participant has higher trust in the forecast than in the sky-picture, these correlations indicate the TIs validity. The same can be said about the negative correlation with Question 4 from the RaB-2 and the positive correlation with Question

5 (both in the fMRI experiment). Both of these items cover trusting the forecast or the personal intuition when deciding about the weather, but are coded conversely. More correlations were found, but the overall picture is such that the construction of the TI as an indicator for trust in the different sources of information seems to have worked. Thus the TI presents a good option to assess trust in information for experimental designs with two sources of information. The TI could have been instrumental in separating the participants into different groups based on their strategy, to compare neural processing between different applied strategies. Alas, the strategies were too varied to create conclusive groups with a sample of only 30 persons.

Clearly, these three aspects of the participants' strategy encompass only some parts of it. Other facets, like the application of rules or heuristics or the motivation of the participant would have to be assessed with different approaches.

6.4. Excursus: abandoning rigid stimulus categories

In the following section, an important change in the strategy of analysis will be outlined. This change was a result of previous analyses, and had a strong impact on the rest of the analyses outlined in this thesis. As such, this section is a mixture of conceptual work, analysis, results, and interpretation.

The original plan, at the inception of the experimental design, had been to divide the stimulus space into nine different categories, based on the combination of low, middle, or high predicted probability of rain by the two stimuli (see figure 12). Each stimulus was thus assigned to one level of probability, with three forecasts and ten sky pictures per level.

It was assumed that participants behaved identically, or at least similarly, in a given category. As such, each category could be assigned to a certain type of decision making:

- The Low-Low category, characterized by the combination of two low-level stimuli, was assumed to prompt a certain decision not to take the umbrella along.

- Conversely, the High-High category was assumed to lead to a certain decision to take the umbrella along.
- The High-Low and Low-High conditions were assumed to cause uncertain decision making because of the contradicting information from the two sources of information.
- The Middle-Middle category was assumed to prompt uncertain decision making due to the ambiguity in the information available.
- The remaining four categories were also assumed to cause uncertain decision making due to varying degrees of contradiction and ambiguity.

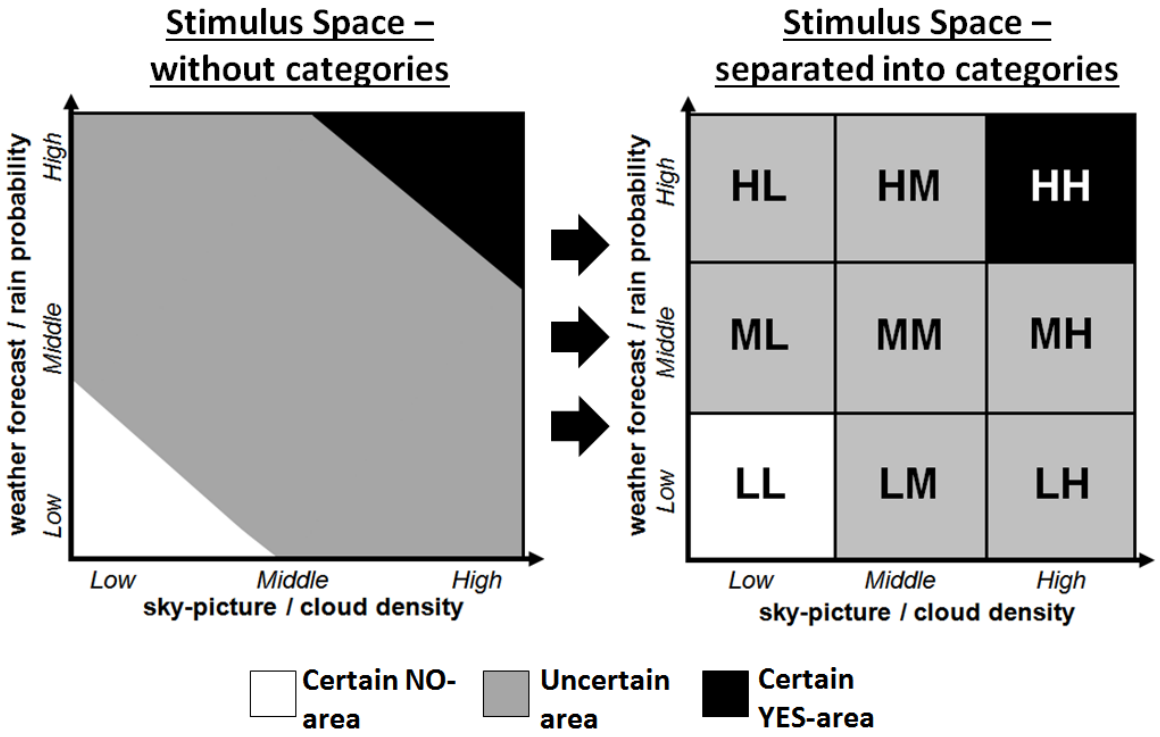

Fig. 12: Visualization of the stimulus space, without division into categories on the left, and with them on the right. The abbreviations found in the right diagram stand for low (L), middle (M), or high (H) predicted probability of rain; The first letter describes the information obtained from the forecast, and the second letter describes the information obtained from the sky picture.

After the experiment had been conducted and the analyses commenced, the performance of the participants in each category was explored with different means. Box plots were created for the mean response times, the PI, and the UI (See figures 13 and 14 [A and B] for the corresponding plots).

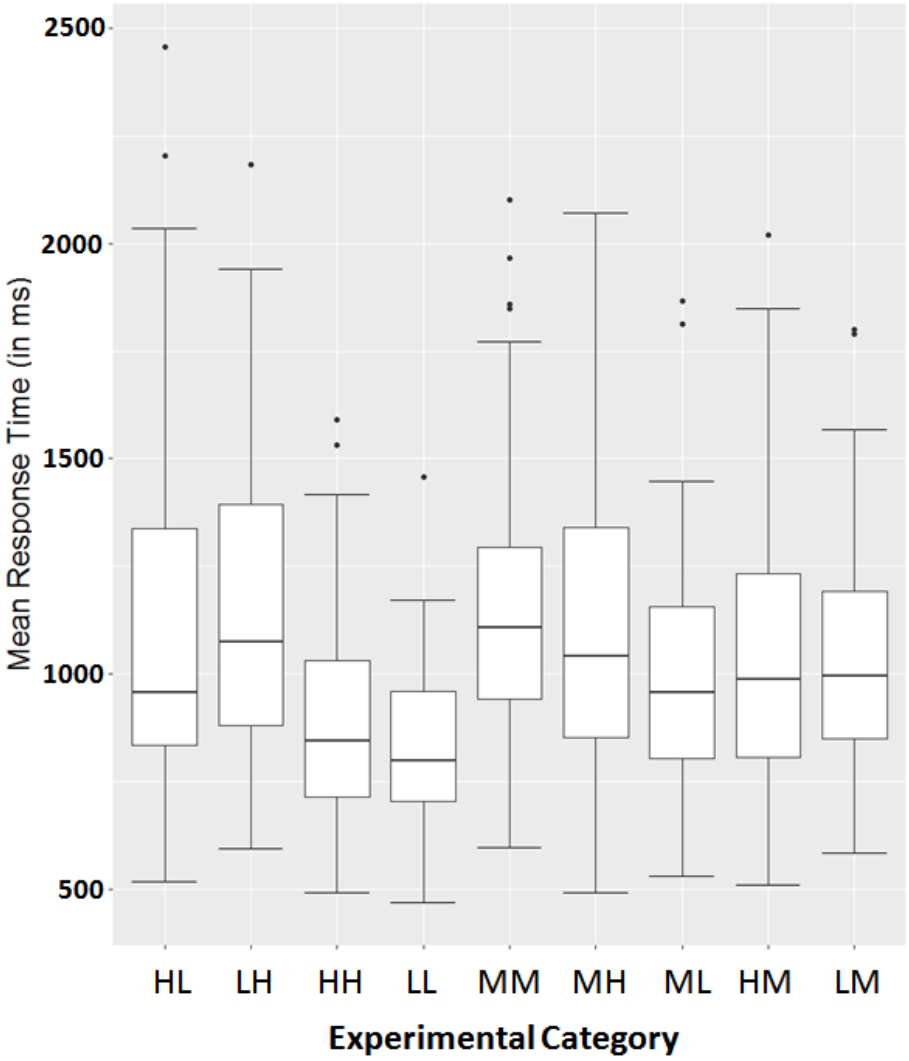

Fig. 13: Box plots visualizing the mean response time in each experimental category (L = low-, M = middle-, H = high probability of rain; the first letter describes the forecast and the second the sky picture). Black dots denote outliers.

The box plot of the response times showed huge variance in the mean response times between participants, in most of the categories. This becomes evident in the difference between the 1st and 3rd quartiles, and in the high number of outliers.

For example, the High-High and Low-Low categories seemed to have the shortest response times, thus inducing certain decision making. However, an ANOVA and successive post-hoc t-tests (alpha = 0.05, bonferroni-holm corrected) revealed that, while there were some significant differences between the conditions, the response times in LL did not differ significantly from ML, and HH did not differ significantly from ML, HM, or LM.

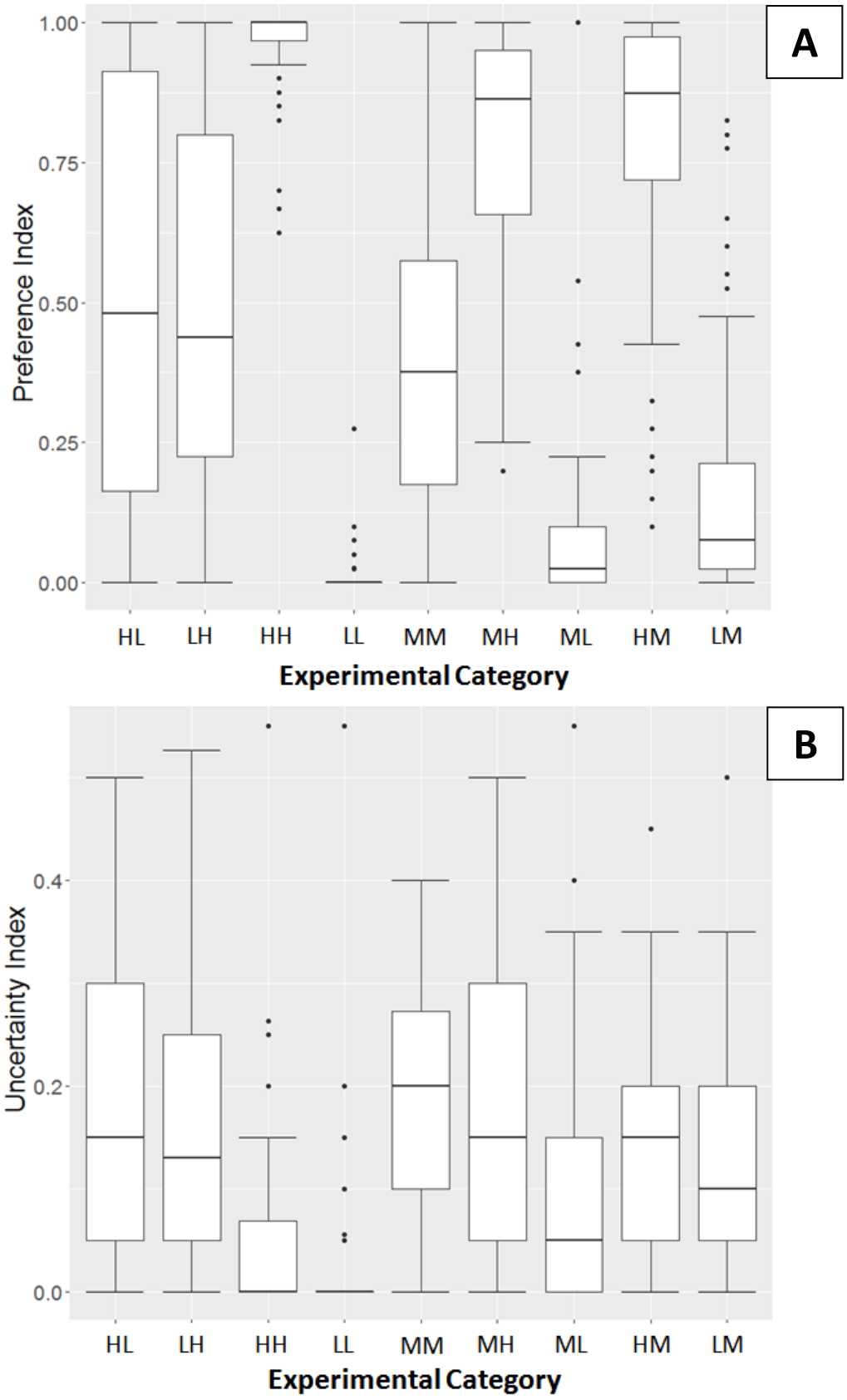

Fig. 14: Box plots visualizing the PI (A) and the UI (B) in each experimental category (L = low-, M = middle-, H = high probability of rain; the first letter describes the forecast and the second the sky picture). Black dots denote outliers.

The picture painted by the box plot for the PI is a diverse one. On the one hand, the categories assumed to be certain are indeed leaning strongly to one end of the spectrum (either 1 in the case of High-High, or 0 in the case of Low-Low). On the other hand, each category has a huge variance between participants. That is especially true for the 'uncertain' categories like High-Low and Low-High, but even the 'certain' categories vary more than one would have expected, if they truly reflected a clear and certain decision situation. Apparently, the participants' response to the categories differed greatly.
The same conclusion can be drawn from the box plots depicting the UI. The amount of incoherent decision varies strongly between the participants, even in supposedly certain conditions, where twice a participant had more than 50% incoherent decisions.

To investigate these interindividual differences, the BSPs are an excellent tool (see figures 9 and 10). After consulting them it became apparent that the participants followed widely different strategies in their approach to the given problem. Therefore, only some adhered to the behavior laid out in the predefined categories, while other differed somewhat from them. Still others had a strategy that completely contradicted all assumptions of certainty and uncertainty within the stimulus space. See figure 15 for examples of all three types of decision makers.

In the end, it was decided to abandon the previously established categories. While they may work on average, there were too many participants that deviated from the expected pattern of decisions. Additionally, even those participants that - unknowingly - conformed to the general structure of the categories did not do so for the entirety of each category. Even if, for example, the Middle-Middle category contained many trials with incoherent decisions, this was never true for every trial in the category. So if the fMRI or EEG analyses aim to compare uncertain and certain decision making, the trials being used for that analysis have to be selected individually for each participant. This was considered to be the only way to ensure that, despite the

participants' individual decision strategies, the basis for following analyses remained as sound as possible.

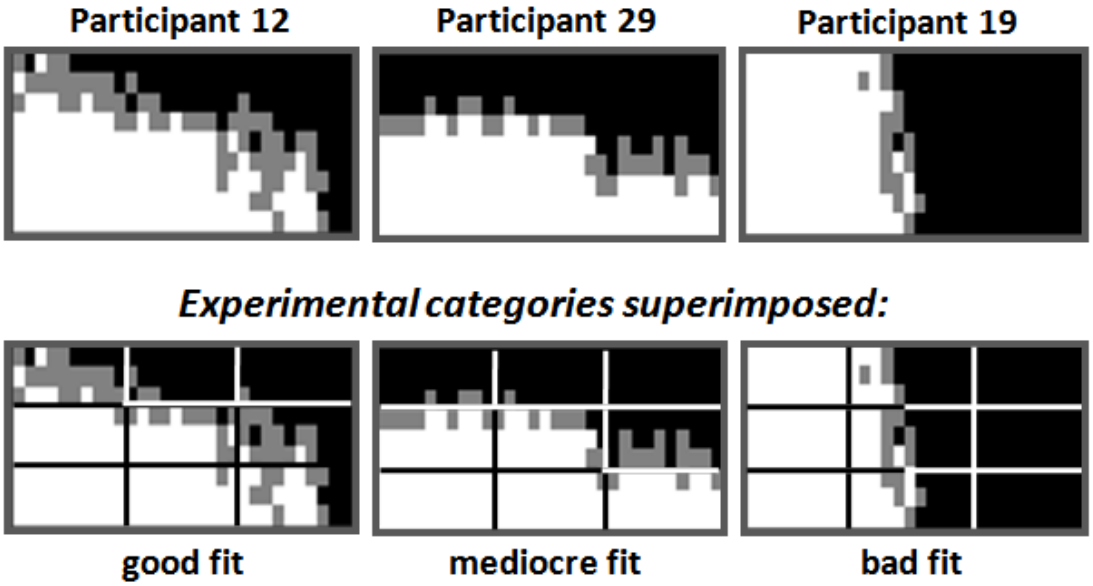

Fig. 15: BSPs for three participants, illustrating a good, a mediocre and a bad fit between the decision pattern and the experimental categories.

6.5. Individual trial selection

As outlined in the excursus above, there had been nine categories of stimulus combinations originally intended for the design and analysis of the present experiment. However, as it has also been explained, no set categories were valid for all participants due to differences in individual strategies; Instead, certain and uncertain trials had to be selected for each participant individually (see figure 16 for an illustration of the selection process).

For the certain category (CER), trials with consistent decisions were chosen, for these were assumed to be the result of certain decisions.

For the uncertain category (UNC), trials with inconsistent decisions were chosen, for these were assumed to be the result of uncertain decision.

However, additional trials were considered uncertain if they were surrounded by multiple uncertain trials in the BSP (if 2/5 or more of surrounding trials were uncertain). The reasoning was that uncertain decision making might potentially lead to consistent answers as well as inconsistent ones. So if surrounding trials (with

similar stimulus qualities) have produced uncertain behavior, a trial with consistent answers may still be the product of two uncertain decisions.

Furthermore, some uncertain trials were removed if they could be considered outliers produced by misclicks. That was the case when no other uncertain trial was present in a 3x7 area (rows x columns) surrounding the trial in question.

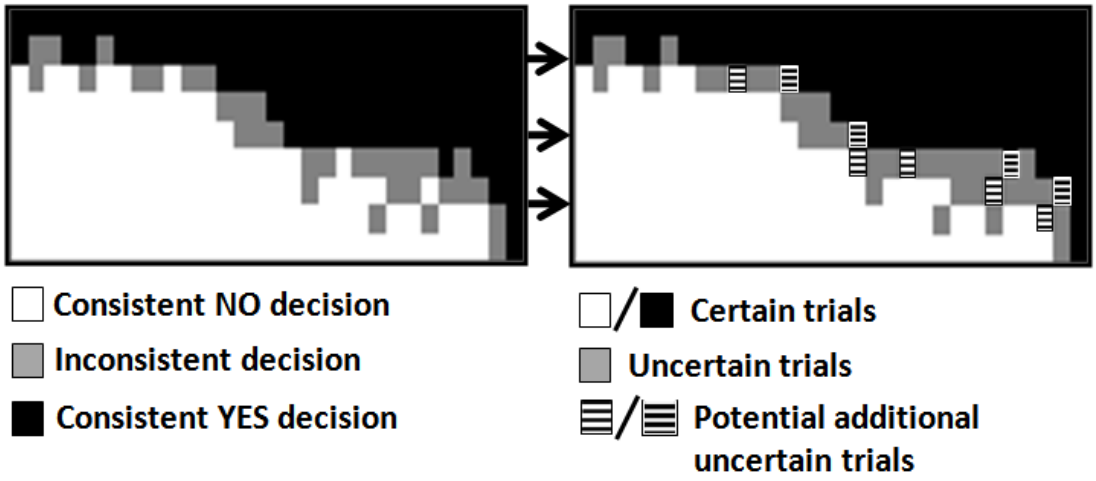

Fig. 16: Visualization of the un/certain trial selection process. The original BSP is on the left, and on the right is the adapted plot showing the selected trials.

The amount of chosen trials differed between participants, usually limited by how many inconsistent trials that participant had produced, since the amount of UNC and CER trials were kept the same.

To prevent a bias towards one response in the CER category, it was ensured that the relative amount of YES and NO responses amongst the chosen certain trials was both ~50%. This value was used because inconsistent trials, and therefore the chosen uncertain trials, show this ratio naturally.

6.6. Response time analysis

To check for a difference in response times between the newly formed categories CER and UNC, a paired t-test (alpha = 0.05) was calculated using the trimmed (trim = 0.05) mean response times of each participant.

This was done for both the data from the EEG experiments and the fMRI experiments, separately.

6.6.1. Response time analysis results

The paired t-tests for the data from the EEG experiments was significant ($p < 0.001$, $d = 0.99$). Uncertain decisions took significantly longer (mean = 1279.37ms, sd = 336.1) than certain decisions (mean = 984.07ms, sd = 226.3).

Likewise, the paired t-test for the data from the fMRI experiments also showed a significant result ($p < 0.001$, $d = 1.72$) with uncertain decisions taking significantly longer (mean = 1314 ms) than certain decisions (mean = 979 ms).

6.6.2. Response times Discussion

The longer response times for uncertain decisions compared to certain trials, both for the fMRI and for the EEG data, are in agreement with the definition of uncertainty as used in this study (see Lipshitz & Strauss, 1997). Therefore, this result improves the trust in the trial selection method, which was supposed to separate between uncertain and certain trials.

6.7. Behavioral Discussion - Concluding remarks

The behavioral analysis has shown that the fundamental idea of the present experimental design worked; The experiment represents a promising example of quasi-realistic decision making research.

The stimuli were rated as expected and in agreement with the data from the pilot study, and the BSPs showed that the participants utilized individual decision strategies, likely reflecting their unique preferences and learning histories. The PI, UI, and TI seem to be useful tools to capture the aspects of individual strategies numerically.

Of course, the fact that the strategies of the participants differed presented a problem in the following analyses, which had to take these individual distributions of uncertainty and certainty into account. The trial selection approach outlined above is an attempt to allow for analysis of this specific type of data. As will be explained in the following section, there are a number of limitations of this approach, that limit the confidence in the following analyses. However, individual strategies and thus differing decision profiles will necessarily be a part of quasi-realistic decision making

since realistic situations are solved differently by different people. Therefore, this trial selection approach is a useful first step that future works can improve upon. Additionally, the response time analysis has shown that the selection seems to have worked to some extent.

7. Limitations of the experiment

Before discussing the fMRI or the EEG analyses and their respective results it is important to note a number of limiting factors on the behavioral level of this experimental design. These limitations have to be kept in mind when one reviews any results based on these procedures.

The core problem this design faces is its relative inability to accurately cause or determine a person's cognitive state in a given trial.

When one aims to compare different types of neural processing (in this case, decision making under certainty and under uncertainty) one should make sure that these types can be caused by the different predefined conditions of the experimental design. Since that is not possible (or desirable) in this case, as the discussion of the varying strategies has shown, the alternative would be to create a reliable method to determine when the targeted processing types have indeed taken place. Exactly that was attempted with the individual trial selection, but the validity of it remains doubtful.

First of all, the amount of information this selection is based on is rather limited. With only two repetitions per trial, there are only three states any trial in the BSP can assume, and misclicks could distort the pattern. Surrounding trials were used to improve the amount of information, but with many possible trial combinations untapped (90 out of 270 potential constellations were not used) there were many holes in the stimulus space, which restricted the effectiveness of using surrounding trials (see figure 17).

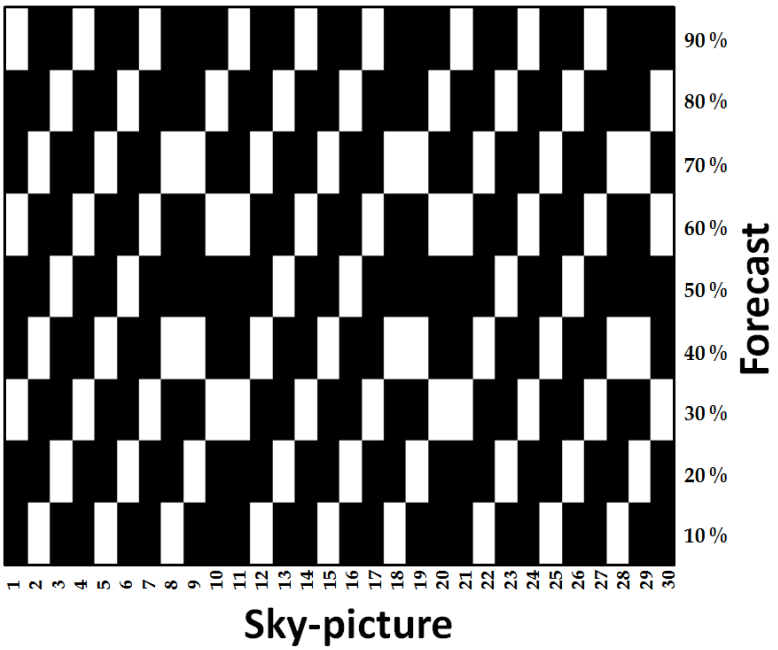

Figure 17: Visualization of the untapped trials within the stimulus space. Every white cell was unused in the experiment, every black cell was used.

Additionally, even if one assumes that trials with inconsistent decisions have been identified correctly, there are different cognitive states the person may have had during those trials. As mentioned in the previous section, the UI correlated only with the TI. Noticeable about this is a lack of correlation with the response time. If the inconsistent trials did indeed reflect uncertainty, one would expect a high UI (many inconsistent trials) to go hand in hand with overall higher response times. What follows is the possibility that inconsistent trials may reflect different behavior and mental states.

The participants might actually feel uncertainty in the respective trials, since they want to make the appropriate decision but find it difficult to do so. On the other hand, some participants might be more relaxed in their attitude towards this matter and less intent on making the 'perfect' choice, which would lead to them making inconsistent choices without ever making a decision under the feeling of uncertainty. Also, there is the possibility of strategy changes: If a participant changes their decision strategy between runs, it will look like uncertain decision making afterwards, even though each decision may have been made under certainty. See figure 18 for an illustrative example of a strategy change.

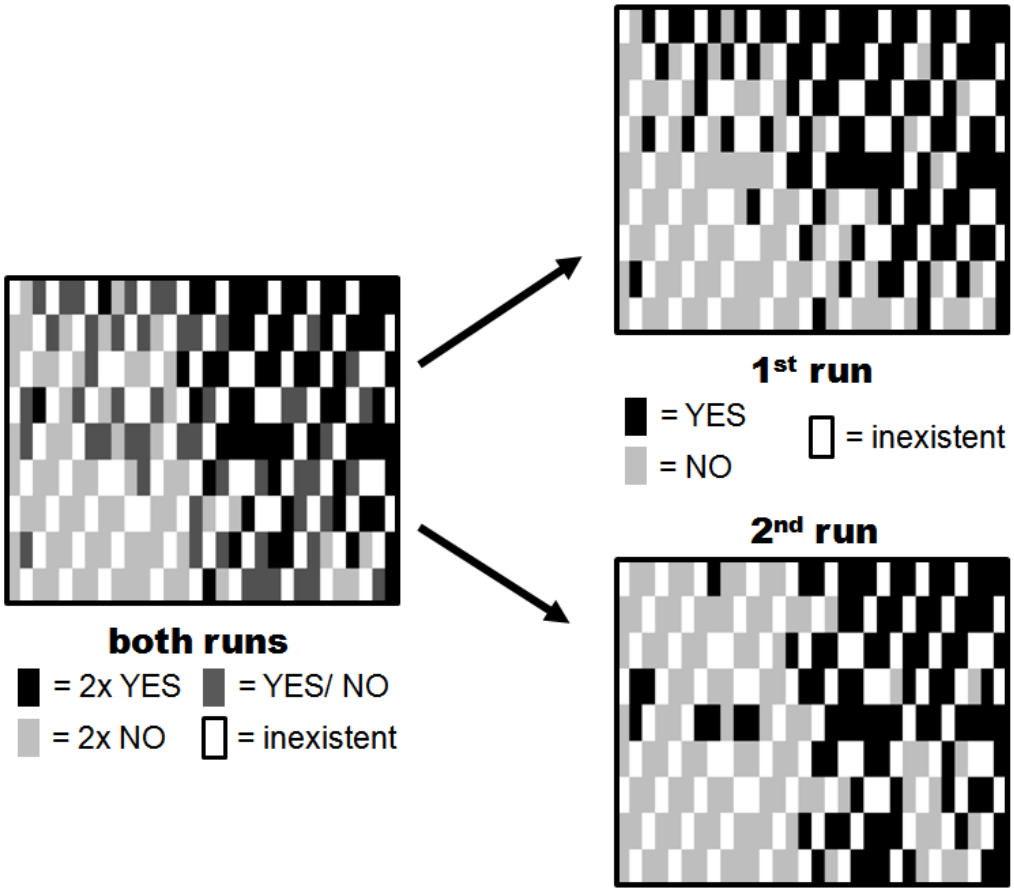

Figure 18: Example for a strategy change between runs, visualized using non-interpolated BSPs. Since there was no interpolation, all white cells denote unused trials. This participant seems to have employed a mixed strategy in the first run and a sky-based strategy in the second run (aside from a few outliers). When both runs are taken together, however, they seem to suggest a largely uncertain mixed strategy.

The strategy change does not have to be one where the trust shifts from one information to the other, as displayed in figure 18. A small but systematic shift in the threshold for taking the umbrella along, or even a more discrete threshold brought on by adaptation to the experimental design would suffice for the described effect of seemingly uncertain decision to appear.

Finally, the opposite effect is also conceivable: A person may feel uncertainty during both decisions for a specific trial, but end up making the same decision. Depending on where in the stimulus space this happens, those trials may be labeled as uncertain (if many inconsistent are around) but may also be incorrectly labeled as certain (if few inconsistent trials are around).

However, despite these doubts there is the significant difference in response times between UNC and CER; Both in the EEG and the fMRI experiment, the trials selected as uncertain took significantly longer than those considered as certain. Since slower decisions indicate uncertainty, this implies that the selection process worked at least on average.

Further limitations originate from the design of the experiment.
The fact that the response can (in fact, *has to*) be given while the sky-picture is still being displayed means that stimulus perception, decision making, and execution of said decision are temporally interlaced. This becomes additionally problematic when one considers the significantly different response times between uncertain and certain trials: Since in uncertain decisions the participants take longer on average, the different processes will be less compounded there than in certain trials. That systematic difference between the conditions introduces potentially immitigable error variance into the analyses.
In the same vein, there is the problem of the actual point in time where the decision is being made, which can differ between people and between trials. If a person has a strategy that places much trust into the forecasts, they will make their decision during the first stimulus presentation. The same would be true for a person with a clear strategy for some levels of the forecast, if they encountered one such trial (e.g. "Always take an umbrella if the forecast is 70% or higher, below that the sky is important"). Conversely, people with a sky-oriented strategy or a mixed strategy would make their decision later, after seeing the second stimulus. This means that not only is the decision making inevitably compounded with the stimulus processing, there are also systematic differences in when in the trial structure it is made and which stimulus processing it is intermixed with.

Furthermore, there is the problem of repetition. As stated in section 3.5.2, the methods of neuroscience demand recurrence of the same or similar tasks, even if that contradicts the goals of NDM. This problem was therefore known beforehand, but

should nonetheless be listed here; especially because the fact that each participant completed the experiment twice doubled the amount of repetition.
This may have caused uncertain decisions to become routine decisions, just as certain decision are, reducing the normally higher cognitive load of uncertain decisions (Jungermann et al., 2010; Volz et al., 2006). Looking at it from the perspective of the RPD model, the prototypes for this decision situation could have been expanded by an adaptation for ambiguous or inconsistent information. This would have erased many of the assumed differences between uncertain and certain decision making.

Another difficulty of this design is the lack of clearly defined probabilities and outcomes. Though this is partly intended, and mostly just a difficulty during analysis, it should still be mentioned here due to the limiting effect this has on the discussion of literature and the analyses.
Classical experimental designs concerning decisions under uncertainty and risk like the Iowa Gambling Task (Bechara, Damasio, Damasio, & Anderson, 1994) or the Balloon Analogue Risk Task (Lejuez et al., 2002) have clearly defined probabilities for the occurrence of each outcome after a decision. As such, participants can learn the probabilities through repeated answers and feedback, and adapt their decision strategies based on those outcome probabilities. This, in turn, allows for the identification of risk seeking participants versus those that try to minimize risk, and allows to differentiate a phase of uncertainty (while probabilities are still being learned) and one of risk (as soon as they are known).
The present design does not give the participants any feedback, meaning they will not adapt their behavior accordingly. No 'true' probabilities for rain or no-rain events exist, meaning the participants' behavior can never be classified as risk seeking or avoiding. All classification of the participants' behavior has to be based on the participants' personal decisions and decision strategies. These differences to classical experimental designs also mean that a lot of the literature gathered for these designs is not directly applicable to this study.
Of course, these circumstances are a necessary side effect of a design that allows the participants to utilize their individual decision strategy without forcing them towards

a 'correct' or optimal strategy. This limitation is therefore one that was purposefully not avoided.

Lastly, one limitation simply stemmed from technical errors in the procedure. There was a considerable unintended time-lag during the fade-in of the sky-picture, apparently an error produced by the presentation software in interaction with the computer's hardware. What should have taken 200 ms to display was prolonged to 350 ms (sd = 16,13) in the EEG experiment and to 510 ms (sd = 23,25) in the fMRI experiment. While the effect this had on the overall duration of the experiment can be ignored, there was a change in the timing of each individual trial. This may have led to different processing in time sensitive decision processes, which stand in the way of directly comparing or associating results obtained from EEG and from fMRI.
The presentation of the forecast also suffered from a similar problem; Instead of the intended 1000 ms, the forecast, including fade-in, took 1246.89 ms (sd = 20.3) to display in the EEG and 1437.51 ms (sd = 15.22) to display in the fMRI experiment. This delay is considerable, but does not have as much impact on the experiment as the delay of the sky-picture fade-in has.

Taken together, these limitations diminish the trust in the results gained from the experiments. This is why both the EEG and the fMRI results should be interpreted carefully. What exactly that means for each analysis shall be mentioned at the beginning of their respective discussions.

7.1. Potential improvements

Of course, the goal of an error analysis should be to not just detect problems but also to mend them. Most of the problems mentioned above cannot be fixed within the present work; it should therefore be considered how future experiments would have to be designed to avoid such obstacles. As such, the present work will have generated valuable information for future study designs.

First of all, the presentation of both stimuli should be equal, possibly with one second presentation per stimulus, and their sequence should be balanced. This would prevent any systematic time effects and distortions of personal strategies based on the stimulus order.

Secondly, the decision should not be executed during the presentation of one stimulus, but should instead have its own separate time frame. After both stimuli were presented, an additional screen could be shown, prompting the participants to give a response. That way the execution of the decision can be separated from the other trial elements. Of course, the decision making process itself could very well have been completed before, but that can never be prevented as long as the stimuli are presented in sequence (and a simultaneous presentation entails many different problems). However, the variation of said sequence would at least prevent a systematic effect of the point in time at which the decision is made.

Thirdly, the amount of sky-pictures should be reduced. Nine out of the thirty images could be chosen based on the evaluation, so that the resulting stimulus pool shows a linear and smooth rise in perceived probability of rain, parallel to that of the forecasts. This reduction would decrease the size of the stimulus space and would thus allow the presentation of each possible trial (each combination of sky-picture and forecast) a total of four times, without leaving holes in the space. That, in turn, would increase the amount of information gathered on each individual trial and its surroundings, allowing for a more precise and more informed judgment about inconsistent and thus, conceivably, uncertain trials.

Fourthly, this selection of uncertain and certain trials could also be enhanced by including the response times. Those can, of course, be distorted by outliers. But four repetitions of the same trial would allow an identification of outliers, which in turn would allow the trimmed average response time of a specific trial to be taken into account in the selection process.

Fifthly, more extensive reports by the participants may be an option to attain more information about their decision behavior. Such reports can always be incomplete or distorted, but additional information may nevertheless be useful. A standardized in-depth strategy questionnaire could be developed, covering trust in the two stimuli,

heuristics, and strategy changes. Also, the uncertainty participants feel while making a decision could be queried directly.

8. fMRI

8.1. fMRI-Recording

A 3-Tesla MR scanner (Siemens, Magnetom Allegra system) fitted with a quadrature head coil was used to record the functional images. A gradient echo- planar imaging (EPI) sequence was used to measure variations in blood oxygenation level-dependent (BOLD) T2 - weighted MR signal (46 3-mm thick axial [AC-PC oriented] slices in interleaved acquisition order covering the whole brain; FOV=192x192 mm, 64x64 matrix, TR=2.5s, flip angle=83°). On average, 914 volumes were obtained during one complete run (standard deviation = 36.04; variations are due to differences in response times).

8.2. fMRI Analysis

The fMRI data was processed using first DicomWorks 1.3.5 to sort the data and then the Statistical Parametric Mapping Software (SPM8 update-version 6313, 02.03.2015; running on Matlab R2017a) for all further steps.

After the import of the data into SPM the slice timing was performed with the first slice as reference. The images were realigned, normalized (template image: standard MNI-space EPI-image; source images: tenth functional scan from each participant), and smoothed (using an 8mm Kernel).

For the calculation of the 1st level beta images the trials were modeled over the duration of the whole trial, since the individual trial elements were too short and too variable in terms of the mental processes that took place during them (see section 7; 'Limitations of the Experiment'). Therefore, to best capture the entire decision making process, the whole trial from the depiction of the forecast until the decision was used, with the presentation of the fixation dot excluded. The fixation dot was modeled separately, for use as a low-level baseline.

Individually selected trials were used to construct the new categories UNC (Uncertainty, containing an individual number of uncertain trials) and CER (Certainty, containing a corresponding number of certain trials). For an explanation of the method with which the trials were selected, see section 6.5; 'Individual trial selection'.

Four contrasts were calculated on the 1st level: Uncertainty versus certainty (UNC > CER), certainty versus uncertainty (CER > UNC), uncertainty versus fixation dot (Unc > fix) and certainty versus fixation dot (CER > fix).

After the 1st level analysis was thus completed, two different routes of analysis were undertaken: a contrast analysis and an individual voxel distribution analysis.

8.2.1. Contrast Analysis

The individual contrast images from the 1st level analysis were used in a 2nd level random effects analysis, applying a one sample t-test. To account for the exploratory nature of the study the results were uncorrected ($p < 0.001$; $k \geq 10$ voxel cluster size). All foci which were at least 10 voxel apart were recorded and the anatomical structures corresponding to the MNI coordinates were determined using the SPM Anatomy Toolbox (Eickhoff et al., 2005).

A conjunction analysis was performed to compare the contrasts of 'UNC vs. fixation dot' and 'CER vs. fixation dot' with each other. This method is designed to reveal the commonly activated regions.

8.2.1.1. Contrast Analysis Results

Table 4 shows the results of the SPM analysis. Each coordinate listed in the table represents a significant activation focus at the level $p < 0.001$. The contrast between UNC and CER revealed higher activity for UNC in the middle cingulate cortex (MCC), the inferior and superior parietal lobule, the precentral gyrus, the superior medial gyrus and parts of the posterior medial frontal cortex. For CER, higher activation was found in the supra marginal gyrus.

The contrasts between both UNC and CER against the low level baseline revealed mostly overlapping activation foci (shown also in the conjunction analysis). The active areas included most prominently, but were not limited to: The cerebellum, the middle and anterior cingulate cortex, the inferior parietal lobule, the insula, the middle frontal cortex, and the postcentral gyrus.

For a visualization of the results of the contrasts UNC>fix and CER>fix, and their conjunction, see figures 19 to 21 (section views, glass brains, and slice views).

Table 4: Listed in this table are all cluster activation foci that were at least 8mm apart, from all contrasts and the conjunction analysis. The hemisphere of the focus can be found in each contrast's left column (H = Hemisphere) and the MNI coordinates in the right.

p = 0.001 (unc.); *k (cluster size) = 10*	**Contrast**									
	UNC > CER		**CER > UNC**		**UNC > fix**		**CER > fix**		**CER>fix & UNC>fix**	
Anatomical Region	H |	MNI coordinates	H |	MNI coordinates	H |	MNI coordinates	H |	MNI coordinates	H |	MNI coordinates
Calcarine Gyrus					R	6 -84 4	R	6 -84 4	R	6 -84 4
Cerebellum					R	36 -56 -30	R	36 -56 -30	R	24 -76 -18
					L	-36 -62 -26	R	24 -76 -18	R	16 -76 -16
					L	-34 -46 -36	L	-40 -54 -32	R	36 -56 -30
					R	16 -76 -16	L	-30 -56 -26	R	42 -56 -24
					L	-16 -80 -20	L	-14 -80 -20	L	-40 -54 -30
					R	18 -52 -24			L	-30 -54 -24
					R	4 -52 -24			L	-34 -46 -36
									L	-14 -80 -18
									L	-24 -78 -20
									R	18 -52 -24
Cingulate Cortex - Anterior					R	4 14 26	R	2 16 28	R	4 16 28
					L	-2 32 24	L	-2 30 24	L	-2 30 24
					R	8 28 28				
					R	2 22 18				
Cingulate Cortex - Middle	R	10 18 32			L	-2 2 36	L	0 8 36	L	-2 4 34
					L	-6 -22 32				

Heschls Gyrus			L -46 -16 10	L -46 -16 10	L -44 -16 10
IFG (p. Opercularis)			L -52 8 6 L -44 18 -4 R 58 16 4	R 52 14 2 R 56 18 12	
IFG (p. Orbitalis)			R 34 22 -10		R 52 14 2
Inferior Frontal Gyrus				L -46 10 0	
Inferior Parietal Lobule	L -28 -54 42		L -54 -24 38 L -44 -50 52 L -34 -60 44 L -44 -44 42 R 48 -50 52 R 48 -38 52	L -54 -26 38 L -44 -50 54 R 48 -50 52 R 48 -40 56	L -54 -24 38 L -42 -50 52 R 48 -48 54 R 52 -48 40
Insula			L -38 6 0 L -36 -8 4 L -36 12 -12 L -36 -18 14 R 46 18 -6	L -36 6 4 L -38 -8 6 R 44 20 -2 R 38 6 2 R 40 16 -12	L -40 6 2 L -38 -10 10 L -36 -8 2 R 40 8 0 R 40 22 0
Intraparietal Sulcus				R 46 -34 36	R 46 -34 36
Middle Frontal Gyrus			L -40 40 20 R 38 38 24	R 26 44 34 R 36 26 44 L -34 24 44	R 36 26 44

Posterior Medial Frontal	L	-2 22 44			R	6 8 70	R	8 8 66	R	6 8 70
	L	-2 10 54			L	-2 -2 74			R	0 2 74
	R	14 20 68								
Postcentral Gyrus					L	-60 -20 20	L	-52 -18 32	L	-58 -20 20
					L	-60 -14 40			L	-54 -30 54
									L	-46 -36 60
Precentral Gyrus	L	-44 10 42								
	L	-38 4 34								
Precuneus					L	-2 -68 50				
					L	-2 -64 64				
Putamen					R	34 4 2	L	-32 -18 -4	L	-32 -4 -4
							L	-32 -4 -4		
Superior Frontal Gyrus					R	24 46 36			R	26 44 36
Rolandic Operculum					L	-44 -26 20	L	-42 -26 18	L	-42 -26 20
										-52 8 2
Superior Medial Gyrus	L	-6 32 32			R	4 24 42				
Superior Parietal Lobule	L	-28 -66 48			L	-34 -60 56				
Supra Marginal Gyrus			L	-48 -40 26	R	46 -36 38	L	-58 -22 22	R	54 -38 40
					R	56 -40 34	L	-54 -38 34		
							L	-60 -18 42		

				L -50 -30 24 R 64 -34 32	

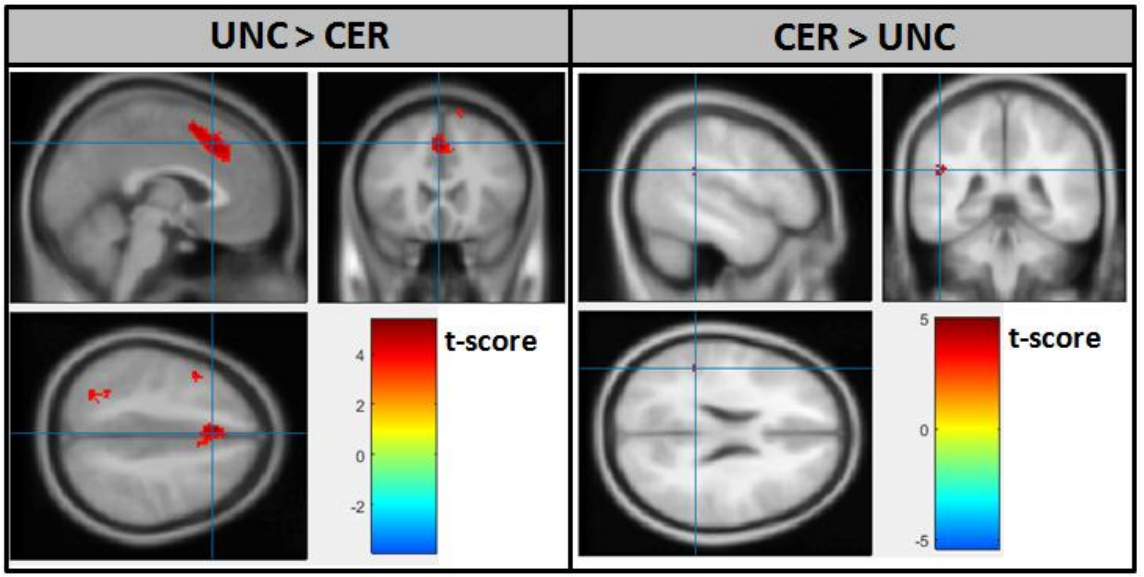

Fig. 19: Section views of the significant differences between UNC and CER ($p < 0.001$ uncorrected; $k \geq 10$).

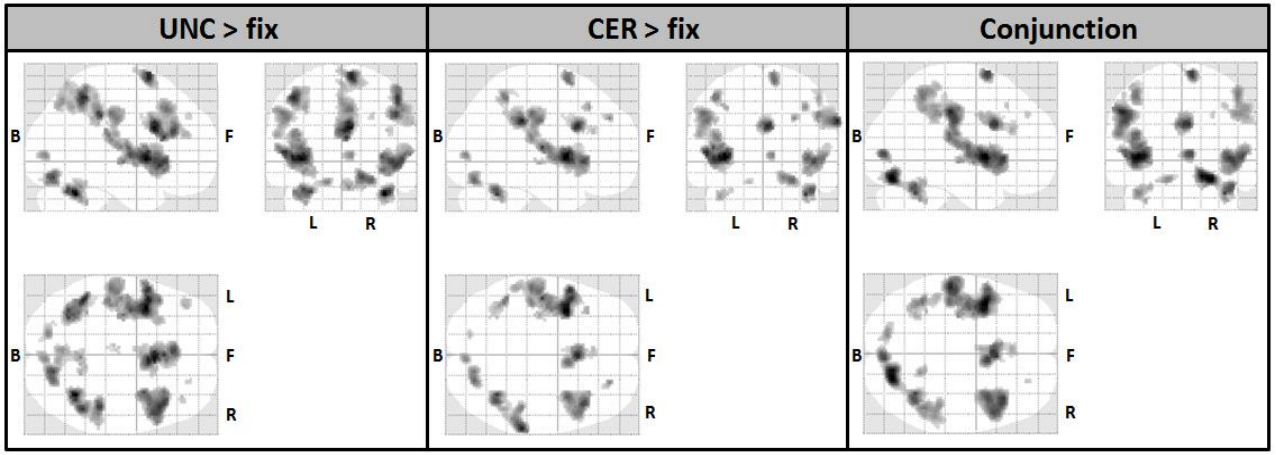

Figure 20: Glass brain views of both contrasts with the fixation dot (UNC>fix; CER>fix) and of the conjunction (null) analysis between the two ([CER>fix]&[UNC>fix]). All contrasts at $p < 0.001$ (uncorrected, $k \geq 10$); L = left; R = right; F = front; B = back.

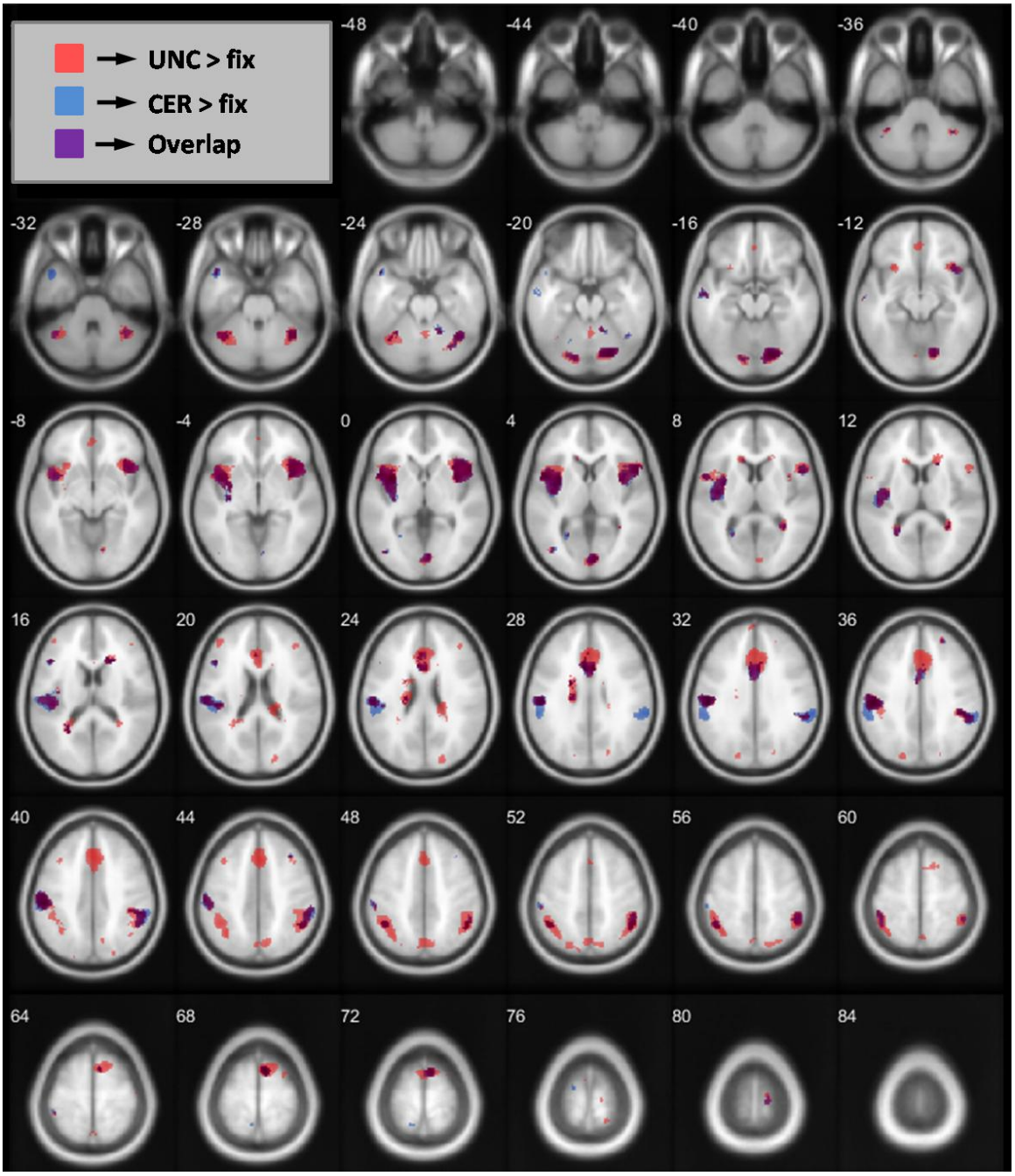

Fig. 21: Horizontal slice views of both contrasts with the fixation dot (UNC>fix; CER>fix). Both contrasts at $p < 0.001$ (uncorrected, $k \geq 10$). Exclusive activation of UNC>fix is colored red, exclusive activation of CER>fix is colored blue, overlapping activation is colored violet.

8.2.1.2. Contrast Analysis Discussion

When interpreting the fMRI results one limitation mentioned in section 7 ('Limitations of the Experiment') has to be taken into account especially: The fact that uncertain and certain decision were difficult to accurately identify and thus likely mixed into the respective opposite group. This entails a similarity of the two experimental conditions unrelated to any similarity between the actual processes of certain and uncertain decision making. That in turn means that the analysis may find fewer different activations than would otherwise have been possible.

The second hypothesis postulated that during uncertain decisions the frontal areas of the brain would be increasingly active, especially the DLPFC and the ACC. In the contrast UNC>CER there was a higher activation in the middle cingulate cortex (MCC), the inferior parietal lobule, the posterior and superior medial frontal gyrus, the precentral gyrus, and the superior parietal lobule.

Neither the DLPFC nor the ACC were found to be active, but in the literature the ACC was often confounded with the MCC, which was also connected to decision making (Vogt, 2016) and which was found to be active in this contrast.

An increased activation of the posterior medial frontal gyrus and the superior medial frontal gyrus can be reconciled with existing literature as well. The medial frontal cortex has been discussed to be involved in the resolution of uncertainty, potentially utilizing the long-term working memory (Mushtaq et al., 2011), in connection with the posterior parietal cortex (Mushtaq et al., 2011; Volz, Schubotz, & von Cramon, 2003, 2005) which was also found to be active in the current study. The involvement of the parietal cortex may also be due to the increased need to estimate probabilities during uncertain situations (see Ernst et al., 2004; Platt & Glimcher, 1999).

Overall, these findings serve to validate results from previous studies, that worked with abstract designs. When limiting the analysis to the direct contrasts between uncertainty and certainty the areas found to be more active in uncertainty largely overlap with the areas commonly found in respective literature.

The first hypothesis stated that the processing of experience-based decisions would involve brain structures connected to perceptual and conceptual-motoric processing. Indeed, when the experimental conditions are contrasted to the low level baseline, a larger fronto-parietal network becomes apparent. In comparison of the two contrasts 'UNC > fix' and 'CER > fix' a generally similar pattern of activation can be observed, which is reflected in the results of the conjunction analysis (see figure 20 for glass brain overview of both contrasts and the conjunction analysis).

The most prominent regions activated in the conjunction analysis are the ACC (both hemispheres), the insula (both hemispheres), and the inferior parietal lobule (IPL, both hemispheres), though previously discussed regions (like the MCC and the medial frontal cortex) are also found here.

Since both contrasts used in the conjunction analysis were task variations contrasted against a low level baseline, these region could be seen as the network common to solving this type of task, or, in this case, making decisions under the given circumstances. As expected based on the model of the perception action cycle, a network of perceptual and executive areas can be found.

The involvement of the ACC in the network was expected, seeing as it is perhaps the most commonly discussed area in research of decision making (see for reviews Ernst & Paulus, 2005; Mushtaq et al., 2011) and has a variety of cognitive tasks attributed to it. The insula, in the context of decision making, has been discussed to be involved in the affective processing of a stimulus or an option (Ernst & Paulus, 2005) and the emotional estimation of value and rewards (Fuster, 2017). The role of the IPL has been discussed to some extent in recent years, with possible roles including maintaining attention, reacting to salient stimuli (Singh-Curry & Husain, 2009), and familiarity based recognition (Yonelinas, Otten, Shaw, & Rugg, 2005). Naturally, maintaining attention was necessary during the tasks, more so than during the baseline. The judgment of familiarity, however, is an especially interesting interpretation of this region's involvement, since the Recognition-Primed Decision model predicts that an effort to relate the current situation to previous similar, and thus familiar, situations would take place. Of course, if this were the IPL's only task, one would expect more pronounced activation in the CER > fix contrast because those situations are more

familiar. Therefore, other tasks like the previously mentioned maintenance of attention likely play a role as well.

8.2.2. Individual voxel distribution

Apart from the standard contrast analysis, a different route was taken with the analysis of individual voxel distribution. The goal of this procedure was twofold.

First, the connection between the pooled amount of active voxel (in a given cerebral lobe and a given contrast) and a number of external variables was supposed to be assessed.

Second, this procedure was supposed to present a different view on the contrasts, taking into account the potentially individually different patterns of active voxel in a given region. A regular 2nd level contrast analysis returns significant results only if many participants have overlapping active voxel. However, the voxel-based analysis ignores that and also produces significant results if many participants have neural activity in the same anatomical region, but in different parts of it. As such, this procedure may uncover differences between contrasts that the 2nd level contrast analysis overlooked.

The 1st level contrasts were processed with SPM for each participant individually, and the coordinates of each significantly different voxel were extracted, in the Montreal Neurological Institute (MNI) coordinate system.

An in-house Matlab-script was then used to transform the MNI coordinates into Talairach coordinates, using the mni2tal transformation algorithm (see the code in appendix H). The resulting Talairach coordinates were then assigned to one of 79 distinct areas of the brain (For a list all areas, refer to appendix I).

The result was a data table containing, for the 25 participants and the 79 brain areas, the number of active voxel. Three such tables existed for every contrast: One for the left hemisphere only, one for the right hemisphere only, and one containing the summed values from both hemispheres.

For an additional, more macroscopic view, several regions were summed up to represent the cortical activity in the different cortical lobes (frontal, parietal,

temporal, and occipital; the assignment of regions to each lobe is also shown in appendix I).

The amount of active voxel in every lobe was correlated with the Neo-FFI scales, the d2-'KL'-value, the Additional Questionnaire, the PI, the UI and the TI, using R. This was done for each hemisphere (left, right, both) respectively. The correlations between the 79 individual regions and the external variables were not calculated, since this would have amounted to 29388 correlations. Without any hypothesis, the expected number of false positives was deemed too large for this procedure to have any value.

Additionally, the contrasts UNC > fix and CER > fix were compared with each other; The number of active voxel in each region and in the cortical lobes were compared using dependant t-tests (alpha = 0.05), for each hemisphere (left, right, both) respectively. Effectively, this constitutes a comparison between UNC and CER.

8.2.2.1. Voxel distribution Results

Appendix J contains a table of the average number of active voxel per anatomical region, for each contrast and both hemispheres separately.

The results of the correlation analysis between the active voxel in the lobes and the external variables, for all four contrasts, can be found in the tables 5 through 10. Tables 5 and 6 contain the results for both hemispheres, tables 7 and 8 those for the left hemisphere, and tables 9 and 10 those for the right hemisphere.

Table 5: Correlations of significantly active voxel in a given contrast and external variables of interest, for both hemispheres. Pearson's correlation coefficient is listed if the correlation was significant at the level 0.05; if not, it is marked as n.s. (not significant). Significant positive correlations are highlighted in blue, negative correlations are highlighted in red. For the content of the RaB-2 questions, see appendix E (additional questionnaire).

Both Hemispheres	UNC > CER				CER > UNC			
	frontal	parietal	temporal	occpital	frontal	parietal	temporal	occpital
Neo: Neuroticism	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Openness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Agreeable.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscient.	n.s.	n.s.	n.s.	-0.41	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; general	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 1 day	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 2 days	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 3 days	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 6	0.46	0.66	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 7	n.s.	0.53	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 9	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 11	n.s.	n.s.	-0.43	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 14	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 16	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 17	n.s.	n.s.	n.s.	-0.47	n.s.	n.s.	n.s.	n.s.
RaB2: Q 18	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 19	n.s.	n.s.	0.5	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
PI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 6: Correlations of significantly active voxel in a given contrast and external variables of interest, for both hemispheres. Pearson's correlation coefficient is listed if the correlation was significant at the level 0.05; if not, it is marked as n.s. (not significant). Significant positive correlations are highlighted in blue, negative correlations are highlighted in red. For the content of the RaB-2 questions, see appendix E (additional questionnaire).

Both Hemispheres	UNC > fix				CER > fix			
	frontal	parietal	temporal	occpital	frontal	parietal	temporal	occpital
Neo: Neuroticism	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	0.41	0.41	n.s.	n.s.	n.s.	0.44	n.s.
Neo: Openness	n.s.	n.s.	n.s.	0.47	n.s.	n.s.	n.s.	0.45
Neo: Agreeable.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscient.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	0.4	n.s.	n.s.	n.s.	0.43
FC-Trust; general	-0.55	-0.43	n.s.	n.s.	-0.42	n.s.	n.s.	n.s.
FC-Trust; 1 day	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 2 days	-0.41	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 3 days	-0.47	-0.49	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 4	n.s.	n.s.	-0.42	n.s.	n.s.	n.s.	-0.5	n.s.
RaB2: Q 5	-0.47	-0.41	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 7	n.s.	n.s.	0.41	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 8	n.s.	0.48	n.s.	0.46	n.s.	n.s.	n.s.	n.s.
RaB2: Q 9	-0.41	-0.54	-0.44	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 11	n.s.	-0.46	n.s.	-0.43	n.s.	n.s.	n.s.	n.s.
RaB2: Q 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 14	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 16	n.s.	-0.45	-0.42	n.s.	n.s.	-0.43	-0.4	n.s.
RaB2: Q 17	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 18	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 19	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
PI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TI	-0.41	-0.42	n.s.	-0.49	n.s.	n.s.	n.s.	n.s.

Table 7: Correlations of significantly active voxel in a given contrast and external variables of interest, for the left hemisphere. Pearson's correlation coefficient is listed if the correlation was significant at the level 0.05; if not, it is marked as n.s. (not significant). Significant positive correlations are highlighted in blue, negative correlations are highlighted in red. For the content of the RaB-2 questions, see appendix E (additional questionnaire).

Left Hemisphere	UNC > CER				CER > UNC			
	frontal	parietal	temporal	occpital	frontal	parietal	temporal	occpital
Neo: Neuroticism	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Openness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Agreeable.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscient.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; general	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 1 day	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 2 days	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 3 days	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 6	0.45	0.63	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 7	n.s.	0.44	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 9	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 11	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 14	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 16	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 17	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 18	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 19	n.s.	n.s.	0.52	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
PI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 8: Correlations of significantly active voxel in a given contrast and external variables of interest, for the left hemisphere. Pearson's correlation coefficient is listed if the correlation was significant at the level 0.05; if not, it is marked as n.s. (not significant). Significant positive correlations are highlighted in blue, negative correlations are highlighted in red. For the content of the RaB-2 questions, see appendix E (additional questionnaire).

Left Hemisphere	UNC > fix				CER > fix			
	frontal	parietal	temporal	occpital	frontal	parietal	temporal	occpital
Neo: Neuroticism	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.41	n.s.
Neo: Openness	n.s.	n.s.	n.s.	0.5	n.s.	n.s.	n.s.	0.5
Neo: Agreeable.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscient.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.42
FC-Trust; general	-0.41	n.s.	n.s.	n.s.	-0.46	n.s.	n.s.	n.s.
FC-Trust; 1 day	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 2 days	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 3 days	n.s.	-0.41	n.s.	n.s.	-0.42	n.s.	n.s.	n.s.
RaB2: Q 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 4	n.s.	n.s.	-0.54	n.s.	n.s.	n.s.	-0.53	n.s.
RaB2: Q 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 7	n.s.	n.s.	0.4	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 8	n.s.	0.46	n.s.	0.51	n.s.	n.s.	n.s.	n.s.
RaB2: Q 9	n.s.	-0.5	-0.42	n.s.	n.s.	n.s.	-0.42	n.s.
RaB2: Q 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 11	n.s.	n.s.	n.s.	-0.46	n.s.	n.s.	n.s.	n.s.
RaB2: Q 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 14	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 16	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 17	n.s.	n.s.	n.s.	n.s.	-0.44	-0.41	n.s.	n.s.
RaB2: Q 18	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 19	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
PI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TI	n.s.	n.s.	n.s.	-0.52	n.s.	n.s.	n.s.	n.s.

Table 9: Correlations of significantly active voxel in a given contrast and external variables of interest, for the right hemisphere. Pearson's correlation coefficient is listed if the correlation was significant at the level 0.05; if not, it is marked as n.s. (not significant). Significant positive correlations are highlighted in blue, negative correlations are highlighted in red. For the content of the RaB-2 questions, see appendix E (additional questionnaire).

Right Hemisphere	UNC > CER					CER > UNC			
	frontal	parietal	temporal	occpital		frontal	parietal	temporal	occpital
Neo: Neuroticism	n.s.	n.s.	-0.41	n.s.		n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
Neo: Openness	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
Neo: Agreeable.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
Neo: Conscient.	n.s.	n.s.	n.s.	-0.41		n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
FC-Trust; general	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
FC-Trust; 1 day	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
FC-Trust; 2 days	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
FC-Trust; 3 days	0.45	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 2	n.s.	n.s.	n.s.	-0.4		n.s.	n.s.	n.s.	n.s.
RaB2: Q 4	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 5	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 6	0.4	0.59	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 7	n.s.	0.53	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 8	n.s.	0.49	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 9	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 10	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 11	n.s.	n.s.	-0.43	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 12	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 13	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 14	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 15	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 16	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 17	n.s.	n.s.	n.s.	-0.54		n.s.	n.s.	n.s.	n.s.
RaB2: Q 18	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 19	0.52	n.s.	0.47	n.s.		n.s.	n.s.	n.s.	n.s.
RaB2: Q 20	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
UI	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
PI	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
TI	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.

Table 10: Correlations of significantly active voxel in a given contrast and external variables of interest, for the right hemisphere. Pearson's correlation coefficient is listed if the correlation was significant at the level 0.05; if not, it is marked as n.s. (not significant). Significant positive correlations are highlighted in blue, negative correlations are highlighted in red. For the content of the RaB-2 questions, see appendix E (additional questionnaire).

Right Hemisphere	UNC > fix				CER > fix			
	frontal	parietal	temporal	occpital	frontal	parietal	temporal	occpital
Neo: Neuroticism	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.44	n.s.
Neo: Openness	n.s.	n.s.	n.s.	0.41	n.s.	n.s.	n.s.	n.s.
Neo: Agreeable.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscient.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	0.42	n.s.	n.s.	n.s.	n.s.
FC-Trust; general	-0.6	-0.5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 1 day	-0.4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 2 days	-0.47	-0.42	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FC-Trust; 3 days	-0.48	-0.48	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 4	0.46	0.44	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 5	-0.55	-0.52	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 7	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 8	n.s.	0.43	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 9	-0.42	-0.51	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 11	n.s.	-0.47	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 14	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 15	n.s.	n.s.	0.47	n.s.	0.48	n.s.	0.48	n.s.
RaB2: Q 16	-0.41	-0.5	-0.45	n.s.	-0.45	-0.52	-0.45	n.s.
RaB2: Q 17	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 18	n.s.	n.s.	0.42	n.s.	0.44	n.s.	n.s.	n.s.
RaB2: Q 19	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Q 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UI	n.s.	n.s.	-0.51	n.s.	n.s.	n.s.	n.s.	n.s.
PI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TI	-0.51	-0.48	n.s.	-0.44	n.s.	n.s.	n.s.	n.s.

Five of the t-tests for differences between the amount of active voxel in the UNC > fix and the CER > fix contrasts returned a significant result. There was a significantly higher amount of active voxel for uncertainty than for certainty in:

- the right anterior cingulate cortex ($p < 0.05$, $t = 2.07$, mean of differences = 16.32)
- the left superior frontal gyrus ($p < 0.05$, $t = 2.46$, mean of differences = 32.76)
- the left middle frontal gyrus ($p < 0.05$, $t = 2.08$, mean of differences = 55.04)
- the left inferior frontal gyrus ($p < 0.05$, $t = 2.46$, mean of differences = 28.88)
- the left middle occipital gyrus ($p < 0.05$, $t = 2.54$, mean of differences = 63.52)

8.2.2.2. Voxel distribution Discussion

Regarding the correlations of active voxel and external variables, the present work will abstain from any form of interpretation. The results produced have explorative value, insofar that they may serve as a basis for hypotheses for future work. Additionally, the process of voxel-based analysis as presented here may be useful for future studies concerned with individually different neural activation.

However, the possibility for an alpha error was deemed too large. Of the 1488 correlation tests that were calculated, 108 were significant. With an alpha level of 0.05, 74.4 test out of 1488 can be expected to return a significant result even though the H0 is in fact true (1488 * 0.05 = 74.4). Considering this, and considering the lack of a clear hypothesis, an interpretation of the potentially random results seems inadvisable.

Concerning the t-tests for the comparison of active voxel in UNC > fix and CER > fix, an interesting situation presents itself.

In all significant tests uncertain decision making showed a higher amount of active voxel than certain decision making, and most significant differences were found in the frontal lobe, with one in the ACC. This is in confirmation with hypothesis 2.

However, when one compares these results with those of the previously presented contrast analysis, only some of the results seem to be in agreement.

The ACC and the superior frontal gyrus are present in the activation foci found in the contrast analysis, and in both cases there are more foci for UNC > fix than for CER > fix, and in the corresponding hemispheres. In this, the two analyses agree.

The middle frontal gyrus also shows an activation focus, but in the contrast analysis there seems to be no difference between UNC > fix and CER > fix. It may be that the voxel-based analysis uncovered an additional difference that was not visible in the contrast analysis. The DLPFC, which was previously discussed in context with uncertainty processing (Broche-Pérez et al., 2016; Carter & van Veen, 2007), is located within the middle frontal gyrus (Mylius et al., 2013). This result is therefore in agreement with previous literature.

According to the t-tests, there is a significantly different amount of voxel in the middle occipital gyrus, an area which does not show up in the contrast analysis at all. The implications of this are unclear. One could, however, view this in light of the reentry model, which describes neuronal interaction across reciprocal axonal connection between different functional areas of the brain (Edelman & Gally, 2013). Occurrence of this recurrent processing in the visual cortex has been shown to be an important basis of visual awareness (Boehler, Schoenfeld, Heinze, & Hopf, 2008). With that in mind, a possible interpretation of increased occipital activity in UNC would be a heightened visual awareness, triggered by an increased attention due to the detected conflict.

Lastly, there is the inferior frontal gyrus. In the contrast analysis, there is an activation focus in that region, but only for CER > fix. It is therefore puzzling that the tests here indicate a higher activity in UNC > fix in that region. At present, no explanation for this incongruence can be given.

8.3. fMRI Discussion - Concluding Remarks

Both the results of the contrast analysis and those of the individual voxel-based analysis point in a similar direction.

Uncertain decision making seems to involve frontal areas of the brain to a larger degree than certain decision making. Multiple areas have been found in the analyses, including the MCC and the expected ACC - in the contrast and voxel-based analysis, respectively. The two approaches found different, yet mostly conforming results. This

indicates that both have different strengths and potentially blind spots and an fMRI analysis can thus profit from using both.

However, despite the differences that were found, the comparisons with the low-level baseline revealed a widely overlapping fronto-parietal network of areas involved in both certain and uncertain decision making. This network becomes active during any type of decision making, but resolving uncertain situations seems to require a greater amount of cognitive resources, especially in frontal areas.

In summary of the aspects addressed above, the value of the QDM approach becomes apparent. Using quasi-realistic scenarios and stimuli it was possible to both validate the results of previous research which used abstract stimuli and at the same time broaden the understanding of the processing of decision making as a network of perceptual and conceptual areas.

9. EEG

9.1. EEG-Recording

The EEG-signal was recorded with 64 silver chloride electrodes distributed over the scalp according to the international 10-20 system, and using a 136 channel electroencephalograph (Refa 136; TMS-International; sampling rate 512 Hz). A high-chloride electrolyte gel was used to lower impedances below 10 kΩ.

The data was recorded by the program eemagine (eemagine Medical Imaging Solutions, Berlin, version 3.3) and was set to average reference. An electrode on the left cheek was used as ground and electrooculogram (EOG)-electrodes were placed above and below the right eye (vertical EOG) and between the eye and the temple on both sides (horizontal EOG).

9.2. EEG Analysis

First, the data was preprocessed using BESA Research (version 6.0; Gräfelfing; Germany). To improve the quality of the data the automatic blink correction was applied and a notch filter of 50 Hz was used, which erased the interference of the commercial power supply. Additionally, a high pass filter of 0.1 Hz was used to filter slow drifts from the data.

Furthermore, particularly noisy channels were interpolated. No more than seven channels were interpolated that way per data set and it was taken care never to interpolate a group of spatially adjacent channels.

Individually selected trials were used to construct the new categories UNC (Uncertainty, containing an individual number of uncertain trials) and CER (Certainty, containing a corresponding number of certain trials). For an explanation of the method with which the trials were selected, see section 6.5; 'Individual trial selection'.

9.2.1. ERP Analysis

After the trials for both conditions were selected, an analysis of Event Related Potentials (ERPs) was conducted, with three separate aspects:

(1.1) A stimulus locked ERP for the presentation of the forecast with a time frame of 1000 ms, spanning the first second of the forecast presentation [n = 19]. 100 ms of the presentation of the fixation dot before the forecast were used as baseline.
(1.2) A stimulus locked ERP for the presentation of the sky-picture with a time frame of 1000ms (from the start of the fade-in until 800ms after the presentation) [n = 21] . There was no fixation dot anywhere close to the stimulus, so 100 ms of the presentation of the forecast had to be used as baseline.
(1.3) A response locked ERP with a time frame of 1000ms before the response and 10ms after [n = 21]. As with the second analysis, no standard baseline was possible, so 100 ms of the fade-out of the sky-picture, following immediately after the response, were used as a baseline.
The same methods were applied to each ERP analysis. First, BESA was used to average the data for each participant and for both conditions (uncertain and certain) separately. During the averaging process the automatic artifact rejection tool was used to reject any trial with an amplitude of ≥ 120 µV or a gradient of ≥ 50 µV. Some participants had fewer than 20 acceptable trials in one or both conditions based on these parameters, in which case they were excluded from further analysis, which is the reason for the varying group sizes. The resulting groups had no significant difference in age.
After that the data was exported and R was used for further analysis.

To check for a P300 component at central and frontal-central electrodes, the average waveforms were plotted for the electrodes Cz, FCz, and Fz, each for UNC and CER respectively and including the standard deviation.

As an explorative analysis, the mean voltage (in µV) across all participants and at each electrode and time point was calculated for both UNC and CER, and plots of these voltages were created. Additionally, the voltage for each electrode in each time point was compared between CER and the UNC using a paired t-test (alpha = 0.05). If a test's result was significant, the difference between the voltages was noted. A plot of these differences was created to enable a simple overview of the significant voltage

differences. After that, topographies of the mean voltages across the scalp were created using BESA, for the time point(s) where the predominant pattern of the ERPs was shown most clearly.

This process was done for all three ERP analyses separately.

9.2.1.1. ERP Analysis Results

The waveforms for the three ERP-analyses (stimulus locked on the forecast, stimulus locked on the sky-picture, and response locked) can be seen in figures 22 to 24, respectively.

The results of the three explorative ERP-analyses (stimulus locked on the forecast, stimulus locked on the sky-picture, and response locked) are shown in figures 25, 27, and 29, respectively. The differences found between UNC and CER in each analysis are shown in figures 26, 28, and 30.

The topographies for the stimulus-locked ERPs are displayed in figure 31 (A for forecast; B for sky-picture) and for the response-locked ERP in figure 32 (A and B).

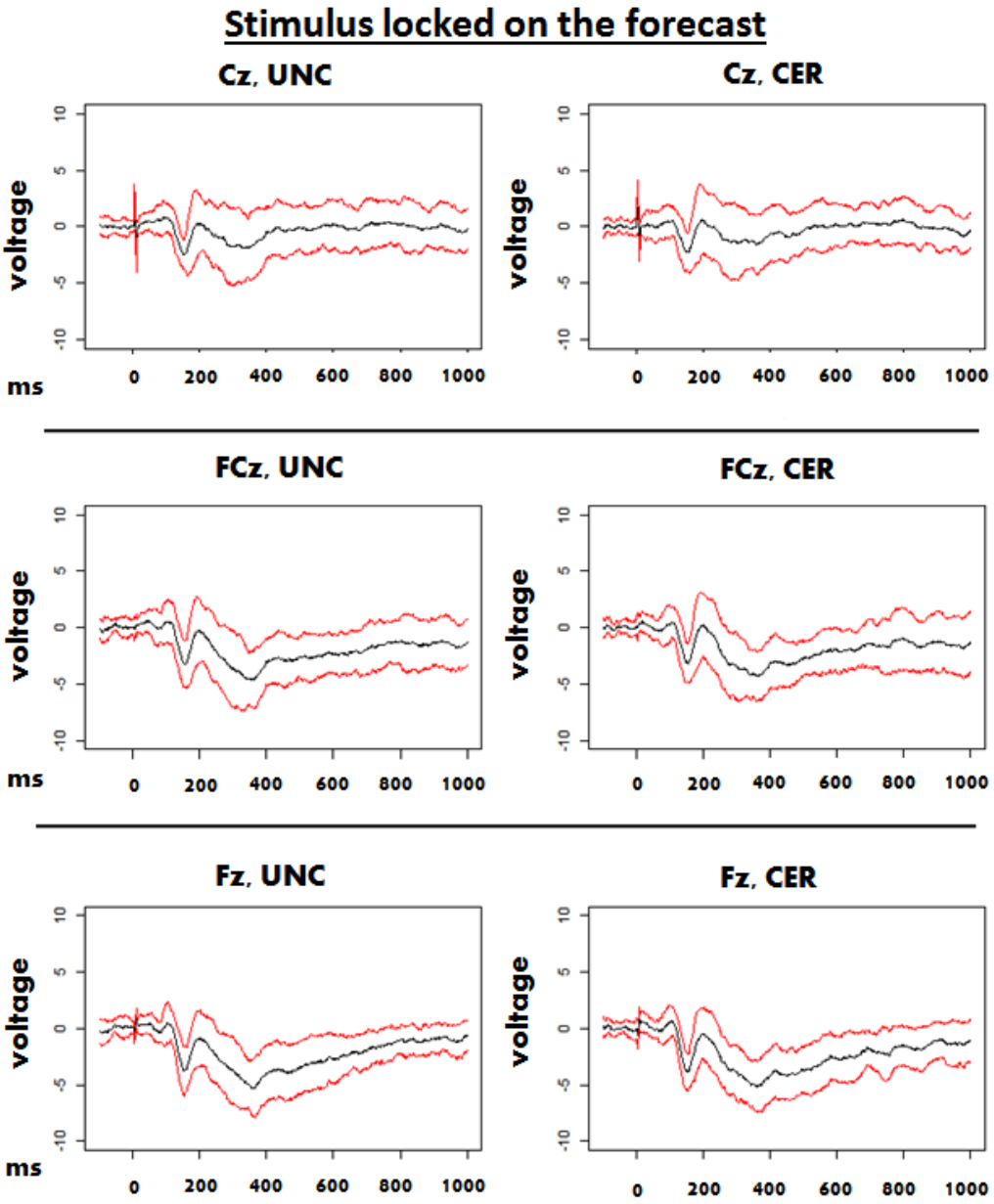

Fig. 22: Waveform plots for the chosen central and frontal-central electrodes of the first stimulus locked (forecast) ERP analysis, for both UNC and CER conditions. The black lines show the voltage (y-axis), while the red lines denote the standard deviation around those values. The x-axis contains the time in ms, from the moment of presentation (0) until the end of presentation 1000 ms later.

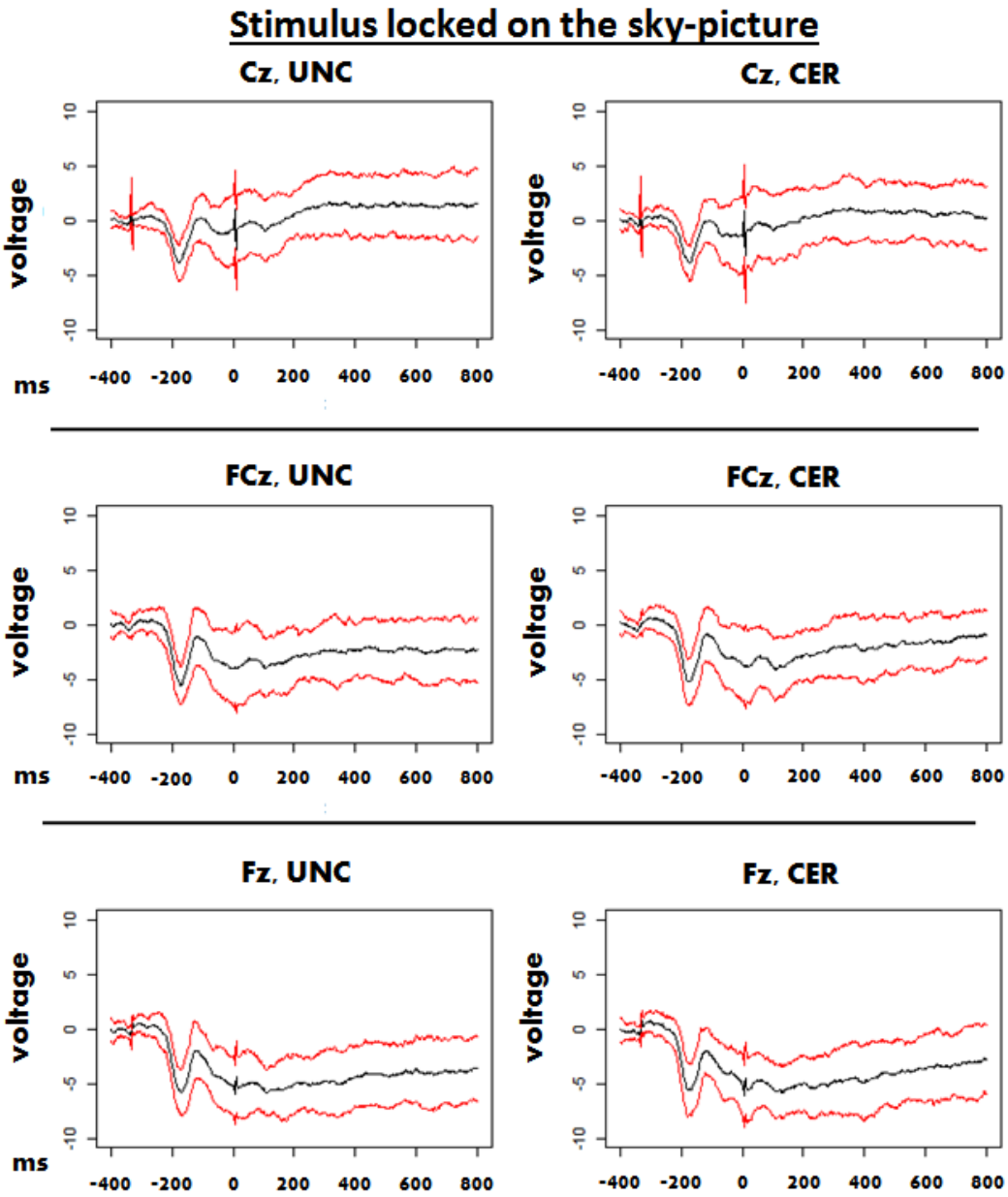

Fig. 23: Waveform plots for the chosen central and frontal-central electrodes of the second stimulus locked (sky-picture) ERP, for both UNC and CER conditions. The black lines show the voltage (y-axis), while the red lines denote the standard deviation around those values. The x-axis contains the time in ms, from 200 ms before complete presentation (covering much of the fade-in), over the moment when the fade-in was complete (0), and up to 800 ms after that.

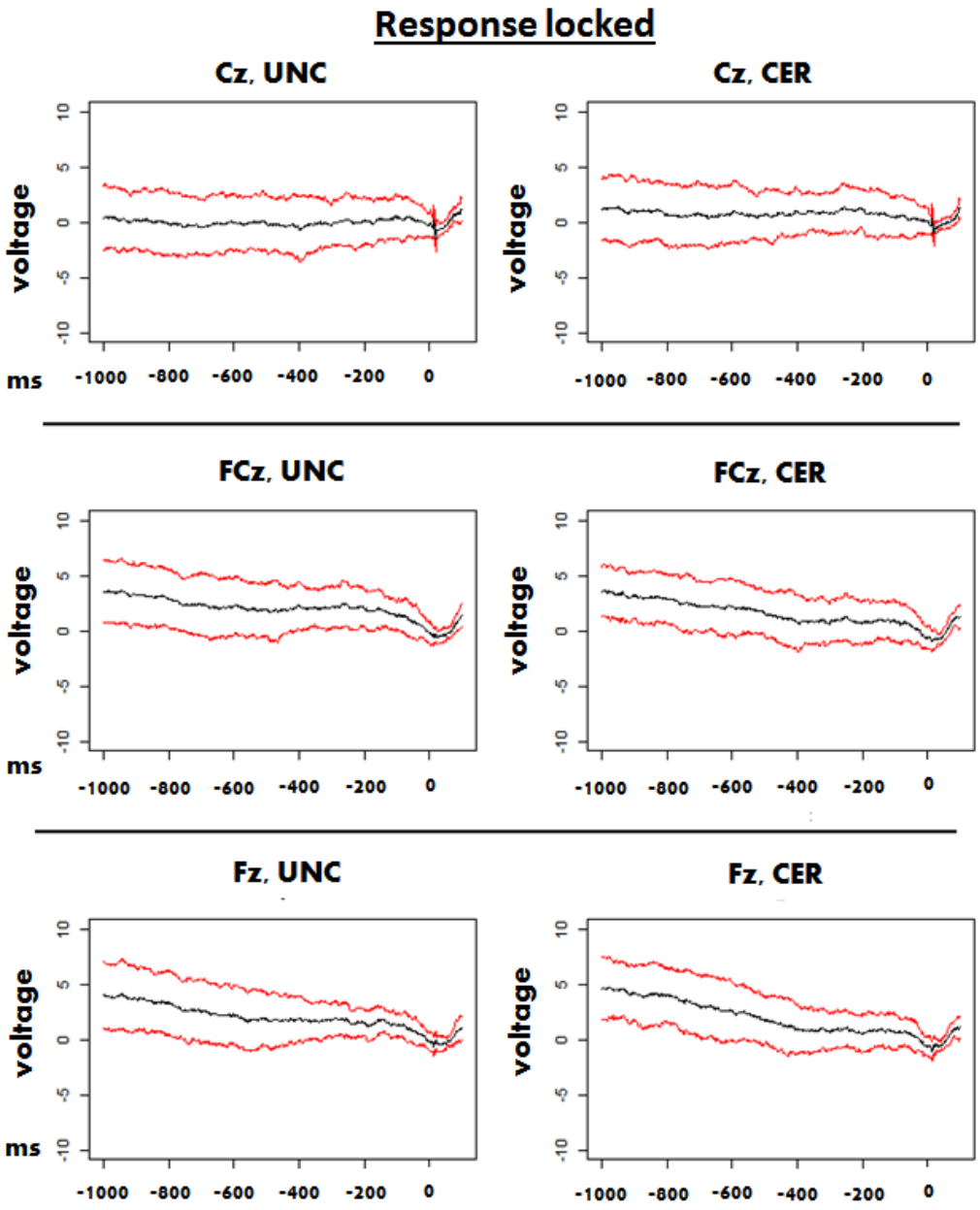

Fig. 24: Waveform plots for the chosen central and frontal-central electrodes of the response locked ERP analysis, for both UNC and CER conditions. The black lines show the voltage (y-axis), while the red lines denote the standard deviation around those values. The x-axis contains the time in ms, from the moment of response (0) 1000 ms second back.

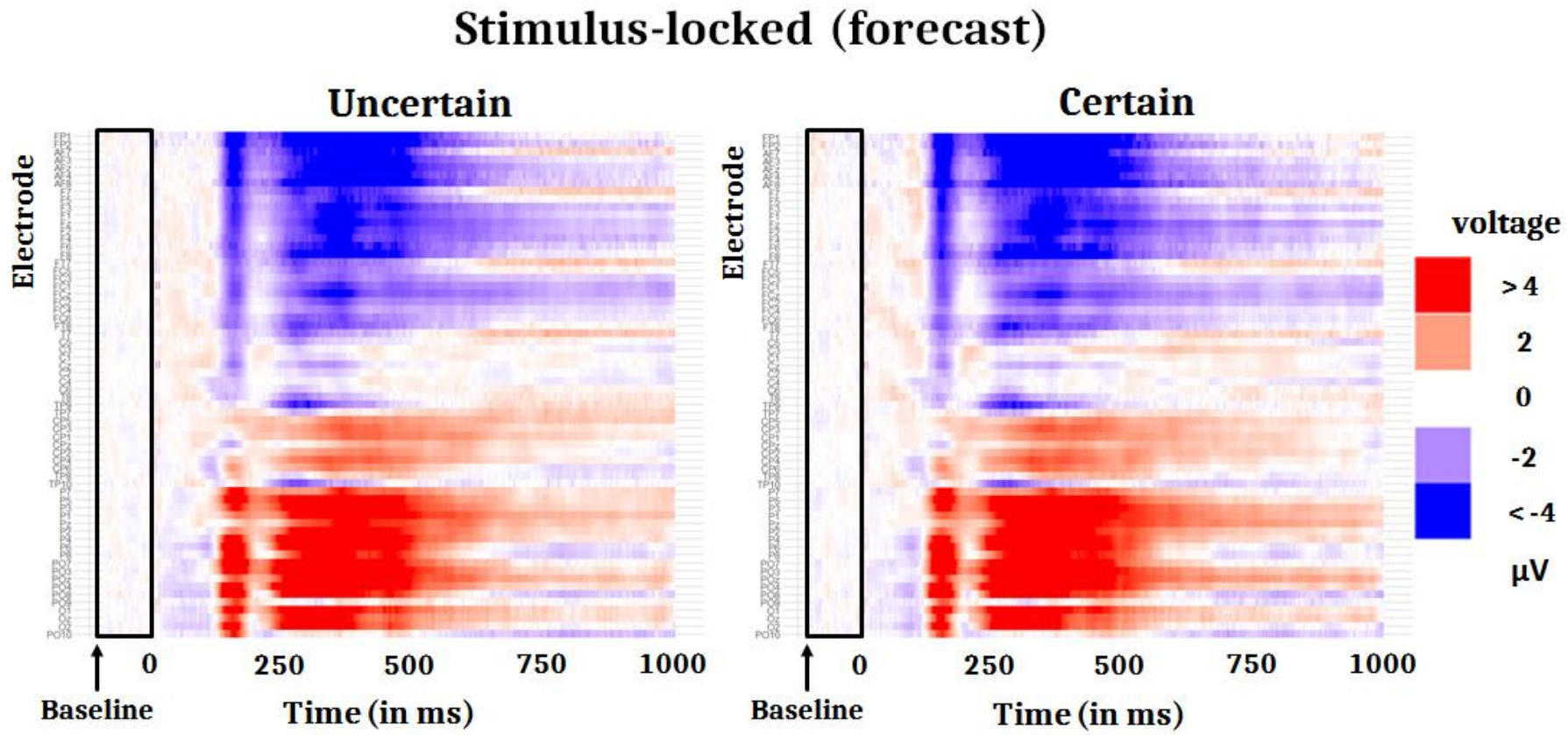

Fig. 25: Mean results of the first stimulus locked ERP analysis, locked on the presentation of the forecast. The mean voltage across participants at each electrode and time point is shown, for both uncertain and certain trials. The electrodes (y-axis) are ordered from frontal over central, temporal, and parietal to occipital. The x-axis shows the time in ms, from the moment of presentation (0) until 1000 ms later.

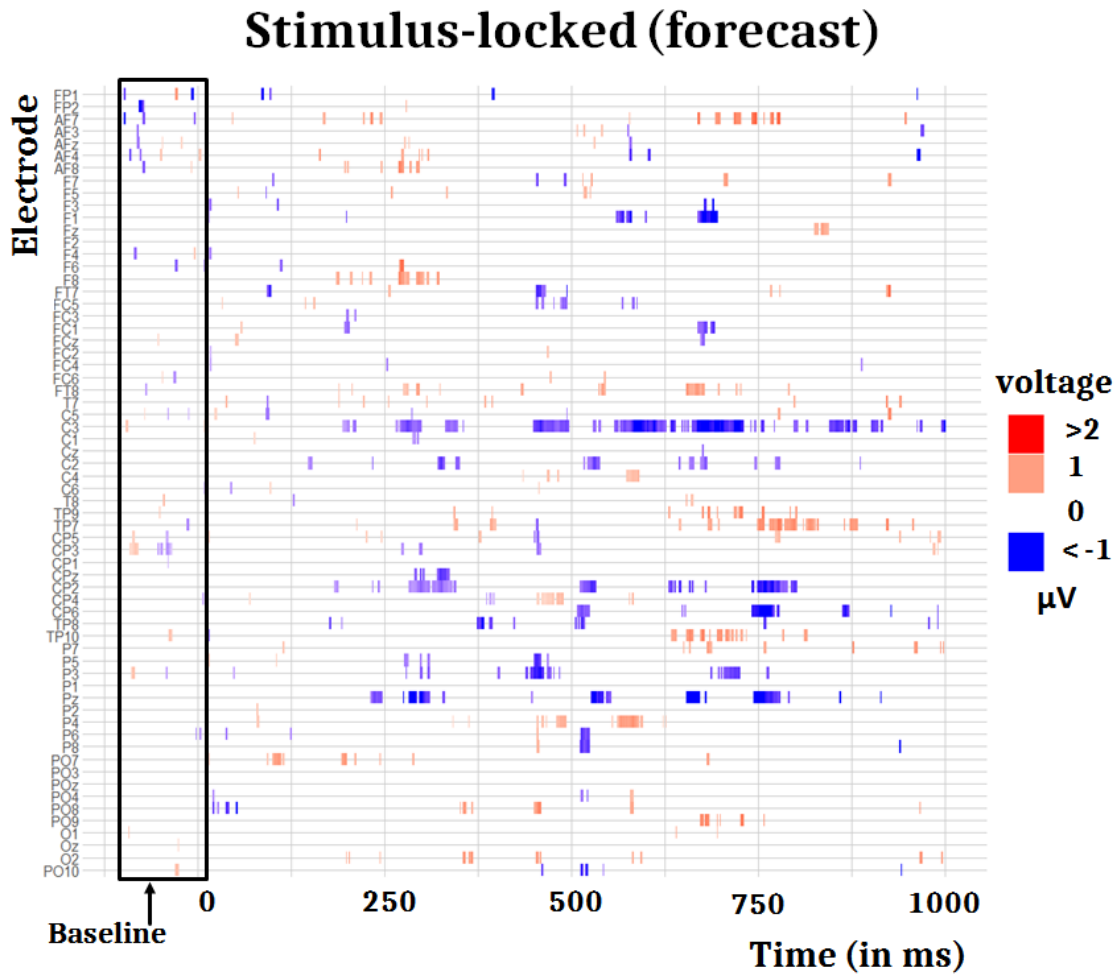

Fig. 26: Overview of the differences found in the first stimulus locked ERP analysis, locked on the presentation of the forecast. Only significant voltage differences between UNC and CER are shown, and the scale is adjusted for UNC (positive values denote relatively higher voltage at the given time and given electrode for UNC than for CER, and vice versa). The electrodes (y-axis) are ordered from frontal over central, temporal, and parietal to occipital. The x-axis shows the time in ms, from the moment of presentation (0) until 1000 ms later.

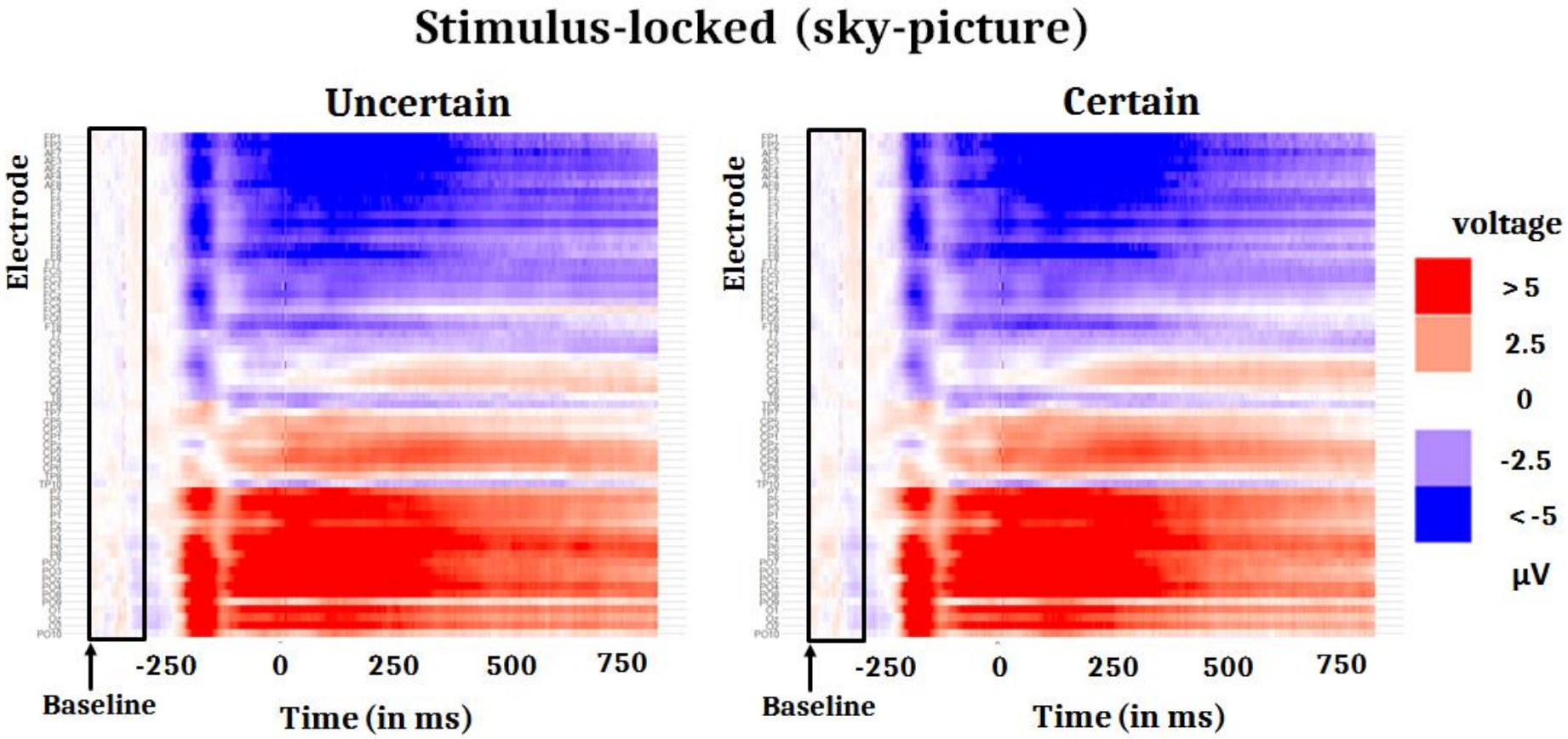

Fig. 27: Mean results of the second stimulus locked ERP analysis, locked on the presentation of the sky-picture. The mean voltage across participants at each electrode and time point is shown, for both uncertain and certain trials. The electrodes (y-axis) are ordered from frontal over central, temporal, and parietal to occipital. The x-axis shows the time in ms, from 400 ms before complete presentation (covering the fade-in), over the moment when the fade-in was complete (0), and up to 800 ms after that.

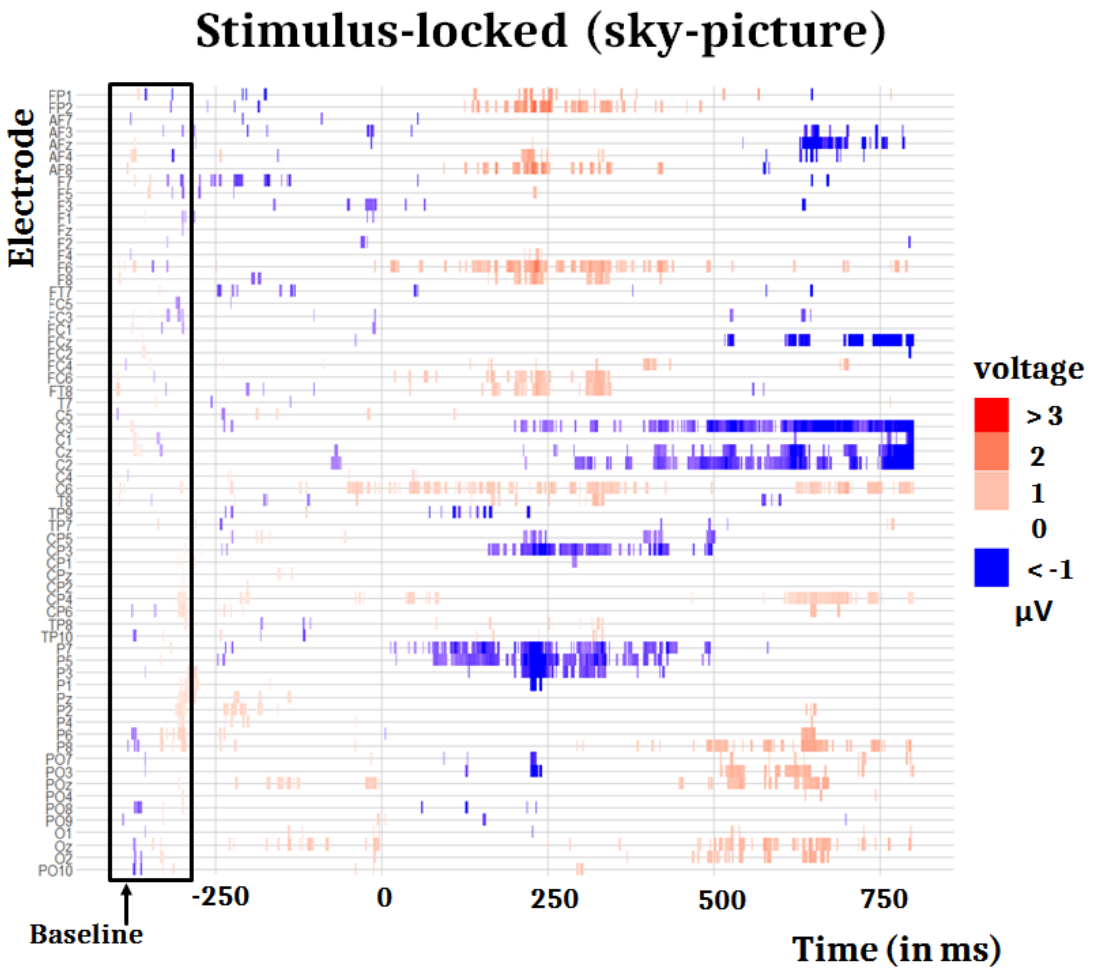

Fig. 28: Overview of the differences found in the second stimulus locked ERP analysis, locked on the presentation of the sky-picture. Only significant voltage differences between UNC and CER are shown, and the scale is adjusted for UNC (positive values denote relatively higher voltage at the given time and given electrode for UNC than for CER, and vice versa). The electrodes (y-axis) are ordered from frontal over central, temporal, and parietal to occipital. The x-axis shows the time in ms, from 400 ms before complete presentation (covering the fade-in), over the moment when the fade-in was complete (0), and up to 800 ms after that.

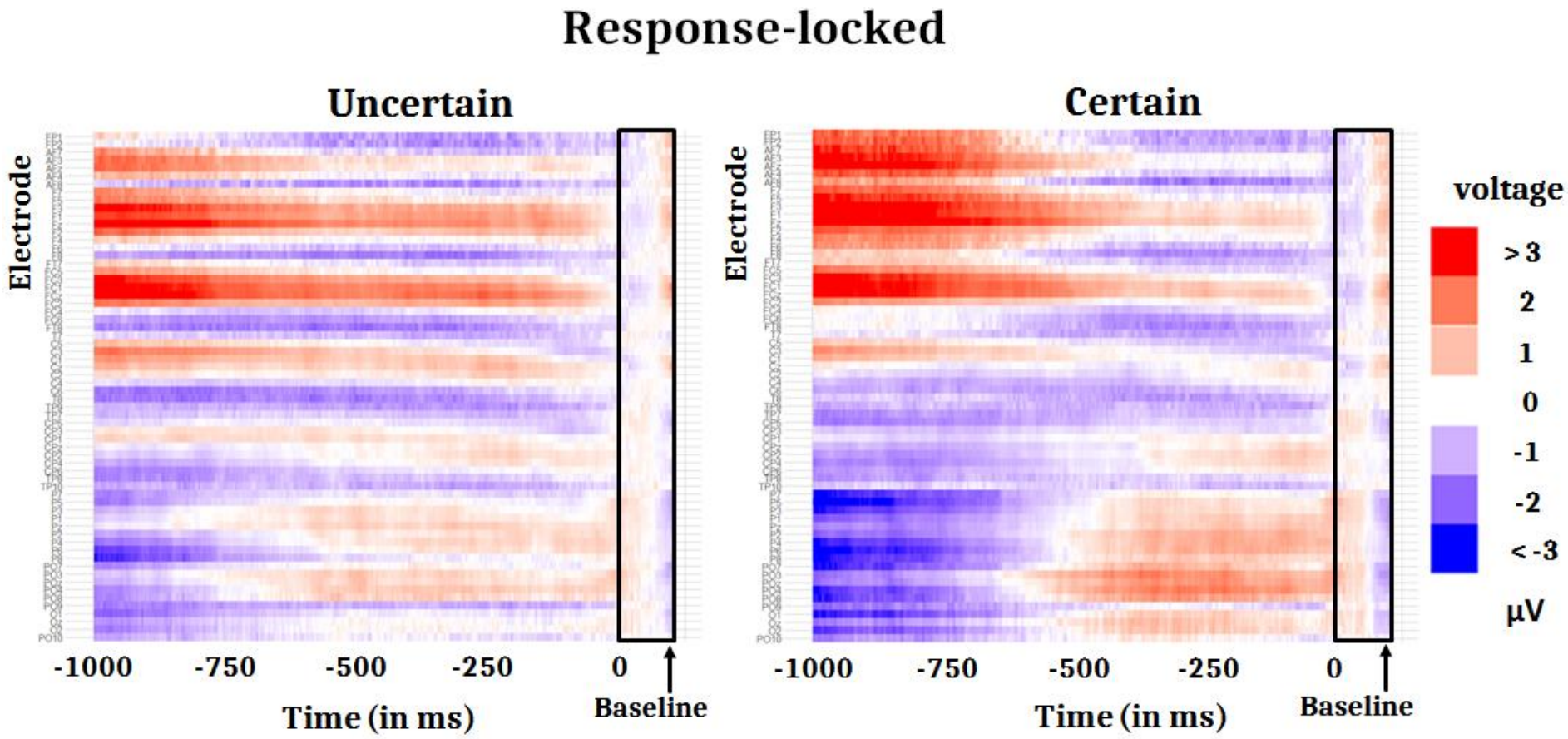

Fig. 29: Mean results of the response locked ERP analysis. The mean voltage across participants at each electrode and time point is shown, for both uncertain and certain trials. The electrodes (y-axis) are ordered from frontal over central, temporal, and parietal to occipital. The x-axis shows the time in ms, from the moment of response (0) 1000 ms second back.

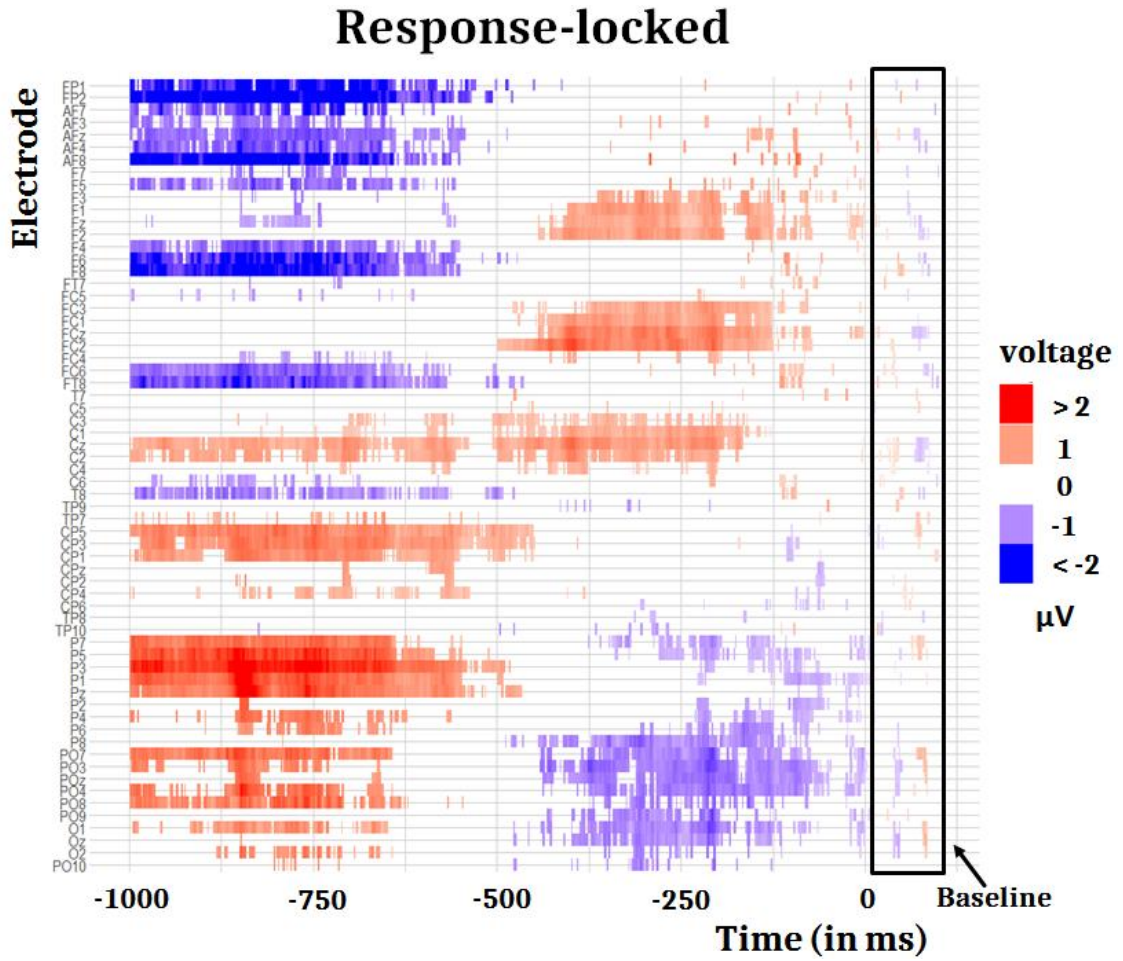

Fig. 30: Overview of the differences found in the response locked ERP analysis. Only significant voltage differences between UNC and CER are shown, and the scale is adjusted for UNC (positive values denote relatively higher voltage at the given time and given electrode for UNC than for CER, and vice versa). The electrodes (y-axis) are ordered from frontal over central, temporal, and parietal to occipital. The x-axis shows the time in ms, from the moment of response (0) 1000 ms second back.

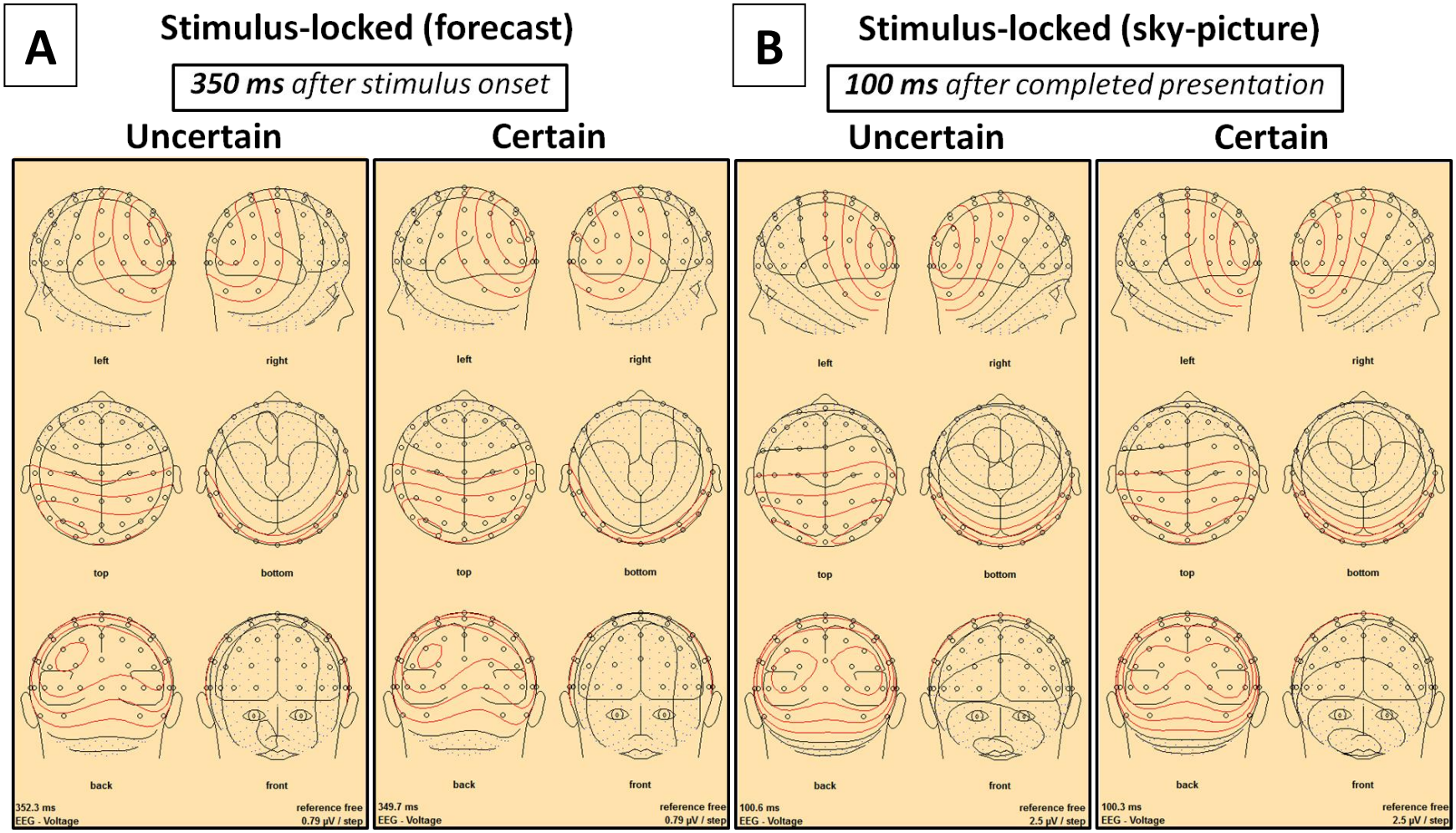

Fig. 31: Topographies for the forecast-locked (figure A) and sky-picture-locked (figure B) explorative ERP analysis.

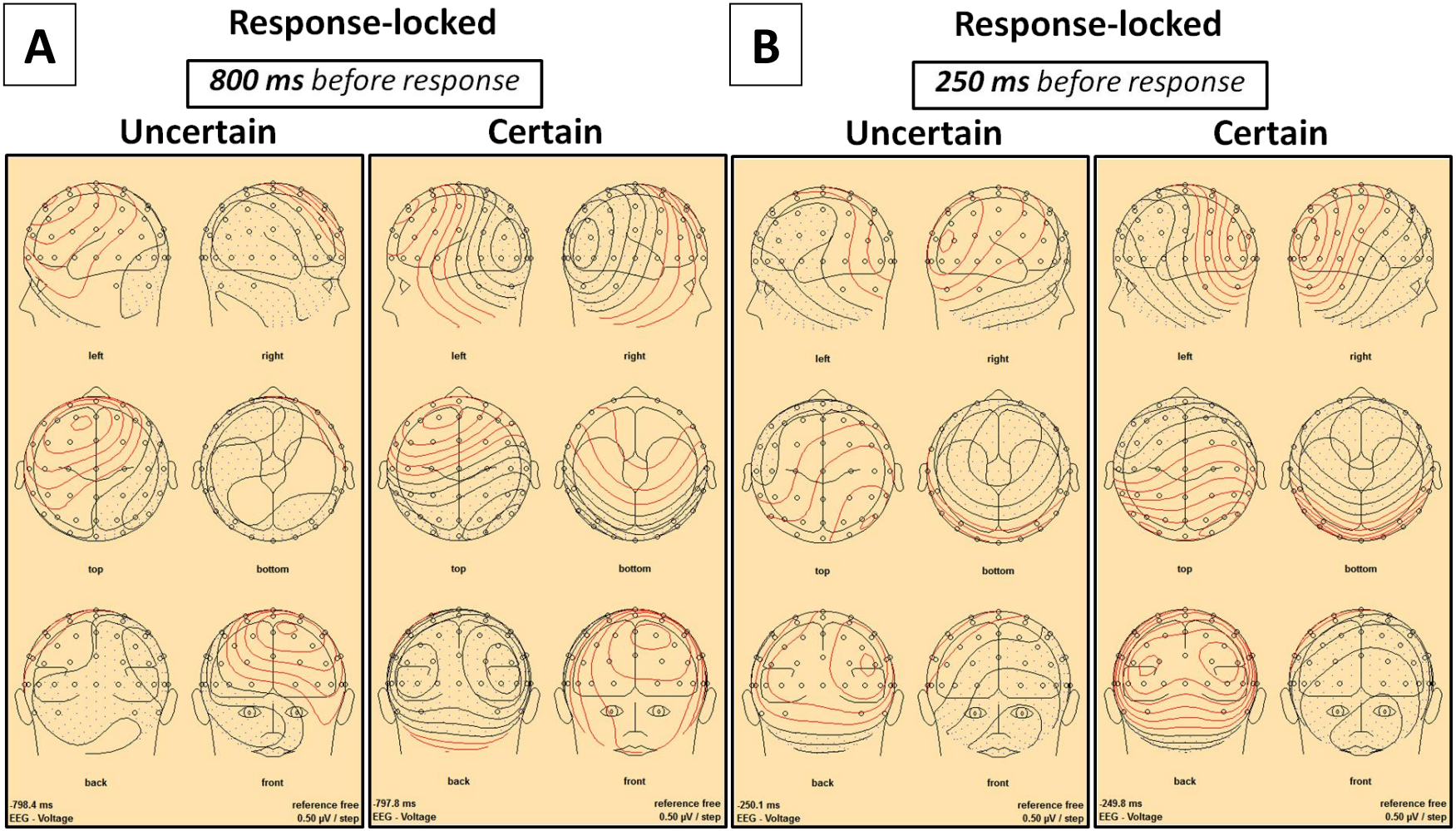

Fig. 32: Topographies for the response locked explorative ERP analysis, showing the topography during the first pattern (800 ms before response; figure A) and the second pattern (250 ms before response; figure B).

9.2.1.2. ERP Analysis Discussion

When interpreting the results of the ERP analysis one aspect of the limitations mentioned in section 7 ('Limitations of the Experiment') has to be taken into account especially: The variations and distortions in time, since ERP analyses are inherently sensitive to variations in the timing of the investigated processes. Therefore, the interpretability of the results is limited because of the fact that participants may make their decisions at different points in the trials, due to different response times between UNC and CER (~300ms), due to different strategies, and due to the jitter in the length of the sky-picture's fade-in.

Additionally, the lack of a proper baseline for the sky-picture locked and the response locked analysis complicate the analysis further. The baselines for both analyses were chosen in the hopes that there would be little difference between UNC and CER in those time frames. As the results of the ERP analysis show, this goal was reached; Only a small number of significant differences appear in the baselines, and those are not sustained over a period of time longer than a few milliseconds. However, the waveforms for the selected electrodes show fluctuations of voltage during the baselines, which limits their usefulness in those cases.

In hypothesis 3 it was stated that uncertain and certain decision making should lead to differences in ERPs, especially the P300 at frontal-central and central electrodes, but further differences were to be explored. No P300 could be found in any of the three analyses, at any of the inspected electrodes.

In the first stimulus locked ERP analysis (locked on the forecast) there is a positive deflection around 200 ms after start of the stimulus fade-in. It is impossible to say whether the participants were able to properly realize the nature of the stimulus at the start of the fade-in, meaning one can't know whether this deflection signifies processing of the decision situation or was simply a reaction to the presentation of the fade-in itself. In any case, no electrode showed a significant difference between UNC and CER during that deflection. A similar case can be observed for the second stimulus locked ERP analysis (locked on the presentation of the sky-picture), which shows a P300-like positive deflection 100 ms before the full presentation of the

stimulus, placing it roughly 250 ms after the start of the fade-in. Again, no electrode showed a significant difference in the time in question.

In the first stimulus locked (forecast) explorative ERP analysis rather similar patterns can be seen for UNC and CER: For the first 100 ms there is barely any difference from the baseline. At around 150 ms after the start of the presentation there is a strong frontal negative deflection and an equally pronounced central, parietal, and occipital positive deflection. The frontal negativity could be the anterior component of the visual N1 (Smit, Posthuma, Boomsma, & De Geus, 2007), which reflects perceptual processing and expert recognition (Woodman, 2010). The N1 is also visible in the waveform-plots.

After that, there is a short period of return towards the baseline, and then, between 250 and 750 ms, the same pattern as described before can be observed. These later deflections likely reflect more complex cognition, involving attention and working memory (Woodman, 2010).

This similarity of UNC and CER is reflected in the difference plot as well. The t-tests returned some significant differences, but scattered across the 1000 ms time frame and across many electrodes. Only the C3 shows sustained significant differences between ~500 and ~700 ms, due to a positive deflection in CER which was not present in UNC. Generally, There seem to be only minor differences in an overall identical pattern. The topographies largely confirm this similarity.

The second stimulus locked (sky-picture) ERP analysis also shows an anterior N1 component, as visible in the waveforms and the explorative analysis. The component peaks roughly at 150 ms after the sky-picture fade-in starts. The same interpretations as described for the FC-locked analysis also apply.

The explorative sky-locked analysis shows a mostly similar pattern between UNC and CER. Again, this similarity is reinforced by the topographies. Both UNC and CER feature a frontal and fronto-central negativity and a centro-parietal, parietal, and occipital positivity. The same pattern is sustained for most of the epoch, with the most extreme values between -100 and 500 ms around the completed presentation of the

sky-picture. The tests for differences between UNC and CER show a period of sustained significant differences around 250 ms after the completion of the fade-in, beginning roughly at 100 ms and ending roughly at 400 ms. Several frontal and some central electrodes (FP1, FP2, AF8, F6, FC6, FT8, C6) show a significantly more positive voltage in uncertain trials. On the other hand, the electrodes CP5, P7, P5, and P3 show a relatively more negative voltage during uncertainty. The electrodes C3 and C2 also show sustained significant negative differences, but for a timeframe of ~250 to 750 ms after fade-in. That being said, the mean voltage plots show that the direction of the differences never aligns with the true voltages at those electrodes and time points; In all cases the deflections into the positive/ negative are present in both UNC and CER, but more pronounced for CER, leading to the differences showing the opposite direction since they are calibrated for UNC.

Seeing as the deflections start more than 100 ms after the start of the fade-in, they are attributable to endogenous ERPs, reflecting conscious processing of the stimuli, rather than exogenous ERP, which reflect automatic stimulus processing (see Sur & Sinha, 2009).

In terms of the temporal sequence of decision making this stimulus-locked analysis can be attributed to the assessment of the situation. As explained above, to NDM this phase is the key moment for decision making.

Considering the multiple cognitive processes that may take place during this time of the trial in uncertain situations, the differences may be related to detecting inconsistencies in stimulus qualities, integrating contradicting information, or applying a given behavioral rule to a more complex situation.

However, one possible explanation of the more pronounced positive and negative deflections for CER could be a smaller variability. This is in regards to the mental processes of the participants, which may be more similar in dealing with certain than with uncertain situations, but especially in regards to the response times. Uncertain decisions showed a longer response time with a higher standard deviation (sd = 336.1 for UNC vs. sd = 226.3 for CER). The time sensitive decision making processes may therefore have been more out of phase in UNC, leading to smaller values in the mean voltages.

Interestingly, both stimulus locked ERP analyses show almost the same pattern of frontal and fronto-central negativity and a centro-parietal, parietal, and occipital positivity. Both start showing this pattern roughly 150 ms after the fade-in of the respective stimulus began, followed by a short return to baseline, and then a prolonged display of the pattern. Based on these regularities, one might come to assume that this distribution is characteristic for processing of stimuli, specifically stimuli which contain uncertain information necessary for decision making. Of course, it may also be connected to the fade-in, which both stimuli shared as well.

The mean voltages of the response locked explorational ERP analysis show largely similar yet in detail distinct voltage distributions for UNC and CER. The early part of the mean voltages is most perplexing, because this part overlaps temporally (on average) with the sky-picture locked analysis, which showed a different pattern of mean voltage. At present, no concrete cause for this could be found. It could be assumed that the separate baseline corrections had an effect, or that differences in accepted trials and participants due to separate artifact rejection caused some changes.

The difference plot of the response-locked analysis revealed large stretches of significant differences between the response locked ERPs of UNC and CER. Those differences were consistent across time and a large number of electrodes, leading to confidence in the statistical reliability of the results. Many frontal electrodes show a more positive voltage in UNC than in CER across ca. 500ms directly before the decision, while parietal and occipital electrodes show more negative voltages in UNC than in CER. Around 500ms before the decision this pattern shifts; The time from -600 ms to -1000 ms shows the reverse pattern. Referring back to the mean voltages, it becomes apparent that almost all of these differences can be traced back to more pronounced deflections (positive and negative) for CER. Only the more positive voltages for UNC in the time frame of 500 ms before the response are due to a more pronounced positive deflection in UNC compared to CER.

Another systematic difference between UNC and CER becomes apparent when one considers the topographies (It is present in the mean voltage plots as well, but more easily spotted in the topographies): In UNC, there is a more pronounced difference between the left and right hemisphere. To some degree, there is some asymmetry in CER as well, but much less pronounced. However, 250 ms before the response, both the topographies of CER and UNC match in the negative deflections above the left motor cortex. This could reflect a lateralized readiness potential (see Vaughan, Costa, & Ritter, 1968), seeing as the response was given with the right hand in all cases.

The interpretation of the response-locked ERP will focus on the later pattern, shown in the 500 ms directly before the response. That is due to the fact that the cognitive activity of the participants can be expected to be more synchronized close to the response, and because less influence of stimulus perception can be expected in that time frame. The ERPs found here should be almost exclusively endogenous (see Sur & Sinha, 2009), since the last stimulus onset has been, on average, more than 500 ms before.

In terms of the temporal sequence of decision making this response-locked analysis can be attributed to the execution of decisions. As explained previously, to NDM this phase is less important than the assessment of the situation, which happens earlier.

The difference during this execution-phase is thus difficult to interpret. Immediately before the decision, the processing of the stimuli and the integration of unclear or contradicting information should have been completed. Only the selection of one option and execution of said selection should take place during this time (see for temporal structure of decision making Ernst & Paulus, 2005). A difference between uncertain and certain decision making during that timeframe was thus unexpected. One could assume that this difference originates in a lingering feeling of uncertainty or insecurity during execution of the decision. Following this line of thinking one would have to assume that the participants never really resolved the feeling of uncertainty, and instead only came to a decision despite that uncertainty. Another possibility would be that the initial assumption was wrong and the uncertain elements of the decision are indeed resolved immediately before the response.

Overall, the patterns of mean voltages were generally similar between UNC and CER. Only very minor differences could be found in the stimulus-locked analyses. The response-locked analysis showed more differences, but nonetheless similar patterns. Given the explorational character of these analyses, the present work will refrain from undue interpretation. Future work can base their hypotheses on the differences found here. Furthermore, in future experiments it could be interesting to test the effect external variables have on the ERPs, for example by means of correlation analyses.

9.2.2. Frequency Analysis

After the ERP analysis, a frequency analysis was performed for two time frames: (1) A stimulus locked time frame of 1 second starting at the fade-in of the sky-picture and (2) A response locked time frame of 1 second before the participants made their decisions.

Both frequency analyses were performed in the same manner. The target sections of data were exported for both CER and UNC respectively and a mean fast Fourier transform (FFT) was used to transform the data from the time- to the frequency domain. It was then divided into 17 frequency bands (in Hertz: delta 1-3; theta 4-7; alpha low 8-10; alpha high 11-13; beta low 14-22; beta high 23-30; gamma1 31-36; gamma2 37-42; gamma3 43-48; gamma4 52-57; gamma5 58-63; gamma6 64-69; gamma7 70-75; gamma8 76-81; gamma9 82-87; gamma10 88-93; gamma11 94-100). The global power was calculated for each of these bands, relative to the total power in all bands. Then the average of this relative global power was calculated for each participant over all trials. The resulting values were compared between UNC and CER, using a dependant t-test (alpha = 0.05) and were correlated with the Neo-FFI scales, the d2-'KL'-value, the Additional Questionnaire, the response times, the PI, the UI and the TI.

9.2.2.1. Frequency Analysis Results

In the following, the results of the two frequency analyses will be presented.

Of the dependant t-test for differences of the relative global power in each band between UNC and CER, two were significant. For the analysis locked on the sky-picture, there was a higher relative power in the theta band for UNC than for CER (t =

2.5, $p < 0.05$). For the analysis locked on the response, there was a higher relative power in the alpha-low band for UNC compared to CER ($t = 2.7$, $p < 0.05$).

Table 11 shows the results of the correlation analyses for the relative global power in each frequency band and the external variables.

Table 11: Correlations between the relative global power in each band and the external variables. Listed is the Pearson correlation coefficient (r), but only for significant correlations, all others are marked as n.s. (not significant). Positive correlations are highlighted in blue and negative ones in red. For the content of the RaB-2 questions, see appendix E (additional questionnaire).

	sky-picture locked; CER																
	d	t	a-l	a-h	b-l	b-h	g 1	g 2	g 3	g 4	g 5	g 6	g 7	g 8	g 9	g 10	g 11
UI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
PI	n.s.	n.s.	n.s.	-0.45	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.48	0.44	n.s.	0.48	n.s.
TI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Response Time	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.44	n.s.	-0.46
Neo: Neuroticism	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Openness	n.s.	n.s.	n.s.	n.s.	0.5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Agreeableness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscientiousness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 7	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 9	n.s.	n.s.	n.s.	-0.46	-0.45	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 11	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 14	n.s.	n.s.	n.s.	-0.42	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

RaB2: Question 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 16	n.s.	n.s.	-0.42	-0.45	-0.44	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 17	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 18	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 19	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	sky-picture locked; UNC																
	d	**t**	**a-l**	**a-h**	**b-l**	**b-h**	**g 1**	**g 2**	**g 3**	**g 4**	**g 5**	**g 6**	**g 7**	**g 8**	**g 9**	**g 10**	**g 11**
UI	n.s.	0.43	n.s.	n.s.	n.s.	n.s.	n.s.	-0.45	-0.49	-0.46	-0.47	-0.47	-0.49	-0.47	n.s.	n.s.	n.s.
PI	n.s.	n.s.	n.s.	-0.45	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Response Time	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.43	-0.45	n.s.	n.s.	n.s.
Neo: Neuroticism	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Openness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Agreeableness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscientiousness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.43	-0.42	-0.43	-0.42	n.s.	n.s.	n.s.
RaB2: Question 7	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 9	n.s.	n.s.	n.s.	n.s.	-0.43	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 11	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

RaB2: Question 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 14	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 16	n.s.	n.s.	-0.43	-0.48	-0.42	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 17	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 18	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 19	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	response locked; CER																
	d	**t**	**a-l**	**a-h**	**b-l**	**b-h**	**g 1**	**g 2**	**g 3**	**g 4**	**g 5**	**g 6**	**g 7**	**g 8**	**g 9**	**g 10**	**g 11**
UI	0.44	0.45	n.s.	n.s.	n.s.	n.s.	n.s.	-0.47	-0.57	-0.5	-0.51	-0.58	-0.62	-0.58	-0.56	-0.56	-0.55
PI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TI	n.s.	n.s.	n.s.	-0.57	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Response Time	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Neuroticism	n.s.	n.s.	0.48	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Openness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Agreeableness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscientiousness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.43	-0.44	-0.42	-0.43	-0.45	-0.45
RaB2: Question 7	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.43	-0.44
RaB2: Question 8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

RaB2: Question 9	n.s.	n.s.	n.s.	n.s.	-0.47	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 11	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 14	n.s.	n.s.	n.s.	-0.55	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 16	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 17	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 18	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 19	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	response locked; UNC																
	d	**t**	**a-l**	**a-h**	**b-l**	**b-h**	**g 1**	**g 2**	**g 3**	**g 4**	**g 5**	**g 6**	**g 7**	**g 8**	**g 9**	**g 10**	**g 11**
UI	0.48	0.43	n.s.	n.s.	n.s.	n.s.	n.s.	-0.56	-0.62	-0.6	-0.58	-0.63	-0.65	-0.62	-0.6	-0.59	-0.59
PI	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TI	n.s.	n.s.	n.s.	-0.5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Response Time	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.42	-0.44	-0.44
Neo: Neuroticism	n.s.	n.s.	0.45	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Extraversion	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Openness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Agreeableness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Neo: Conscientiousness	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
d2: KL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

RaB2: Question 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 7	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 9	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 10	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 11	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 12	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 14	n.s.	n.s.	-0.41	-0.6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 15	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 16	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 17	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 18	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 19	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RaB2: Question 20	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

9.2.2.2. Frequency Analysis Discussion

In hypothesis 2.1 it was postulated that uncertain decision situations ought to show a higher relative power in the delta frequency band than certain situations. No such global difference in delta power was found, neither in the response-locked nor in the stimulus-locked frequency analysis.

Instead there was a significantly higher global power in the alpha-low band for the response-locked analysis and a higher global power in the theta band for the stimulus-locked analysis, both for UNC compared to CER. Curiously, the results of the two analyses differ, even though, with a time frame of 1 second each and an average response time of ~1 second, their time frames overlap for an average of 800ms.

Activity in the alpha band has been inversely connected to attention, meaning that relatively less alpha was observed during phases of higher attention in participants (Knyazev, 2007). This connection would be counterintuitive for the present data, since it would imply lower attention during uncertain trials. At the same time, alpha has been connected to working memory (Başar et al., 1999; Knyazev, 2007). It is conceivable that during decision making in uncertain trials the working memory load was higher, leading to relatively more alpha-low. The higher working memory load could be explained with the RPD; In uncertain situations the prototypical situation does not apply perfectly, so adaptations have to be made. This process would require working memory resources.

Theta, on the other hand, has been connected to cognitive processing (Başar et al., 1999) and working memory (Sauseng, Griesmayr, Freunberger, & Klimesch, 2010). Therefore, a higher theta response could be due to the higher cognitive load during uncertain trials compared to certain ones. Additionally, theta was also identified as an important component in emotional regulation, be it positive or negative emotion (Knyazev, 2007). Uncertain situations may have been perceived as more negative, since the uncertainty hinders decision making, causing the relatively higher theta.

Regarding the correlations of the relative global power values with the external variables, there is one that is most noticeable: The correlation between the UI and a number of bands. In three of the four analyses there is the trend of a positive

correlation between the UI and slow wave components (delta and theta) and a negative correlation between the UI and fast wave components (the upper gamma bands). The reason for this pattern is difficult to pin down because of the previously mentioned unclear nature of the UI. That parameter's lack of correlation with other variables and its obscure association to actual uncertainty complicates any interpretation. If, however, one was willing to accept the UI as a measure for uncertainty, an explanation for this correlation would present itself. As mentioned previously, slow wave frequencies have been connected to global processing and fast wave components to local processing (Gupta & Chen, 2016; von Stein & Sarnthein, 2000). In line with this argument, it could be assumed that decisions under uncertainty require more integration of large scale cortical networks than those under certainty, leading to a higher relative power in slow wave bands for people who make more uncertain decisions. Decisions under certainty, on the other hand, may be processed locally and thus go in hand with a relatively higher power in fast wave bands.

This interpretation is also in agreement with the overall higher relative theta band power in UNC, as theta has been discussed to be instrumental in cortical integration for the purposes of working memory (Sauseng et al., 2010).

Relating these findings back to the RPD model, it would seem that certain, prototypic situations can be processed by locally limited System 1 networks. Uncertain situations do not fit a prototype perfectly und thus require the integration of larger, more spread out networks due to the analytic and working memory intensive System 2 processes that need to be employed.

9.3. EEG Discussion - Concluding Remarks

Compared to the fMRI analyses, the EEG analyses suffer more directly from the temporal imprecision of the decision making process in this experiment, as already noted in the discussion of the ERP analysis.

As stated in the limitations, the participants could make their decision at any point in time, depending on a variety of reasons, the most notable of which being the trust in either the forecast or the sky-picture. Therefore, no single time point in each trial can

be identified in which a decision has been made. Furthermore, each moment in which a decision may have been made also contains other processes, like stimulus processing or integration of information. In many cases, these processes can be assumed to vary with uncertain or certain decision making.

The fMRI analyses were affected only marginally by this, because the trial was considered as a whole. The EEG analyses, on the other hand, used segments of the trials for analysis. This causes the facts stated above to become a problem, because no interpretation for either the ERP or the frequency analysis can be given with confidence, if the cognitive processes at each time point are in doubt.

Future studies should attempt to avoid these problems as much as possible, or adapt their analyses, to be able to make proper use of the high temporal resolution the EEG is capable of. For example, single-trial analyses could be used to adapt the analysis for temporal variations between trials and participants.

10. Excursus: Successor experiment

During the analysis of the data gleaned from experiment described so far, a number of limitations and shortcomings were noticed (see section 7; 'Limitations of the Experiment'). Based on those, several possible improvements of the experimental design were considered (see section 7.1; 'Potential Improvements'). Some of those suggestions were included in a secondary behavioral experiment (referred to here as the successor experiment). This experiment produced some results that shed light on questions left open by the previous version, and shall therefore be outlined here roughly.

10.1. Methods

The general task and overall design of the successor experiment was the same as that of the previous experiment, albeit with the following changes:

- Both the sky-picture and the forecast were presented equally, for one second, including a fade-in and a fade-out (see figure 33 for an overview of the successor experiment's trial structure).
- The sequence of forecast and sky-picture stimuli was balanced. Each trial was presented three times with the forecast and three times with the sky-picture as first stimulus.
- Additional trial elements were introduced. A screen showing a scale was added after presentation of the stimuli. The participants were instructed to weight the two pieces of information and make their decision during this part. As soon as they had, they were supposed to press a button with their left hand. Then, a black screen with a question mark was shown, during which the participants were supposed to execute their decision with button press using their right hand (as before: index finger = NO, middle finger = YES).
- The duration of the fixation dot was reduced.

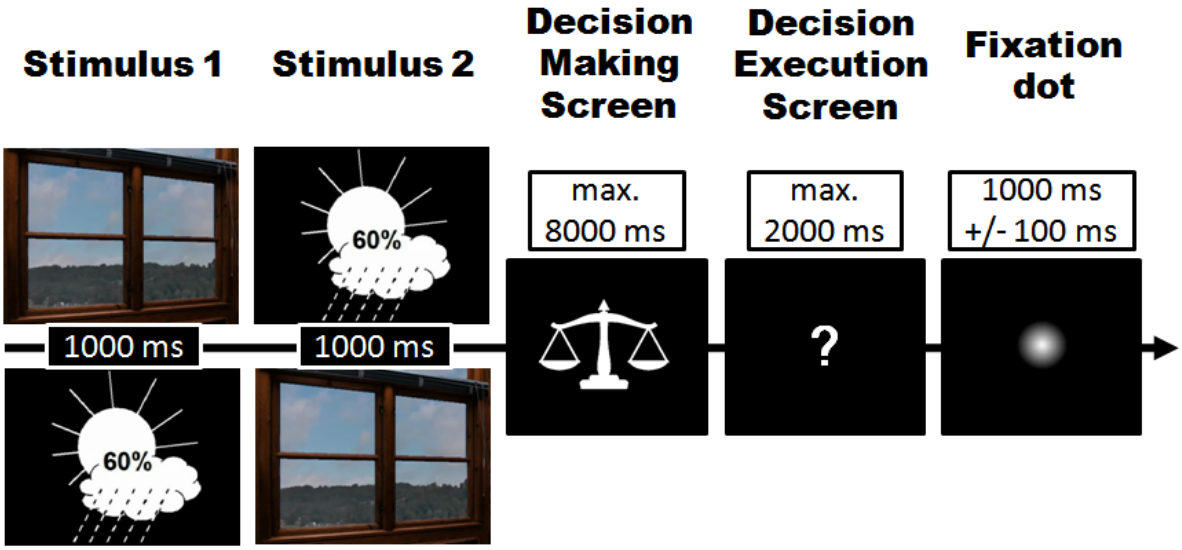

Fig. 33: Visualization of the successor experiment's trial structure. Stimulus 1 and 2 were either in the upper or in the lower sequence. Both the decision making screen and the decision execution screen were displayed for the depicted time, or until a response was given by the participant.

- The amount of sky-pictures was decreased to nine. This reduction allowed each trial to be presented six times (three times for each sequence of stimuli) adding to a total number of 270 trials.
- The stimulus space was reduced to five ninths of its potential (see figure 34). Three sections of 3x3 possible trials each were unused.
- An evaluation of un/certainty was added. To get more information about each individual's uncertainty, each trial was shown again, after the experiment. The participants were instructed to rate how much uncertainty each particular trial evokes, on a scale from 1 (high uncertainty) to 8 (low uncertainty).

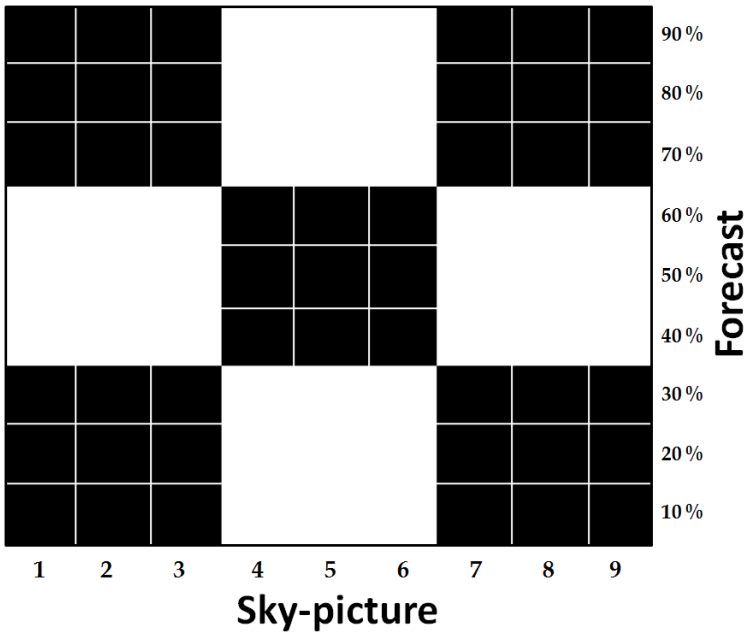

Fig. 34: Visualization of the stimulus space in the successor experiment. Only the stimulus combinations shown in black were included into the experiment's trials. Conversely, the white cells denote unused stimulus combinations.

24 participants were tested with this design. All were healthy female students of the University of Bremen with an age between 18 and 30, inclusively (mean age = 22.8 years, sd = 3.24 years). All participants were naive to the experiment or similar experiments and gave their written informed consent.

Two participants were excluded from the analysis due to a misunderstanding of the instructions, leaving 22 participants [n = 22] for all analyses.

10.2. Analysis

The analysis was performed using the free statistical software R (R Development Core Team, 2017).

To obtain an overview of the participants' decision strategies, the BSPs were plotted. Additionally, the evaluation of certainty and uncertainty were also plotted in the manner of a BSP, to easily compare each evaluation with the participant's behavior. In order to test the match between evaluation and decision behavior statistically, the evaluations and decisions were pooled for each unique trial and for each participant.

The evaluations were then summed, so that a high value denotes low uncertainty (= certainty), while a low value denotes high uncertainty. The decisions were used as categorization: If all six or five were NO the trial was counted as a certain NO-trial (CER-NO), if all six or five were YES the trial was counted as a certain YES-trial (CER-YES), everything in between was counted as uncertain trials (UNC). An ANOVA for repeated measurements was performed to find significant differences in the evaluation based on the categories constructed from the participants' decisions.

Response times were defined as the time between the presentation of the decision making screen (the scales) and the button press indicating the participants had made their decision.

The behavioral parameters UI and PI were calculated for this experiment as well, using the same methods as described previously; the TI was not calculated since the empty areas in the stimulus space impaired its calculation.

A dependant t-test was then performed for the response times, the UI and the PI respectively, to test for differences between the two stimulus sequences (forecast first or sky-picture first).

10.3. Results

Showing all BSPs and BSP-styled decision evaluation results would take up more space than can be justified by the information they provide. Therefore, three participant's graphs were chosen to illustrate possible types of agreement or disagreement between the two results (see figure 35).

The participant shown in the first line had a very clear rule during the experiment, taking the umbrella along every time when the forecast was at 70 percent or higher, and never when it was lower. No uncertainty at all was shown in the decisions, and with an absolute rule like that one would not expect the participant to feel uncertainty either. However, in the evaluation the participant assigned high values of uncertainty to the middle section of the stimulus space and the two section with contradicting information (upper left and lower right). There is, thus, a mismatch between the participant's evaluation and their own choices during the experiment.

The participant shown in the second line followed a less absolute rule. The umbrella was taken along if the forecast was at or higher than 70%, but also if it was lower and combined with a more cloudy sky. Therefore, some uncertainty would be expected in the middle section of the stimulus space. However, while the evaluation does show some uncertainty there, the participant rated the contradicting sections as most uncertain, despite the fact that her own rule seemed to have clear, certain answers for those decisions. The match between the behavior and the evaluation is therefore mediocre for this participant.

The participant shown in the third and last line seemed to have followed a mixed strategy, where an umbrella was taken along with certainty if both sources of information agreed on a high chance of rain. Additionally, it was also taken along if one source predicted a particularly high probability, even if the other disagreed. Thus, the participant shows uncertainty in the middle section and the two contradicting sections of the stimulus space. Exactly those are the sections the participant assigned high values of uncertainty to in the evaluation. As such, the match between the decisions in the experimental situations and the evaluation of said situations is good for this participant.

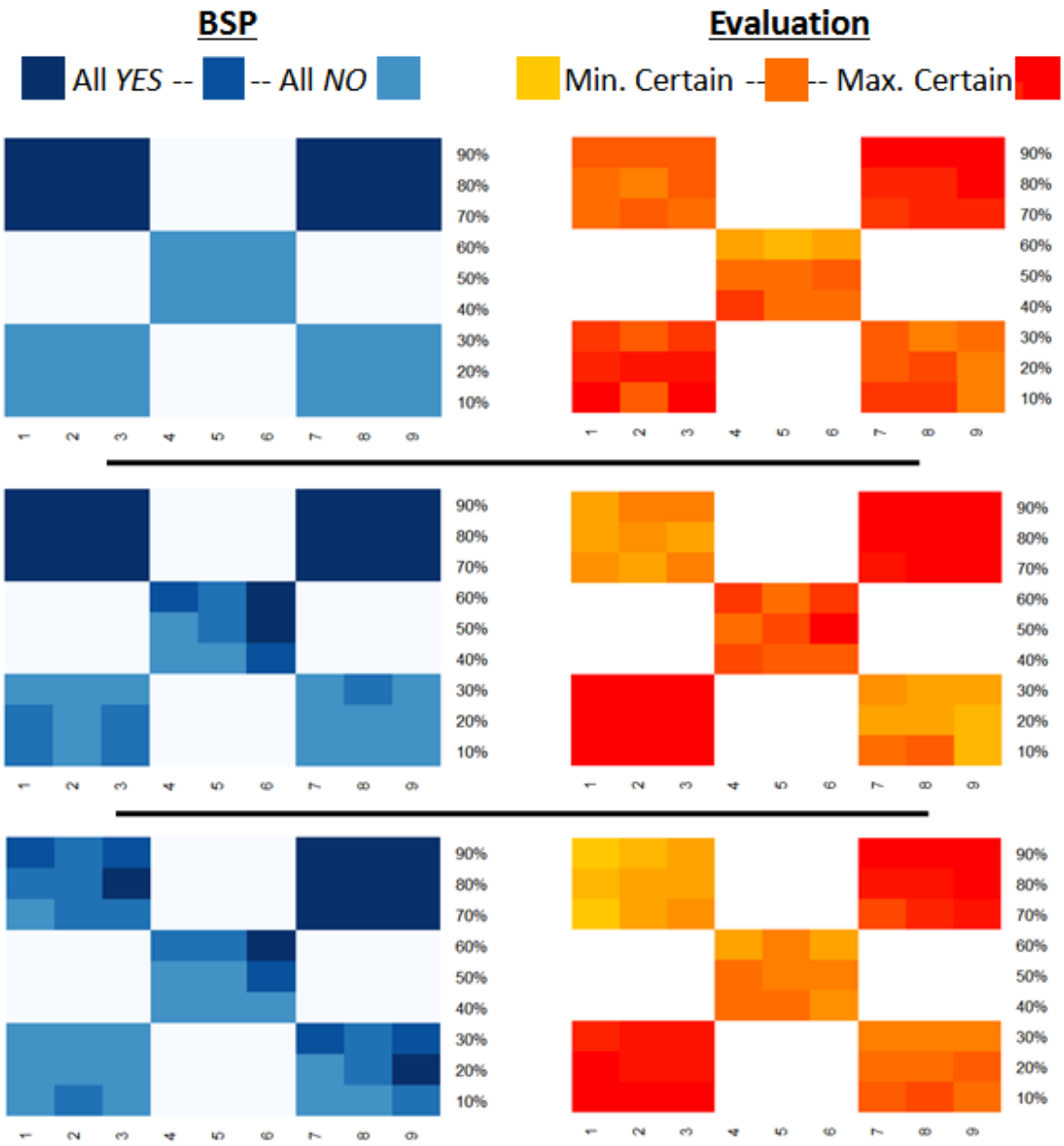

Fig. 35: Each line shows the BSP (left) and the BSP-styled evaluation of certainty (right) for one participant. On the x-axis there are the nine sky-pictures (from bright and blue to dark and cloudy) and on the y-axis the nine forecasts (from 10% to 90%). These three participants were chosen as an example of a poor (1st), mediocre (2nd) and good (3rd) fit between the behavior in the experiment and the post-hoc evaluation.

The ANOVA testing for differences in the certainty/ uncertainty evaluation between the different categories of decisions (CER-YES, UNC, CER-NO) was significant ($F = 8.08$, $p < 0.01$; see figure 36 for box-plots of the results). Post hoc t-tests revealed a significant difference between UNC and CER-YES ($p < 0.01$) and between UNC and CER-NO ($p < 0.001$). The trials, in which inconsistent decisions were made were rated as more uncertain in the evaluation than the others.

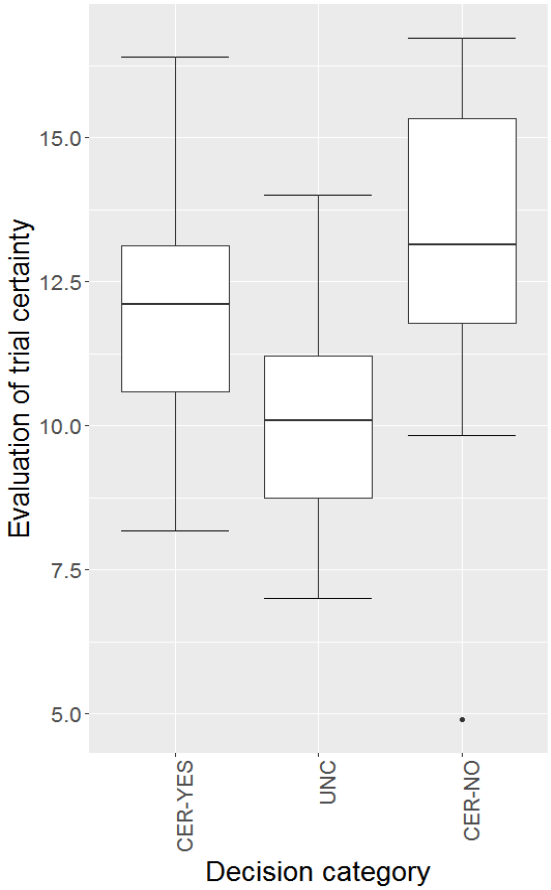

Fig. 36: Box-plots showing the evaluation of trials (y-axis), separated into groups based on the decisions made for the corresponding trials within the experiment (x-axis). A high value on the y-axis corresponds to low perceived uncertainty (= certainty), a low value to high perceived uncertainty.

Of the dependant t-test for effects of the stimulus sequence on the response times ($t = 0.10$, $p > 0.05$), the PI ($t = 0.16$, $p > 0.05$) and UI ($t = 1.17$, $p > 0.05$) none were significant.

10.4. Discussion

The most direct conclusion that can be drawn from the results presented previously is that the stimulus sequence does not have a noticeable effect on any of the behavioral indicators. This means that one problem of the main experiment, namely the lack of balancing of stimulus sequence, may not be as severe as could have been possible. Yet, it is still preferable to balance the stimuli, to avoid any number of sequence

effects that are potentially invisible to the behavioral analyses performed in the successor experiment.

Secondly, there is the matter of the uncertainty evaluation of each trial. The evaluations given by the participants were significantly lower (more uncertain) for inconsistent trials compared to both types of consistent ones, suggesting that the decisions made in the experiments are, on average, reflected by the evaluation. However, as the exemplary BSPs and evaluation-BSPs shown in figure 33 illustrate, there were several participants for whom the two did not overlap well. This may be due to a multitude of reasons; For example, the participants may have had a different understanding of 'uncertainty' when they were asked to evaluate the trials in that regard. As such, they may have rated objective uncertainty, even though their individual, subjective rules excluded uncertainty completely (see the first participant in the figure). On the other hand, the evaluation may reflect their actual feeling of uncertainty, even though their decision profile made it seem like there was none.
As a bottom line, it can be said that the direct evaluation of uncertainty by the participants can be a useful additional tool for categorizing trials, which may be more reliable than the decision profile alone. But it is not a perfect tool by itself, and should be combined with careful and clear instructions and a comprehensive strategy interview.

As a side note, it shall be mentioned that the technical problems of video-time-lag did not appear in the successor experiment. The videos of the forecast and sky-picture were supposed to take 1 second to present; The means of the presentation time were 1.083 s (sd = 0.050) for the forecast and 1.047 s (sd = 0.048) for the sky-picture.

In summary, the successor experiment was a meaningful variation on the previous experiment and gave some additional insight into its characteristics and possible future additions and corrections.

Regrettably, some major changes (like the addition of the decision making screen as a new trial element and the reduction of the stimulus space) made it difficult to draw further inferences from the successor experiment for the original experiment.

11. Conclusion and Outlook

In conclusion, this study has shed some light on the neural processing of certain and uncertain decision making in quasi-realistic scenarios, but even more on the vast complexity of this field of research.

The design and analysis process allowed participants to utilize individual decision strategies, as they would in a real life context. This is one of the core goals any QDM design must strive towards. As such, the present study serves as a stepping stone for following studies, which may base their experimental design and analysis strategies on the experiences made here. Utilizing an improved version of the design presented in this study, in combination with the method of analysis for individual trial selection and the numerical parameters for aspects of decision strategies, neuroscience can approach realistic designs by another small step.

For future research it might be interesting to explore different aspects or variations of the present design. Of course, the most immediate goal would be to create a variation that incorporates all improvements suggested in section 7.1. After that has been tested, different routes would be conceivable.

One might, on the one hand, conduct that new experiment with different cohorts. Where this study focused on women of high education between 18 and 30 years, another study could focus on a different socio-demographic group.

On the other hand, the design could be adapted to allow investigation of different questions. Adding a feedback after the decision, for example, could be used to research the influence of feedback on individual decision strategies.

Yet another option would be to use the same design with a different real life context and, thus, different realistic stimuli. Of course, it would have to be another context in which participants have already gathered expertise through repeated decisions combined with feedback.

In terms of analyses, a stronger focus on individually different neural activation could be beneficial. Studies have shown that neural processing can differ based on the strategy employed by the participants, even intra-individually and for the same task (Fehr, Wallace, Erhard, & Herrmann, 2011; Houde et al., 2000). A task such as the one

presented in this thesis, which allows for individual strategies to be used, would therefore benefit from analyses which can detect and quantify (Fehr & Milz, 2019) the possibly resulting neuronal differences. The behavioral indicators mentioned and developed in this thesis could then serve to differentiate between different groups of strategies, or as a continuous variable for correlative measures. Naturally, the present work would also have benefited from an implementation of such methods of analysis. The lack of such has to be taken into account as a shortcoming of this thesis; utilizing those methods might have produced a more complete picture of quasi-realistic decision making.

Last but not least there is the constant endeavor to simulate real-life decision situations as well as possible in order to approach the criteria set by NDM. As technical improvements are being made for the EEG and fMRI context, it may always become possible to further improve the design in terms of realism.

Such improvements of realism may also enable neuroscientific experiments to make clear statements about decision making in realistic situations. Despite all efforts to that end, the present work was not able to arrive at an accurate assertion about whether or not people use mechanisms akin to the ones predicted by the RPD model in real life decisions. Some results fit potential predictions by the model, but overall the results gathered by both EEG and fMRI show more similarities than differences between UNC and CER, and many expected differences were not found. These results may have been due to an actual similarity of uncertain and certain decision processing, or due to inter- and intra-individual differences that the analyses were not sensitive for (as mentioned above). In the end, however, the lack of differences is inconclusive due to the restrains of the experimental methods that have been discussed at length previously. The situations of uncertainty and certainty may have been too similar within the experiment, prompting similar processing.

Future studies can build on the experiences made here, so that adapted and improved versions of this experiment, in combination with advances in neuroscientific methods, may be able to arrive at a clear statement about complex decision making in real life.

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List of abbreviations

ACC	Anterior Cingulate Cortex
ANOVA	Analysis of Variance
BSP	Behavioral Signature Plot
CDM	Classical Decision Making
DLPFC	Dorsolateral Prefrontal Cortex
EEG	Electroencephalography
EOG	Electrooculogram
ERP	Event Related Potential
fMRI	functional Magnetic Resonance Imaging
Hz	Hertz
MCC	Middle Cingulate Cortex
MNI	Montreal Neurological Institute
NDM	Naturalistic Decision Making
Neo-FFI	Neo Five Factor Inventory
OFC	Orbitofrontal Cortex
PI	Preference Index
QDM	Quasi-Realistic Decision Making
RPD	Recognition- Primed- Decision Model
sd	standard deviation
TI	Trust Index
UI	Uncertainty Index

Appendix A - Information for participants about fMRI experiment

Informationsblatt für Probanden

Sehr geehrte Untersuchungsteilnehmerin, sehr geehrter Untersuchungsteilnehmer,

vielen Dank für Ihr Interesse an einer Studie, bei der die Aktivität im Gehirn unter Ruhe und beim Lösen von Aufgaben untersucht werden soll. Wir möchten Sie zunächst über den Ablauf informieren, um Ihnen einen Überblick über die geplanten Messungen zu ermöglichen und Ihnen das Ziel der Untersuchungen zu erklären.

Die Untersuchungen werden mit einem Magnetresonanztomographen (kurz MRT) durchgeführt, der uns Messungen der Durchblutung im Gehirn schmerzfrei und ohne zusätzliche Gabe von Medikamenten ermöglicht.

Ziele und Ablauf der Untersuchung

In dieser Studie soll die Aktivität des Gehirns während kognitiver Entscheidungsaufgaben bestimmt werden. Die Art der Aufgabe wird Ihnen vor der Messung ausführlich vom Versuchsleiter erklärt. In dieser Studie werden eine Reihe von Situationen präsentiert werden, in denen eine Entweder-Oder Entscheidung getroffen werden soll. Die Entscheidung soll dabei durch einen Tastendruck angezeigt werden.

Insgesamt wird die Messung im MRT-Scanner ca. eine Stunde dauern.

Was ist eine Magnetresonanztomographie?

Im Rahmen der Studie ist eine funktionelle Magnetresonanztomographie des Gehirns vorgesehen. Mit Hilfe dieser Methode ist es möglich, die Durchblutung in Ihrem Gehirn zu messen und daraus Rückschlüsse auf die bei der Aufgabe beteiligten Bereiche zu ziehen. Hierbei treffen Radiowellen, die in dem Magnetfeld erzeugt worden sind, auf den Körper, der Signale zurückschickt. Diese Echosignale werden von speziellen Antennen aufgefangen und in einem Computer ausgewertet.

Ein Kontrastmittel ist **n i c h t** erforderlich. Es werden **k e i n e** Röntgenstrahlen eingesetzt.

Wie läuft die Untersuchung ab?

Vor der Untersuchung werden Sie vom Untersuchungsleiter ausführlich über die für den Tag geplanten Messungen und Ziele informiert. Auch im Verlauf der Untersuchung werden Sie vom Untersucher jederzeit gehört. **Sie haben das Recht, ohne Angabe von Gründen jederzeit die Teilnahme an der Messung abzulehnen bzw. abzubrechen.**

Für die Untersuchung legen Sie sich auf eine Liege, wo Ihr Kopf in einer Kopfspule positioniert wird. Anschließend werden Sie langsam in die Öffnung des Magnetresonanztomographen geschoben. Dort befinden Sie sich während der gesamten Untersuchung. Während der Messungen sind sehr laute Klopfgeräusche zu hören, die völlig normal sind und von den schnell geschalteten Magnetfeldgradienten verursacht werden. Um Ihrem Gehör nicht zu schaden,

müssen Sie einen geeigneten Hörschutz (Ohrstöpsel oder Schallschutz‘hörer') tragen. Für die Qualität der Messungen ist es wichtig, während der Untersuchung möglichst ruhig liegen zu bleiben. Um dies zu erleichtern, werden Kopf, Arme und Beine mit Polstern und anderen Hilfsmitteln schmerzfrei und bequem gelagert. Die Aufgaben, die Sie während der Untersuchung bearbeiten sollen, werden Ihnen über einen an der Kopfspule angebrachten Spiegel oder Kopfhörer dargeboten.

Mögliche Risiken der Methode:

Im Magnet des Magnetresonanztomographen herrscht mit 3Tesla (T) ein Magnetfeld, das in etwa 62.500-mal stärker als das Erdmagnetfeld in Mitteleuropa ist. Dieser Magnet wird nie ausgeschaltet und zieht mit sehr starker Kraft alle magnetischen und magnetisierbaren Gegenständen an, welche in seine Nähe geraten. Die größte Gefahr geht von Unfällen mit solchen Gegenständen aus, die angezogen werden und mit sehr großer Geschwindigkeit in den Magneten fliegen und anschließend an ihm „festkleben“. Deshalb wird mit größter Sorgfalt darauf geachtet, dass keine magnetischen oder magnetisierbaren Gegenstände in die Nähe des Magneten geraten.

Der Magnetresonanztomograph hält alle für die Sicherheit des Betriebes und insbesondere die Sicherheit der Probanden/Patienten erforderlichen Grenzwerte ein. Er wurde vom TÜV einer Sicherheitsprüfung unterzogen und wird darüber hinaus in den vorgeschriebenen Intervallen überprüft. Dennoch müssen folgende Punkte beachtet werden.

1. ***Magnetische und magnetisierbare* Gegenstände *dürfen nicht in den Messraum gelangen.***

   Auf Gegenstände, die Eisen oder Nickel enthalten, wie z.B. Messer, Schraubenzieher, Kugelschreiber, Münzen, Haarspangen, etc., wird im Bereich des Magneten eine starke Anziehungskraft ausgeübt. Dadurch werden die Gegenstände mit großer Geschwindigkeit in den Magneten gezogen und können Personen gegebenenfalls lebensgefährlich verletzten. Metallkörper (Metallplatten etc.) und andere Fremdkörper wie Geschossteile können ebenfalls ferromagnetisch sein und durch magnetische Kräfte ihre Position im Körper verändern, die dann innere Verletzungen hervorrufen.
   Kleine Metallsplitter im Auge können durch magnetische Kräfte bewegt oder gedreht werden und das Auge verletzen.

2. Personen mit Chochlea-Implantaten, Defibrillatoren oder Pumpensystemen dürfen nicht einem starken Magnetfeld ausgesetzt werden, da es auch in diesen Fällen zu Risiken durch magnetische Kräfte kommen kann.

3. ***Personen mit Herzschrittmachern dürfen nicht an Untersuchungen teilnehmen.***
   Herzschrittmacher können im Magnetfeld ihre Funktionsfähigkeit verlieren Zumindest ist es sehr wahrscheinlich, dass diese in einen Grundzustand („Reset“) versetzt werden.

4. Bei der Messung mit dem Magnetresonanztomographen kommt es zur Abstrahlung von hochfrequenter elektromagnetischer Strahlung, wie sie z.B. bei Radiosendern und Funktelefonen auftritt. Dies kann zu einer geringfügigen

Erwärmung des untersuchten Gewebes führen, wird aber sowohl geräte- als auch steuerungstechnisch kontrolliert.

5. ***Bei allen Messungen müssen entweder schallabsorbierende Kopf'hörer' oder Lärmschutzstopfen getragen werden, die wir zur Verfügung stellen.*** Das Schalten der Magnetfeldgradienten führt in Teilen des Gradientensystems zu mechanischen Verformungen, die Geräusche mit Lautstärken über 100 dB erzeugen können. Bei Einhaltung dieser Vorsichtsmaßnahmen kann eine Schädigung des Hörsystems ausgeschlossen werden.

6. Manche Menschen erleben enge Räume als bedrohlich. Sie berichten über Unwohlsein z.B. in Fahrstühlen oder in großen Menschenansammlungen. Obwohl diese Angstgefühle meist über die Anamnese ausgeschlossen werden können, ist ein erstmaliges Auftreten während der Messung im Magnetresonanztomographen möglich. Der Untersucher ist bei der Messung anwesend; bei dem Auftreten von Symptomen kann der Proband über Sprechkontakt bzw. über eine Notklingel jederzeit auf sich aufmerksam machen, so dass eine rasche Intervention bei Symptomen gewährleistet ist.

Zufallsbefunde

Obwohl die Messungen an einem klinisch üblichen Magnetresonanztomographen stattfinden, handelt es sich bei den Messungen **um keine medizinische Untersuchung**. Die Messungen sind daher auch nicht dazu geeignet, pathologische Veränderungen zu entdecken. Auch werden die Daten nicht von fachkundigen Neuroradiologen oder Neurologen begutachtet. Deshalb können keine Rückschlüsse auf den gesundheitlichen Status gezogen werden. Trotzdem besteht die Möglichkeit, dass sich in den aufgezeichneten MRT-Bildern strukturelle Anomalien, sog. Zufallsbefunde, finden lassen. Im Falle eines Zufallsbefundes oder eines Verdachts auf einen Zufallsbefund werden in der Regel repräsentative Bilder einem fachkundigen Arzt vorgelegt, um eine erste Einschätzung einzuholen. Falls der Verdacht auf einen Zufallsbefund weiterhin vorliegt, wird Ihnen die Vorstellung bei einem Facharzt empfohlen. In jedem Fall werden wir Ihnen diese Beobachtung mitteilen.

Ihr Einverständnis dazu ist Voraussetzung dafür, an der Untersuchung teilnehmen zu können.

Appendix B - Information for participants about EEG experiment

Informationsblatt zur Untersuchung mittels EEG

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank für Ihre Bereitschaft, an unserer Studie teilzunehmen, bei der die Aktivität des Gehirnes unter Ruhe und beim Lösen von Aufgaben untersucht werden soll. Mit den folgenden Zeilen möchten wir Ihnen wichtige Informationen über diese Studie geben. Bitte lesen Sie die nachstehenden Informationen sorgfältig durch.

Sie haben das Recht, jederzeit ohne Angabe von Gründen und ohne persönlichen Nachteil die Teilnahme an der Untersuchung abzulehnen oder während der Messung abzubrechen.

Ziel und Ablauf der Untersuchung

Die Studie soll die Aktivität im Gehirn unter Ruhe und beim Treffen von Entscheidungen in Alltagssituationen bestimmen. Die jeweilige Aufgabenstellung wird vom Versuchsleiter vorher ausführlich erklärt. Während der Durchführung der Aufgaben wird die Hirnaktivität gemessen.

Die Untersuchungen werden mit Hilfe der Elektroenzephalographie (kurz EEG) durchgeführt, welche Messungen der Aktivität des Gehirnes ohne Eingriff, schmerzfrei und ohne zusätzliche Gabe von Medikamenten ermöglicht. Vor und nach der Untersuchung können Vorversuche und Fragebögen zum Einsatz kommen, die im Zusammenhang mit der EEG-Untersuchung stehen.

Beschreibung des Messverfahrens

Elektroenzephalogramm (EEG)

Aufgrund der Aktivität der Nervenzellen lässt sich an der Kopfoberfläche fortlaufend eine elektrische Spannung messen –das Elektroenzephalogramm (EEG). Für die EEG-Messung müssen an verschiedenen Stellen des Kopfes Elektroden platziert werden. Die Elektroden bestehen aus Silber/Silberchlorid. Zur Verbesserung der Leitfähigkeit wird eine Paste verwendet, die im Wesentlichen aus Wasser, Kochsalz und Verdickungsmittel besteht. Um zwischen Haut und Elektrode einen hinreichend guten Kontakt herzustellen, werden die Elektroden an einer speziellen Haube, ähnlich einer Badekappe, fixiert.

Ablauf der EEG-Untersuchung

Vor der Untersuchung werden Sie vom Untersuchungsleiter ausführlich über die für den Tag geplanten Messungen und Ziele informiert. Die Untersuchung dauert ungefähr 60 Minuten.

Während der Untersuchung sitzen Sie auf einem Untersuchungsstuhl. Um Störungen der Messung zu vermeiden, findet die Untersuchung in einem eigenen, abgeschirmten und störungsarmen Raum statt. Während der Messung wird ein Mitarbeiter mit im Raum sitzen.

Mögliche Einschränkungen und Risiken der Untersuchungen

Die EEG-Messung ist völlig gefahrlos. Für das EEG werden nur solche Geräte verwendet, die den einschlägigen Sicherheitsbestimmungen genügen. Sie werden in gleicher Form auch für die klinische Routine eingesetzt. Die während der Untersuchung erforderlichen Konzentrationsleistungen können zu einer leichten Ermüdung führen.

Bei dieser Studie handelt es sich nicht um eine medizinische Untersuchung. Daher können aus der EEG-Messung auch keine Informationen über den gesundheitlichen Zustand abgeleitet werden.

Freiwilligkeit der Teilnahme

Sie haben das Recht, jederzeit ohne Angabe von Gründen und ohne persönlichen Nachteil die Teilnahme an der Untersuchung abzulehnen oder während der Messung abzubrechen.

Sollte Sie zur Speicherung der Daten Fragen haben oder andere Auskünfte benötigen, können Sie sich an die folgende Personen wenden:

- PD. Dr. Thorsten Fehr (Tel.: *[OMITTED HERE]*)

- M. Sc. Kilian Gloy (Tel.: *[OMITTED HERE]*)

Appendix C - Statement of Consent fMRI

Einwilligungserklärung

Über Art und Durchführung der geplanten MRT- Untersuchung im Rahmen dieser wissenschaftlichen Studie hat mich Frau / Herr ..... in einem Aufklärungsgespräch ausführlich informiert. Das Informationsblatt für Probanden ist mir ausgehändigt worden. Ich konnte alle mir wichtig erscheinenden Fragen, z.B. über spezielle Risiken und mögliche Komplikationen oder Maßnahmen stellen, die zur Vorbereitung oder während der Untersuchung erforderlich sind. Die mir erteilten Informationen habe ich verstanden.

Ich erkläre mich hiermit bereit, an der im Informationsblatt beschriebenen freiwilligen Untersuchung im Rahmen der oben genannten wissenschaftlichen Studie teilzunehmen und gebe meine Einwilligung, dass bei mir im Rahmen der wissenschaftlichen Studie eine MRT-Untersuchung des Gehirns durchgeführt wird.

Ich erkläre mich damit einverstanden, dass die im Rahmen der Messungen erhobenen Daten in verschlüsselter Form (pseudonymisiert) auf elektronischen Datenträgern gespeichert und verarbeitet werden dürfen. Ich bin auch damit einverstanden, dass die Untersuchungsdaten in anonymer Form, d.h. ohne dass Rückschlüsse auf meine Person gezogen werden können, veröffentlicht werden. Ich habe davon Kenntnis genommen, dass sofort nach Auswertung und Abschluss der Studie – spätestens jedoch Ende 2018, die personenbezogenen Daten gelöscht werden und so keine Zuordnung der erhobenen Untersuchungsdaten zu meiner Person mehr möglich sein wird. Die anonymisierten Untersuchungsdaten werden spätestens zehn Jahre nach Abschluss der Studie vollumfänglich gelöscht.

Ich erkläre mich damit einverstanden, dass die erhobenen persönlichen Daten in einer der Öffentlichkeit nicht zugänglichen Datenbank erfasst werden. Die Speicherung dieser personenbezogenen Daten dient ausschließlich der Zuordnung der pseudonymisierten Untersuchungsergebnisse zu meiner Person für den Fall, dass ich meine Einwilligung zurückziehe und die Löschung der Daten verlange.

Mir ist bekannt, dass es sich bei der magnetresonanztomographischen Untersuchung nicht um eine medizinische Untersuchung handelt und ich daher keine Rückschlüsse auf meinen gesundheitlichen Status ziehen kann. Im Falle eines Zufallsbefundes oder eines Verdachts auf einen Zufallsbefund im Rahmen der MRT-Messung möchte ich informiert werden.

Mir ist bekannt, dass ich meine Einwilligung in die Datenverarbeitung jederzeit und ohne Angabe von Gründen widerrufen kann und die Löschung der Daten verlangen kann.

_____ _____ _____

Ort, Datum Unterschrift Untersuchungsteilnehmer/in Unterschrift Untersucher

Appendix D - Statement of Consent EEG

Einwilligungserklärung

Über Art und Durchführung der geplanten EEG- Untersuchung im Rahmen dieser wissenschaftlichen Studie hat mich Frau / Herr ..... in einem Aufklärungsgespräch ausführlich informiert. Das Informationsblatt für Probanden ist mir ausgehändigt worden. Ich konnte alle mir wichtig erscheinenden Fragen, z.B. über spezielle Risiken und mögliche Komplikationen oder Maßnahmen stellen, die zur Vorbereitung oder während der Untersuchung erforderlich sind. Die mir erteilten Informationen habe ich verstanden.

Ich erkläre mich hiermit bereit, an der im Informationsblatt beschriebenen freiwilligen Untersuchung im Rahmen der oben genannten wissenschaftlichen Studie teilzunehmen und gebe meine Einwilligung, dass bei mir im Rahmen der wissenschaftlichen Studie eine EEG-Untersuchung des Gehirns durchgeführt wird.

Ich erkläre mich damit einverstanden, dass die im Rahmen der Messungen erhobenen Daten in verschlüsselter Form (pseudonymisiert) auf elektronischen Datenträgern gespeichert und verarbeitet werden dürfen. Ich bin auch damit einverstanden, dass die Untersuchungsdaten in anonymer Form, d.h. ohne dass Rückschlüsse auf meine Person gezogen werden können, veröffentlicht werden. Ich habe davon Kenntnis genommen, dass sofort nach Auswertung und Abschluss der Studie – spätestens jedoch Ende 2018, die personenbezogenen Daten gelöscht werden und so keine Zuordnung der erhobenen Untersuchungsdaten zu meiner Person mehr möglich sein wird. Die anonymisierten Untersuchungsdaten werden spätestens zehn Jahre nach Abschluss der Studie vollumfänglich gelöscht.

Ich erkläre mich damit einverstanden, dass die erhobenen persönlichen Daten in einer der Öffentlichkeit nicht zugänglichen Datenbank erfasst werden. Die Speicherung dieser personenbezogenen Daten dient ausschließlich der Zuordnung der pseudonymisierten Untersuchungsergebnisse zu meiner Person für den Fall, dass ich meine Einwilligung zurückziehe und die Löschung der Daten verlange.

Mir ist bekannt, dass es sich bei elektroenzephalografischen Untersuchung nicht um eine medizinische Untersuchung handelt und ich daher keine Rückschlüsse auf meinen gesundheitlichen Status ziehen kann.

Mir ist bekannt, dass ich meine Einwilligung in die Datenverarbeitung jederzeit und ohne Angabe von Gründen widerrufen kann und die Löschung der Daten verlangen kann.

_____ _____ _____

Ort, Datum Unterschrift Untersuchungsteilnehmer/in Unterschrift Untersucher

Appendix E - Additional Questionnaire

RaB - Fragebogen 2 **RaB_P0.....**

Beruf: .....

Ich schaue/ höre mir Wettervorhersagen an? ..... Ja [ ] Nein [ ]

Wenn ja, über welches Medium? _____

Wie regelmäßig? _____

Ich vertraue den Aussagen von Wettervorhersagen? eher nein — eher ja

Ich vertraue Wettervorhersagen zu folgendem Grad: |0%----------100%|

Vorhersagen **einen** Tag in die Zukunft

Vorhersagen **zwei** Tage in die Zukunft

Vorhersagen **drei** Tage in die Zukunft

Angenommen, der folgende Text wäre die Wettervorhersage für Morgen: „Es gibt eine Wahrscheinlichkeit für Regen von 60%" Welche der hier aufgeführten Optionen beschreibt die Bedeutung dieser Vorhersage Ihrer Meinung nach am Besten?

- Es wird morgen in 60% des Gebietes regnen
- Es wird morgen 60% der Zeit über regnen
- Es wird an 60% von Tagen wie morgen regnen
- 60% von Meteorologen denken, es wird morgen regnen
- Ich weiß es nicht
- Anderes, und zwar:_____

Gab es in Ihrer Vergangenheit besondere Erlebnisse mit dem Wetter? Wenn ja, welche?

_____

_____

Sind Sie beruflich oder in Zusammenhang mit Hobbys mit Wetterfragen beschäftigt? Wenn ja, inwiefern?

_____

_____

01	Bevorzugen Sie bei der Wettervorhersage eher Prognosen in Prozent oder in Worten?	Prozent — Worte
02	Wie oft finden Sie in Zahlen ausgedrückte Informationen nützlich?	nie — sehr oft
03	Ab wie viel Prozent Regenwahrscheinlichkeit gehen Sie davon aus, dass es regnen wird?	0% — 100%

04	Wenn es um das Wetter geht, vertraue ich meinem Bauchgefühl.	eher nein	eher ja
05	Ich vertraue den Wettervorhersagen mehr als meinem Bauchgefühl.	eher nein	eher ja
06	Ich halte mich häufig im Freien auf.	eher nein	eher ja
07	In den letzten 12 Monaten habe ich mich häufig im Freien aufgehalten.	eher nein	eher ja
08	In meiner Kindheit habe ich mich häufig im Freien aufgehalten.	eher nein	eher ja
09	Ich finde es unangenehm, vom Regen durchnässt zu werde.	eher nein	eher ja
10	Ich finde bin empfindlich gegenüber Kälte.	eher nein	eher ja
11	Es ärgert mich, wenn die Wettervorhersage falsch liegt.	eher nein	eher ja
12	Ich bin der Meinung: Es gibt kein schlechtes Wetter, sondern nur schlechte Kleidung.	eher nein	eher ja
13	Ich finde es unangenehm, viel Gepäck zu tragen.	eher nein	eher ja
14	Entscheidungen, die mich selbst betreffen, gehen mir leicht von der Hand.	eher nein	eher ja
15	Entscheidungen, die andere betreffen, gehen mir leicht von der Hand.	eher nein	eher ja
16	Ich würde meine Statistikkenntnisse als gut bezeichnen.	eher nein	eher ja
17	Meine Entscheidungen sind pragmatisch und an rationalen Kriterien orientiert.	eher nein	eher ja
18	Meine Entscheidungen kommen aus dem Bauch heraus.	eher nein	eher ja
19	Meine Entscheidungen sollen den Spaß an meinem Leben steigern wo es geht.	eher nein	eher ja
20	Ich finde eine höhere Regenwahrscheinlichkeit geht auch mit stärkerem Regen einher.	eher nein	eher ja

Appendix F - Context Story

Einführung

Stellen Sie sich folgende Situation vor:
Sie sind über das Osterwochenende zu Besuch bei Freunden und wollen am Nachmittag eine Grillparty auf einer Lichtung im nahen Wald veranstalten. Die anderen sind schon vorgegangen. Sie kennen den ca. 30 minütigen Weg jedoch schon und können daher nachkommen. Da Sie während des Grillens lange draußen sein werden überlegen Sie, ob Sie einen Regenschirm mitnehmen sollen. Doch Sie müssen schon eine Salatschüssel und eine Kühltasche mit Grillzeug tragen, und der einzige Schirm, den Sie finden können, ist groß und unhandlich. Ob es sich lohnt, ihn mitzunehmen? Sie hören gerade die Wettervorhersage im Radio und werfen dann einen Blick aus dem Fenster…

Im Folgenden werden Sie unterschiedliche Variationen dieser Entscheidung erleben. Zuerst sehen Sie die prognostizierte Regenwahrscheinlichkeit in Prozent. Dann sehen Sie Bilder, die den Blick aus dem Fenster zeigen. Auf Basis dieser Informationen treffen Sie Ihre Entscheidung. Wenn Sie den Regenschirm mitnehmen wollen, drücken Sie mit dem Mittelfinger der rechten Hand eine Taste. Wenn Sie ihn nicht mitnehmen wollen, drücken Sie mit dem Zeigefinger der rechten Hand eine andere Taste.

Für diese Entscheidung werden Sie nur eingeschränkt Zeit haben, so wie Sie auch im realen Leben nicht immer viel Zeit haben, sich zu entscheiden.

Es gibt insgesamt zwei Durchgänge. Die Dauer der Durchgänge ist auch von Ihrer Entscheidungsgeschwindigkeit abhängig. Lassen Sie Ihre Entscheidung einfach spontan kommen und handeln Sie danach. Sie können nichts falsch machen.

Nach einem kurzen Übungsdurchgang haben Sie nochmals die Gelegenheit Fragen zu stellen, bevor es dann losgeht.

Appendix G - Complete table of Cohen's kappa values

The table below contains the values of Cohen's kappa, for every participant, indicating reliability between the decision behavior in the fMRI and the EEG measurements.

participant	kappa
1	0.69
2	0.61
3	-0.20
4	0.49
5	0.67
6	0.64
7	0.55
8	0.82
9	0.59
10	0.54
11	0.78
12	0.58
13	0.54
14	0.60
15	0.77
16	0.64
17	0.53
18	0.59
19	0.78
20	0.63
21	0.54
22	0.53
23	0.52
24	0.56
25	0.54
26	0.71
27	0.71
28	0.45
29	0.82
30	0.51

Appendix H - mni2tal Matlab code

Shown is the transformation of the coordinate space. 'AC' is the anterior cingulate cortex.

```
inpoints = MNImatrix'; % MNI-Coordinates, before transformation
% Transformation matrices, different zooms above/below AC
upT     = spm_matrix([0 0 0 0.05 0 0 0.99 0.97 0.92]);
downT   = spm_matrix([0 0 0 0.05 0 0 0.99 0.97 0.84]);

tmp = inpoints(3,:) < 0;        % 1 if below AC
inpoints = [inpoints; ones(1, size(inpoints, 2))];
inpoints(:, tmp) = downT * inpoints(:, tmp);
inpoints(:, ~tmp) = upT * inpoints(:, ~tmp);
outpoints = inpoints(1:3, :);

TALmatrix = round(outpoints'); % Talairach-Matrix, transformed
```

Appendix I - List of Areas in Voxel-distribution Analysis

The list below shows which anatomical brain areas were differentiated in the voxel distribution analysis, how many voxel belonged to which area in each hemisphere, and which areas were assigned to each of the lobes.

Area	Voxel (left)	Voxel (right)	Lobe
Precentral Gyrus	28217	28271	frontal
Superior Frontal Gyrus	40982	41373	frontal
Medial Frontal Gyrus	28335	28793	frontal
Middle Frontal Gyrus	50299	50302	frontal
Inferior Frontal Gyrus	30089	30433	frontal
Orbital Gyrus	2268	2268	frontal
Rectal Gyrus	2352	2368	frontal
Paracentral Lobule	4980	5400	parietal
Postcentral Gyrus	20557	20823	parietal
Superior Parietal Lobule	5940	5935	parietal
Inferior Parietal Lobule	20024	19984	parietal
Supramarginal Gyrus	6179	6229	parietal
Angular Gyrus	2791	2825	parietal
Precuneus	26997	27919	parietal
Superior Occipital Gyrus	1579	1597	occipital
Middle Occipital Gyrus	16568	16718	occipital
Inferior Occipital Gyrus	4438	4511	occipital
Cuneus	20753	21120	occipital
Lingual Gyrus	14330	14501	occipital
Fusiform Gyrus	10900	10952	
Superior Temporal Gyrus	34644	34341	temporal
Middle Temporal Gyrus	33062	33183	temporal
Inferior Temporal Gyrus	8525	8510	temporal

Transverse Temporal Gyrus	1700	1688	temporal
Insula	14679	14841	
Anterior Cingulate	10832	11342	
Cingulate Gyrus	23820	25292	
Posterior Cingulate	7008	7112	
Subcallosal Gyrus	1796	1848	
Parahippocampal Gyrus	12057	12099	
Uncus	4151	4147	
Hippocampus	891	782	
Dentate	1240	1240	
Caudate	2	4	
Caudate Body	2536	2408	
Caudate Head	1540	1556	
Caudate Tail	358	387	
Lentiform Nucleus	150	55	
Putamen	5690	5694	
Lateral Globus Pallidus	1549	1558	
Medial Globus Pallidus	548	587	
Thalamus	2216	2234	
Anterior Nucleus	224	216	
Pulvinar	1846	1865	
Lateral Dorsal Nucleus	80	80	
Lateral Posterior Nucleus	264	264	
Medial Dorsal Nucleus	910	902	
Midline Nucleus	40	44	
Ventral Anterior Nucleus	232	224	
Ventral Lateral Nucleus	765	753	

Ventral Posterior Lateral Nucleus	297	299
Ventral Posterior Medial Nucleus	165	150
Lateral Geniculum Body	26	28
Medial Geniculum Body	44	38
Subthalamic Nucleus	138	116
Hypothalamus	80	80
Claustrum	1472	1546
Amygdala	1036	1036
Mammillary Body	241	233
Midbrain	6274	6754
Red Nucleus	238	238
Substania Nigra	212	216
Pons	6517	6650
Medulla	1398	1440
Cerebellar Lingual	517	565
Cerebellar Tonsil	13552	13578
Culmen	16832	17285
Culmen of Vermis	210	244
Declive	14419	14401
Declive of Vermis	296	317
Inferior Semi-Lunar Lobule	7960	7992
Pyramis	6200	6180
Pyramis of Vermis	120	124
Tuber	8003	8177
Tuber of Vermis	76	100
Uvula	4097	4015
Uvula of Vermis	136	184

Fastigium	328	300
Nodule	1036	1072

Appendix J - Active voxel in each contrast

The table below contains the mean number of active voxel per anatomical region over all participants and the respective standard deviation, both for all four contrasts.

Anatomical Region	UNC > CER		CER > UNC		UNC > fix		CER > fix	
Left Hemisphere	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Precentral Gyrus	65.68	167.12	90.84	326.68	110.64	146.78	171.44	244.36
Superior Frontal Gyrus	57.40	137.91	49.92	148.49	78.12	151.48	45.36	92.77
Medial Frontal Gyrus	60.64	209.25	64.56	195.25	64.52	130.46	45.16	77.16
Middle Frontal Gyrus	120.40	306.55	86.08	259.49	114.76	202.11	59.72	134.84
Inferior Frontal Gyrus	52.60	98.16	17.32	44.71	68.76	113.02	39.88	75.68
Orbital Gyrus	0.00	0.00	0.00	0.00	0.36	1.76	0.32	1.57
Rectal Gyrus	0.00	0.00	0.00	0.00	0.04	0.20	0.00	0.00
Paracentral Lobule	4.00	13.67	21.72	73.10	1.72	5.70	7.08	21.55
Postcentral Gyrus	30.68	96.39	85.76	271.59	246.60	262.06	273.16	287.98
Superior Parietal Lobule	21.08	69.13	15.92	54.15	52.28	98.18	21.36	53.00
Inferior Parietal Lobule	19.92	47.40	52.16	148.93	137.24	146.77	112.52	146.57
Supramarginal Gyrus	13.16	52.66	10.68	28.74	5.16	13.56	5.40	15.34
Angular Gyrus	22.20	65.36	5.28	20.44	0.88	2.85	2.44	6.49
Precuneus	77.12	165.35	91.64	342.96	100.00	233.90	70.16	171.06
Superior Occipital Gyrus	3.24	8.94	2.12	10.39	17.00	33.03	14.08	29.86
Middle Occipital Gyrus	28.52	62.99	6.08	18.98	285.64	316.12	222.12	244.85
Inferior Occipital Gyrus	8.08	23.33	2.60	9.23	33.72	49.40	24.32	33.56
Cuneus	29.64	55.59	25.40	119.42	284.36	255.07	226.60	186.46
Lingual Gyrus	25.28	53.11	8.08	25.80	340.40	349.43	285.08	292.58
Fusiform Gyrus	8.28	22.28	2.96	10.72	75.76	89.50	71.20	79.01
Superior Temporal Gyrus	34.04	94.08	66.52	162.90	78.92	246.77	85.92	259.56
Middle Temporal Gyrus	30.16	63.44	90.92	269.50	67.44	168.62	66.76	141.74
Inferior Temporal Gyrus	6.92	15.49	3.76	11.43	6.08	15.51	4.80	11.34
Transverse Temporal Gyrus	0.64	2.33	2.68	9.86	11.08	29.30	10.68	31.06
Insula	17.40	44.49	36.64	112.01	107.56	139.91	103.48	137.79
Anterior Cingulate	10.08	31.86	9.76	38.33	23.64	87.08	14.88	56.46
Cingulate Gyrus	40.12	105.98	41.92	129.08	62.72	133.67	47.32	80.01
Posterior Cingulate	6.48	16.95	7.48	33.85	7.76	17.58	6.32	17.29
Subcallosal Gyrus	0.00	0.00	0.68	3.33	0.88	3.24	0.80	3.33
Parahippocampal Gyrus	2.36	7.72	9.04	31.71	21.56	47.75	16.96	41.13
Uncus	0.20	0.80	0.04	0.20	0.04	0.20	0.84	4.12
Hippocampus	0.72	3.53	0.64	2.76	0.12	0.59	0.00	0.00
Dentate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caudate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caudate Body	0.20	0.80	0.52	1.55	0.20	0.98	0.00	0.00
Caudate Head	0.12	0.43	0.00	0.00	0.80	3.92	0.12	0.59

Caudate Tail	0.32	1.57	0.52	1.65	0.00	0.00	0.00	0.00
Lentiform Nucleus	0.00	0.00	0.28	1.37	0.08	0.39	0.00	0.00
Putamen	2.68	11.96	9.72	46.00	4.12	19.38	4.04	16.44
Lateral Globus Pallidus	0.00	0.00	2.80	13.72	0.16	0.78	0.20	0.80
Medial Globus Pallidus	0.00	0.00	0.32	1.57	0.00	0.00	0.00	0.00
Thalamus	1.96	6.18	3.36	16.26	0.28	1.04	0.12	0.59
Anterior Nucleus	0.12	0.59	0.00	0.00	0.00	0.00	0.00	0.00
Pulvinar	1.88	5.35	2.20	10.78	0.04	0.20	0.00	0.00
Lateral Dorsal Nucleus	0.20	0.98	0.00	0.00	0.00	0.00	0.00	0.00
Lateral Posterior Nucleus	0.04	0.20	0.08	0.39	0.00	0.00	0.00	0.00
Medial Dorsal Nucleus	1.44	5.01	0.88	3.10	0.08	0.39	0.00	0.00
Midline Nucleus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ventral Anterior Nucleus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ventral Lateral Nucleus	0.12	0.43	0.00	0.00	0.00	0.00	0.00	0.00
Ventral Posterior Lateral Nucleus	0.08	0.39	0.24	1.18	0.00	0.00	0.00	0.00
Ventral Posterior Medial Nucleus	0.04	0.20	0.32	1.57	0.00	0.00	0.00	0.00
Lateral Geniculum Body	0.00	0.00	0.08	0.39	0.00	0.00	0.00	0.00
Medial Geniculum Body	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subthalamic Nucleus	0.00	0.00	0.04	0.20	0.00	0.00	0.00	0.00
Hypothalamus	0.00	0.00	0.08	0.27	0.00	0.00	0.00	0.00
Claustrum	1.16	3.87	2.60	10.71	8.24	13.17	7.84	13.61
Amygdala	0.00	0.00	1.52	4.72	0.00	0.00	0.12	0.59
Mammillary Body	0.32	1.57	0.68	2.95	0.00	0.00	0.00	0.00
Midbrain	5.44	25.05	7.28	30.04	0.60	2.04	0.36	1.20
Red Nucleus	0.00	0.00	0.00	0.00	0.44	2.16	0.00	0.00
Substania Nigra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pons	4.40	16.63	1.64	5.56	0.52	2.55	0.20	0.98
Medulla	1.12	4.74	0.00	0.00	0.00	0.00	0.00	0.00
Cerebellar Lingual	1.44	7.05	0.96	4.70	0.00	0.00	0.16	0.61
Cerebellar Tonsil	8.68	39.19	0.00	0.00	10.00	29.80	5.88	21.73
Culmen	25.32	64.17	12.64	46.10	30.88	59.32	35.56	63.35
Culmen of Vermis	0.12	0.43	0.52	2.02	0.00	0.00	0.00	0.00
Declive	8.00	15.19	9.52	24.18	67.44	70.22	70.68	91.53
Declive of Vermis	0.00	0.00	0.56	2.74	0.16	0.78	0.16	0.61
Inferior Semi-Lunar Lobule	0.24	1.18	3.80	17.82	17.08	54.33	15.36	46.34
Pyramis	4.60	22.54	2.88	13.71	6.44	14.65	5.96	17.41
Pyramis of Vermis	0.00	0.00	0.40	1.96	0.00	0.00	0.04	0.20
Tuber	3.00	10.22	1.04	5.09	3.04	13.90	2.16	8.33
Tuber of Vermis	0.00	0.00	0.08	0.39	0.00	0.00	0.00	0.00
Uvula	2.28	10.20	2.40	11.56	0.80	2.58	1.04	3.96
Uvula of Vermis	0.00	0.00	0.20	0.98	0.16	0.78	0.12	0.59
Fastigium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nodule	0.28	1.37	0.00	0.00	0.00	0.00	0.00	0.00

Right Hemisphere	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Precentral Gyrus	39.72	139.21	178.88	580.11	26.48	60.88	49.40	105.70
Superior Frontal Gyrus	55.16	114.66	43.56	111.25	138.08	254.26	83.72	100.41
Medial Frontal Gyrus	42.52	85.97	61.72	201.81	89.28	161.99	65.64	126.41
Middle Frontal Gyrus	56.84	114.73	98.72	280.17	176.32	412.94	85.40	108.53
Inferior Frontal Gyrus	20.40	45.64	74.88	261.79	121.32	212.63	84.20	125.44
Orbital Gyrus	0.00	0.00	0.00	0.00	0.12	0.59	0.12	0.59
Rectal Gyrus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paracentral Lobule	4.72	14.55	22.60	71.70	5.20	16.65	13.28	55.18
Postcentral Gyrus	20.12	51.91	136.40	444.81	42.72	88.97	75.08	132.01
Superior Parietal Lobule	39.36	114.27	32.56	112.49	58.40	158.37	14.60	41.85
Inferior Parietal Lobule	20.20	45.47	97.40	312.29	115.00	247.16	63.20	115.22
Supramarginal Gyrus	9.24	28.58	28.72	85.44	6.48	16.72	17.56	56.49
Angular Gyrus	4.72	21.72	14.48	51.45	10.64	23.73	5.60	13.57
Precuneus	85.16	212.19	104.20	455.21	126.12	315.18	63.16	138.22
Superior Occipital Gyrus	0.96	3.26	0.28	1.37	22.40	41.03	21.68	39.89
Middle Occipital Gyrus	34.08	90.20	14.32	50.15	335.56	372.95	288.56	336.31
Inferior Occipital Gyrus	3.80	12.52	2.00	9.60	36.52	57.83	29.60	41.01
Cuneus	35.88	83.11	64.12	274.20	222.52	176.21	198.04	168.83
Lingual Gyrus	27.08	80.06	14.60	66.35	252.56	242.31	249.20	265.94
Fusiform Gyrus	7.60	20.42	6.00	19.90	94.76	112.78	99.36	94.28
Superior Temporal Gyrus	46.60	185.77	105.12	332.00	35.96	80.18	45.64	116.15
Middle Temporal Gyrus	22.48	70.66	106.44	329.81	102.00	198.70	84.64	121.71
Inferior Temporal Gyrus	3.64	11.25	9.00	23.85	13.24	29.30	15.80	32.56
Transverse Temporal Gyrus	0.40	1.96	3.76	15.45	0.76	3.52	4.00	17.60
Insula	15.44	40.83	28.80	101.68	57.40	107.09	46.40	74.86
Anterior Cingulate	2.84	8.27	8.12	31.68	31.36	91.23	15.04	56.33
Cingulate Gyrus	31.84	65.21	53.32	177.18	85.76	191.74	66.96	116.64
Posterior Cingulate	14.96	53.26	22.80	111.49	9.52	30.17	5.80	18.80
Subcallosal Gyrus	0.00	0.00	1.60	5.78	1.44	6.65	1.04	4.50
Parahippocampal Gyrus	8.24	27.09	16.48	62.54	37.80	78.14	37.76	67.49
Uncus	0.72	2.97	0.00	0.00	0.00	0.00	0.00	0.00
Hippocampus	0.16	0.78	1.92	5.49	0.00	0.00	0.00	0.00
Dentate	0.00	0.00	1.76	8.42	0.16	0.78	0.16	0.54
Caudate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caudate Body	2.80	11.78	0.80	1.94	1.36	6.66	0.08	0.39
Caudate Head	0.12	0.59	0.92	3.92	0.32	1.12	0.08	0.39
Caudate Tail	0.44	2.16	0.24	0.99	0.00	0.00	0.00	0.00
Lentiform Nucleus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Putamen	1.48	3.41	19.32	72.53	1.48	5.37	5.36	17.01
Lateral Globus Pallidus	0.60	2.40	3.08	14.89	0.76	3.72	1.32	6.47
Medial Globus Pallidus	0.48	1.72	0.24	1.18	0.00	0.00	0.32	1.57
Thalamus	2.08	5.95	2.16	9.03	0.20	0.98	0.20	0.80
Anterior Nucleus	0.72	2.13	0.00	0.00	0.08	0.39	0.00	0.00

Pulvinar	1.60	6.85	2.00	9.80	0.00	0.00	0.00	0.00
Lateral Dorsal Nucleus	0.08	0.39	0.00	0.00	0.00	0.00	0.00	0.00
Lateral Posterior Nucleus	0.00	0.00	0.04	0.20	0.00	0.00	0.00	0.00
Medial Dorsal Nucleus	1.16	5.09	0.76	2.96	0.00	0.00	0.32	1.57
Midline Nucleus	0.12	0.43	0.00	0.00	0.00	0.00	0.00	0.00
Ventral Anterior Nucleus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ventral Lateral Nucleus	0.00	0.00	0.44	2.16	0.00	0.00	0.12	0.59
Ventral Posterior Lateral Nucleus	0.04	0.20	1.00	4.90	0.00	0.00	0.00	0.00
Ventral Posterior Medial Nucleus	0.00	0.00	0.48	2.16	0.00	0.00	0.00	0.00
Lateral Geniculum Body	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medial Geniculum Body	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subthalamic Nucleus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hypothalamus	0.04	0.20	0.08	0.39	0.00	0.00	0.00	0.00
Claustrum	0.68	2.57	2.24	7.25	3.44	10.29	2.24	7.03
Amygdala	0.00	0.00	1.04	5.09	0.00	0.00	0.00	0.00
Mammillary Body	0.12	0.59	0.56	2.08	0.00	0.00	0.00	0.00
Midbrain	6.00	22.50	7.64	32.93	0.36	1.41	0.00	0.00
Red Nucleus	0.00	0.00	0.12	0.59	0.00	0.00	0.00	0.00
Substania Nigra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pons	5.48	21.98	4.28	14.79	0.28	1.37	0.64	2.59
Medulla	0.12	0.59	0.00	0.00	0.00	0.00	0.00	0.00
Cerebellar Lingual	1.24	6.07	0.84	4.12	0.00	0.00	0.00	0.00
Cerebellar Tonsil	11.96	51.66	1.96	7.86	3.96	16.17	2.80	12.33
Culmen	17.36	59.55	26.88	96.82	65.28	89.65	85.80	122.11
Culmen of Vermis	0.04	0.20	1.16	5.48	0.00	0.00	0.48	2.16
Declive	7.24	23.45	34.72	127.17	97.12	104.25	105.44	122.81
Declive of Vermis	0.00	0.00	0.88	4.31	0.20	0.98	0.08	0.27
Inferior Semi-Lunar Lobule	0.04	0.20	18.64	64.49	8.44	36.39	11.32	36.23
Pyramis	1.52	7.45	9.16	30.30	4.68	22.93	6.00	21.04
Pyramis of Vermis	0.00	0.00	0.52	2.35	0.00	0.00	0.00	0.00
Tuber	1.04	3.01	3.08	9.95	5.16	18.43	5.96	15.68
Tuber of Vermis	0.00	0.00	0.28	1.18	0.00	0.00	0.00	0.00
Uvula	0.60	2.94	6.20	16.82	2.12	7.30	1.04	3.26
Uvula of Vermis	0.00	0.00	0.16	0.78	0.08	0.39	0.04	0.20
Fastigium	0.00	0.00	0.64	2.59	0.00	0.00	0.00	0.00
Nodule	0.88	4.31	0.08	0.39	0.00	0.00	0.00	0.00

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