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AC	alternating current
ACTH	adrenocorticotrophic hormone
Ag/AgCl	silver/silver chloride
a.m.	ante meridiem, "before midday"
ANOVA	Analysis of Variance
BART	Balloon Analogue Risk Task
BMI	Body-Mass-Index
CRH	corticotrophin-releasing hormone
dB	Decibels
ECG	electrocardiogram
EEG	electroencephalogram
EOG	electrooculogram
ERP	event-related potential
fMRI	functional magnetic resonance imaging
FRN	feedback related negativity
HCR	high cortisol responder
HPA	hypothalamic-pituitary-adrenal
Hz	Hertz
IGT	Iowa Gambling Task
KΩ	Kiloohm
LCR	low cortisol responder
MEG	magnetoencephalogram
mg	milligram
min	minutes
ml	milliliter
MΩ	megaohm
ms	milliseconds
µV	microvolt
nmol/l	nanomol per liter
s	second
SD	standard deviation
SEM	standard error of measurement
SECPT	social evaluated cold-pressor test
SEWPT	social evaluated warm pressure test
TSST	Trier Social Stress Test

Abstract

Economic decisions or any other type of decisions are sometimes made after an acute stress situation. Acute stress leads on the behavioral level often to negative mood and elicits a twofold biological stress response. Immediately after the stressor is experienced a fast, adrenergic stress response is observed, which provides the body with energy for a fight or flight response. At the same time the hypothalamus–pituitary–adrenal axis is activated, leading to the secretion of the stress hormone cortisol, which reaches its peak around 20 to 30 minutes after the stressor occurred.

In this thesis the influence of acute stress on decision making under uncertainty is being investigated. Uncertain decisions are those, where the outcome possibilities are known, but not their associated probabilities. Hence, optimal decision making can only be achieved by learning from positive or negative previous experience, which is the feedback obtained in previous similar situations.

From the published literature it can be concluded that the experience of an acute stressor leads to suboptimal decision-making, but only for those subjects who show a strong cortisol response. The assumed mechanism suggests, that the stress hormone cortisol biases the dopaminergic reward system towards a preference for positive feedbacks, while ignoring or neglecting negative feedbacks. This process is thought to be subconscious.

Neoclassical economic decision theories cannot explain a negative influence of a subconscious process on decision-making, as they axiomatically assume that all decisions are based on rationality. Behavioral economics, a discipline which combines economic and psychological theories, provides explanations, for example by proposing two interacting systems, a fast, subconscious system, which uses only part of the information available, and a slow, rationality driven system, which balances all available information to reach an optimal decision. Information processes in the brain, activated by the acute stressor, are thought to rely on the fast, subconscious system.

A critical review of the published literature comes to the conclusion that there is not a single study that fulfilled basic desiderata to set up the best possible design to test the hypothesis, that acute stress has a negative influence on decision making under uncertainty. The three desiderata request (1) the use of a stressor, which includes a strong evaluative (psychological) component, (2) that the decision paradigm used is valid with respect to economic decisions and (3) that the two axes of the stress response are validated by

biological measures. Moreover, some studies show severe methodological problems and should not be considered to evaluate the present hypothesis. To further ensure a strict and fair test of the hypothesis additional desiderata were considered: (4) the acute stress paradigm should allow to group the acutely stressed subjects into low and high cortisol responders, (5) the stress paradigm should allow sorting decision trials according to the feedback obtained in the previous trial and (6) a direct measure of the fast feedback processing should be used.

The Feedback Related Negativity (FRN), a component of the event-related potential, which can be extracted from the electroencephalogram, is directly related to the processing of feedback in the brain.

Two experiments are reported in this thesis, which test the hypothesis that acute stress leads to suboptimal decisions under uncertainty, due to a stressor caused bias toward the preference for positive feedbacks. They are designed to fulfill the six requested desiderata and use a combination of a psychological stressor and decision paradigms, which produced the largest negative effect (around 10%) of acute stress on decision making in the published literature.

The first experiment (32 male and female subjects) used the Social Evaluated Cold Pressure Test (SECPT) as a stress paradigm and the Balloon Analogue Risk Task (BART) as a valid decision-making procedure. Based on the results and experiences from experiment 1, a second experiment (36 male subjects) was run, which used again the SECPT and introduced two main changes. Instead of the BART, the Iowa Gambling Task (IGT) was used as the decision paradigm and a short version of the SECPT was repeated several times to obtain a larger and more stable cortisol response.

In both experiments the FRN was measured contingent on positive and negative feedbacks during the decision task. Three groups were analyzed: a SECPT group which showed high cortisol responses to the acute stressor, a SECPT group which showed low cortisol responses, and a control group, which performed a control condition, the so called Social Evaluated Warm Pressure Test (SEWPT).

The results from both experiments were clear: Though all manipulation checks regarding the behavioral and biological results of the acute stressor and the BART or the IGT could be validated empirically, both experiments revealed no influence of the acute stressor on decision making under uncertainty or on feedback processing, as indexed by the FRN.

These results were mainly based on the interpretation of statistical null hypotheses. It could be shown that for the assumed population effect of 10% or more, the probability of falsely interpreting the null hypothesis (type II or β-error) is in most cases less than 5%. Thus, statistical null hypotheses could be interpreted with confidence.

The general conclusion is drawn that acute stress has no negative influence on decision-making under uncertainty and that early and fast feedback processing is not changed by acute stress. Contradicting results, reported in the literature, might be due to the fact that one or more influential variables, which could be derived from the proposed desiderata, were not controlled in these studies.

Still, some objections can be formulated to question the present results. These possible objections are discussed in the final sections of this thesis, before developing a basic paradigm, which might guide future research in this field.

Summary in German

Ökonomische und auch jede andere Art von Entscheidungen müssen manchmal nach einer akuten Stresssituation gefällt werden. Akuter Stress führt oft auf der Verhaltensebene zu einer negativen Stimmung. Auf einer biologischen Ebene ist eine zweifache Reaktion zu beobachten. Unmittelbar nach einem Stressor entwickelt sich eine schnelle, adrenerge Reaktion, die die notwendige Energie für eine Annäherungs- oder Fluchtreaktion zur Verfügung stellt. Gleichzeitig wird die Hypothalamus- Hypophysen-Nebennierenrinde Achse aktiviert. Dadurch wird 20 bis 30 Minuten nach dem akuten Stressor das Stresshormon Kortisol ausgeschüttet.

In dieser Dissertationsschrift wird der Einfluss von akutem Stress auf Entscheidungsverhalten unter unsicheren Bedingungen experimentell untersucht. Entscheidungen unter unsicheren Bedingungen sind solche, in denen alle Entscheidungsalternativen, nicht aber deren Auftretenswahrscheinlichkeiten, bekannt sind. Unter diesen Umständen können nur dann optimale Entscheidungen getroffen werden, wenn man auf positive oder negative Erfahrungen, die in ähnlichen Situationen erworben wurden, zurückgreifen kann. Erfahrungen in ähnlichen Situationen werden über die Verarbeitung positiver oder negativer Rückmeldungen erworben.

Die publizierte Literatur legt nahe, dass die Auseinandersetzung mit einem akuten Stressor zu suboptimalen Entscheidungen unter unsicheren Bedingungen führt. Der vermutete Mechanismus besagt, dass die Ausschüttung des Stresshormons Kortisol zu einer einseitigen Präferenz für die Verarbeitung positiver Rückmeldungen führt, während negative Rückmeldungen vernachlässigt werden. Diese Tendenz ist der bewussten Erfahrung nicht zugänglich.

Neoklassische ökonomische Entscheidungstheorien können diesen negativen Einfluss von Stress auf Entscheidungen, die auf nicht bewussten Prozessen basieren, nicht erklären, weil diese Theorien postulieren, dass alle Entscheidungen ausschließlich auf der Basis rationaler Denkprozesse getroffen werden. Die Verhaltensökonomie, eine Disziplin, die ökonomische und psychologische Entscheidungstheorien zusammenführt, ist in der Lage gute Erklärungen zu liefern. So werden für Entscheidungen zwei empirisch gut begründete Systeme angenommen: Eines ist schnell, parallel und nicht bewusst und benutzt nur einen Teil der zur Verfügung stehenden Informationen, um zu einer Entscheidung zu gelangen. Das zweite System ist langsam, sequentiell und von der Vernunft getrieben und wägt alle vorhandenen Informationen ab, um zu guten Entscheidungen zu kommen. Informationsverarbeitungs-prozesse, die durch akuten Stress angestoßen werden, laufen eher in dem schnellen, parallelen und nicht-bewusstem System ab.

Eine kritische Durchsicht der publizierten Literatur kommt zu dem Ergebnis, dass es keine einzige Studie gibt, die grundlegende Desiderate, die für optimale Studien zur Untersuchung des Einflusses von akutem Stress auf Entscheidungsverhalten wünschenswert wären, erfüllt. Die ersten drei Desiderate verlangen, (1) dass der akute Stressor eine starke sozial-evaluative

Komponente enthält, (2) dass das Entscheidungsparadigma im Hinblick auf riskante ökonomische Entscheidungen valide ist und (3) dass die schnelle, adrenerge Stressantwort und die langsamere Antwort (Ausschüttung des Stresshormon Kortisol) angemessen erfasst werden. Zudem zeigen einige Studien schwerwiegende methodologische Probleme, so dass ihre Ergebnisse für die Evaluation der Fragestellung nicht berücksichtigt werden können. Die Erfüllung dreier weiterer Desiderate sollte zu einer weiteren Optimierung von Experimenten in diesem Bereich führen: (4) das Stressparadigma sollte eine Kategorisierung der Probanden mit geringer und hoher Kortisolantwort erlauben; (5) das Stressparadigma sollte es möglich machen die aktuelle Entscheidung danach zu sortieren, ob die Probanden in der vorherigen Entscheidung eine positive oder negative Rückmeldung erhalten haben; und (6) -am wichtigsten- ein kortikales Signal, welches optimale Verarbeitung von Rückmeldungen indiziert, sollte benutzt werden. Die „Feedback Related Negativity“ ist ein solches Signal. Sie ist eine Komponente des ereigniskorrelierten Potenzials, die aus dem fortlaufenden Elektroenzephalogramm extrahiert werden kann.

In dieser Dissertationsschrift werden zwei Experimente berichtet, die die Hypothese testen, dass akuter Stress zu suboptimalen Entscheidungen in unsicheren Situationen führt, weil der Stressor die Verarbeitung der Rückmeldungen derart beeinflusst, dass positive Rückmeldungen bevorzugt verarbeitet und negative Rückmeldungen weitestgehend ignoriert werden. Die Experimente sind so konstruiert, dass die sechs Desiderate erfüllt werden. Es wird eine Kombination eines Stressors mit einer sozial-evaluativen Komponente (Social Evaluated Cold Pressure Tests SECPT) und einem Entscheidungsparadigma (Experiment 1: Ballon Analogue Risk Task BART; Experiment 2: Iowa Gambling Task IGT) eingesetzt, weil diese Kombination in der publizierten Literatur die größten systematischen Effekte (um 10%), bezüglich eines negativen Einflusses von akutem Stress auf Entscheidungsverhalten, produziert.

In beiden Experimenten wurde die FRN kontingent auf die Präsentation von positiven oder negativen Rückmeldungen gemessen. Es wurden jeweils drei Gruppen analysiert. Eine SECPT Gruppe mit einer niedrigen Kortisolantwort, eine SECPT Gruppe mit einer hohen Kortisolantwort und eine Kontrollgruppe, die den sogenannten „Social Evaluated Warm Pressure Test“ (SEWPT) absolvierten.

Die Ergebnisse beider Experimente waren eindeutig: Obwohl das korrekte Funktionieren des SECPT, des BART und des IGT empirisch zweifelsfrei attestiert werden konnte, fand sich in beiden Experimenten kein hypothesenrelevanter Einfluss des akuten Stressors auf die Entscheidungen in dem BART Paradigma oder der IGT Aufgabe. Ebenso zeigte sich die Verarbeitung der Rückmeldungen, indiziert durch die FRN, in allen Gruppen gleich und vom akuten Stressor unbeeinflusst. Diese Ergebnisse verlassen sich überwiegend auf die Interpretation statistischer Nullhypothesen. Unter der Annahme eines erwarteten Populationseffekts von 10% oder größer, ist die Fehlerwahrscheinlichkeit, sich fälschlicherweise für die Nullhypothese zu entscheiden (Typ II oder β-Fehler), für die

relevanten inferenzstatistischen Tests in der Regel kleiner als 5%. Somit gibt es keinen Grund die nicht signifikanten Ergebnisse der statistischen Tests anzuzweifeln.

Insgesamt sprechen die Ergebnisse eindeutig dafür, dass akuter Stress weder einen negativen Einfluss auf Entscheidungen in unsicheren Situationen hat, noch, dass die Verarbeitung von Rückmeldungen beeinflusst würde. Dieser Schluss widerspricht einigen publizierten Ergebnissen. Dies mag daran liegen, dass keine dieser Studien optimal, im Sinne der sechs formulierten Desiderata, durchgeführt wurde.

Auch wenn die beiden vorliegenden Experimente in mancherlei Hinsicht optimiert waren, können Einwände gegen die erfolgte Schlussfolgerung vorgebracht werden. Diese möglichen Einwände werden abschließend formuliert und diskutiert, bevor zu guter Letzt ein Paradigma entwickelt wird, das für zukünftige Forschungen in diesem Feld nützlich sein könnte.

1 General Introduction

1.1 An example of decision making under acute stress

John is a competent and successful portfolio manager, working for a well-known financial services company. His investment strategies are on average better than those of his colleagues and he regularly outperform his benchmark indices. He has to reorganize the portfolio for an important customer with the clear expectation to increase the return on investment while minimizing risk increase. He has carefully pre-screened a long list of very promising new shares, checking their pros and cons, and based his analysis on fundamentals and projected sales figures, a work which took several days. Next Monday at 10 am he will meet with his client to present the final recommended changes to the portfolio, the selected shares out of the long list to be added.

That Monday morning at 8 am, he has a severe confrontation with his wife. The atmosphere in the family – they have two small children- was very tense throughout the weekend and exploded shortly before he had to leave for work. His wife accused him of being a bad father and workaholic, who has no time for wife and children. She threatened to leave him, taking the children with her. But he has no time to discuss this with her as he is already late for work. He needs to finish the selection of the shares from the long list to be added to the portfolio. On his way to the office, he feels extremely stressed and uncomfortable. He arrives at work at 8:30 am and within only 15 minutes he selects the shares from his long list for the client meeting at 10 am. The meeting goes very well and the client accepts all proposals he recommended.

After the meeting he informed his broker to execute the buy order, and takes two days off which he used to find an agreement with his wife to save their marriage. When he arrived two days later back in his office, he looked again at the selected shares he recommended to his client. He was very surprised that he had made his decisions within 15 minutes after his arrival in the office and more importantly, he was astonished by his selection of stocks he put into the portfolio. Today he would take more time for his decisions. He also realizes, that his decisions were mostly guided by the pros for the companies he chose, nearly ignoring all cons. During the course of the year, it turns out that his decisions lead to clear losses of money.

Obviously, he made a bad decision under the influence of an acute stressor. Moreover, these decisions were characterized by the fact, that he did not know the probability that the companies, whose shares he had bought, would make an above average return on investment. He could only use his experience, which is reflected in his list of pros and cons he constructed.

But why did he rely mostly on the pros, ignoring the cons, and making a very fast decision? Is this due to the stress with his wife?

The answers to these questions should be found in science. In the following sections, I will first try to find out whether his decision making can be explained by rational choice theories or whether theories from behavioral economics can explain it. Subsequently, the stress response is characterized on a behavioral and biological level. This is the basis for explanations how an acute stressor can bias decision making. Thereafter, the current literature regarding the influence of acute stress on decision making is summarized, a first hypothesis is generated and, shortcomings of the literature which led to the first hypothesis are discussed. Desiderata are formulated, which should lead to design better experiments to study the influence of acute stress on decision making. Then the final general hypothesis is formulated. From time to time, I will return to the above example to show how the topic dealt with may help to characterize and explain the decision-making process of our portfolio manager.

1.2 Theories of decision making

1.2.1 Rational theories

For a long time, economic theories stated that only completely rational thinking drives decision making. Examples of these positions are the classical economic theories such as the Weak Axiom of Revealed Preference theory (WARP; Samuelson, 1938) and the Generalized Axiom of Revealed Preference (GARP; Houthakker, 1956) and their neoclassical theoretical (Von Neumann & Morgenstern, 1947) and statistical (Savage, 1954) extensions. The classical expected utility theory assumes that decision makers always choose the option with the highest expected utility with expected utility calculated as the weighted sum of the utilities of all outcomes multiplied by the probability of occurrence of the respective outcome (Caplin & Glimscher, 2014).

Within these economic decision theories phenomena like stress, emotions or situational and environmental boundary conditions were not considered important for the rational decision maker, who is sometimes also called ‘homo economicus’.

1.2.2 Behavioral Economics

The Nobel prize winner Herbert A. Simon (1955; 1997) applied psychological ideas to economic theories. Instead of assuming that people are perfectly rational and aspire to optimize economic outcomes by their decisions, he put forward the idea that human rationality is not perfect and constrained by capacity limitations of the decision maker. Furthermore, he argues

that people seek satisfactory rather than ideal, rational outcomes. With these ideas he paved the way for the seminal work of Kahneman and Tversky and their Prospect Theory (Kahneman, 2003; Kahneman, 2011; Kahneman, Slovic, Slovic, & Tversky, 1982; Kahneman & Tversky, 1979; Tversky & Kahneman, 1974, 1981), which was based on the expected utility theory (Von Neumann & Morgenstern, 1947). These authors demonstrated inconsistencies in human decisions and judgements, which cannot be explained by rational theories. The following examples are adopted from Tversky and Kahneman (1981):

Decision 1:

> Option A: win $ 1000 with a probability of 25 %, 0 otherwise
> vs
> Option B: win $ 240 for sure (100%)
>
> 84% of subjects preferred option B, a risk averse choice, though option A has a higher utility.

Decision 2:

> Option A lose $ 1000 with a probability of 75%, lose 0 otherwise
> vs
> Option B: loose $ 750 for sure (100%)
>
> 87% chose option A, a risky choice, though option B has the higher utility,

Theories based on the rational choice assumptions would predict just the opposite, since the expected wealth is maximized by these choices.

In Kahneman's and Tverky's view these inconsistencies in probability judgement are driven by a fast, intuitive, and emotional system they named System 1. In contrast, System 2 is more deliberative and more logical. Kahneman (2011) described these two systems as follows: "When all goes smoothly, which is most of the time, System 2 adopts the suggestions of System 1 with little or no modification. When System 1 runs into difficulty, it calls on System 2 to support more detailed and specific processing that may solve the problem of the moment. System 2 is mobilized when a question arises for which System 1 does not offer an answer" (p. 24).

This research established a field named "behavioral economics". Thaler (2015) characterized behavioral economics as "an enriched version of economic theory" and "…it is still economics, but it is economics done with strong injections of good psychology and other social sciences" (p. 10). In a report to the National Bureau of Economic Research Mullainathan and Thaler (2000) define: "Behavioral Economics is the combination of psychology and economics that

investigates what happens in markets in which some of the agents display human limitations and complications" (p .2)

Two (or dual)-process theories are an important input from psychology to understand decision making processes in economics (see Albert & Steinberg, 2011 for a review). The System1 – System2 distinction is called by other scholars 'hot' and 'cold' cognitions (Zajonc, 1980) or automatic and controlled processing (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). System 1 in different designs of this dichotomy is described as unconscious or preconscious, implicit, automatic, rapid, less effortful, evolutionary old or parallel. On the other hand System 2 is described as conscious, explicit, controlled, high effortful, evolutionary recent and sequential (see Evans, 2008 for a review).

The consequence of these processes is that even in very complex decisions situations often very simple heuristics guide the process of choosing seemingly meaningful, but irrational actions. (Gigerenzer, 2013; Gigerenzer & Gaissmaier, 2011; Kahneman et al., 1982). Heuristics are efficient, automatic or controlled information processes, which only use a small amount of the available information, thus being prone to irrational decisions. They guide decisions in situations where no clear strategies are available or where there is no time to invest the effort required to find a rational solution. Heuristics contain often rules of thumb which are based on subjective experiences or traditional behaviors.

A good example of a very simple but very efficient heuristic is the so-called recognition heuristic. Goldstein and Gigerenzer (1999) define this heuristic as follow: "If one of two objects is recognized and the other is not, then infer that the recognized object has the higher value".

For example, when the choice is to name the larger one of two cities (i.e., San Francisco or San Antonio) 100% of German student give the right answer, which is simply based on the fact, that all of the German students had heard or read of San Francisco at least once in their lives, but many of these subjects did not recognize San Antonio (Goldstein & Gigerenzer, 1999). The theoretical explanation is called the 'mere exposure effect' (Zajonc, 1980). If subjects are repeatedly confronted with an object (here for example the mentioning of San Francisco in newspapers or news broadcasts) this results in a positive attitude or preference for this object (Bornstein, 1989).

The application of the recognition heuristic can even be advantageous in economic decision making. Goldstein, Ortmann, and Gigerenzer (1999) provide some interesting studies where the application of the recognition heuristic leads to better performance, when putting together stock portfolios as compared to market indices or professionally managed funds.

Recognition is considered to result from two independent processes, namely 'recollection' and 'familiarity'. Whereas recollection is a conscious, rational based process, familiarity is thought to result from an automatic, fast and less effortful process (Jacoby, 1991; Yonelinas, 2002). Familiarity has a positive emotional connotation and, in case where not all information is available, the recognition process relies on the feeling of similarity. In this sense the recognition heuristic can be viewed of subclass of the broader "affect heuristic" (Slovic, Finucane, Peters, & MacGregor, 2007). These authors characterize the affect heuristic as follows: "it is proposed that people use an affect heuristic to make judgments. That is, representations of objects and events in people's minds are tagged to varying degrees with affect. In the process of making a judgment or decision, people consult or refer to an ''affect pool'' containing all the positive and negative tags consciously or unconsciously associated with the representations. Just as imaginability, memorability, and similarity serve as cues for probability judgments (e.g., the availability and representativeness heuristics), affect may serve as a cue for many important judgments. Using an overall, readily available affective impression can be far easier—more efficient—than weighing the pros and cons or retrieving from memory many relevant examples, especially when the required judgment or decision is complex or mental resources are limited. This characterization of a mental short-cut leads to labeling the use of affect a 'heuristic' "(p. 1335f).

Let us come back to our portfolio manager. What have we learned from science so far to explain his suboptimal investment decisions? Obviously, his behavior did not follow classical axiomatic, rational based economic decision theories. Rather he has not used all available information to come up with a strictly rational investment decision. His ‚irrational' choices can be explained by theories from behavioral economics. It is plausible to assume, that he relied on more intuitive, automatic processes generated by what Kahneman called System1. In this special situation he relied perhaps on a recognition heuristic by choosing those stocks he felt familiar with. An affect heuristic might also explain his behavior. He chose those stocks to invest in which were due his previous experience tagged with a positive emotional connotation, because he found more pros than cons for these companies which led to a positive emotional connotation. Thus, we have to ask science how emotional states and more specific stress influence decision making.

There is clear evidence in the literature that emotions influence decision making (see Bechara & Damasio, 2005; George & Dane, 2016; Lerner, Li, Valdesolo, & Kassam, 2015; Loewenstein, 2000 for reviews). Two aspects have to be differentiated: First, the decision process itself might give rise to emotions (see for example Loewenstein, 1996; Loewenstein,

Weber, Hsee, & Welch, 2001). These are called integral emotions. As the present topic does not deal with emotions generated by the decision process itself, we will concentrate on the so-called incidental emotions, defined as an emotion or an emotional state unrelated to the decision process.

In our example the acute stressor, which produces negative emotions and a general negative feeling, is unrelated to the decision process itself. A typical empirical study in this field is reported by Johnson and Tversky (1983). They found that subjects who read emotional positive stories in newspapers subsequently were more optimistic about risks than people who read emotional negative articles. Another study (Lerner, Small, & Loewenstein, 2004) studied the influence of emotions on the endowment effect (Kahneman, Knetsch, & Thaler, 1991). The endowment effect refers to the fact that people value an owned object higher than market value. In the study of Lerner et al. (2004) subjects either viewed a sadness or a disgust or a neutral-emotion inducing film clip. Thereafter, they performed a classical endowment paradigm. The endowment effect varies with the induced emotion: disgust eliminated the endowment effect, sadness reversed it, whereas in the neutral condition the classical endowment effect was observed. These authors explain these and similar results by the appraisal-tendency framework. According to this hypothesis "appraisal tendencies" are goal-directed processes through which emotions exert effects on judgement and decision until the emotion-elicited problem is solved" (Lerner et al., 2015, p. 805).

Applied to our example, our portfolio manager is in a bad, negative mood, though this emotional state is incidental to the decisions he took. This negative emotional state might have motivated him to search for immediate reward to simply feel better, a process quite likely below his conscious experience. This might lead to the mentioned bias that he overestimates the positive information he has gathered on the different stocks.

In the research discussed so far, the influence of specific basic emotions as sadness, fear or disgust were investigated to find out how they influence decision making. However, stress is a much more complex construct, which might produce negative mood but surely leads to more complex reactions on the behavioral, physiological and hormonal levels. Before turning to the literature, which looks at the influence of stress on decision making, the research scope has to be reduced to those aspects of stress and decision making, which will be investigated in both experiments reported later.

1.3 Stress

A stressor, which can be anything (physical or psychological) severe enough to produce a major physiological or psychological imbalance, elicits an adaptive stress response. This should bring mind and body back into balance. Important parts of the physiological stress response are the immediate secretion of noradrenalin and adrenalin and shortly after the stressor the secretion of the stress hormone cortisol (Kirschbaum & Hellhammer, 1999).

The much larger part of this thesis deals with the influence of acute stress on decision making. Chronic stress, which is the wear and tear on body and mind that results from repeated exposure to stressors, will only be a minor topic in experiment 2 (see 2.1).

In this chapter I will first give a short outline of stress theories before describing in more detail the stress reaction with emphasis on those aspects which are important for decision making.

1.3.1 The concept of stress

The scientific study of stress started with Walter Canon (1922; 1935). In his 1935 publication "Stresses and Strains of Homeostasis" he identified the "sympatho-adrenal system" which he thought is responsible for the reestablishing of physiological homeostasis after a stress experience. Homeostasis is the process which brings bodily parameters, as blood pressure, back to their original values after a challenge. Canon was mostly interested in the contribution of adrenaline and noradrenaline to challenging situations.

Hans Selye (1907 – 1982), the founder of modern biological oriented stress research, adopted Canon's concept of homeostasis. In his famous article in Nature (Selye, 1936) he defined the "general adaption syndrome" consisting of three stages in response to stress (a) an alarm reaction challenging homeostasis, (b) a stage of resistance, where the return to homeostasis can be achieved and (c) the stage of exhaustion which can be reached if homeostasis does not sustain. Later Selye (1976) summarized his thinking about stress "…. Stress is not identical to emotional arousal or nervous tension...I recommend the following definition: Stress is the nonspecific response to any demand" (p.15).

Until today the main body of stress research literature considers stress as a primary negative experience. To account for the observation that stress can be accompanied by positive feelings Selye (1976) introduced the terms "eustress" (good stress) and "distress" (bad stress). Stress eliciting stimuli or situations can be interpreted as being positive leading to eustress or as being negative leading to distress. Eustress can originate for example from potential live threatening activities as free climbing, skydiving or wing suit flying, which the subjects appraise as positive. Recent research indicates, that subjects, who report a positive appraisal of a stressful situation,

show the full physiological stress response (see 1.3.2). Yonelinas, Parks, Koen, Jorgenson, and Mendoza (2011) and Meyer et al. (2015) investigated the stress response in first time skydivers. In both studies skydivers reported absolute positive feelings before and during the situation. However, they also exhibited a full physiological stress response. Only recently, Everaerd et al. (2020) examined in a well-planned field experiment the emotional and physiological reactions of voluntary stage performers who acted in front of a large crowed during a large-scale music festival. Nearly all performers liked very much what they did, however, compared to a control group they showed a strong physiological stress reaction.

As noted above most of the stress research following Selye's deals with stressors producing distress. However, Mason (1968, 1975) criticized Selye's idea of an unspecific stress response. He demonstrated the importance of emotional reactions that determine a specific stress response. If a stressor is perceived as novel, unpredictable, ambivalent or uncontrollable, or the subject anticipates negative physical or psychological consequences, a strong stress response is elicited (Dickerson & Kemeny, 2004). Based on these developments stress nowadays is defined as "[...] an actual or anticipated disruption of homeostasis or an anticipated threat to well-being" (Ulrich-Lai & Herman, 2009, p. 397) or as "any disruption of homeostasis"(Miller & O'Callaghan, 2002, p. 5). This challenge of homeostasis results in adaptive responses of the individual, in order to re-establish homeostasis (Levine, 2005).

McEwen and coworkers (Lupien et al., 2006; McEwen, 2008; McEwen & Akil, 2020; McEwen et al., 2015; McEwen & Wingfield, 2003, 2010) criticized the concept of homeostasis (which can be translated as "standing at about the same level") as too narrow and introduced the concept of allostasis, which means "remaining stable by being variable" or "achieving stability through change (McEwen & Wingfield, 2010, p. 106). "Allostasis refers to the active process of adapting and maintaining stability (or homeostasis) through the production of mediators like cortisol, that promote adaption" (McEwen & Akil, 2020, p. 12)

The concept of allostasis broadens and supplements the concept of homeostasis. Allostasis is a more complex form of adaption. A stressor elicits a complex stress reaction (to be explained in detail below) which enables the organism to maintain homeostatic balance. When the stressor disappears, the organism returns to a balanced state, which is not necessarily identical to the original level. Thus, new stable states are established. This new level is called "allostatic state". In McEwen's words: "..allostasis refers to the ability of a regulatory system to change a set point and operate at an elevated or reduced level" (McEwen & Wingfield, 2010, p. 106). As long as a stressor results in allostasis no negative consequences will occur and the organism is

in a state of eustress. However, when the response to the stressor is unbalanced (too little cortisol or too low blood pressure) and this continues for a longer time, this is called “allostatic load”. Allostatic load refers to the wear and tear on the body that results from repeated exposure to stressors that produce distress. This results in chronic stress which is a reason for a lot of diseases (McEwen & Akil, 2020).

Thus, the brain and body respond to potential and actual stressful events by activating hormonal and neural mediators and modifying behaviors to adept. These responses help maintain physiological stability (allostasis) and allows a return to psychological well-being. The stress reaction and its consequences for an acute stressful situation will be described in the next paragraphs.

1.3.2 The stress response

A stressor elicits a stress response. A stressor can virtually be anything, as long as it is severe enough to require major physiological and psychological adjustments (Lovallo, 1997). In real life there are physical stressors such as heat, pain or cold and psychological stressors such as giving a speech in front of an audience, having an exam or witnessing a deadly car accident. We find the same sort of stressors in a scientific laboratory. A typical physical stressor often used in the laboratory is the cold pressure test (Velasco, Gómez, Blanco, & Rodriguez, 1997), the best known psychological stress test is the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993) A combination of a physical and psychological stressor is the Social Evaluated Cold Pressure Test (SECPT; Schwabe, Haddad, & Schaechinger, 2008; Schwabe & Schaechinger, 2018).

The organism reacts to the stressor with a complex stress response that expresses itself at physiological, behavioral, cognitive, and emotional level (Steckler, 2005). The physiological stress response manifests itself on two stress axes: On the one hand, a stressor leads to a rapid activation of the sympathetic nervous system, involving the release of noradrenaline and adrenaline (de Kloet, Joels, & Holsboer, 2005) an increase of heart rate, a change of skin conductance, blood pressure, and muscle activity (Birbaumer & Schmidt, 2010, pp. 141-156). On the other hand, shortly after the stressor, the hypothalamic-pituitary-adrenal axis (HPA) is activated, leading to an increased concentration of glucocorticoid hormones.

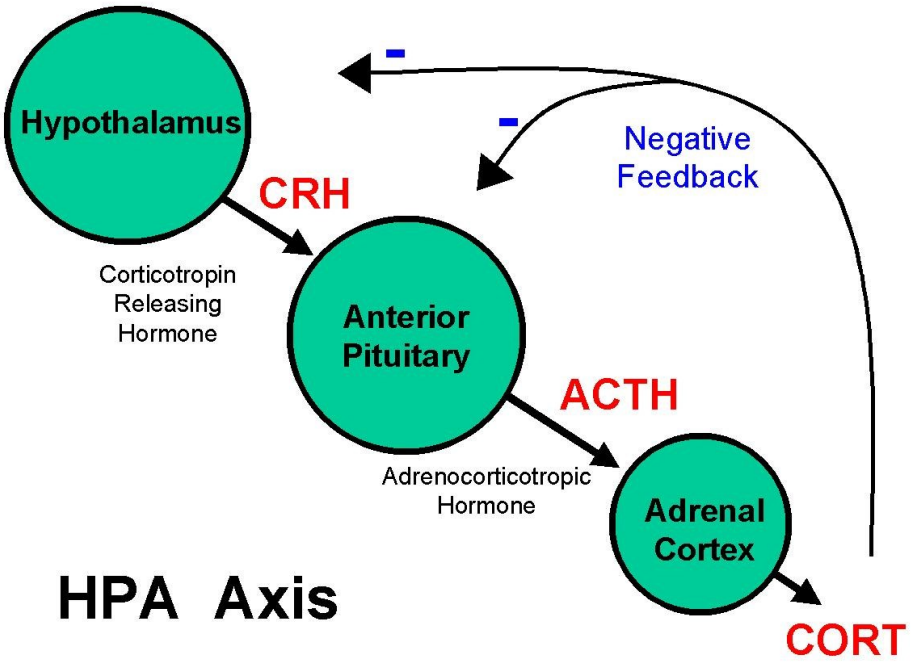

Figure 1.1: Illustration of the HPA-Axes. Details see text.[1]

These steroid hormones are produced in the adrenal glands and primarily cortisol in humans and corticosterone in rodents (de Kloet et al., 2005). As displayed in Figure 1.1, the hormonal cascade begins with stimulation of the hypothalamus, a brain structure that is importantly involved in the regulation of homeostasis (Sapolsky, Romero, & Munck, 2000). Thereupon, the hypothalamus secretes the corticotropin-releasing hormone (CRH) into the blood system and, further stimulates the pituitary gland which then start to secrete the adrenocorticotrophic hormone (ACTH). This leads to a release of the end product cortisol by the adrenal glands (Kirschbaum & Hellhammer, 1999). The maximum of cortisol secretion is usually reached around 10 to 20 minutes after the onset of an acute stressor and lasts up to 40 minutes post stressor onset (Dickerson & Kemeny, 2004; Juster, Perna, Marin, Sindi, & Lupien, 2012). The crucial function of the so-called stress hormone cortisol lies in the mobilization of energy reserves via gluconeogenesis, in order to prepare the organism for coping with the challenging situation (Sapolsky et al., 2000). To facilitate recovery, the released cortisol inhibits further activity of the HPA axis by negative feedback. This interplay of the activation of the sympathetic nervous system and the HPA axis acts on the organism to prepare rapid behavioral responses, such as fight-or-flight responses (de Kloet et al., 2005). Acute stress particularly

[1] Free picture from https://commons.wikimedia.org/wiki/File:Basic_HPA_Axis.jpeg

leads to a strong activation of the HPA axis, if the situation is perceived as uncontrollable or characterized by social-evaluated threat (Dickerson & Kemeny, 2004).

Research in the past 20 years has clearly demonstrated that the stress hormone cortisol negatively influences cognitive functions. More specific, so called 'executive functions' are strongly impaired under acute stress (Arnsten, 2009). Executive functions are cognitive abilities which allow us to hold information in working memory, to inhibit automatic responses to stimulation and focus attention to deal appropriately with a given situation. For example, acute stress severely impairs memory retrieval (de Quervain, Roozendaal, & McGaugh, 1998; Guenzel, Wolf, & Schwabe, 2013; Wolf, 2019), impairs cognitive flexibility (Alexander, Hillier, Smith, Tivarus, & Beversdorf, 2007; Plessow, Kiesel, & Kirschbaum, 2012) and also working memory performance (Luethi, Meier, & Sandi, 2008). These slow, rule-based, analytic and thoughtful cognitive processes anatomically rely on processes implanted in the prefrontal cortex. However, also fast, automatic emotional encoding, anatomically located in the amygdala, can be impaired by acute stress (Roozendaal, McEwen, & Chattarji, 2009). As will be described in chapter 1.4, both anatomical structures are important for decision making under uncertainty.

Another important aspect is, that the stress hormone cortisol enhances dopaminergic activity (Ungless, Argilli, & Bonci, 2010). Dopamine is closely related in feedback learning (Shohamy, Myers, Kalanithi, & Gluck, 2008), the basic mechanism to optimize decision-making in uncertain situations.

To come back to our example: Our portfolio manager has experienced a strong acute psychological stressor (the severe dispute with his wife and the possible threatening consequences). When he arrived at his office the fast adrenergic stress response is over and he is in the middle of the somewhat later starting HPA-axis activation, resulting in a high level of cortisol in his blood and brain.

To generalize from the example: This thesis deals with the influence of an acute stressor on economic decision making. It investigates the influence of an acute physical and psychological stressor during the period of maximal cortisol concentration (experiment 1 & 2) and in experiment 2 also during the period immediately after the stressor (during the fast adrenergic stress response).

Before turning to the state of research regarding the influence of an acute stressor on decision making, the concept of 'decision' needs some clarification.

1.3.3 Decision making: A clarification and restriction

According to (Balleine, 2007) "Decision making refers to the ability of humans and other animals to choose between competing courses of action based on their relative value of their consequences" (p.8159). Decisions vary with the degree of uncertainty about the expected outcome (Weber & Johnson, 2009). Degree of uncertainty can be localized "on a continuum from 'complete ignorance' (not even the possible outcomes are known) through 'uncertainty or 'ambiguity' (the outcomes are known, but their probabilities are not known) to 'risk' (the outcome probabilities are specified) and, finally, to 'certainty' (only a single outcome is known to result)" (Starcke & Brand, 2012, p. 1230).

There is good evidence from functional magnetic resonance imaging (fMRI) studies that decisions under risk and decisions under uncertainty recruit different brain regions. Decisions under risk recruits the orbitofrontal cortex, striatum, insula and posterior parietal cortex, whereas decisions under uncertainty activates a network including the amygdala, parts of the frontal cortex, and the dorsolateral prefrontal cortex (Bach, Seymour, & Dolan, 2009; Huettel, Stowe, Gordon, Warner, & Platt, 2006; Krain, Wilson, Arbuckle, Castellanos, & Milham, 2006; Schultz et al., 2008). It is noteworthy that only decision under uncertainty or ambiguity activate the amygdala, a core structure for emotions. Thus, decisions under ambiguity might be more prone to emotional influences than decisions under risk.

Referring back to our portfolio manager. He made a decision under uncertainty[2] or ambiguity under the influence of an acute stressor.

In uncertain situations, the decision maker knows the possible outcomes but has none or insufficient information about the outcome probabilities (De Groot & Thurik, 2018). Therefore, the decision maker can only make judgement about these probabilities he or she has obtained in previous similar situations. Thus, learning from feedback is of special importance in these situations. By reinforcement learning (Sutton & Barto, 1998) information on the unknown outcome probabilities can be gathered. Thus, expected reward values can be estimated and behavior can be optimized to achieve the highest expected value. Results from feedback processing can be used to change strategies in the course of a decision-making task, for example behaving in the same manner when the outcome was a win and changing behavior when the outcome was a loss.

[2] Based on this definition uncertainty and ambiguity are used interchangeably throughout this thesis.

Thus, this thesis investigates decision making after an acute stressor for a class of decisions which is characterized by the fact that the decision maker knows the possible outcomes, but has no or only marginal information about the probabilities of the possible outcomes. These are decisions under uncertainty or ambiguity (De Groot & Thurik, 2018*).*

As noted above, to obtain good estimates of outcome probabilities in decision situations under uncertainty experience from previous similar situations and the feedback obtained there, is of utmost importance to come up with good decisions.

On the neural level, feedback processing acquires a complex network in the brain. Structures involved are the amygdala, the ventral striatum, the anterior and posterior cingulate cortex and the dorsolateral/ventromedial prefrontal cortex and the orbitofrontal cortex (Liu, Hairston, Schrier, & Fan, 2011). For example, performing an Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994), a paradigm widely used to study decision making in normal and clinical populations, activates consistently a neural circuitry (Li, Lu, D'Argembeau, Ng, & Bechara, 2010) important for

(a) thoughtful cognitive processes (dorsolateral prefrontal cortex),
(b) fast emotional categorizations (amygdala and anterior cingulate cortex) and
(c) areas combining the result of both processes (ventromedial and orbitofrontal cortex and posterior cingulate cortex).

Thus, both parts of a dual process theory of feedback processing and decision making have a clear implementation in the brain.

On an endocrine level the dopaminergic system is strongly involved in decision making (Shohamy et al., 2008). The dopamine system encodes the difference between reward value and expected value. This difference is called reward prediction error. It can be positive when there is an unexpected reward, zero when an expected reward is obtained, or negative when an expected reward does not occur. The group of Wolfram Schulz in Fribourg, Switzerland (see Schultz, 2004 and the literature cited there) convincingly demonstrated that the dopamine system encodes signals that predict reward and also responds to failures in those predictions. Phasic dopamine release in the mesolimbic dopaminergic system is part of the processes, that extract value-related parameters during decision making. More recently, it has been shown that dopaminergic neurons encode the certainty about the expected outcome and optimize decision making by using information from the reward prediction error (Friston et al., 2013, 2014; Schwartenbeck, Fitzgerald, Mathys, Dolan, & Friston, 2015). That is, the dopaminergic system encodes a wealth of information related to rewards in the past and future. Moreover, this system

innervates key brain structures (prefrontal cortex and amygdala) playing a major role in economic decision-making (Gan, Walton, & Phillips, 2010; Glimcher, 2011).

In the following chapters the literature dealing with the influence of acute stress on decision making under uncertainty is evaluated, Shortcomings of the scientific work published so far will be discussed and finally the general hypothesis guiding the setup of two experiments will be derived.

1.4 State of Research: Decisions under ambiguity and acute stress

1.4.1 A critical review of the relevant literature

Frequently decisions have to be made under acute stress. However, the effects of acute stress on decision making seems to be rather neglected so far. A recent narrative (Starcke & Brand, 2012) and a later meta-analytic (Starcke & Brand, 2016) review identifies only 26 empirical studies that addressed the possible deteriorating effects of acute stress on decision making under risk and uncertainty.

The general result of Starcke & Brand (2016) was, that over all data sets "the results indicate that stress has an effect on subsequent decisions. The effects are small but significant" (p. 18). Expressed in Cohen's d (Cohen, 1988) the overall negative effect of stress on decision making was d=.18 (90% confidence interval -.02 to .32)[3]. Expressed in terms of variance explained acute stress accounts only for less than 1% (exactly 0.008%) of the variability in the decision-making variables over all datasets. This is a very small effect indeed. This estimate contains a lot of papers dealing with decision making under risk, which show on average small effect sizes (see Starcke & Brand, 2016, p. 13, figure 2). The largest average effect size (d=.44; according to Cohen (1988) a medium-sized effect) was reported in situations where a processive stressor was used in ambiguous decision-making situations and risk taking was disadvantageous for the outcome. According to these authors a processive stressor "results from interpreting a situation" as opposed to a "systemic stressor" which only "include physiological stress" (Starcke & Brand, 2016, p. 4). The nomenclature is somehow unusual. In the stress literature their systemic stressors are usually called physiological stressors and their processive stressors are called psychological stressors (see 1.3).

[3] Cohen's d is an appropriate effect size for the comparison of two means. It is especially useful, as a d computed from sample means and standard deviations is a consistent and unbiased estimate of the population effect site δ. This makes d especially useful for meta-analysis (Borenstein, Hedges, Higgins, & Rothstein, 2011). See Starcke & Brand (2016) for a metanalytic review dealing with stress and decision making.

To study the possible influence of acute stress on decision making under uncertainty two important points emerge so far from these reviews

(1) the stressor has to be a psychological (processive) one and
(2) when a subject makes riskier decisions under acute stress this should be disadvantageous for them (i.e., losing money).

There are decision and stress inducing paradigms which fulfill these requirements. Details will be discussed in the introduction sections of the experiments.

According to Starcke & Brand (2016) two mechanisms influence decision-making under uncertainty. First, acute stress leads to a strategy, that relies on immediate and potentially high rewards. The argument is developed as follows: Stress increases the activity of the dopaminergic system by the secretion of cortisol (de Kloet et al., 2005; Holly, DeBold, & Miczek, 2015; Ungless et al., 2010). As discussed in chapter 1.3.2 the dopaminergic system is strongly involved in reward prediction and feedback learning (Shohamy et al., 2008). The enhanced dopamine reaction should lead to rely more on immediate and high rewards and disregard the negative consequences of potential losses. As Mather & Lighthall (2012) concluded in their review: “Stress enhances learning about positive outcomes but impairs learning about negative outcomes of choices” (p. 40). Second, stress should result in faster decisions, because not all available options are considered. This is due to a negative influence on the so-called executive functions (see 1.3.2). Additionally, the exposure to acute stress strengthens the activity of an emotional network, which includes the amygdala and anterior cingulate cortex, at the cost of the executive control network (Hermans, Henckens, Joels, & Fernandez, 2014). Due to the secretion of cortisol, after acute stress, these executive processes are impaired. Hence, not all possibilities are evaluated in depth. Decisions will be made faster and less thoughtful, because fast automatic emotional processes become more important for decision making.

If these thoughts hold true, a negative influence of an acute stressor should only be observed, when the stressor leads to a substantial cortisol secretion. Thus, the stress paradigm, to be used in the experimental studies, should produce psychological and adrenergic stress responses in all subjects. Also, the stress response should differ in the level of HPA-axes activation, equal to a strong and minor cortisol secretion. The SECPT fulfills these requirements (see 2.2).

In the time after, the Starcke & Brand (2016) review only a few relevant additional papers were published. Here only experiments are discussed, which used a processive acute stressor as the SECPT or the TSST. Additionally, the decision situation has to be ambiguous. For this reason,

several papers using systemic stressors (Canale, Rubaltelli, Vieno, Pittarello, & Billieux, 2017; Lenow, Constantino, Daw, & Phelps, 2017; von Helversen & Rieskamp, 2020) or risk paradigms where the outcome probabilities were known to the subjects (Nowacki et al., 2019) were not taken into account.

Wemm & Wulfert (2017) used a processive stressor (TSST) and a decision task where the outcome probabilities were not known (Iowa gambling task). Their results are in line with the prediction that acute stress leads to a decreased decision-making performance. Stressed subjects showed impaired decision making by choosing more often the disadvantageous than the advantageous choice. Cohen's d calculated from their data was .6, which is a medium-sized effect.

In two experiments Byrne, Cornwall, & Worthy (2019) used the SECPT to study long-term reward maximization in decision making under uncertainty. They used a task where positive feedback leads to long-term wins. Their main result in experiment 1was that after an acute stressor subjects chose more often the positive feedback option (d=.11). This rather small effect could not be replicated in experiment 2. Thus, from their result it remains unclear whether an acute stressor leads to an enhanced seeking for positive feedback. Moreover, there are other shortcomings which make their results difficult to integrate into the literature. First, little is known about the reliability and validity of their decision task. Second, they had no cortisol measurement in the first experiment. Third, in the second experiment they measured cortisol 5 minutes before and 50 minutes after the SECPT. Schwabe & Schächinger (2018), reviewing 10 years of SECPT used in stress research stated "that peak cortisol responses can be expected at about 25 min after SECPT onset and that cortisol levels are back at baseline after about 60 min after the beginning of the SECPT" (p.156). Thus, it is unclear, whether the SECPT in experiment 2 indicates a strong cortisol response.

Another line of research supports the assumption that enhanced risk taking in ambiguous decision making is dependent on the activation of the HPA-Axes (Kluen, Agorastos, Wiedemann, & Schwabe, 2017). In their pharmacological experiment male and female subjects received either a placebo, cortisol, yohimbine (induces adrenergic stimulation) and a combination of both drugs before performing the BART task (for a description of the BART task see 2.3). They observed increased risk-taking only for the groups which received cortisol. However, these effects held only for men[4]. This contradicts somehow a result from the meta-

[4] As the means and standard deviations for the risk measures were not reported, it is not possible to compute Cohen's d.

analysis (Starcke & Brand 2016), where risk taking under uncertainty was independent of gender. Risk taking in situations where outcome probabilities are known to the subjects, did either not result in enhanced risk taking when cortisol was administered (Margittai et al., 2018) or even reduced risk taking after the intake of cortisol (Metz et al., 2020).

There were only three papers relevant to this research question, which appeared after 2016. The results are mixed. Whereas Wemm & Wulfert (2017) add evidence to the hypothesis that an acute stressor leads to worse decision making under ambiguity, the paper by Byrne, Cornwall, & Worthy (2019) is difficult to interpret due to several shortcomings. Finally, the pharmacological study by Kluen et al. (2017) demonstrated that the intake of cortisol leads to more risky decisions in uncertain decision situations.

1.4.2 A first hypothesis

Let us return a last time to our example the general introduction started with and apply the knowledge gathered so far. At the time the portfolio manager has to make his decisions, which stocks to select from the long list, he is under the influence of an acute psychological stressor. He feels bad, his first physiological reaction (sweating, strong cardiac activation), which appeared immediately after the threatening announcement of his wife to leave him and take the children with her, had faded away. The physiological reaction calms down after he had to leave the house. Shortly after the stressful event he arrives at the office and in the next half hour has structured the portfolio for his client meeting. Without his knowing, the activation of the HPA-axis has produced an unusual high amount of the stress hormone cortisol in his blood and brain. This activation reaches its maximum at the time he made his decisions. The stress hormone leads to an increase in the activity of the dopaminergic system, also called reward system. This unconsciously biases his information processing towards previously rewarding aspects and to an avoidance of previously negative outcomes. Thus, he chooses those companies which received strong pros in his previous prepared analysis and pays much less attention to the cons. It must not, but it might lead to a bad decision.

Given the published literature one can conclude that acute stress leads to more risky decisions in ambiguous decision-making situations. Medium-sized effects (around 10% of variance explained) can be observed when the acute stressor is processive and riskier decisions are disadvantageous to the subject.

The literature discussed so far leads to a first hypothesis how acute stress influences decision behavior under uncertainty:

Acute stress leads to faster, riskier decisions under ambiguity only in subjects who show a clear cortisol increase in response to the acute stressor

The next chapter will evaluate in more detail shortcomings of the published literature as far as the above formulated hypothesis is concerned. Six desiderata will be formulated, which should be considered when designing studies to evaluate the above formulated hypothesis.

1.4.3 Desiderata to consider

Several points have been discussed in the previous paragraphs and these will be formulated as desiderata to be considered for empirical studies described and analyzed in chapter 2 and 3.

These are:

1. Use a psychological (processive) stressor.
2. Use a decision paradigm which is validated with respect to economic decision making and where risk taking is disadvantageous for the decision maker.
3. Validate the acute stressor by measuring the fast adrenergic and the slower cortisol response.

I will now have a closer look at those five "studies examining the effect of acutely induced stress on decisions made under ambiguity and in which reward seeking and risk taking were disadvantageous" which according to Starcke and Brand (2016, p. 9; table 1) showed on average the strongest negative influence of acute stress on decision making under uncertainty. Basically, these studies fulfill only one of the above criteria, namely that decisions and risk taking are disadvantageous for the decision maker.

The study of Kassam, Koslov, and Mendes (2009) used a processive stressor and measured the fast adrenergic stress response via heart rate and blood pressure. The cortisol response was not registered and no detailed information is given about the decision paradigm (an anchoring and adjustment task), nor any information is provided regarding its validity. Furthermore, though they reported a sample size of 103 subjects, their statistics (analysis of variance) used only 98 subjects. No reasons were given, why five subjects were not included in the analysis, Also, the relevant statistical test, which compared the stress conditions to a control condition, was not significant. The probability of falsely interpreting the statistical null hypothesis (Type II or β-error) assuming a real population effect size of 10% is larger than 40% (for more detail how to calculate Type II- errors see 2.4.3). In my view this paper does not contribute to the research question.

The second study (Lighthall, Gorlick, Schoeke, Frank, & Mather, 2013) fulfills only the criterion that decisions and risk taking are disadvantageous for the decision maker. The stressor used (Cold Pressure Test) is a physical stressor, which produces a cortisol response which is well below those usually reported with psychological stressors. Additionally, it is unclear how the decision task (a probabilistic selection task) relates to economic decision making. Their main result was that stress reduced sensitivity to recent feedback. This result holds for positive and negative feedback, a result which is not in line with the hypothesis formulated above.

The other three studies (Preston, Buchanan, Stansfield, & Bechara, 2007; Van den Bos, Harteveld, & Stoop, 2009; Wemm & Wulfert, 2017) all used a psychological (processive) stressor and the Iowa Gambling Task (IGT; see 3.1) an often used and well validated decision task.

The most problematic of these three is the study of Preston et al. (2007). In this study male and female subjects performed the IGT in four consecutive blocks after a psychological stressor (anticipated speech) or a control condition. This resulted in a group by gender by block design. The statistical tests (interaction group by block and group by gender by block) which should have been significant to confirm their hypothesis that acute stress detoriates decision making under uncertainty, failed to reach statistical significance. Based on additional statistical tests of the non-significant interactions they concluded: "Data indicated that male and female participants might have been differentially affected by the stressor, with female participants performing better under anticipatory stress and male participants performing worse" (p.261). In my view, as the Type II error of falsely interpreting the null hypothesis for the statistical tests is below 1%[5] the correct interpretation would have been that there is no influence of the acute stressor on decision making under uncertainty, neither in men nor in women. Additionally, no cortisol measurement was used. Thus, this study does not support the hypothesis formulated above.

The study of Wemm and Wulfert (2017) was cited in the meta-analysis as Wemm (2014, unpublished). Obviously, these data were published in 2017. 24 male and 32 female students performed the IGT after a psychological stressor or after a control condition. The fast adrenergic stress response was assessed by measuring heart rate and the galvanic skin response. Cortisol levels were not measured. Gender was not included in the analysis of the IGT performance and

[5] Assuming a population effect size of at least 10% and an average correlation between blocks of 0.60 (estimated from our own data in experiment 2) the type II error for the block by group and the block by group by gender interaction is below 1%. Formal logic and formulas to calculate post hoc type II error probabilities are explained in chapter 2.4.3.

the result indicates riskier decision making in the stress condition compared to the control condition. The study included in the meta-analysis reports 56 subjects, and the removal of 9 subjects in the published paper was justified "due to malfunction of the physiological recording devices" (p.5). Thus, this study shows that an acute stressor leads to worse decision making only on the behavioral level only partly supporting the above formulated hypothesis.

The best of the five studies is the experiment by Van den Bos et al. (2009). They used the Iowa Gambling Task (IGT) to measure decision making under uncertainty and used the TSST as a psychological (processive) stressor. They fulfilled nearly all criteria formulated above, perhaps with the small objection that they did not check for the fast adrenergic stress response. These authors divided the male and female stressed groups into low cortisol responders and high-cortisol responders, a further desideratum to improve the quality of experiments in this field (see below). Their important result in their own words "The data shows that the more (salivary) cortisol levels are elevated after the TSST the poorer the subsequent performance in the IGT in male subjects. In female subjects an inverse relationship between cortisol levels and IGT performance is observed: slightly elevated levels of cortisol after the TSST improve IGT performance, while highly elevated levels decrease IGT performance. Thus, acute stress as induced by the TSST affects decision-making behavior of men and women differently and cortisol reactivity is associated with decision-making performance". An important result supporting the above formulated hypothesis but only for men.

In summary, the evidence for the above stated hypothesis is very limited on the behavioral level, and the possible role of the stress hormone cortisol is rarely investigated properly and finds some support in the study of Van den Bos et al. (2009) and in the pharmacological study of (Kluen et al., 2017). Both studies support the hypothesis that an acute stressor leads to worse decision making only if high levels of the stress hormone cortisol are observed.

Thus, the empirical basis for the hypothesis that acute stress detoriates decision making under uncertainty in subjects with high cortisol response rates finds only limited support in the published literature. With one exception (Van den Bos et al., 2009), there is no study which fulfills the three desiderata formulated above. However, even a study considering these three desiderata can be more convincing if three additional desiderata are considered:

4. Use an acute stressor, which allows to categorize the subjects into low and high cortisol responders.
5. Use a decision paradigm, which allows to categorize an actual decision trial according to the previous trial's positive or negative feedback.
6. Use a direct cortical measure for feedback processing.

Desideratum 4 is derived directly from the above formulated hypothesis. A strong test needs a group which is psychologically stressed but shows only a negligible cortisol response.

Desideratum 5 is inspired by the study of Lighthall et al. (2013), who sorted their trials in their probability learning paradigm according to previous feedback. On the behavioral level they found reduced feedback processing after a physical acute stressor for positive and negative feedback. This is the only study I am aware of, which used this classification. The theoretical position states, that acute stress leads to worse decision-making in uncertain situations only when cortisol is secreted. Cortisol acts on the dopaminergic system, resulting in a shift to prefer positive over negative feedback. As Mather & Lighthall (2012) wrote: "…stress alters decision value assignments because stress triggers additional reward salience" (p. 37). If this is correct, decisions made after a positive feedback should be riskier than decisions after negative feedback. *Therefore, the quality of the previous feedback will be considered in all relevant analysis.*

Desideratum 6 establishes the link to neuroeconomics. "Neuroeconomics emerged, from within behavioral and experimental economics because behavioral economics often proposed theories that could be thought of as algorithms about both how information was processed, and the choices that result from that information processing" (Glimcher, Camerer, Fehr, & Poldrack, 2014, p. xx). Neuroeconomics analyzes brain activity by using up to date neuroscientific methods as electroencephalography, magnetoencephalography (MEG) or functional magnetic resonance imaging (fMRI; see Ruff & Huettel, 2014 for an overview of neuroscientific methods)

Theoretically, good decisions under uncertainty have to rely on previous experience, that is, the feedback obtained and processed at that time. These processes happen in the brain and are observable by using adequate measures. No study published so far has used a direct index of feedback processing when studying how acute stress influences choices made under uncertainty. The direct reaction of the brain to a positive or negative feedback can be observed with an index, which can be extracted from the electroencephalogram (EEG) and is called the Feedback Related Negativity (FRN). What follows is a short introduction to the FRN.

1.4.4 Feedback Related Negativity

As repeatedly formulated, decisions under uncertainty are dependent on the processing of feedbacks in preceding similar decisions. On a neural level the EEG and the embedded event related potentials (ERPs) are suitable to measure feedback related information processes. ERPs are composed of several components, which index early automatic, as well as late controlled information processes. For the research question investigated in this thesis the Feedback Related Negativity (FRN) is most suitable to observe a possible change in feedback processing due to acute stress. The FRN was first reported by Miltner and colleagues (Miltner, Braun, & Coles, 1997) and since then has led to hundreds of experiments, searching for the functional significance of this component, which is closely related to the Error Related Negativity, which is elicited by false responses (Gehring, Goss, Coles, Meyer, & Donchin, 2018).

The FRN is an electrical negative deflection appearing around 250 to 350 milliseconds, following perceptually salient external feedback about errors and losses of reward. It is normally calculated from the difference of ERPs elicited by negative and positive feedbacks. It has a fronto-central topography and is generated in the anterior cingulate cortex (Gehring & Willoughby, 2002; Hewig et al., 2007; Miltner et al., 1997; Miltner et al., 2003; Potts, Martin, Burton, & Montague, 2006; Zhou, Yu, & Zhou, 2010). Holroyd & Coles (2002) argued that the FRN represents the neural information transmission from midbrain dopaminergic systems to the cingulate cortex. When the outcome of the actual behavior is worse than expected dopamine activitiy in the midbrain dopaminergic systems is reduced or dropped (Schultz et al., 1997). The consequence is a negative going potential over fronto-central scalp (Holroyd & Coles, 2002; Holroyd et al., 2004; Miltner et al., 1997). Positive performance feedback and monetary gains result in an increase in the activity of midbrain dopamine neurons, leading to a relative positive scalp amplitudes (Potts et al., 2006). It has been argued, that the negative scalp potential is the default response and that this response is changed by the positivity, elicited by rewarding events (Holroyd, Pakzad-Vaezi, & Krigolson, 2008).

There are several studies looking at the FRN in decision-making (see Chandrakumar, Feuerriegel, Bode, Grech, & Keage, 2018, p. for a recent review). The general result is that in the time range of the FRN the electrical potential is more negative following negative prediction errors feedback as opposed to a positive potential following a positive prediction error. Whether the FRN amplitude is dependent on the value of the feedback is an open question, as some papers report larger amplitudes on high vs low wins or losses (e.g. Wang, Gu, Luo, & Zhou, 2017; Yu & Zhou, 2006), whereas other studies showed just the opposite result (e.g. Santesso & Segalowitz, 2009; Zhu et al., 2014).

How could the FRN change after an acute stressor? The availability of dopamine in the prefrontal cortex, more specific in the anterior cingulate cortex, increases, when a the result of an action is better than expected and the availability of dopamine decreases when the result of an action is worse than expected (Schultz, 1998, 2004; Schultz, Dayan, & Montague, 1997; Schultz et al., 2008). In this case the FRN get negative over prefrontal cortex (Holroyd & Coles, 2002). The secretion of the stress hormone cortisol after an acute stressor leads to an increase of dopamine availability in the prefrontal cortex (Ungless et al., 2010). If a worse-than-expected experience (a negative feedback) meets this increased level of dopamine could overlay the negative prediction error response and thus lead to a reduction of the FRN negativity.

Due to this mechanism the learning from negative feedback might be suboptimal as the cortical basis for optimal processing of negative feedback is reduced. On the behavioral level this might lead to a less optimal learning process to differentiate on the basis of previous experiences (feedback learning) between optimal and suboptimal decisions. In consequence, it might well be that bad choices might only get recognized suboptimally. Thus, a per se bad choice might become biased towards a positive prediction error. In sum this can result in a preference for positive feedbacks (Starcke & Brand, 2016) leading to faster and riskier decisions.

It should be noted that the cortical processes in response positive prediction error, i.e., a better-than-expected outcome will not be considered here. Positive feedback results in a feedback related positivity (FRP). However, the decision paradigm used here (see chapter 2.4.2.1 and 3.2.2.1) does not create a situation where the outcome of a decision can get better than expected, thus, a feedback related positivity cannot be elicited by the present paradigms. Thus, the difference potential (negative minus positive feedback, from which the FRN is derived in the paragraphs following, juxtapose a condition where expectations are met, from a condition where the outcome is worse than expected.

1.5 Final Hypothesis

From the literature discussed above it is argued:

- Decision-making in ambiguous situations has to rely on feedback from previous, similar situations. Feedback processing is closely related to activity in the dopaminergic system. Positive feedback leads to enhanced dopamine brain activity.
- Acute stress leads to a response composed of a fast increase of adrenergic brain activities and a subsequent endocrine cortisol secretion. The endocrine stress response can then significantly affect the dopaminergic response to positive and negative feedback.
- A direct neural indicator of feedback processing is the Feedback Related Negativity.

From these lines of evidence, the first hypothesis is extended and leads to the formulation of the general hypothesis of this thesis:

Acute stress leads to faster, riskier decisions under ambiguity only in subjects who show a clear cortisol increase in response to the acute stressor. The mechanism behind this cortisol induced change is a switch in feedback processing, preferring positive over negative feedback, resulting in a decrease in FRN amplitudes.

The experiments described and discussed in chapter two and three were designed in a way that the six desiderata formulated above will be implemented.

2 Experiment 1

2.1 Introduction

Experiment 1 was a first test of the general hypothesis developed in the general introduction. It reads:

Acute stress leads to faster, riskier decisions under ambiguity only in subjects who show a clear cortisol increase in response to the acute stressor. The mechanism behind this cortisol induced change is a switch in feedback processing, preferring positive over negative feedback, resulting in a decrease in FRN amplitudes.

In order to achieve an optimal test of the hypothesis six desiderata were formulated. In the general discussion they were sorted according to the development of the argument. Here their sequence is rearranged to fit better to the information provided in the next paragraphs:

1. Use a psychological (processive) stressor.
2. Validate the acute stressor by measuring the fast adrenergic and slower cortisol response.
3. Use an acute stressor, which allows to categorize the subjects into low and high cortisol responders.
4. Use a decision paradigm which is validated with respect to economic decision making and where risk taking is disadvantageous for the decision maker.
5. Use a decision paradigm, which allows to categorize an actual decision trial according to the previous trial's positive or negative feedback.
6. Use a direct cortical measure for feedback processing.

2.2 The Social Evaluated Cold Pressure Test

To induce an acute stressor the SECPT (Schwabe et al., 2008) was used. The principal procedure is that subjects have to immerse one hand into ice-cold water. The social evaluated component is introduced by a strict observer, dressed in a doctor's white coat, being very serious and unapproachable and obviously noticing every detail of the subject's response. Additionally, subjects are made to belief that their reaction is videotaped and used for later analysis of their behavior. The SECPT is widely used in stress research and is one of the most accepted procedures to induce acute stress (see Schwabe & Schaechinger, 2018 for a recent review).

There were two reasons to prefer this stress inducing procedure over the widely known and often used TSST (Kirschbaum et al., 1993). First, the TSST is difficult to conduct in the EEG-

laboratory. The TSST is a motivated performance task consisting of a brief preparation period (3 min) followed by a test period in which the subject has to deliver a free speech (5 min) and perform mental arithmetic (5 min) in front of an audience. Beside the problem that you need an audience and an appropriate facility the more severe problem is that you need some 30 minutes after the test to prepare the subject for EEG-measurement. At that time the maximum of the cortisol response has passed.

Second, and more important, research has shown (see Schwabe & Schaechinger, 2018 for a recent review) that roughly 50% of participants performing the SECPT show a strong endocrine reaction. This is of importance for the hypothesis developed here, as it is expected that only those subjects, who show a strong reaction on the HPA-axes, measured by cortisol secretion, should show riskier decisions after an acute stressor. A strong cortisol response rate to the TSST is observed in around 70% (Kudielka, Hellhammer, & Wüst, 2009) of the subjects, which would make it difficult to create even sized high cortisol responder and low cortisol responder groups.

Like the TSST, the SECPT is a psychological (processive) stressor, which fulfills desideratum 1. The SECPT is well manageable in the EEG-laboratory and from the published literature it can be expected that half of the subjects will show a strong HPA-axis activation, making it possible to classify the subjects into low and high cortisol responders (desideratum 3). This makes it possible to test the prediction that acute stress negatively influences decision making under uncertainty, only if a strong HPA-axis activation had occurred. The validation of the SECPT (desideratum 2) will be done by measuring heart rate to index the fast adrenergic stress response before and after the procedure and by taking salivary samples to measure cortisol levels at different points in time during the experiment.

2.3 The Balloon Analogue Risk Task

To study decision making under uncertainty, a modified version of the Balloon Analogue Risk Task (BART; Lejuez et al., 2002) was used. This paradigm has proven its value in several experiments in the laboratory of Miltner (Hewig, Miltner, & Silbereisen, 2012; Kessler, Hewig, Weichold, Silbereisen, & Miltner, 2017). In this task subjects are asked to inflate a balloon. Each pump enhances the monetary value of the balloon. Two outcomes are possible after a pump: (a) the balloon bursts and the money earned so far in the running trial is lost or (b) the balloon does not burst and the monetary value of the balloon is added to the amount of money earned so far. On the other hand, the subject can decide not to further inflate the balloon and the amount of money earned so far is added to his running account. There is a maximum of six

successful pumps in one trial. Subjects are informed that the probability of a burst is increasing with every pump, without giving them any information about the probabilities that a burst will occur on a specific pump level. This satisfies the condition of uncertainty: subjects know the different outcomes but not their probabilities.

The BART has acceptable psychometric properties. White, Lejuez & De Wit (2008) report a retest-reliability of .77. Other studies were able to demonstrate that this task predicts economic risk behavior (Aklin, Lejuez, Zvolensky, Kahler, & Gwadz, 2005; Lejuez et al., 2007; Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Lejuez et al., 2002). Besides the fact that the BART shows satisfactory reliability and validity, two other reasons guided the choice of this paradigm:

(a) it is very suitable to extract event related potentials from the ongoing EEG as enough positive and negative feedback signals will occur during this task and

(b) several studies using this paradigm were run in the laboratory of Miltner (Hewig et al., 2012; Kessler et al., 2017).

Thus, we have a good basis to compare the outcome with other studies run in this laboratory.

With the implementation of the BART desiderata 4 and 5 are fulfilled. Desideratum 6, which demands a direct measure of feedback processing in the brain, is adequately met by measuring EEG and extracting event-related brain potentials contingent on negative and positive feedback stimuli.

The BART does not allow to classify the result of a decision as better than expected. When subjects inflate the balloon, it is reasonable to assume that they expect a positive outcome. If this occurs, their expectation is met. If this is correct, subjects never experience an outcome that will be better than expected. However, if the balloon bursts, their expectations are not met, they experience an outcome that is worse than expected. In that case a strong negative FRN should be elicited and a reduced (less negative) FRN should be observed in the subjects with a strong cortisol response elicited by the acute stressor (see chapter 1.4.4).

The above formulated hypothesis furthermore depends on the following preconditions (manipulation checks):

- The acute stressor should lead to cortisol secretion and subjects should show a clear cortisol increase following the stressor.

- The acute stressor should lead to a psychological negative affect and elicit a strong and fast adrenergic stress response, as confirmed by the electrocardiogram.
- The decision-making paradigm should correspond to expected results as published in the literature.
- The FRN should show a fronto-central distribution over the scalp with relative more negative amplitudes after negative feedback than positive feedback (recall the discussion in section 1.4.4).

2.4 Methods

In the following paragraphs the experimental procedure and the measurement instruments are specified and independent and dependent variables are introduced. Where necessary (i.e., EEG) the processing steps which lead to the calculation of the dependent variables are explained.

2.4.1 Subjects

34 female and male subjects (all students at the University of Jena) participated in the experiment. They were all right-handed and with normal or corrected-to-normal vision. Exclusion criteria were defined, overweight or underweight (body mass index above 25 kg/m^2 or below 18 kg/m^2), left-handers, smokers, no long-term medication, no presence of a medical condition, and no night shift workers. All participating women used birth control via oral contraceptives. Those who took contraceptives which could influence cortisol measurement[6] were excluded from the study. Due to these criteria two female subjects had to be excluded. Thus, 16 female (mean age 22.43 years; SD =2.99; Range 18 to 29) and 16 male (mean age 23.55 years; SD =3.24; Range 19 to 32) subjects were included in the statistical analysis (independent variable GENDER). Two third were randomly assigned to the SECPT, the remaining subject performed the **S**ocial **E**valuated **W**arm **P**ressure **T**est (SEWPT). Later the SECPT subjects were subdivided into Low Cortisol Responders (SECPT-LCR) and High Cortisol Responders (SECPT-HCR). This constitutes the independent variable STRESS GROUP with the levels SECPT-HCR, SECPT-LCR and SEWPT. Participants were requested not to drink any alcohol in the evening prior to the experiment and to refrain from extensive sports during the morning of the day their experiment was scheduled.

After reading a description of the experiment, the risks of participation and the procedure of anonymization of data gathered from them, participants gave written consent (see Attachment

[6] Aida, Angeliq, Daylette, Drosfemine, Drospifen, Eliza, Lamiva, Layaisa, Layanina, Laynes, Maitalon 20/30, MYWY, Petibelle, Sidretelle, Veya ratio, Veyanne, Yara, Yasmine, Yasminelle, Yaz, Yiznell

6.2). At the end of the experiment, they received course credit or monetary compensation (10 € /hour). Additionally, participants were paid for wins in the BART task (mean 10.68 €, sd=1.43, range 8.57 to 14.75). The experiment was conducted in accordance with the Declaration of Helsinki, and was approved by the ethics committee of the Faculty of Social and Behavioural Sciences of the University of Jena.

2.4.2 Procedure

The experiment was conducted between 1.30 and 6:30 p.m. in order to examine the subjects at a time when the endogenous cortisol level is relatively low, due to the circadian rhythm of HPA axis activity (Kirschbaum & Hellhammer, 1999; Schreiber et al., 2006). Before the experiment participants were randomly assigned to the different treatment groups (see 3.2.1). Figure 2.1 shows the time course of the experiment.

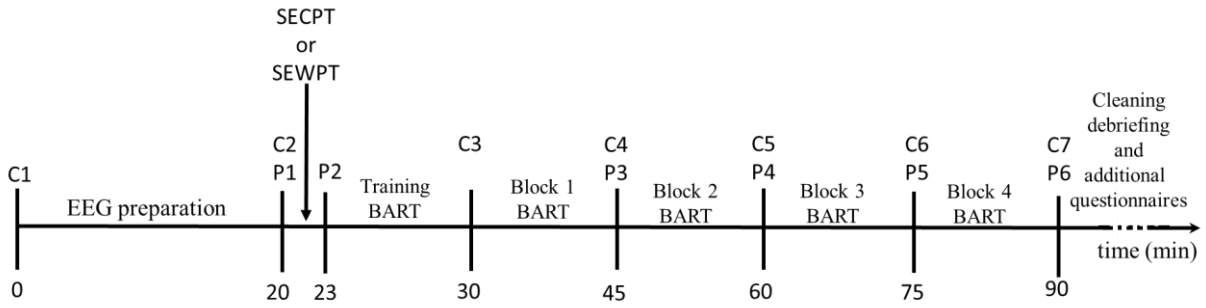

Figure 2.1: Time line of experiment 1. Abbreviations: C: Cortisol measurement; P: State questionnaire (PANAS-State); SECPT: Social Evaluated Cold Pressure Test; SEWPT: Social Evaluated Warm Pressure Test. BART: Balloon Analogue Risk Task

Immediately after arriving in the laboratory the first salivary cortisol sample was gathered. Subjects then were guided into a sound attenuated, electrically shielded cabin and seated on a comfortable chair in front of a 21-inch computer screen. Then the electrode cap with integrated electrodes for measuring the electrocardiogram (ECG) was attached. At that time a woman wearing a doctor's coat entered the cabin, introduced herself as the personal assistant of the chair of the department and as the person who is responsible for the correct conduction of the experiment. She answered all questions posed by the participant.

Then subjects for the first time filled out the Positive and Negative Affect Schedule (PANAS; Krohne, Egloff, Kohlmann, & Tausch, 1996). Details for the PANAS are given in section 2.4.2.5.

This was followed by taking the second salivary sample. Then SECPT or SEWPT (see 2.4.2.2) was performed, immediately followed by a second PANAS-State. Then 10 training trials of the **B**alloon **A**nalogue **R**isk **T**ask (BART, see 2.4.2.1.) were done. Ten minutes after the start of the

SECPT or SEWPT 200 trials of the BART task were executed. There were 4 blocks (independent variable BLOCK) with 50 trials each. After each block a salivary sample was collected and subjects filled out another sheet of the PANAS-State. After the 4th block the EEG-cap was removed and subjects were given the opportunity to clean and dry their hair. Then they filled out additional personality questionnaires (results will be not reported here), were completely informed about the scientific goals of the study and received 20 Euros as compensation for their time spend in the laboratory and were paid their gain in the BART task.

2.4.2.1 Balloon Analogue Risk Task

Subjects performed 10 training trials of the BART before the SECPT or SEWPT and four blocks of 50 trials each, starting 7 minutes after the completion of the acute stressor. In the BART task (Lejuez et al., 2002), participants were requested to inflate a balloon up to a maximum of six times (levels). This was done by pressing a button for each step (independent variable LEVEL). With a second button (the stop button), pumping of the balloon could be stopped whenever the participant decided that the balloon was blown up enough before blasting. When pumping was finished and the balloon did not blast, the trial's proceeds were added to the money earned so far. The buttons were attached to the left and right backrest of the chair. The positions of both buttons were counterbalanced over subjects. With each pump, the balloon increased in size and the amount of money that could be won (positive feedback) increased.

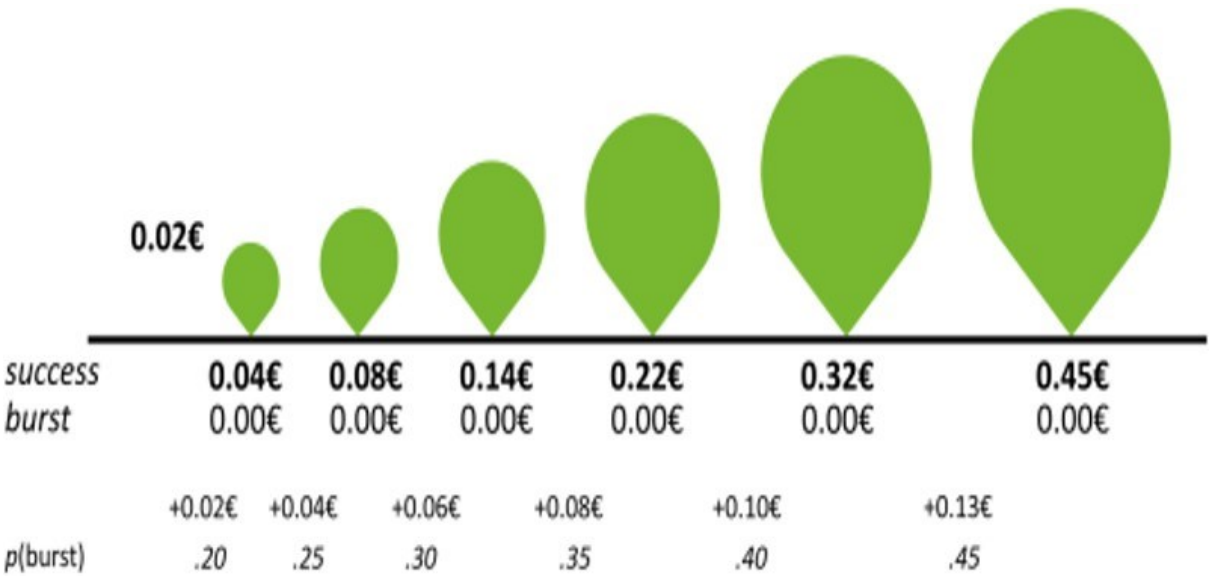

Figure 2.2: Schematic display of the Balloon Analogue risk task. The upper row shows the six possible sizes of the balloon. The amount of 0.02 € is won, when cashing out before the first pump. The second row (success) gives the amount of money that could be won in case of positive feedback. The third row (burst) says that the money gained up to a certain level is lost after negative feedback. The fourth row gives the increase in gains after each decision to continue and the last row shows the probability of negative feedback after a decision to continue at one of the six levels. From Kessler et al. (2017) with friendly permission.

Also, the probability for a blast of the succeeding trial(s) increased. When the balloon blasted (negative feedback), all the money won so far in a trial was lost. Figure 2.2 provides the amount of money at each risk level and the negative feedback probabilities for each level.

Figure 2.3 depicts a trial of the BART task. It started with the presentation of a fixation cross in the center of the screen. After a random interval of 500 to 1000 milliseconds, the first balloon, worth 2 cents, appeared for a maximum of 4 seconds. Now, the participants had to choose either to stop pumping the balloon and cash-out or to continue pumping. When decided to cash-out, the amount won so far was shown 400ms after the decision for 2 seconds and the next trial started with a new fixation cross at the lowest risk level (2 cents). Choosing to continue, either a thumb-down sign or a thumb-up sign appeared after 400ms. Thumb-down (negative feedback) meant that the balloon has exploded, and that the money gained so far in the trial was lost. Then the next trial started at the lowest risk level. Thumb up (positive feedback) meant that the next larger balloon will be shown and the subject would be requested to decide whether to cash out or to continue the trial.

Choosing to continue, either a thumb-down sign or a thumb-up sign appeared after 400ms. Thumb-down (negative feedback) meant that the balloon has exploded, and that the money gained so far in the trial was lost. Then the next trial started at the lowest risk level. Thumb up (positive feedback) meant that the next larger balloon will be shown and the subject would be requested to decide whether to cash out or to continue the trial. With each additional pump, the amount of money that could be won increased (2, 4, 8, 14, 22, 32, 45 cents). Simultaneously, the probability that the ball would burst increased from 20% in 5% steps up to 45%. Subjects were only told that the probability to lose increases with the size of the balloon, without giving any further information about the exact probabilities.

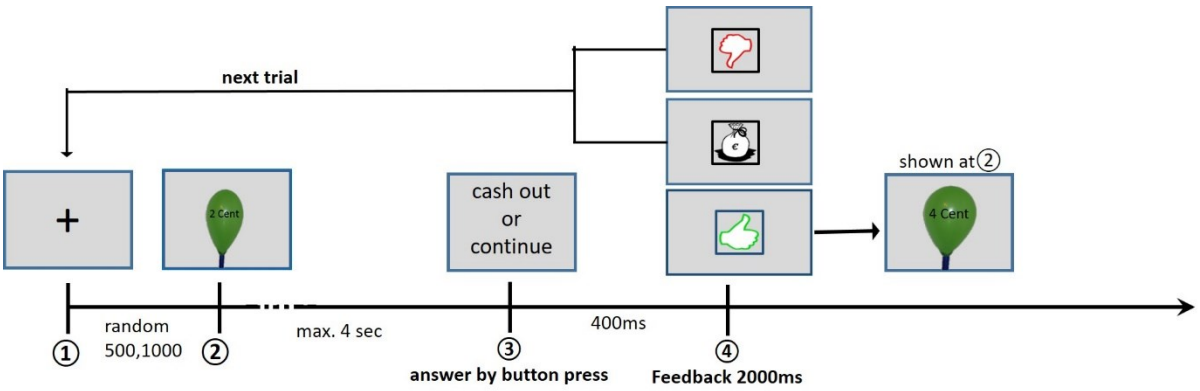

Figure 2.3: A trial of the BART task. Details see text.

As argued in the introduction, the feedback to the previous trial is crucial for the behavior in the succeeding trial. Thus, variables described below were calculated under the condition whether the feedback in the previous trial was positive or negative. This constitutes the independent variable PREVIOUS FEEDBACK with the levels positive and negative.
Two dependent variables were calculated from the BART: the *adjusted number of pumps* "defined as the average number of pumps, excluding balloons that exploded (i.e., the average number of pumps on each balloon prior to money collection), were preferable because the number of pumps was necessarily constrained on balloons that exploded, thereby limiting between subjects variability in the absolute averages" (Lejuez et al., 2002, p. 78).

Kessler et al. (2017) computed the percentage, to which participants decided to inflate the balloon to a certain level, after they received a positive or negative feedback in the preceding trial. Both dependent variables will be used here.

2.4.2.2 Social Evaluated Cold and Warm Pressure Tests

In order to induce acute stress, the SECPT (Schwabe et al., 2008; Schwabe & Schaechinger, 2018) was used. Under the stress condition, subjects had to immerse their right hand for 3 minutes into ice-cold water of 1-3 °C. The water in the container was moved constantly with a small propeller. At the same time, they were videotaped and observed by the female with the doctor's coat. She was instructed to behave as seriously and unapproachable as possible and as a person who was carefully observing every detail of the subject's response. In order to further increase the psychosocial stressor component, subjects were led to believe that their mimics and gestures during the task would be precisely noted by the investigator. The non-stressful control procedure (SEWPT) was similar than that of SECPT with the exception that the water was at body temperature (36-38 °C). The stressed participants would be classified into low cortisol responders and high cortisol responders, depending on their cortisol rise score in response to the SECP. In order to obtain equal sized groups, two-thirds of the subjects were randomly assigned to the stress condition and one third to the warm water condition.

2.4.2.3 Salivary Cortisol Measurement

Salivary samples were taken at seven time points during the experiment, with subjects requested to chew a cotton ball for one minute, using standard Eppendorf tubes, (1.5 ml, Eppendorf, Hamburg, Germany) which were newly presented at each time point. The tubes were stored at room temperature until completion of the session, and then kept at -20 °C until analysis. After thawing for biochemical analysis, the fraction of free cortisol in saliva (salivary cortisol) was determined using a radioimmunoassay kit (Kirschbaum, Strasburger, Jammers, & Hellhammer,

1989) with Salivettes (Sarstedt Inc., Texas). Inter- and intra-assay coefficients of variance were below 9%. These are coefficients of variability, the larger the value, the greater the error in the assay (Hanneman, Cox, Green, & Kang, 2011). For each subject, there were 7 cortisol intensities measure in nanomol per liter (nmol/l), defining the independent repeatedly measured variable TIME OF MEASUREMENT with 7 levels.

2.4.2.4 EEG and ECG Acquisition and Analysis

EEG was recorded from 64 electrodes placed at locations defined by the extended 10-10 electrode reference system (Chatrian, Lettich, & Nelson, 1988) using an Easy-Cap electrode system (Easycap M64, Easycap GmbH, Herrsching, Germany). All sites were referenced to FCz, the ground electrode was Iz. Silver/silverchlorid (Ag/AgCl) electrodes were used, and the impedances of the EEG electrodes were kept below 5 kiloohm (kΩ). EEG was amplified by means of two 32-channel BrainAmp amplifiers (input impedance: 10 megaohm (MΩ); Brain Products, GmbH) in alternate current (AC) mode. The pass-band was set to .016 to 499 Hz (-12 dB/octave rolloff). Signals were digitalized at a rate of 1000 Hz and stored on hard disk for later analysis. There was an additional electrode below the left eye, exactly vertical to FP1. The bipolar derivation of these two electrodes provided the vertical EOG (VEOG) used for later eye movement and blink artifact analyses.

The processing steps described below follow the recommendations given in the standard textbook on ERP and EEG analysis of Luck (2014). All processing steps were done with Brain Vision Analyzer 2.1.2 (Brainproducts, Gilching).

After rereferencing the data to a linked mastoid reference, all channels were digitally filtered with a non-phase distorting Butterworth bandpass filter, set from .1 to 12 Hz half power cut-offs at -24db. This filter removes slow drifts and high frequency artifacts (i.e. muscle activity) from the data without distorting the phases for the different frequencies. For each block segments from -500 to 5500 ms around the feedback stimuli (see Figure 3.2) were extracted and the vertical EOG was extracted from the EEG at each electrode by the correction procedure described by Gratton, Coles & Donchin (1983). The long segments avoid possible edge artifacts of the eye correction procedure. Then segments were shortened (-200 to 800 ms around feedback stimuli), baseline corrected (average amplitude between -200 to 0 ms with reference to stimulus presentation) and segments containing voltage steps of more than 30 µV from one sampling point to the next, showed larger amplitude differences than 150µV between the smallest and largest amplitude in the segment or showed low activity (less than .5 µV) for more

than 100ms were rejected as artifacts. Finally, artefact free averages in each block were calculated contingent on the positive and negative feedback stimulus.

The difference potential (negative minus positive feedback) was calculated for each block[7]. Then the amplitude and latency of the FRN was determined by a semiautomatic procedure. At the latency of the FRN at FCz the average amplitude ± 15ms around the base to peak was computed and used as a dependent variable in the statistical analyses.

The electrocardiogram was measured by an additional electrode which is part of the EEG-cap system. Five 30 seconds segments from 30 seconds before the start to 120 seconds after the start of the SECPT or SEWPT were extracted. The peak of the R-wave was marked (Analyzer Solution ECG Markers) and the interbeat intervals were transformed to beats per minute (bpm) indexing the pace of heard activity. This defines the independent repeatedly measured variable TIME OF MEASUREMENT with five levels.

2.4.2.5 Questionnaires

Self-reported mood was assessed with the German version of the Positive and Negative Affect Schedule (PANAS; Krohne et al., 1996). It measures the actual positive and negative affect. The questionnaire consists of twenty adjectives (e.g. ‘aktiv`, ‘nervös’) scaled from 1 (very little) to 5 (very much). The positive affect score consists of the sum of 10 positive adjectives, the negative affect score is calculated accordingly for 10 negative adjectives. It was administered six times during the experiment (see 2.4.2). This defines for the analysis of positive and negative affect the repeatedly measured independent variable TIME OF MEASUREMENT with 6 levels.

In addition, after the experiment participants were asked to estimate the probabilities that a balloon at each of the six levels exploded. The difference between these subjective probabilities and the real ones (see Figure 2.2) is an estimate of subjects over- or underestimation of the real probabilities (prediction error).

Furthermore, subjects filled out the *Sensitivity to Punishment and Sensitivity to Reward* Questionnaire (SPSRQ; Torrubia, Avila, Moltó, & Caseras, 2001). These data will not be reported here.

2.4.3 Statistical Analysis

All statistical analysis was done with IBM SPSS Statistics Version 22. The F-Value from analysis of variance (ANOVA) effects will be reported as follows (here exemplified for a

[7] As discussed in chapter 1.4.4. this difference potential subtracts a condition where expectations are met (positive feedback) from a condition where expectations are not met (negative feedback=worse than expected).

STRESS GROUP by TIME OF MEASUREMENT interaction for salivary cortisol measures): $F(12,156)=13.15$; $p<.01$;$\varepsilon=.41$;$\eta^2=.50$. The values after the F give nominator and denominator degrees of freedom, followed by the empirical F-Value and the actual p-value (probability of F given the null hypothesis). If necessary, the p value for repeatedly measured independent variables is corrected by the method proposed by Greenhouse & Geisser (1959). In this case, the Greenhouse-Geisser correction factor ε is reported. It varies between 0 and 1 and corrects for possible violations of the sphericity assumption, which postulates homogenous correlations between levels of repeatedly measured independent variables. Additionally, for all significant effects ($p<.05$), the partial effect size measure η^2 (Lakens, 2013) is reported. It gives the amount of variance explained by the independent variable(s).

Significant main effects and interactions are further analyzed by Dunn's multiple comparison procedure (Kirk, 2007). This is basically a Bonferroni corrected t-tests for pairwise comparisons against the error term of the specific effect. However, in contrast to most follow-up procedures the number of pairwise comparisons (C), relevant to disentangle the effect under consideration, is specified. For example, the interaction STRESS GROUP by GENDER by TIME OF MEASUREMENT for salivary cortisol measures looks at 3 x 2 x 7=42 means. If all possible pairwise comparisons would be considered (as for example as in the TUKEY test) 861 pairwise comparisons have to be computed, resulting in a corrected significance level of .05/861=.000058. Most of the 861 possible pairwise comparisons are irrelevant for the hypothesis under test. Here we can for example reduce the number of comparisons to 42 to look at the differences of the 3 stress groups separate for males and females[8] at each time of measurement. This results in a much more comfortable significance level of .05/42=.0012 for each comparison. For the sake of simplicity, not all pairwise comparisons are calculated, but the critical difference (ψ_{crit}), which has to be exceeded for the given measurement unit, is reported. Together with the critical difference, the number of pairwise comparisons C, the degrees of freedom for the error term and the mean squares error (MSE) for the effect under consideration, is reported. The complete notation is ($\psi_{crit,\ C=42;\ df=156;\ MSE=1.61} =2.42$). The critical t-values and formulas can be obtained from the tables published in Kirk (2007).

It is well known that a non-significant result of a statistical test (empirical $\alpha >.05$) does not automatically allow deciding in favor of the statistical null hypothesis. To avoid this often-committed error (Button et al., 2013; Camerer et al., 2016; Cohen, 1988, 1990; Sedlmeier &

[8] To compare the three stress groups at each time point 7 * 3 =21 pairwise comparisons are needed. As this has also be computed for female subjects one obtains C=42 pairwise comparisons

Gigerenzer, 1989) the probability of falsely deciding in favor of the statistical null hypothesis (β-error) has to be computed. This can only be done if the size of the effect of interest is specified (Cohen, 1988). Here the type II error β or the power of the statistical tests (1-β) is reported whenever a statistical test, which is relevant for the hypotheses under test (e.g. STRESS GROUP by BLOCK), is not significant. These probabilities are based on the assumption that a medium-sized effect (10% of systematic variance) is really present in the population. Following the recommendation of Cohen (1988) null hypotheses will only be interpreted if the power is larger than .8. A power of .8 means that in an exact replication of this study, the probability to come up with the same result is 80%.

The calculation of the power values is demonstrated for one example. For the reaction times, the triple interaction STRESS GROUP by FEEDBACK by BLOCK is not significant and reported (see 2.5.2.1) as STRESS GROUP by FEEDBACK by BLOCK [F(6,78)=1.24; p=.29;ε=.84; power($\Omega^2 \geq .10$; ρ=.7)> .99].

As mentioned above, we assume a population effect size of $\Omega^2 \geq .10$. Ω^2 is defined as the population effect variance (σ^2_{effect}) divided by the sum of population effect variance and population error variance ($\sigma^2_{effect} + \sigma^2_{error}$). To calculate the power of the statistical test for a given effect size Ω^2 for between subjects factors, the noncentralicity parameter λ is needed to calculate the non-central distribution. It is defined as

$$\lambda = \frac{\sigma^2_{effect}}{\sigma^2_{error}} * N = \Phi^2 * N \qquad \text{with} \qquad \Phi^2 = \frac{\Omega^2}{1-\Omega^2}$$

where N is the number of subjects (here 32).

In case of repeated measurement, two additional population variables have to be considered. First the average population correlation ρ and second the number of levels (s) of the involved repeatedly measured independent variable(s). In general:

$$\lambda = \frac{\Phi^2}{1-\rho} * N * s$$

The population correlation ρ can be estimated from the empirical data.

For our example ρ is estimated as .70. FEEDBACK has 2 levels and BLOCK 4 levels resulting in s=2*4=8. Thus

$$\lambda = \frac{\Phi^2}{1-\rho} * N * s = \frac{0.11}{1-0.7} * 32 * 8 = 93.87$$

From published tables (Hager, 2004) one can see that the power for the given degrees of freedom of the numerator of the F-Tests is in this case larger .99, which is equal to a β-error of less than 1%. The exact value is .9991. This result can be obtained by using one of several freeware programs as for example GPOWER3 (Faul, Erdfelder, Lang, & Buchner, 2007).

2.5 Results

The results are reported in two main sections, namely “Manipulation Checks” and “Influence of Stress and Feedback”. The first section illustrates the results, demonstrating that all the manipulations in this complex experiment worked as expected, which means that

a) cortisol was secreted in the SECPT,
b) subjective mood measures varied with the experimental conditions,
c) the BART replicated published results and
d) the FRN showed its typical latency and a fronto-central negative topography.

The second section then evaluates the results relevant to the hypothesis under test.

2.5.1 Manipulation Checks

In this chapter statistical information is given whether the basic paradigms used in this experiment, namely the SECPT, the BART and the Feedback Related Negativity functioned as expected.

2.5.1.1 Social Evaluated Cold Pressure Test (SECPT)

If the SECPT works as a valid acute stressor, cortisol secretion should show the expected profiles for high cortisol responders, low cortisol responders and controls. Heart rate should increase with the beginning of the SECPT indicating the early adrenergic stress response and self-reported mood should result in enhanced negative affect and decreased positive affect.

2.5.1.1.1 Salivary Cortisol

Half of those subjects who passed through the SECPT should show a strong cortisol secretion, whereas the other half of these subjects should show a nearly identical cortisol reaction as the SEWPT subjects.

Based on the difference score, between C3+C4 minus C1+C2 (see Figure 2.1), SECPT subjects were divided by median split into high cortisol responders and low cortisol responders separate for each gender. The median for male subjects was -.46 nmol/l, for females -.12 nmol/l. The range for the male high cortisol responders was 1.50 to 11.95 nmol/l, male low cortisol responders from -3.98 to .46. The respective ranges for the females were .13 to 3.84 nmol/l and from -.94 to -.36 nmol/l. The cortisol profiles for the different groups are shown in Figure 2.4. Using the criteria taken from the review Schwabe et al. (2008), which defines a high cortisol responder by an increase of 1.5 nmol/l from baseline, all male subjects in the high cortisol responder group showed a reliable increase of HPA- axis activity, whereas only 1 female subject was above this criterion.

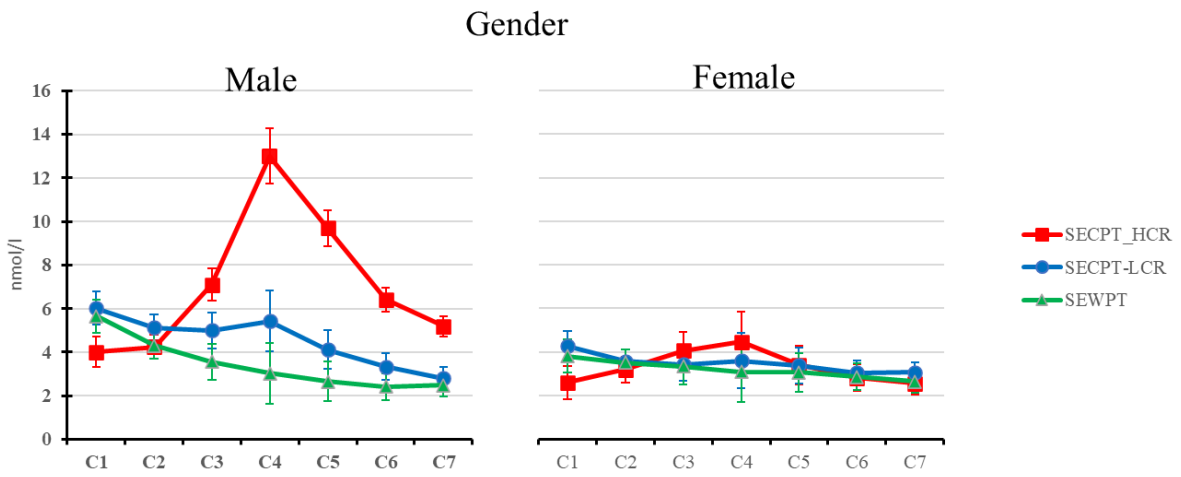

Figure 2.4: Cortisol intensities measured from salivary samples at each of 7 times of measurement for each gender and for each of the stress groups. Vertical lines indicate 1 standard error of measurement (SEM). The grey bar indicates the timing of the SECPT or SEWPT.

For the manipulation check we expected stronger cortisol reactions after the SECPT in both genders compared to SEWPT and approximately 50% high cortisol responders in both genders. The statistical analysis by a STRESS GROUP by GENDER by TIME OF MEASUREMENT ANOVA with repeated measurement on the last factor showed the expected interaction of STRESS GROUP by TIME OF MEASUREMENT [$F(12,156)=13.15$; $p<.01$;$\varepsilon=.41$;$\eta^2=.50$], which was further modified by the triple interaction STRESS GROUP by GENDER by TIME OF MEASUREMENT [$F(12,156)=6.55$; $p<.01$;$\varepsilon=.41$;$\eta^2=.15$]. The means are shown in Figure 2.4. Follow-up tests for the triple interaction, comparing the stress groups for each gender at each measurement point ($\psi_{crit,\ C=42;\ df=156:\ MSE=1.61} = 2.42$) revealed, that male high cortisol responders differed from male low cortisol responders and male controls at C4, C5 and C6. At C3 and C7 high cortisol responders only differed from the controls. There were no statistically significant differences between male low cortisol responders and the male control group, at any measurement point, as there were no group differences at C1 and C2. There was no difference between stress groups at any measurement point for the female subjects.

Thus, the manipulation check for the cortisol reaction met the expectations only for male subjects.

2.5.1.1.2 Electrocardiogram

The SECPT should result in a clear increase in heart rate, when immersing the hand into the cold water. This indicates the fast, adrenergic stress reaction.

The average heart rate for five consecutive 30 second intervals, from 30 second before the start of the SECPT to 2 minutes after its start (see 2.4.2.4), were submitted to a STRESS GROUP by GENDER by TIME OF MEASUREMENT ANOVA. The main effect of TIME OF MEASUREMENT

[F(4,104)=46.14; p<.01;ε=.40;η^2=.24] was qualified by a STRESS GROUP by TIME OF MEASUREMENT INTERACTION [F(8,104)=4.83; p<.01;ε=.46;η^2=.37], depicted in Figure 2.5.

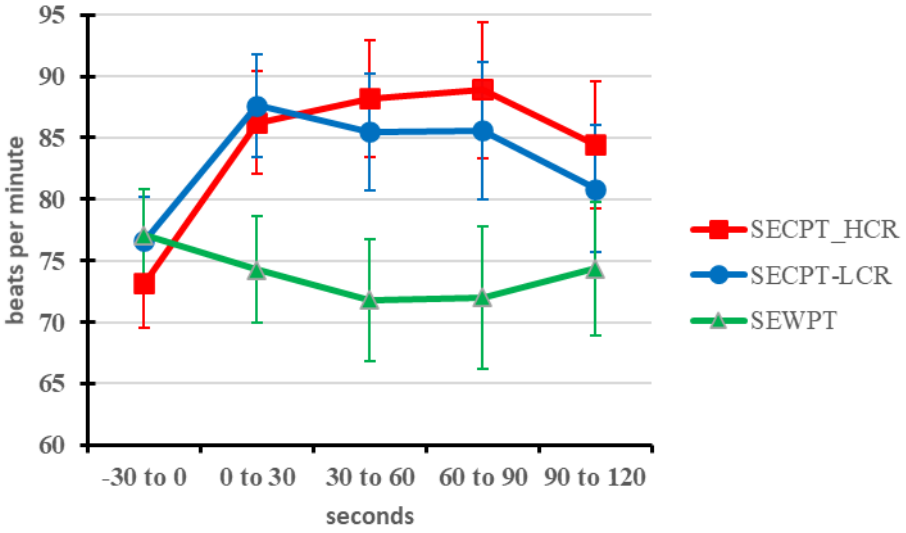

Figure 2.5: Mean heart rate of consecutive 30 seconds interval before and after the SECPT or SEWPT for the three stress groups. Error bars indicate 1 SEM

Post-hoc tests, comparing the baseline (-30 to 0 seconds) before the SECPT or SEWPT to each of the measurements after the stress test ($\psi_{crit,\ C=12;\ df=104;\ MSE=43.4}$ =8.23), reveal that both SECPT groups show a significant increase from baseline (-30 to 0 seconds) to measurement 4 (60 to 90 seconds). For the SEWPT group there was no difference in heart rate between baseline and all other measurement points. When looking at group differences at each measurement ($\psi_{crit,\ C=12;\ df=104;\ MSE=43.4}$ =8.42), both SECPT groups differed from the SEWPT at measurement 2 to 4, with no differences observed between low and high cortisol responders at any measurement.

Thus, the fast, adrenergic stress reaction occurs as expected.

2.5.1.1.3 Positive and Negative Affect Schedule

The PANAS gives an index for negative and positive self-reported mood. The possible range for each of these measures is from 0 to 24. For the SECPT to influence mood as expected, negative affect is expected to go up and positive affect should go down at measurement point 2. There were six times of measurement (see Figure 2.1), with time point P1 immediately before and P2 immediately after the SECPT or SEWPT. Time points P3 to P6 were immediately after each block of the BART.

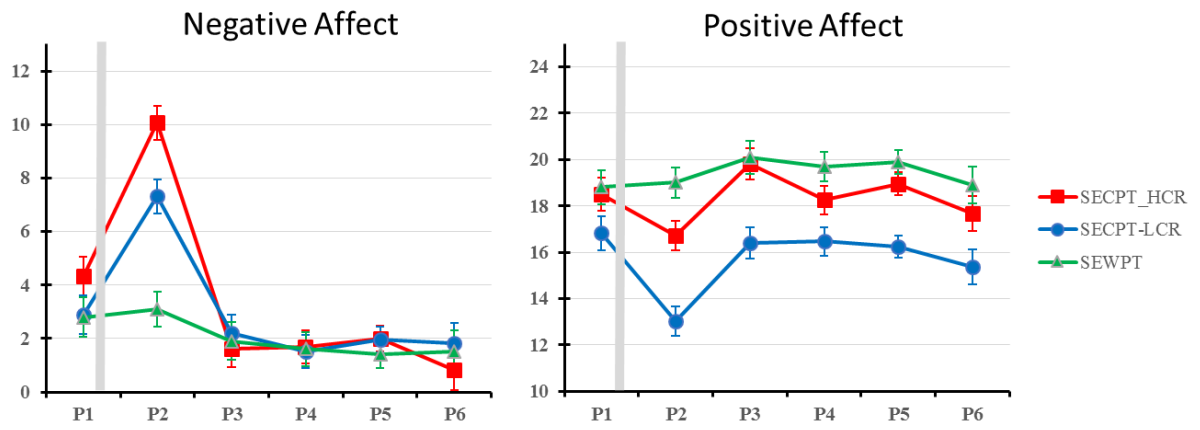

Figure 2.6: Negative (left) and positive (right) affect as measured by the Positive and Negative Affect Schedule. Grey line indicates the timing of the SECPT or SEWPT. Error bars are ±1SEM.

For the STRESS GROUP by GENDER by TIME OF MEASUREMENT ANOVA for negative affect (see Figure 2.6 left), the crucial interaction STRESS GROUP by TIME OF MEASUREMENT interaction was significant [$F(10,130)=10.60$; $p<.001$;$\varepsilon=.74$;$\eta^2=.45$]. Follow-up pairwise comparisons of the groups at each measurement point ($\psi_{crit,\ C=18;\ df=130:\ MSE=2.08} =1.80$) showed, that only at P2 both SECPT groups differ from the warm water control group.

The other significant effect was a GENDER by TIME OF MEASUREMENT interaction [$F(5,130)=4.27$; $p<.01$;$\varepsilon=.74$;$\eta^2=.14$]. Post-hoc tests, comparing male and female subjects at each measurement point ($\psi_{crit,\ C=6;\ df=130:\ MSE=2.08} =1.24$), showed that females had a reduced negative affect, compared to males, only at P5 and P6.

The same ANOVA for the positive affect measure showed no significant results. Though a look at Figure 2.6 (right side) suggests that positive affect dropped at P2 only for the SECPT groups the interaction STRESS GROUP by TIME OF MEASUREMENT interaction was clearly not significant $F[10,130)<1$; $p=.79$;$\varepsilon=.63$;power($\Omega^2\geq.10$; $\rho=.80)>.99$], as was the triple interaction STRESS GROUP by GENDER by TIME OF MEASUREMENT [$F(10,130)<1$; $p=.48$;$\varepsilon=.63$; power($\Omega^2\geq.10$; $\rho=.80)>.99$].

The expected variation in actual self-reported mood was found for the negative affect measure.

2.5.1.1.4 Balloon Analogue Risk Task

For the manipulation check three dependent variables were examined. First, the number of pumps. Second, the number of cash-outs and third the number of blasts. For each of these measures a STRESS GROUP by GENDER by LEVEL ANOVA was computed. If the BART task worked properly, we would expect a main effect of LEVEL for all three measures. The number of pumps should decrease from level 1 to 6, the number of cash-outs should be maximal around

level 3 and 4, as this is the optimal strategy (Lejuez et al., 2002, p. 78) to maximize gains. For the number of blasts, we expect a monotonic decrease from level 1 to 6.

The results of the ANOVAS clearly support the above formulated expectations. All three dependent variables showed a clear main effect of LEVEL, with its structure in line with the predictions. The details can be taken from Table 2.1

Table 2.1: Means for the main effect LEVEL for three dependent variables from the BART task. The last two rows give the empirical F-value and the critical difference for a complete pairwise comparison of the six means. MSE=Mean Squares Error.

Level	Pumps	Cash-Outs	Blasts
1	48.10	1.88	9.59
2	36.97	1.40	8.93
3	23.95	4.06	7.24
4	11.04	5.71	3.72
5	3.38	3.90	1.32
6	.94	1.13	.42
F-value main effect LEVEL, df(5,130)	1631.01	14.65	61.16
MSE	28.18	14.27	3.19
$\psi_{crit,\ C=15}$	3.07	2.82	1.34

2.5.1.1.5 Feedback Related Negativity

For the FRN, we expected a fronto-central negativity, elicited by relatively stronger negativity for negative feedbacks, when compared to positive feedbacks.

The FRN has an average latency of 260 milliseconds. As can be seen in Figure 2.7 (right) the FRN had the typical fronto-central topography, resulting from the expected difference between negative and positive feedback (Figure 2.7 left). To confirm the visual topographical interpretation statistically, the FRN amplitude was submitted to a MIDLINE (anterior-frontal, frontal, fronto-central) by HEMISPHERE (left, middle, right) by BLOCK repeated measurement ANOVA. This constellation includes 9 electrodes (Af3, Afz, AF4, F3, Fz, F4, Fc3, FCz, Fc4) defined by the combination of the independent variables MIDLINe and HEMISPHERE.

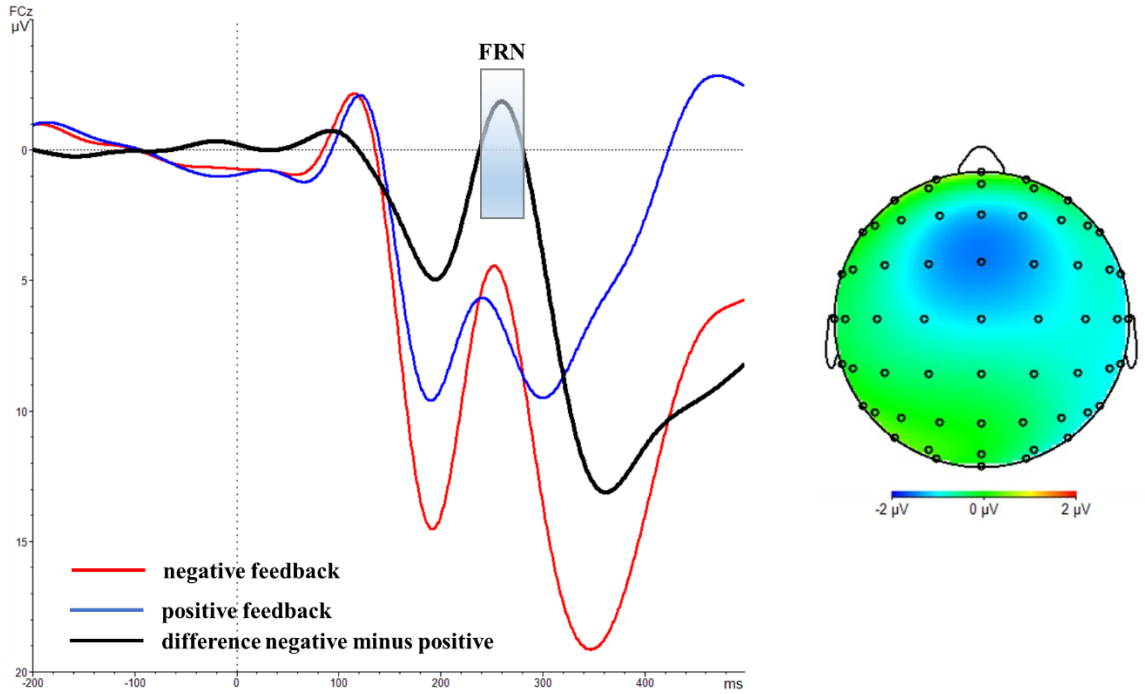

Figure 2.7: Grand averages at FCz for all subjects (left). Plotted together are the potentials elicited by the negative feedback stimulus (red), by the positive feedback stimulus (blue) and the difference potential negative minus positive feedback (black). Time axes from -200 to 500 ms; y-axes from -5 to 20 µV. Row (left) 2 shows the topographies of the average amplitude (from 245 to 275 ms) from the difference potential. The right side shows the topography of the FRN for the grey shaded area in the difference potential.

There was a main effect of MIDLINE [$F(2,62)=7.47$; $p<.01$;$\varepsilon=.56$;$\eta^2=.19$] showing the largest amplitudes at F (-1.54µV) and FC (-1.73 µV) compared to AF (-.752 µV). Additionally, a main effect of HEMISPHERE [$F(2,62)=6.91$; $p<.01$;$\varepsilon=.94$;$\eta^2=.18$] was observed, showing the largest negative amplitudes at midline (-1.78µV), compared to left (-1.00µV) and right (-1.23 µV). No effect, which included BLOCK, was significant.

This confirms a classical FRN topography with a midline fronto-central negative maximum and a symmetric reduction over both hemispheres.

2.5.2 Influence of Acute Stress and Feedback

The central hypothesis states that acute stress changes feedback processing, leading to faster and riskier decisions in situations of uncertainty, in which the outcomes are known, but not their associated probabilities.

2.5.2.1 Reaction time

From the general hypothesis, it is expected that reaction times are faster after acute stress, especially for those subjects who showed a strong cortisol reaction. Thus, reaction times after a positive or negative feedback, were submitted to a STRESS GROUP by GENDER by PREVIOUS FEEDBACK by BLOCK ANOVA. The only significant effect was a main effect of BLOCK

[F(3,78)=4.83; p<.01;ε=.64;η^2=.33], with decreasing reaction times from block 1(399 ms), over block 2 (377 ms) and block 3 (353 ms) to block 4 (347 ms).

The interactions relevant to the hypothesis STRESS GROUP by PREVIOUS FEEDBACK [F(2,26)<1; p=.78; power(Ω^2≥ .10; ρ=.7)> .95] and STRESS GROUP by PREVIOUS FEEDBACK by BLOCK [F(6,78)=1.24; p=.29;ε=.84; power(Ω^2≥ .10; ρ=.7)> .99] were not significant. Power is sufficient and would be the same if the independent variable GENDER had been involved. Thus, the null hypothesis of the interaction relevant for the theoretical hypothesis can be accepted.

2.5.2.2 Balloon Analogue Risk Task

Two dependent variables were tested with respect to their dependence on acute stress and positive and negative feedback (see 2.4.2.1).

For the average number of adjusted pumps, it is expected, that high cortisol responders show riskier behavior (more pumps), especially after positive feedback. As women did not show a strong cortisol response in the SECPT this is expected to be moderated by gender.

The STRESS GROUP by GENDER by PREVIOUS FEEDBACK by BLOCK ANOVA did *not* show the expected STRESS GROUP by GENDER by PREVIOUS FEEDBACK [F(2,26)=2.25; p=.13; power(Ω^2≥ .10; ρ=.5)> .93] interaction, nor the STRESS GROUP by GENDER by PREVIOUS FEEDBACK by BLOCK [F(2,78)<1; p=.52; ε=.90; power(Ω^2≥ .10; ρ=.5)> .99] interaction. Power is identical for the interactions without GENDER. Thus, for this measure, risk behavior is not influenced by acute stress and/or feedback.

The only significant result was a GENDER by PREVIOUS FEEDBACK interaction [F(1,26)=5.26; p<.05;η^2=.17], with no difference in average number of adjusted pumps between positive and negative feedback in men (4.01 vs 4.04), whereas women were more cautious after negative feedback (4.08 vs 3.65).

For the percentage to which participants decided to inflate the balloon to a certain level after they received a positive or negative feedback in the preceding trial, expectations are identical to those formulated above. However, here, the independent variable LEVEL is used. As too many subjects would have been lost due to cash-outs on level 5 and 6, only levels 1 to 4 were considered.

The STRESS GROUP by GENDER by PREVIOUS FEEDBACK by LEVEL ANOVA showed the expected STRESS GROUP by GENDER by PREVIOUS FEEDBACK interaction [F(2,26)=3.88; p<.05; η^2=.23], shown in Figure 2.8.

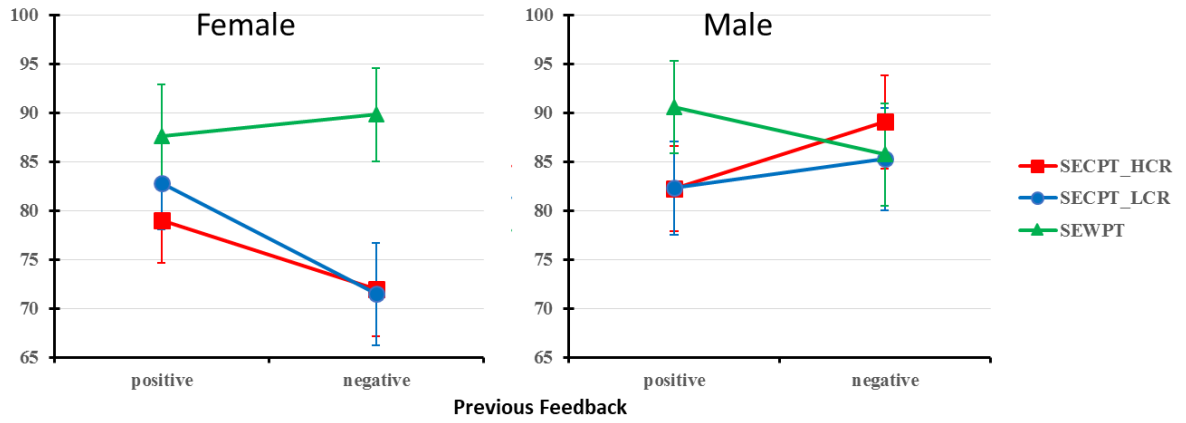

Figure 2.8: Conditional probabilities of pumping a balloon after having received a positive or negative feedback in the previous trial in percent (y-axes) for females (left) and males(right) for each of the stress groups, The higher the value on the y-axis, the higher the probability of making a risky decision. Error bars denote 1 SEM.

Descriptively, it does not look as if the male SECPT groups behaved riskier than males of the SEWPT group, nor that previous positive feedback led to more risky decisions. The follow-up tests confirm this impression. From the perspective of differences between positive and negative feedback ($\psi_{crit,\ C=6;\ df=126;\ MSE=197.2}$=7.70), female SECPT subjects had larger values after positive than after negative feedback, with all other comparisons not being significant. From the perspective of gender differences in different conditions ($\psi_{crit,\ C=6;\ df=126;\ MSE=197.2}$ =7.70), the only significant gender difference was, that male SECPT (HCR and LCR) subjects made more risky decisions after negative feedback. Finally, from the perspective of stress group differences ($\psi_{crit,\ C=12;\ df=126;\ MSE=197.2}$ =8.53), females SECPT-HCR subjects had smaller values than female SEWPT participants after negative feedback, with no difference observed between SECPT groups. After positive feedback, female SECPT_HCR subjects has lower values than SEWPT females, with no other comparison between these groups being significant.

No significant differences between stress groups were observed for males. However, within positive feedback, the difference between the SECPT groups and the control group approached significance (p=.06).

The other relevant interaction STRESS GROUP by GENDER by PREVIOUS FEEDBACK by LEVEL [$F(6,78)=1.66$; $p=.18$; $\varepsilon=.60$, power($\Omega^2 \geq .10$; $\rho=.6$)$> .99$] was not significant and the null hypothesis can be accepted with an error probability of less than one percent.

After the experiment, subjects estimated the probability of a burst for each of the six possible balloon sizes. The prediction error, which is the difference between these subjective probabilities and the objective ones (see Table 2.2) is an estimate of subjects over- or underestimation of the real probabilities. These data were submitted to a STRESS GROUP by

GENDER by LEVEL ANOVA, with repeated measurement on the last factor. The only significant result was a main effect of LEVEL [$F(5,130)=4.94$; $p<.05$; $\varepsilon=.38$; $\eta^2=.16$].

Table 2.2: Subjective estimated percentages for a balloon to burst (second column) for each balloon size (level), the real burst percentages (third column) and the difference between estimate and real burst percentages (prediction error; fourth column).

Level	Estimated	Real	Prediction Error
1	16.033	20	-03.97
2	20.483	25	-04.52
3	30.244	30	00.24
4	37.806	35	02.81
5	49.750	40	09.75
6	56.961	45	11.96

Follow-up tests ($\psi_{crit,\ C=15;\ df=130;\ MSE=306}=10.63$) revealed that only at level 6 subjects overestimated the probability that a balloon would burst. No other effect was significant. For each effect, involving LEVEL, power ($\Omega^2\geq .10$; $\rho=.2$) is larger than 95%.

In summary, the statistical analysis of the BART measures, which are relevant for the hypothesis under test, did not show the expected results.

2.5.2.3 Feedback Related Negativity

Preliminary note: There were 4 blocks of the BART task and within each trial there were six probability levels. As a reliable event related potential (ERP) needs at least 20 artifact free trials (Luck, 2014), it is impossible to obtain an ERP for each combination of BLOCK and LEVEL. In order to obtain enough trials for a reliable average ERP levels were aggregated over blocks. This would still have eliminated more than 10 subjects, who mostly cashed out before level 5. Thus, only levels 1 to 4 were included in the analysis.

The average latency of the FRN was 264 milliseconds. The statistical analysis of FRN-latency by a STRESS GROUP by GENDER by LEVEL ANOVA showed not a single significant result.

The hypothesis states, that feedback processing should be impaired after acute stress for high cortisol responders. To statistically evaluate this hypothesis, a STRESS GROUP by GENDER by LEVEL ANOVA was calculated separately at electrode positions FCz and Fz. The dependent variable was the average amplitude (±15ms) around the FRN peak, obtained from the difference of the negative and positive feedback potentials.

The expected STRESS GROUP by LEVEL [$F(6,78)=.94$; $p=.44$; $\varepsilon=.59$, power($\Omega^2\geq .10$; $\rho=.65$)> .95] or STRESS GROUP by GENDER by LEVEL [$F(6,78)=.66$; $p=.36$; $\varepsilon=.59$, power($\Omega^2\geq .10$;

ρ=.65)> .95] were not significant at FCz. The probability of falsely accepting the null hypothesis is less than 5%, thus it can be stated that acute stress does not influence the FRN. A similar result was observed at Fz.

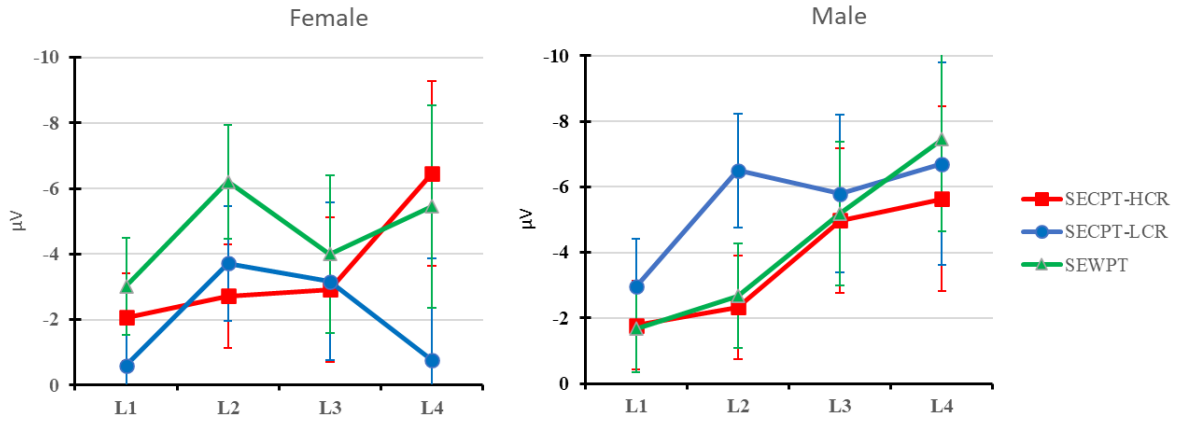

Figure 2.9: FRN amplitudes at FCz, for each stress group separately for female (left) and male (right) subjects for balloon sizes (levels) 1 to 4. Error bars are 1 SEM.

The only significant result was a main effect of LEVEL [$F(3,78)=4.97$; $p<.01$;$\varepsilon=.59$;$\eta^2=.16$], with monotonically more negative FRN-amplitudes from level 1 (-2.01µV) to level 2 (-4.02µV) to level 3 (-4.38µV) and level 4 (-5.41µV).

2.6 Discussion

The hypothesis developed in the general introduction stated:

Acute stress leads to faster, riskier decisions under ambiguity, only in subjects who show a clear cortisol increase in response to the acute stressor. The mechanism behind this cortisol induced change is a switch in feedback processing, preferring positive over negative feedback, resulting in a decrease in FRN amplitudes.

The logic relies on an argument chain that acute stress leads (in part of the subjects) to strong cortisol secretion, which then induces an activation of the dopamine system. On the behavioral level positive feedback becomes more important, the subjective importance of negative feedback is reduced. This is due to a fast, automatic, and intuitive driven process, which Kahneman (2011) attributes to the activity of System 1.

Given the results reported here one can only state, that the hypothesis failed at the behavioral and biological level. The most important point is that no influence of acute stress on the FRN was observed. The whole argument chain collapses with this result. To repeat: acute stress leads to a secretion of cortisol (which is at least true for the male subjects in the experiment). This leads to an activity increase of the dopaminergic system, resulting in higher availability of dopamine. This changes the preference for the processing of negative feedback (which is thought to represent the default mode of the feedback processing system; see 1.4.4) to positive feedback due to the increased availability of dopamine. In consequence, the FRN should be reduced, which would have been an indication of changed feedback processing after acute stress in ambiguous decision-making situations. Thus, the present data suggests, that feedback learning, which is the crucial process to learn from previous experience in uncertain decision-making situations is not influenced by the hormonal response to the acute stressor. Whether cortisol secretion leads to the expected influence of the dopaminergic system cannot be verified by the present study, as in this setup no indicator indexing the activity of the dopaminergic system is available. In consequence, changed feedback processing is possibly not the responsible mechanism for the reported negative influence of acute stress on decision making under uncertainty (see Starcke & Brand, 2012; 2016 for reviews).

On the behavioral level, the only interesting results showed up for the conditional risk measure, which indicates risk behavior after a positive or negative feedback. Here, male high cortisol responders showed riskier decisions after negative feedback, but the control group and the low cortisol responder group did not statistically differ from each other (see Figure 2.8). Also, male controls (warm water condition) acted riskier than both SECPT groups. This is opposite to the

effect expected from the hypothesis. The same holds true for female subjects. Though both SECPT groups showed enhanced risk taking after positive feedback (which is partly in line with the hypothesis), the absolute amount of risk taking is larger in the warm water control group, again contradicting the hypothesis.

As stated at the end of the introduction, the results can only be reliably interpreted if the preconditions (manipulation checks) show the expected result. This is the case. In the following paragraphs the results of the manipulation checks will be discussed in detail.

For the acute stressor, a strong cortisol response was expected in half of the subjects (Schwabe et al., 2008; Schwabe & Schaechinger, 2018). Statistically, this was the case for male subjects but not for female subjects. This statement holds true if cortisol responders and non-responders are defined statistically by a median split, which was performed separately for male and female subjects. However, healthy females have a significantly smaller salivary cortisol response than healthy men, with no difference between the genders in baseline levels (Kudielka et al., 2009). It is a matter of debate, what might be the best criterion to separate high cortisol responders from low cortisol responders. Sometimes an absolute value of an increase between 1.5 and 2.5 nmol/l (normative aspect) is used (Kirschbaum, Wüst, & Strasburger, 1992; Schwabe et al., 2008; Schwabe & Schaechinger, 2018; Wust et al., 2000). Miller, Plesow, Kirschbaum & Stalder (2013) found this criterion overly conservative and proposed a baseline to peak increase of 15.5% as a threshold to categorize responders. By this criterion all female and male low cortisol responders are below this threshold (male -3.98% - .46%; female -.94% - .25%) and all high cortisol responders are above this threshold (male 44.62% - 276.78%; female 16.54% - 74.57%). From Miller's et al. (2013) point of view, the important classification into cortisol-high and low cortisol responders worked perfectly.
Thus, the classification of cortisol-low and high-responders depends on the selected criterion. From a statistical point of view only male only half of the males showed a string cortisol response to the acute stressor. From a normative point of view (Miller et al., 2013) cortisol high responders are found in males and females. It has to be clarified in future research, which the best criteria to categorize subjects into low and high cortisol responders.

The first and fast part of the stress response is the adrenergic reaction, as described in section 1.3.2. There was a clear increase in heart rate for the subjects which underwent the SECPT, confirming that this part of the stress response occurred as expected.

Another important aspect of the manipulation check was the expectation, that the SECPT leads to an increase in negative affect. With respect to the emotional reaction to the SECPT (as

measured by the Positive and Negative Affect Schedule PANAS; see 2.3.1.1.3), an increased negative effect was observed after the SECPT, whereas the stressor had no effect on the actual positive affect. This is in line with most of the literature (for comparable results see Haushofer et al., 2013; Lempert, Porcelli, Delgado, & Tricomi, 2012; Pabst, Schoofs, Pawlikowski, Brand, & Wolf, 2013).

Another objection to question the validity of the experiment might be that the person, who observed the SECPT procedure in the EEG-cabin was always a female. This could have caused a psychological and biological stress response, which is smaller for females, as observed at least for the salivary cortisol response. However, a recent review (Schwabe & Schaechinger, 2018) looking at ten years of research with the SECPT came to the conclusion: "Thus, although an opposite-sex experimenter might have (small) potentiating effects, for the successful stress induction by the SECPT it appears not to be essential to have an experimenter of the opposite sex." (p. 160).

In sum these results show, that the SECPT was a valid procedure to induce acute stress on the behavioral, adrenergic and hormonal level. Thus, the non-results for the influence of acute stress on decision making in the BART task cannot be explained by an invalid stress induction procedure.

The next question is, whether the BART task worked as expected. From the literature (Lejuez et al., 2003; Lejuez et al., 2002) it was concluded that

a) the number of pumps and the number of blasts should decrease from level 1 to level 6
b) that the number of cash-outs should be largest for level 3 and 4

Exactly this pattern of results was obtained (see 2.5.1.1.4), making it very unlikely that problems with the BART task are responsible for the failure of the hypothesis.

Finally, it had to be checked, whether the FRN is expressed in the data as expected. The FRN, as calculated from the difference of the potentials elicited by negative and positive feedback, should have a latency between 250 and 350 milliseconds and should show a fronto-central topography (Gehring & Willoughby, 2002; Hewig et al., 2007; Miltner et al., 1997; Miltner et al., 2003; Potts et al., 2006; Zhou et al., 2010). As shown in chapter 2.5.1.1.5 the observed FRN has a latency of 260 milliseconds and showed the expected fronto-central negative maximum. The reported result that the FRN is not influenced by acute stress, cannot be explained by problems of EEG-measurement or EEG-analysis.

To summarize the analysis of the manipulation checks, it is concluded that the reported results, which showed no influence of acute stress on risk taking and feedback processing, cannot be attributed to possible shortcomings in the operationalization of the SECPT, the BART task, nor the FRN paradigm or their measurements.

Another objection could be a statistical one. The observed results rely mainly on non-significant statistical tests. It is well known that a non-significant result of a statistical test (empirical $\alpha > .05$) does not automatically allow deciding in favor of the statistical null hypothesis. To avoid this often-committed error (Button et al., 2013; Camerer et al., 2016; Cohen, 1988, 1990; Sedlmeier & Gigerenzer, 1989), the probability of falsely deciding in favor of the statistical null hypothesis (β-error) has to be computed. The computation of power (1-β) for the statistical tests relevant to the hypothesis showed mainly β-errors of less than 5% (assuming a population effect size of at least 10%). Thus, the null hypothesis of these statistical test can be interpreted with confidence.

Despite that the present experiment did not reveal any influence of acute stress on decision making and feedback processing, it is too early to deny the hypothesis developed in the introduction. In the literature small effects (range d=.06 up to d=.12) in the expected direction are reported for adolescent samples in the BART task with processive stressors (Daughters, Gorka, Matusiewicz, & Anderson, 2013; Finy, Bresin, Korol, & Verona, 2014; Reynolds et al., 2013) and larger effects (d=.07 to d=.62) with adult samples and systemic stressors (Lighthall, Mather, & Gorlick, 2009; Lighthall et al., 2012; Mather & Lighthall, 2012). None of the above cited studies is fully comparable to the present study, either because the samples were not comparable or the stressor was a systemic one.

To shed more light on the putative influence of acute stress on decision-making under ambiguity and feedback processing, a second experiment was set up to test the current hypothesis more rigorously.

3 Experiment 2

3.1 Introduction

The second experiment was designed to test the same general hypothesis as in experiment 1 more rigorously. The hypothesis is that acute stress leads to riskier decision making in ambiguous situations due to a change in feedback processing, favoring positive over negative feedback. To achieve a more rigorous test of the hypothesis, several changes in the experimental design and procedure are introduced. The following paragraphs will substantiate these changes. These modifications were:

1. Instead of the Balloon Analogue Risk Task a variant of the Iowa Gambling Task (IGT) was used.
2. Only male subjects participated in the experiment.
3. In order to stabilize the cortisol response and to increase negative emotional aspects of the SECPT part of the subjects repeated a shortened version of the SECPT.
4. The first block of the IGT was performed immediately after the SECPT or SEWPT.

No changes were made with respect to FRN measurement.

One of the major changes is the switch from the BART risk task to the IGT (Bechara et al., 1994). The IGT is widely used in all possible studies of economic decision-making, mainly due to the excellent results in validation studies (Bechara, 2007; Buelow & Suhr, 2009). It is a laboratory measure of reward or punishment based economic decision making (Bechara & Damasio, 2005).

During the IGT, subjects are told to maximize profit over the course of several 100 trials. In the computerized version they see four card desks, two of them advantageous, the other two disadvantageous. In our version, desk 1 and 2 are advantageous, with a relatively small amount of money to win. These wins occur with a high probability (70% or 60%). Desks 3 and 4 are disadvantageous, with relatively high monetary wins, but with win probabilities below 50% (40 or 30%). Subjects are only informed that the win probabilities decrease from desks 1 to 4, without being given any further information. In the version applied in this experiment, the motivation to maximize profit is increased by the information that those participants who will have the highest profits will receive an additional 100 € after the data collection has finished. During the task no information is given on the actual balance. For a detailed description see section 3.2.2.1.

There are several reasons to decide on the IGT for the present experiment. First of all, results of studies should be independent of the operationalization procedure. As the BART task and

the IGT are valid procedures to investigate decision making under uncertainty, both should lead to identical results. Additionally, a conceptually replicated experiment allows a broader generalization compared to a replication with the exact same procedure.

It might be a weakness of the BART task, that the actual monetary balance is shown after each positive or negative feedback, as in case of losing, only the amount of money in the current trial is lost but is not deducted from the complete balance. Thus, subjects are sure that their balance grows, which makes it a very convenient situation for the subjects after some trials. As pointed out by Kahneman (2011), this positive situation might lead to less risky behavior, due to an increase of loss aversion. The psychological value of losses is larger, the more financially positive the given situation is. That is, in the BART task the balance is continuously increasing and is known by the subject, resulting in an increase in loss aversion. A possible negative influence of acute stress on decision making under uncertainty might be counteracted by this increase in loss aversion due a increasing positive balance. Tversky and Kahneman (1992) call this in their New Prospect Theory the dependence of decision on reference points. The more positive the reference point is (i.e., high amount of money), the larger the influence of loss aversion. The possible impact of the actual value of the balance on risk taking in the BART task, has not been studied so far.

During the IGT, no information of the current balance is given to the subjects. Additionally, in case of a loss, the value of the chosen card is deducted from the not known balance.

The final reason to change to the IGT is that the effect sizes for the negative influence of acute stress on decision making are somehow larger (between d=.06 to d=.59), as compared to the BART (between d=.06 to d=.18; see Starcke & Brand, 2016, table 1).

The IGT does also not allow to classify the result of a decision as better than expected. When subjects choose a card, it is reasonable to assume that they expect a positive outcome since their expectations are met. Thus, the positive feedback presented to the subjects after each trial represents a condition where expectations are met. However, if the balloon bursts, their expectations are not met, they experience an outcome that is worse than expected. In that case a strong negative FRN should be elicit in the control group and a reduced (less negative) FRN should be observed in the subjects with a strong cortisol response elicited by the acute stressor (see chapter 1.4.4).

The second change is, that experiment 2 will only use male subjects. In the first study, we followed recommendations developed at the University of Trier[9] by selecting only women who use contraceptives, excluding those who might influence salivary cortisol measurement. This method is used in a lot of published papers. However, several publications (Espin, Villada, Hidalgo, & Salvador, 2019; Montero-López et al., 2018; Roche, King, Cohoon, & Lovallo, 2013) showed recently that the hormonal and psychological stress response is different in women using contraceptives, when compared to those not using contraceptives. Additionally, when working with women not using contraceptives, the phase of the menstrual cycle should be controlled or used as a control variable in the experimental design (Duchesne & Pruessner, 2013; Lovallo, Cohoon, Acheson, Vincent, & Sorocco, 2019), as phase within the menstrual cycle also influences hormonal and psychological results induced by an acute stressor. Duchesne & Prüssner (2013) showed a clear influence of the menstrual cycle on the subjective and cortisol stress response. They concluded: "…. the immediate recommendation for any study in the field investigating men and women is to include menstrual cycle phase as an important factor in their experimental design, as it can cause opposite associations among the various stress measures." (p. 3158). Thus, the hormonal status of women and the menstrual cycle might influence the psychological and hormonal stress response in many ways. This can only be controlled by an enormous effort, which could not be realized at the time when experiment 2 was planned and carried out. Therefore, it was decided only to invite male subjects.

The third important change is due to the definition of an acute stressor, which was formulated in section 1.3. In this section stress was defined as an actual or anticipated disruption of homeostasis or an anticipated threat to well-being. In a classical SECPT, the anticipation of a stressor is no longer present after the cold-water procedure with the social evaluated component is over. This led to a decrease in the salivary cortisol response 20 minutes after the stressor (only for man see Figure 2.4). Also, only a short negative emotional response (see Figure 2.6) occurred, where the negative affect was only present immediately after the acute stressor. In order to stabilize the cortisol response on a high level and to establish a persistent negative emotional response to the acute stressor, a short version of the SECPT will be repeated after 50 trials of the IGT, resulting in three additional stress challenges. This aims to lead to a longer lasting and stronger cortisol response, increasing the chance that feedback processing is changed due to the cortisol induced influence on the dopaminergic system.

[9] Special thanks to Prof. H. Schächinger, University of Trier, for sharing his expert knowledge on this issue with me.

Finally, the first block of the IGT will be performed immediately after the SECPT or SEWPT. The idea behind this change is to get a comparison of decision behavior and FRN amplitudes in a situation where development of the hormonal stress response and cortisol levels are relatively low. This gives two opportunities to observe a possible influence of the stress hormone on the dependent variables: First, the stress groups can be compared (between subjects) with the expectation that the SECPT and SEWPT subjects will not differ in their behavior immediately after the stressor, as in the SECPT group and in the SEWPT group cortisol levels should be minimal. Second, later in the experiment cortisol levels should be high at least in part of the subjects which performed the SECPT, allowing to check for the influence of cortisol on decision behavior and FRN within subjects.

In summary, these changes should overall lead to a more rigorous test of the hypothesis as

(a) a possibly better decision-task is used,
(b) responses by female subjects which are difficult to interpret due to their unclear hormonal status are excluded and
(c) the hormonal and psychological stress response is strengthened and
(d) a between and within comparison of the influence of the cortisol is possible.

The general hypothesis remains unchanged:

Acute stress leads to faster, riskier decisions under ambiguity only in subjects who show a clear cortisol increase in response to the acute stressor. The mechanism behind this cortisol induced change is a switch in feedback processing, preferring positive over negative feedback, resulting in a decrease in FRN amplitudes.

As in experiment 1 this hypothesis can only be tested, if all the following side hypothesis (manipulation checks) can be confirmed:

- The acute stressor leads to cortisol secretion, where half of the subjects show a clear cortisol increase after the stressor. Also, those subjects who repeat a shorter version of the SECPT should show a longer lasting salivary cortisol response.
- The acute stressor leads to a negative emotional reaction, lasting longer for those subjects who repeat the SECPT. The acute stressor elicits a strong adrenergic fast stress response, measured here by the electrocardiogram.
- The decision-making paradigm shows the expected results as published in the literature.

- The FRN shows a fronto-central distribution over the scalp with relative more negative amplitudes after negative feedback, compared to positive feedback.

An open question in this field is whether chronic stress might moderate the influence of acute stress on decision making. A marker for chronic stress load is the basal cortisol level. The term "basal" refers to trait-like aspects of HPA-reactivity, whereas "acute" corresponds to state or situational aspects of HPA-reactivity. The basal aspects of the HPA-axis show a clear circadian rhythm with cortisol level reaching its maximum shortly after awakening. Then cortisol levels decline slowly during the morning and afternoon, until it reaches the minimum during the night (Kirschbaum & Hellhammer, 1999). Consequently, the cortisol awakening response is often used to measure trait aspects of the HPA axis. As shown by Hellhammer et al. (2007), four morning measurements of salivary cortisol immediately after wake up, separated by 15 minutes, on two (better 3) consecutive days are at least necessary to achieve a reliable and valid trait measure of the individual basal cortisol level. This is a very laborious procedure and this might be the reason that to my knowledge there is no paper published, investigating the influence of basal cortisol levels on decision making under uncertainty.

However, only recently Stalder and colleagues (Stalder & Kirschbaum, 2012; Stalder et al., 2017; Stalder, Steudte, Alexander, et al., 2012; Stalder, Steudte, Miller, et al., 2012) invented an easier to use and valid a method to measure the exposure to stress in the last three months by extracting cortisol intensity from hair strains (Hair Cortisol Concentration HCC). *Thus, an additional exploratory goal of experiment 2 is to look at possible influences of chronic stress, as measured by HCC, to investigate a putative interaction of chronic and acute stress on decision-making under uncertainty.*

3.2 Methods

In the following paragraphs the experimental procedure and the measurement instruments are specified and the dependent variables are introduced. Where necessary (i.e., EEG), the processing steps leading to the calculation of the dependent variables are explained.

3.2.1 Subjects

37 male subjects (all students at the University of Jena) participated in the experiment. They were all right-handed and with normal or corrected-to-normal vision. Exclusion criteria were defined as follows; overweight or underweight (body mass index above 25 kg/m^2 or below 18 kg/m^2), left-handedness, smokers, any long-term medication, or presence of a medical condition and night shift workers. After reading a description of the experiment, the risks of participation

and the procedure of data anonymization was explained. Afterwards participants gave written consent (see Attachment 6.2). They confirmed to spent the evening prior to the experiment without drinking alcohol and to refrain from extensive sports during the morning of the day their experiment was scheduled. At the end of the experiment, they received course credit or monetary compensation, which was 10€ per experimental hour. The experiment was conducted in accordance with the Declaration of Helsinki, and was approved by the ethics committee of the Faculty of Social and Behavioural Sciences of the University of Jena.

The data of one subject was discarded, since the water temperature during the cold-water condition was too high. Two thirds of the remaining 36 subjects (mean age 23.19 years; SD =3.11; Range 19 to 32) were randomly assigned to the SECPT, the remaining subjects performed the SEWPT. Later the SECPT subjects were divided into Low Cortisol Responders (SECPT-LCR) and High Cortisol Responders (SECPT-HCR). This constitutes the independent variable STRESS GROUP with the levels SECPT-HCR, SECPT-LCR and SEWPT. Additionally, half of the SECPT and SEWPT subjects were randomly assigned to the repetition condition. Repetition means that a shortened version of the water procedure (description see below) was repeated between blocks of the risk task. This constitutes the second independent variable REPETITION, with the levels yes and no.

3.2.2 Procedure

The experiment was conducted between 1.30 and 6:30 p.m. in order to examine the subjects at a time when, due to the circadian rhythm of HPA axis activity, the basal cortisol level is relatively low (Kirschbaum & Hellhammer, 1999; Schreiber et al., 2006). Before the experiment began, the participants were randomly assigned to the different treatment groups (see 3.2.1). The time line of the experiment is shown Figure 3.1.

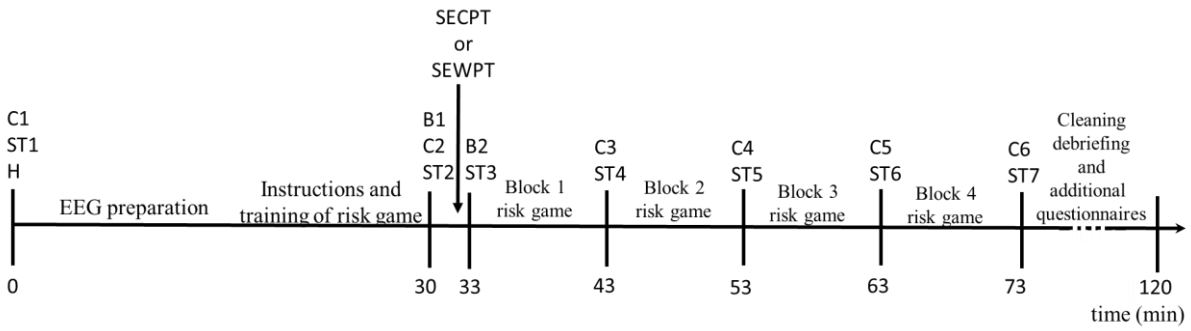

Figure 3.1: Time line of experiment 2. Abbreviations: C: Cortisol measurement; ST: State questionnaire; H: Hair strands taken for measuring cortisol intensity in the last three months; B: blood pressure measurement; SECPT: Social Evaluated Cold Pressure Test; SEWPT: Social Evaluated Worm Pressure Test. R: Repetition of the shortened version of the SECPT or SEWPT for half of the subjects.

Immediately after arriving in the laboratory the first salivary cortisol sample was gathered (see 3.2.2.3), a paper version of the state questionnaire (see 3.2.2.5) was completed, and a bundle of hair was removed for measuring the intensity of cortisol secretion in the last three months (Stalder & Kirschbaum, 2012; Stalder et al., 2017). Subjects were then led into a sound attenuated, electrically shielded cabin and seated in a comfortable chair in front of a 21-inch computer screen. The electrode cap, with integrated electrodes for measuring the electrocardiogram (ECG), was attached. Then a woman wearing a white overall entered the cabin, introduced herself as the personal assistant of the chair of the department, being responsible for the correct execution of the experiment. She handed out written instructions for the risk game and answered all questions of the participant. Then a training of a minimum of 20 trials of the IGT started. This was followed by the second salivary sample, the second state questionnaire (from now on presented on the computer screen) and a blood pressure measurement. The SECPT or SEWPT (see 3.2.2.2) was performed and immediately followed by the first experimental block (50 trials) of the IGT. There were 4 blocks with 50 trials. Each block was followed by a salivary sample and a state questionnaire. This defines the independent variable BLOCK with four levels.

For half of the subjects a shortened version of the SECPT or SEWPT was established prior to blocks 2, 3, and 4 of the IGT. Compared to the initial long version of SECPT or SWPT, the shortened lasted 90 seconds, with only 45 seconds of holding one hand in the water. Those subjects who did not repeat the SECPT or SEWPT started these blocks with a delay of 90 seconds.

After the 4th block, the EEG-cap was removed and subjects were offered to wash and dry their hair. Then they filled out additional personality questionnaires (results will be not reported here) and were informed about the scientific goals of the study and received 20 Euros as compensation for their time spend in the laboratory.

3.2.2.1 Iowa Gambling Task

After attachment of the EEG-cap, a woman wearing a white doctor's coat introduced the participants to the IGT and emphasized that those 5 subjects, who win the highest amount of money will receive an additional 100 Euros after the study is finished.

She then trained participants in the IGT at least for 20 trials of the decision task. Immediately after the SECPT or SEWPT, the first experimental block of 50 trials of the IGT started, followed by 3 additional blocks of 50 trials each. The blocks 2 to 4 began exactly at 13, 23 and 33 minutes

after the end of the SECPT or SEWPT. Half of the subjects repeated the shortened version of the SECPT or SEWPT at the beginning of blocks 2, 3 and 4.

The decision game was a variant of the Iowa Gambling Task (IGT). Subjects were informed that in each trial four playing cards will be disclosed in the middle of the screen. The amount of money shown on the cards could be won or lost. They should decide, which card they choose by pressing the appropriate button. Shortly after their decision they received feedback, whether they won (symbol: thumb up) or lost (symbol: thumb down). This defines the independent variable FEEDBACK, with the levels positive and negative.

At each armrest of the chair two response switches were mounted. Subjects were instructed to place their left ring finger on the outer switch, their left index finger on the inner switch of the left armrest. Their right index finger was placed on the right inner switch on the right backrest and their right index finger on the outer switch of the right backrest. Thus, the left ring finger was assigned to the leftmost card, the left index finger to the next card etc. Participants were further informed that the amount of money, that could be won or lost, increases from left to right, but at the same time the risk of losing the shown amount increases from left to right too. No further information of the probability to lose or win was given. Only as part of the training trials and only after the completion of the last trial in block 4 subjects were informed about their balance, which was set to zero before the first trial of block 1.

The winning probabilities from left to right were 70%, 60%, 40% and 30%. Four different card values were used. Either 10, 20, 30 and 40 Euros, 11, 21, 31 and 41 Euros, 12, 22, 32 and 42 Euros and finally 13, 23, 33 and 43 Euros. This was done to impede silent estimates of the actual balance.

Pseudo-random sequences for each subject were constructed that guaranteed

a) that the losing probabilities of each card would come out exactly to the predefined probabilities if the subject would always press the same button,
b) a balance of zero would result if each card was chosen 50 times and
c) that the different card values appear equally often and never more than three times in a row.

Subjects were further instructed to make their choice as fast as possible. The maximum time for the decision-making was 1500 ms. If there was no reaction after 1500 ms, the symbol  appeared on the screen and the trial was added at the end of the training or the actual block.

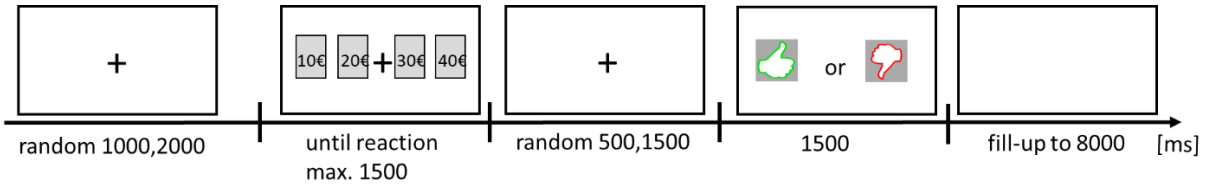

Figure 3.2: Timeline of a single trial in the risk game. The rectangles symbolize the computer screen.

A trial started with the presentation of a fixation cross in the middle of the screen. Subjects were asked to fixate the cross. Between 1000 and 2000ms (random interval) after the appearance of the cross, four playing cards, centered left and right from the cross were shown for a maximum of 1500 ms. Subjects were instructed to make their choice by pressing the appropriate switch as fast as possible (speed instruction). The reaction time for choices was taken. Between 500 and 1500 ms (random interval) post reaction, the feedback stimulus appeared in the middle of the screen for 1500 ms. Finally, the trial time was filled-up to 8 seconds and the next trial started with the presentation of the fixation cross.

Several dependent variables were calculated from the decision task. As argued in the general introduction feedback, obtained in the previous trial, is very important for the behavior in the next trial. Thus, variables described below were calculated under the condition whether the feedback in the previous trial was positive or negative. This constitutes the independent variable PREVIOUS FEEDBACK with the levels positive or negative. The dependent variables were:

- The amount of money won or lost in each block.
- Mean reaction times in each block after a win or loss.
- *Conditional Risk Measure*: The classical risk measure used to analyze IGT is defined as the difference of the number of decisions for the low-risk cards (1 and 2) minus the number of decisions for the high-risk cards (3 and 4). Large values in this measure indicates low risk. When considering the previous feedback this measure has to be computed from the conditional probabilities of choosing a low- or high-risk card after a previous win or loss. This is because the number of previous wins and losses vary. Thus, the frequency card 1 or 2 was chosen after a win was divided by the total number of wins, and the frequency card 1 or 2 was chosen after negative feedback was divided by the number of total losses. The same was done for cards 3 and 4. The conditional risk measure was calculated separately for previous wins and losses as the difference of the conditional probabilities for cards 1and 2 minus cards 3 and 4.

3.2.2.2 Social Evaluated Cold and Warm Pressure Tests

In order to induce acute stress, the SECPT (Schwabe & Schaechinger, 2018) was used. Under the stress condition, subjects had to immerse their right hand for 3 minutes into ice-cold water of 1-3 °C. The water in the container was moved constantly with a small propeller. At the same time, they were videotaped and observed by a female investigator. She wore a doctor's coat and was introduced as the assistant of the department chair being responsible for the accurate execution of the study. She behaves very seriously and unapproachable and obviously notices every detail of the subject's response. In order to increase her psychosocial stressor attribute and role, subjects were led to believe that their mimics and gestures during the task would be recorded by her. The non-stressful control procedure (SEWPT) was very similar, except that the water was at body temperature (36-38 °C). Since the stressed participants would be classified into low cortisol responders and high cortisol responders, depending on their cortisol rise due to the SECPT for later analyses, two-thirds of the sample were randomly assigned to the stress condition and one third to the warm water condition.

Half of the subjects in the SECPT and SEWPT conditions repeated a shortened version of the test before blocks 2, 3 and 4 of the IGT. The procedure was identical to the one described above, with the only difference that the time to keep the hand in the cold or warm water was reduced to 45 seconds.

3.2.2.3 Salivary and Hair Cortisol Measurement

Salivary samples were taken at six time points during the experiment. Saliva was collected by the subjects by chewing a cotton ball for one minute, using standard Eppendorf tubes (1.5 ml, Eppendorf, Hamburg, Germany). The tubes were stored at room temperature until completion of the session, and then kept at -20 °C until analysis. After thawing for biochemical analysis, the fraction of free cortisol in saliva (salivary cortisol) was determined using a radioimmunoassay with Salivettes (Sarstedt Inc., Texas). Inter- and intra-assay coefficients of variance were below 9%. These are coefficients of variability, the larger the value, the greater the error in the assay (Hanneman et al., 2011). For each subject there were 6 cortisol intensity measures in nanomol per liter (nmol/l), defining the independent repeatedly measured variable TIME OF MEASUREMENT with 6 levels.

Additionally, to estimate the stress burden in the last three months before the experiment hair strains were collected from the subjects. Hair Cortisol Concentration (HCC) is a sensible measure for the cortisol secretion in the last three-months (Stalder & Kirschbaum, 2012; Stalder et al., 2017; Stalder, Steudte, Alexander, et al., 2012; Stalder, Steudte, Miller, et al., 2012).

Hair strands were taken from the head with scissors, as close as possible to the scalp. Hair was collected from the vertex posterior region of the head, since it has been found that this area of the scalp has the greatest growth cycle synchrony and exhibits the lowest intra-individual variability in hair cortisol concentrations (Sauvé, Koren, Walsh, Tokmakejian, & Van Uum, 2007). Steroid concentrations were determined from the 3 cm segment of hair closest to the scalp. This represents hair growth over the three month period prior to sampling based on an average hair growth of 1 cm/month (Wennig, 2000). The samples were analysed using a column switching LC–APCI–MS/MS assay, which has been found to be a sensitive, reliable method for quantifying steroids in human hair (Gao et al., 2013). The samples were washed and steroids extracted following ta published protocol (Stalder, Steudte, Miller, et al., 2012). The intra and inter-assay coefficients of variation (CVs) for cortisol analysis by this method have been reported to range between 3.7% and 8.8%. For each subject the hair cortisol concentration (HCC) was measured in pikogram per milligram (pg/mg). This defines the independent continuously measured variable HCC.

3.2.2.4 EEG, ECG and Blood Pressure Acquisition and Analysis

EEG was recorded from 64 electrodes placed at locations defined by the extended 10-10 electrode reference system (Chatrian, Lettich, & Nelson, 1988) with an Easy-Cap electrode system (Easycap M64, Easycap GmbH, Herrsching, Germany). All sites were referenced to FCz, ground electrode was Iz. Ag/AgCl electrodes were used, and the impedances of the EEG electrodes were below 5 kΩ. EEG was amplified by means of two 32-channel BrainAmp amplifiers (input impedance: 10 MΩ; Brain Products, GmbH) in AC mode. The pass-band was set to .016 to 499 Hz (-12 dB/octave rolloff). Signals were digitalized at a rate of 1000 Hz. There was an additional electrode below the left eye, exactly vertical to FP1. The bipolar derivation of these two electrodes gives the vertical EOG (VEOG).

The processing steps described below follow the recommendations given in Luck (2014). All processing steps were done with Brain Vision Analyzer 2.1.2 (Brainproducts, Gilching). After re-referencing the data to a linked mastoid reference, all channels were digitally filtered with a non-phase distorting Butterworth bandpass filter, set from .1 to 12 Hz half power cut-offs at -24db. This filter removes slow drifts and high frequency artifacts (i.e., muscle activity) from the data, without distorting the phases for the different frequencies. For each block segments from -500 to 5500 ms around the feedback stimuli (see Figure 3.2) were extracted and submitted to the eye activity correction procedure, as described by Gratton, Coles & Donchin (1983). The long segments avoid possible edge artifacts of the eye correction procedure. Then segments were shortened (-200 to 800 ms around feedback stimuli) and baseline corrected (-200 to 0).

Segments containing voltage steps of more than 30 µV from one sampling point to the next, or showed amplitudes differences larger than 150µV between the smallest and largest amplitude in the segment, or showed low activity (less than .5 µV), were rejected as artifacts. Finally, artifact free averages in each block were calculated contingent on the positive and negative feedback stimulus.

From the difference potential (negative minus positive feedback) in each condition[10] the amplitude and latency of the FRN was determined by a semiautomatic procedure. At the latency of the FRN at FCz the average amplitude ± 15ms around the peak was computed at all electrode locations and used as a dependent variable in the statistical analyses.

The electrocardiogram was measured by an additional electrode which is part of the EEG-cap system and has a long enough wire to be positioned on the back at the height of the heart. Five 30 seconds long segments, ranging from 30 seconds before the start to 120 seconds after the start of the SECPT or SEWPT, were extracted. The peak of the R-wave was marked (Analyzer Solution ECG Markers) and the interbeat intervals were transformed to beats per minute (bpm), indexing the pace of heard activity. This defines the independent repeatedly measured variable TIME OF MEASUREMENT with five levels.

Systolic and diastolic blood pressure was measured just before the SECPT or SEWPT and immediately afterwards with a model SBR50 (Sanitas, Germany) in millimeters of mercury (mmHg), defining for systolic and diastolic blood pressure the independent repeated measured variable TIME OF MEASUREMENT with the levels before and after.

3.2.2.5 Questionnaires

Though the PANAS is often used to measure the psychological stress response, the effect is often restricted to the negative effect only and is of relatively small magnitude. More direct questions, describing the stress situation more specifically lead to better results.

Subjects filled out (first measurement) or answered five items presented on the computer screen (measurements 2 to 7) to check their actual state. All items were scaled from 1(not at all) to 9 (very much). Each item was headed by the adjectives ‘aroused’, ‘pleasant’, ‘stressed’, ‘painful’ or ‘averse’. In the computerized version the items appeared on the computer screen until the subject orally gave an answer, which was logged by the investigator. For the analysis of

[10] As discussed in chapter 1.4.4. this difference potential subtracts a condition where expectations are met (positive feedback) from a condition where expectations are not met (negative feedback=worse than expected)

questionnaire data this defines the repeatedly measured independent variable TIME OF MEASUREMENT with 7 levels.

At the end of the experiment subjects filled out a follow-up survey, composed of four questions concerning their feelings during the SECPT or SEWPT. The items were scaled from 0 (not at all) to 100 (very much) and covered the following:

1. How difficult was it for you to keep the hand in the water?
2. How unpleasant was this situation for you?
3. How stressed were you in the situation?
4. How painful was it keeping the hand in the water?

Finally, subjects wrote down their estimated win probabilities for each of the four cards. For the sake of completeness it should be noted that two additional personality questionnaires were finished by the subjects, namely the German version of the sensitivity to punishment and sensitivity to reward questionnaire (Torrubia et al., 2001) and the German risk questionnaire (Rost-Schaude, 1975). Those data will not be reported here.

3.2.3 Statistical Analysis

We mind the reader of the statistical analysis described in Section 2.4.3 and focus on the analysis of the influence of the chronic stress measure, which has not been analyzed in the previous experiment.

To analyze the influence of the chronic stress measure (HCC) the ANOVAs for the dependent variables of the IGT and for the FRN will be repeated by adding a continuous independent variable HCC. This is equal to an additional grouping factor and reduces the degrees of freedom for the error term by one. It is not possible to conceptualize this factor by a median split, as this would lead to very different group sizes within the combined levels of STRESS GROUP and REPETITION. Different group sizes within the cells of an ANOVA may produce spurious interactions due to reliability differences in the cells. Thus, the method described by Aiken, West, and Reno (1991) is used to explore the influence of hair cortisol concentration on the dependent variables. As in this case the independent variable is not categorical but continuous, the follow-up tests are correlations.

3.3 Results

The results are reported in two main sections, namely “Manipulation Checks” and “Influence of Stress and Feedback”. The first section covers the results of all manipulations checks in this complex experiment, which means

a) cortisol should be secreted in the SECPT,

b) subjective mood measures should vary with the experimental conditions,

c) the decision task should replicate published results and

d) the FRN should show its typical latency and a fronto-central negative topography.

The second section then evaluates the results, relevant to the hypothesis under investigation.

3.3.1 Manipulation Checks

In this chapter statistical information is given whether the basic paradigms used in this experiment, namely the SECPT, the decision task and the FRN, functioned as expected.

3.3.1.1 Social Evaluated Cold Pressure Test

If the SECPT works as a valid acute stressor, cortisol secretion should show the expected profiles for high cortisol responder (SECPT-HCR), low cortisol responders (SECTP-LCR) and controls (SEWPT). The heart rate should increase with the beginning of the SECPT, indicating the early adrenergic stress reaction and pleasantness should decrease. The subjective experience of stress should increase after the SECPT.

3.3.1.1.1 Salivary Cortisol

Half of those subjects, who passed through the SECPT, should show a strong cortisol secretion, whereas the other half of these subjects should show a nearly identical cortisol reaction as the SEWPT subjects.

Based on the difference in scores between C3+C4 minus C1+C2 SECPT subjects, were divided by median split into high cortisol responders (HCR) and low cortisol responders separate for each repetition condition. Medians for the repetition subjects was 5.15 nmol/l, for no repetition subjects 4.40 nmol/l. The range for the LCR, with repetition, was from 3.15 nmol/l to 4.61 nmol/l, for the HCR from 5.70 nmol/l to 11.56 nmol/l. The respective ranges for the SECPT group without repetition was LCR -3.04 to 3.00 nmol/l and HCR from 4.48 nmol/l to 13.34 nmol/l.

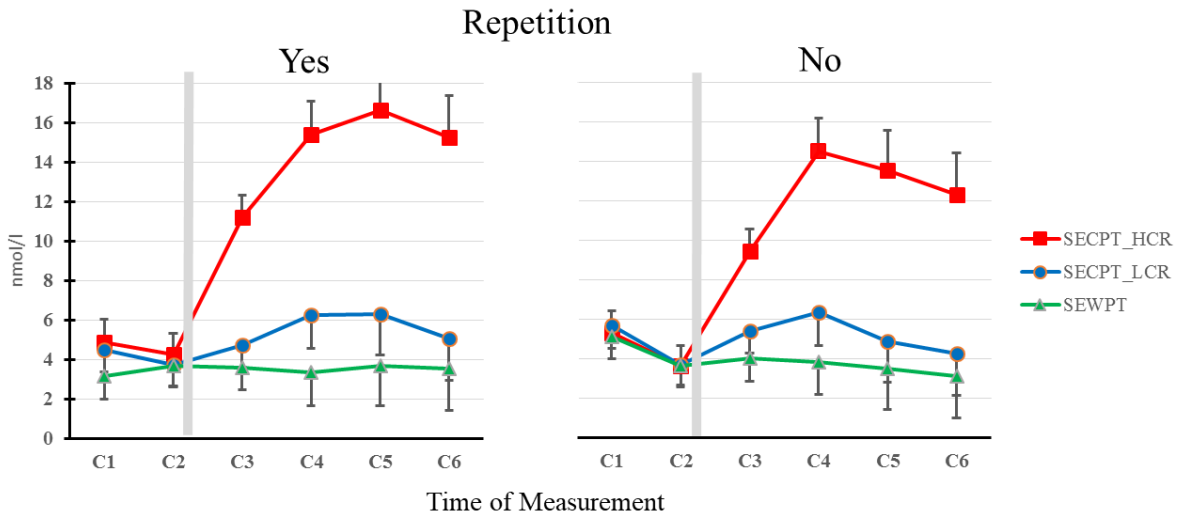

Figure 3.3: Cortisol intensities measured from salivary samples at each of 6 times of measurement for each level of repetition (yes: left; no: right) for each of the stress groups. Vertical lines indicate 1 standard error of measurement (SEM). The grey bar indicates the timing of the first SECPT or SEWPT.

On the descriptive level, SECPT_LCR and SEWPT subjects showed almost identical cortisol levels across both repetition conditions. Also, for these groups, cortisol levels at each of the six measurements look very similar, whereas SECPT_HCR subjects showed a clear increase after the SECPT. Furthermore, the SECPT_HCR subjects with repetitions after C3, C4, C5 and C6, seem to show higher cortisol levels at these measurement times, compared to the SECPT_HCR group without repetitions.

The statistical analysis by a STRESS GROUP by REPETITION by TIME OF MEASUREMENT ANOVA, with repeated measurement on the last factor, showed the expected interaction of STRESS GROUP by TIME OF MEASUREMENT [$F(10,150)=14.15$; $p<.001$;$\varepsilon=.27$;$\eta^2=.49$]. Follow-up tests, comparing the three groups at each time of measurement ($\psi_{crit,\ C=18;\ df=150;\ MSE=6.04} =2.81$), revealed that there were no differences between the three groups at time point C1 and C2 and no differences between SECPT-LCR and SEWPT groups at time points C3 to C6. However, in both repetition conditions the high cortisol responders differ from the low cortisol responders and warm water group at time points C3 to C6. As the triple interaction STRESS GROUP by REPETITION by TIME OF MEASUREMENT was clearly not significant [$F(10,150)<1$; $P=.94$; $\varepsilon=.27$; power ($\Omega^2\geq.10$; $\rho=.7$) = .93], no statistically reliable differences in the cortisol profiles of the three groups was present for the comparison of the repetition conditions (compare left and right side of Figure 3.3).

The SECPT led to cortisol secretion as expected.

3.3.1.1.2 Electrocardiogram and Blood Pressure

Heart rate was measured to make sure that the initial adrenergic stress response was present for the first SECPT. The five measurements (see 3.2.2.4) were submitted to a STRESS GROUP by TIME OF MEASUREMENT ANOVA. The main effect of TIME OF MEASUREMENT [$F(4,132)=4.57$; $p<.01$;$\varepsilon=.46$;$\eta^2=.12$] was qualified by a STRESS GROUP by TIME OF MEASUREMENT interaction [$F(8,132)=4.93$; $p<.01$;$\varepsilon=.46$;$\eta^2=.23$], depicted in Figure 3.4.

Post-hoc tests, comparing the baseline (-30 to 0 seconds) before the SECPT or SEWPT to each of the measurements after the stress test ($\psi_{crit,\ C=12;\ df=132;\ MSE=36.66}=7.19$), revealed that both SECPT groups increased from baseline to measurements 2 (1 to 30 seconds) and 3 (31 to 60 seconds) significantly, whereas the SEWPT group showed a significant decrease from baseline to measurement 3. When looking at group differences at each measurement ($\psi_{crit,\ C=12;\ df=132;\ MSE=36.66}=7.39$), both SECPT groups differed from the SEWPT group at measurement 2 and 3, with no differences between low and high cortisol responders at any measurement point.

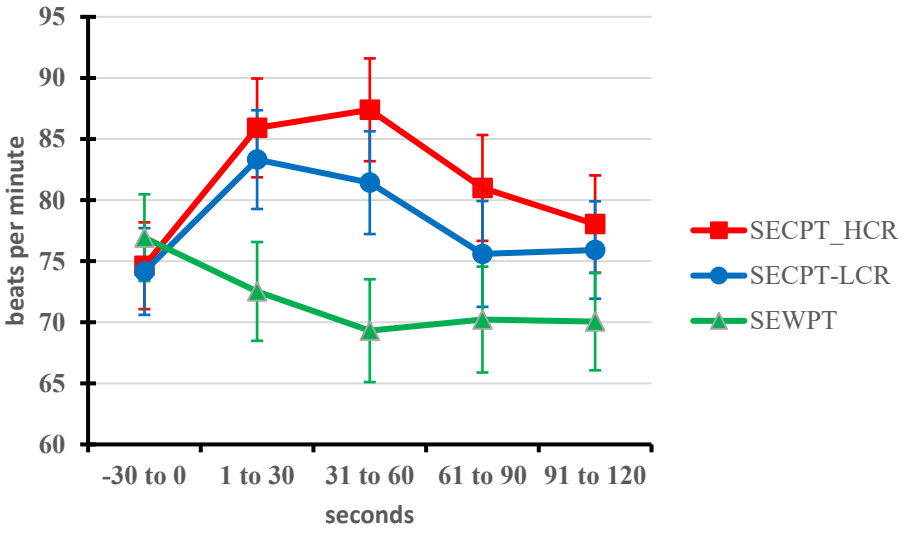

Figure 3.4: Mean heart rate of consecutive 30 seconds interval before and after the cold or warm pressure tests for the three stress groups. Error bars indicate 1 SEM.

The diastolic and systolic blood pressure levels, measured immediately before and after the SECPT or SEWPT, were submitted to a STRESS GROUP by TIME OF MEASUREMENT ANOVA. No significant effects were observed. Power ($\Omega^2 \geq .10$; $\rho=.4$) for the crucial STRESS GROUP by TIME OF MEASUREMENT was larger than .95.

3.3.1.1.3 Questionnaires

The answers to each of the four state questions (see 3.2.2.5) were submitted to a STRESS GROUP by REPETITION by TIME OF MEASUREMENT ANOVA with repeated measurement on the last factor. From the hypothesis the triple interaction and the two-way interaction STRESS GROUP by TIME OF MEASUREMENT is of primary interest. For brevity's sake, we report in detail the items showing the strongest triple interaction and then describing the difference to all other items, followed by looking at the relevant two-way interaction.

All items were scaled from 1(not at all) to 9 (very much). The clearest results were obtained for the item 'painful'. All effects were significant, with a strong triple interaction [$F(12,180) = 7.43$; $p < .001$; $\varepsilon = .51$; $\eta^2 = .33$] STRESS GROUP by REPETITION by TIME OF MEASUREMENT (see Figure 3.5).

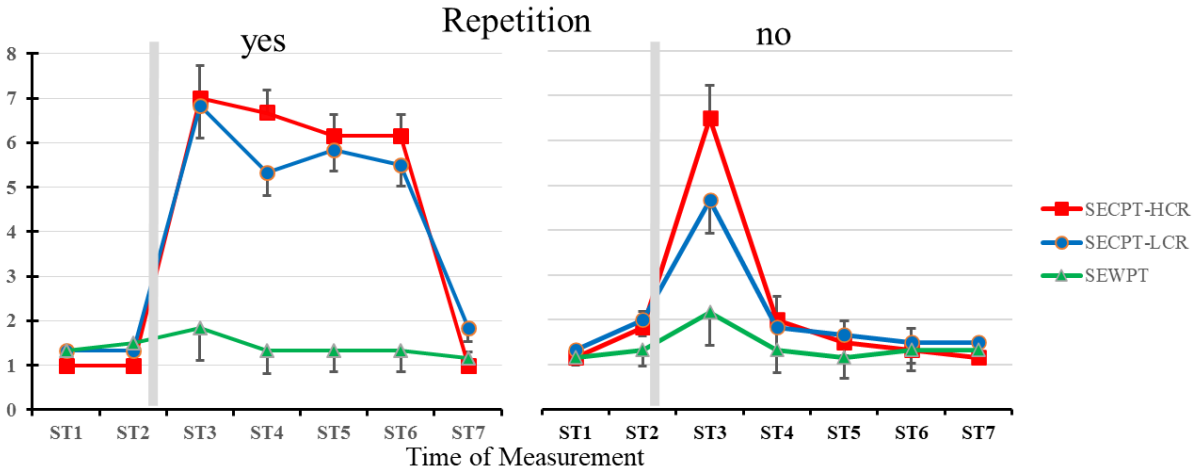

Figure 3.5: State questionnaire, item 'painful' (1=not at all; 9=very much) at 7 time points during the experiment. For each level of repetition (yes: left; no: right), for each of the stress groups. Error bars indicate 1 SEM. The grey bar indicates the timing of the SECPT or SEWPT. Note that ST3 was immediately after the SECPT or SEWPT and a shortened version of the SECPT or SEWPT was done directly before ST3 to ST6.

The follow-up test, checking the group differences at each repetition condition at each time of measurement ($\psi_{crit,\ C=42;\ df=180;\ MSE=.81} = 1.69$), revealed a clear structure: For the repetition condition, stress groups did not differ from each other at the baseline (ST1 and ST2) and at ST7. At ST3, ST4, ST5 and ST6 SECPT_LCR and SECPT_HCR subjects experienced much more pain than the SEWPT subjects, with no differences between high cortisol responders and low cortisol responders. In the no repetition condition, the only significant group differences occurred at ST3. High cortisol responders experienced more pain than low cortisol responders, with both groups reporting higher values than the SEWPT subjects.

Only the item ‘pleasant` showed a significant triple interaction [$F(12,180)=2.53$; $p<.05$;$\varepsilon=.71$;$\eta^2=.14$]. Though the effect is much smaller, the structure was very similar to the item ‘painful’.

The analysis of items ‘stressful’ and ‘aversive’ showed a significant two-way interaction STRESS GROUP by TIME OF MEASUREMENT [stressful: $F(12,180)=3.55$; $p<.01$;$\varepsilon=.65$;$\eta^2=.19$; aversive: $F(12,180)=2.36$; $p<.05$;$\varepsilon=.64$;$\eta^2=.14$] depicted in Figure 3.6.

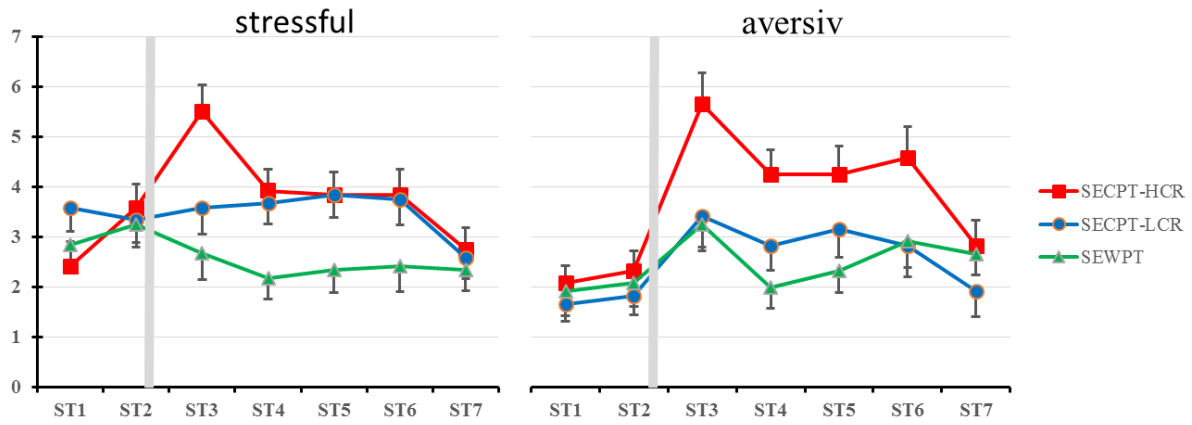

Figure 3.6: State questionnaire, item ‘stressful’(left) and item ‘aversive’ (right; 1=not at all; 9=very much) at 7 time points during the experiment for each of the stress groups. Error bars indicate 1 SEM. The grey bar indicates the timing of the SECPT or SEWPT. Note that ST3 was immediately after the SECPT or SEWPT and a shortened version of the SECPT or SEWPT was done directly before ST3 to ST6.

The follow-up tests for the item ‘stressful’, comparing the three groups at each time of measurement ($\psi_{crit,\ C=18;\ df=180;\ MSE=1.31} =1.42$), showed significant differences at time point ST3 immediately after the SECPT or SEWPT [SECPT-HCR>(SECPT_LCR=SEWPT)]. At ST4, ST5 and ST6 the SECPT-HCR and SECPT-LCR groups had higher values than the SEWPT, with no difference between SECPT-HCR and SECPT-LCR groups. No statistically reliable differences occurred at time point ST1, ST2, and ST7.

The same follow-up test for the item ‘aversive’ ($\psi_{crit,\ C=21;\ df=180;\ MSE=1.56} =1.55$) showed larger values for the SECPT-HCR group at ST3 to ST6, compared to SEWPT subjects. At ST3 and ST6 the SECPT-HCR group had significant higher values than the SECPT-LCR group, with the latter never differing from the SEWPT group between ST4 and ST6. At the baseline (ST1 and ST2) and after block 4 (ST7) no differences between groups were identifiable.

No relevant effects were observed for the item ‘arousal’. The power ($\Omega^2\geq.10$; $\rho=.3$) in all these analyses for the non-significant interactions STRESS GROUP by TIME OF MEASUREMENT and STRESS GROUP by REPETITION by TIME OF MEASUREMENT is larger than .95.

The four questions of the follow-up survey (see 3.2.2.5) were analyzed by a STRESS GROUP by REPETITION by ITEMS ANOVA, with the last repeatedly measured factor representing the answer profile of the four questions. The main effect of STRESS GROUP was significant [$F(2,30)=19.9$; $p<.001$;$\eta^2=.57$] with significant differences between all possible group comparisons (SECPT_HCR 68.54; SECPT-LCR 49.17; SEWPT 22.92). This main effect was qualified by the two interactions, STRESS GROUP by ITEMS [$F(6,90)=3.12$; $p<.05$;$\varepsilon=.82$;$\eta^2=.17$] and REPETITION by ITEMS [$F(3,90)=3.22$; $p<.05$;$\varepsilon=.82$;$\eta^2=.10$]. Follow-up tests for the STRESS GROUP by ITEMS interaction, comparing the stress groups for each item ($\psi_{crit,\ C=18;\ df=180;\ MSE=247} =17.32$), showed the following results:

1. How difficult was it for you to keep the hand in the water?
   SECPT_HCR>SECPT-LCR>SEWPT

2. How unpleasant was this situation for you?
   SECPT_HCR>(SECPT-LCR=SEWPT)

3. How stressed were you in the situation?
   SECPT_HCR>SECPT-LCR>SEWPT

4. How painful was it keeping the hand in the water?
   (SECPT_HCR=SECPT-LCR)>SEWPT

Follow-up tests for the REPETITION by ITEMS interaction, comparing the two repetition groups for each item ($\psi_{crit,\ C=6;\ df=90;\ MSE=247} =12.78$), showed that only subjects repeating the SECPT or SEWPT revealed smaller values in item 1, compared to those subjects without repetition. For the other items there was no difference between repetition and non-repetition. As this effect does not include the independent variable STRESS GROUP, it is only of minor interest.

The measurement of the actual feelings of the subjects during the experiment and the results of the follow-up survey, support the notion that the SECPT resulted in a strong psychological reaction, which met the expectations.

3.3.1.2 Iowa Gambling Task

For the decision task to work properly, subjects should have learned across the experiment (from block 1 to block 4) that cards 1 and 2 are more favorable.

Table 3.1 illustrates the percentage of each card selected in each block. Descriptively, card 1 and 2 are chosen more frequently than card 3 and 4. This difference becomes more visible, the more the experiment progressed from block 1 to block 4.

Table 3.1: Percent of choices for each card in each block

	Card1	Card2	Card3	Card4
Block 1	**28.17**	**38.89**	**19.00**	**13.94**
Block 2	**35.50**	**38.00**	**14.89**	**11.61**
Block 3	**42.83**	**33.61**	**13.22**	**10.33**
Block 4	**45.72**	**35.89**	**11.06**	**7.33**

Statistically, this is confirmed by the results of a STRESS GROUP by REPETITION by CARD by BLOCK ANOVA, with repeated measurement on the last two factors. The main effect of CARD [$F(3,90)=17.65$; $p<.01$;$\varepsilon=.58$;$\eta^2=.37$] is qualified by a CARD by BLOCK interaction [$F(9,270)=6.80$; $p<.01$;$\varepsilon=.28$;$\eta^2=.19$]. Follow-up tests, comparing the cards in each block, showed that there was never a difference ($\psi_{crit,\ C=24;\ df=270;\ MSE=38.11} = 4.53$) between card 3 and 4 in any block. In block 1 card 1 was chosen less often than card 2 and cards 1 and 2 were more often selected than cards 3 and 4. In block 2, cards 1 and 2 did not differ, and again these cards were more frequently used than card 3 and 4. Finally, in blocks 3 and 4 card 1 was chosen more often than card 2 and these two cards were more often selected than cards 3 and 4.

This clearly demonstrates that, as expected, subjects learned very fast that cards 1 and 2 are more favorable than cards 3 and 4.

These results show that the decision task worked as expected.

3.3.1.3 Feedback Related Negativity

For the FRN we expected a fronto-central negativity, elicited by relatively stronger negativity for negative feedbacks than for positive feedbacks. The FRN had an average latency of 272 milliseconds. Its amplitude was calculated as the average amplitude ±15 ms around the individual FRN-peaks. As illustrated in Figure 3.7 (right), the FRN showed the expected topography, resulting from the typical difference between positive and negative feedback. To confirm the visual topographical interpretation statistically the FRN amplitude was submitted to a MIDLINE (anterior-frontal, frontal, fronto-central) by HEMISPHERE (left, middle, right) by BLOCK repeated measurement ANOVA. This constellation includes 9 electrodes (Af3, Afz, AF4, F3, Fz, F4, Fc3, FCz, Fc4) defined by the combination of the independent variables MIDLINe and HEMISPHERE.

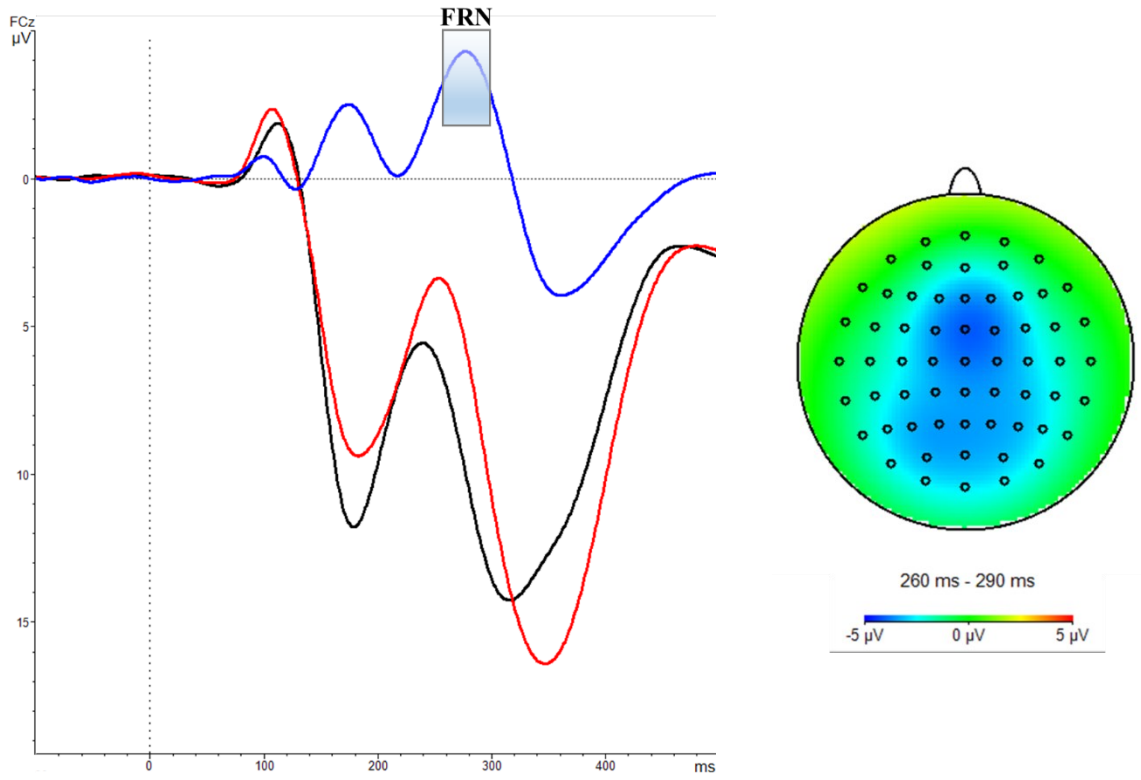

Figure 3.7: Grand averages at FCz for all subjects (left). Plotted together are the positive feedback stimulus (black), negative feedback stimulus (red) and the difference potential negative minus positive feedback (blue). Time axes from -100 to 500 ms; y-axes from -5 to 20 µV. The right part shows the topographies of the average amplitude (from 260 to 290 ms) from the difference potential. The right side shows the topography of the FRN.

There was a main effect of MIDLINE [$F(2,70)=21.2$; $p<.001$;$\varepsilon=.63$;$\eta^2=.38$] showing the largest amplitudes at Fz (-4.64 µV) and FCz (-4.21 µV) compared to AFz (-3.18 µV). Additionally, a main effect of HEMISPHERE [$F(2,70)=25.34$; $p<.01$;$\varepsilon=.93$;$\eta^2=.42$] was observed, showing the largest amplitudes at midline (-4.89µV), compared to left (-3.28 µV) and right (-3.58 µV). No effect which included BLOCK was significant.

3.3.2 Influence of Acute Stress and Feedback

The central hypothesis states that acute stress changes feedback processing and leads to faster and riskier decisions in situations of uncertainty, where the outcome probabilities of the decisions are not known.

3.3.2.1 Reaction Times

From the hypothesis we expect faster reaction times for SECPT high cortisol responders, especially after positive feedback.

The mean reaction times, measured as the time elapsed from showing the four cards to the subject's choice, were submitted to a STRESS GROUP by REPETITION by PREVIOUS FEEDBACK by BLOCK ANOVA, with repeated measurement on the last two factors. The only significant effects were a main effects of BLOCK [$F(3,90)=4.64$; $p<.01$;$\varepsilon=.69$;$\eta^2=.13$] and a main

effect of PREVIOUS FEEDBACK. [$F(1,30)=11.84$; $p<.01$;$\eta^2=.28$].The follow-up tests for Block ($\psi_{crit,\ C=6;\ df=90;MSE=11390}$ =48) showed that subjects were slower in Block 1 (568 ms) than Block 3 (503 ms), with all other comparisons to block 2 (528 ms) and block 4 (526 ms) not being significant. After a positive feedback subjects were slower (543 ms) than after a negative feedback (520 ms).

The prediction that SECPT_HCR subjects should react faster after positive feedback, which could only occur, after a cortisol reaction is possible (blocks 2 to 4) should result in a triple interaction STRESS GROUP by PREVIOUS FEEDBACK by BLOCK. This interaction was not significant and reveals a power ($\Omega^2 \geq .10$; $\rho=.50$) of more than .95.
This allows for the rejection of the alternative hypothesis with an error of less than 5%.
Thus, reaction times were not influenced by the acute stressor.

3.3.2.2 Iowa Gambling Task

The amount of money won or lost was submitted to a STRESS GROUP by REPETITION by BLOCK ANOVA. On average subjects won 14.35 € (sd=279.27). The range extends from a loss of 2076 € to a win of 994 €. The only significant result was a main effect of BLOCK [$F(3,90)=4.21$; $p<.01$;$\varepsilon=.71$;$\eta^2=.12$]. There were no differences in the average amount of money won or lost in block 1 (-49.53 €), block 2 (-7.17 €) or block 3 (12.08 €). However, in block 4 the average win over all subjects was 111.86 €. No interaction, including STRESS GROUP by REPETITION, was significant. The power ($\Omega^2 \geq .10$; $\rho=.50$) for all interactions which include BLOCK is larger than .95. However, for the main effects and the interaction of the independent variables STRESS GROUP and REPETITION, power for a medium-sized effect is only .70. Thus, these null hypotheses will not be interpreted.

The conditional risk measure (see 3.2.2.1) was submitted to a STRESS GROUP by REPETITION by PREVIOUS FEEDBACK by BLOCK ANOVA The main effect of BLOCK [$F(3,90)=13.49$; $p<.01$;$\varepsilon=.82$;$\eta^2=.31$] was qualified by a STRESS GROUP by BLOCK interaction [$F(6,90)=5.30$; $p<.001$;$\varepsilon=.82$;$\eta^2=.26$], shown in Figure 3.8. Post-hoc tests, comparing the profiles for each stress group ($\psi_{crit,\ C=36;\ df=90;\ MSE=.066}$ =.25), showed that there were no differences in the risk measure between blocks for the SECPT-HCR and SEWPT groups. Only for the cold-water low cortisol responders (SECPT-LCR) block 1 was slightly different from block 2 ($p=.07$) and clearly different from blocks 3 and 4. Additionally, block 2 was smaller than block 4 with no differences between blocks 2 and 3.

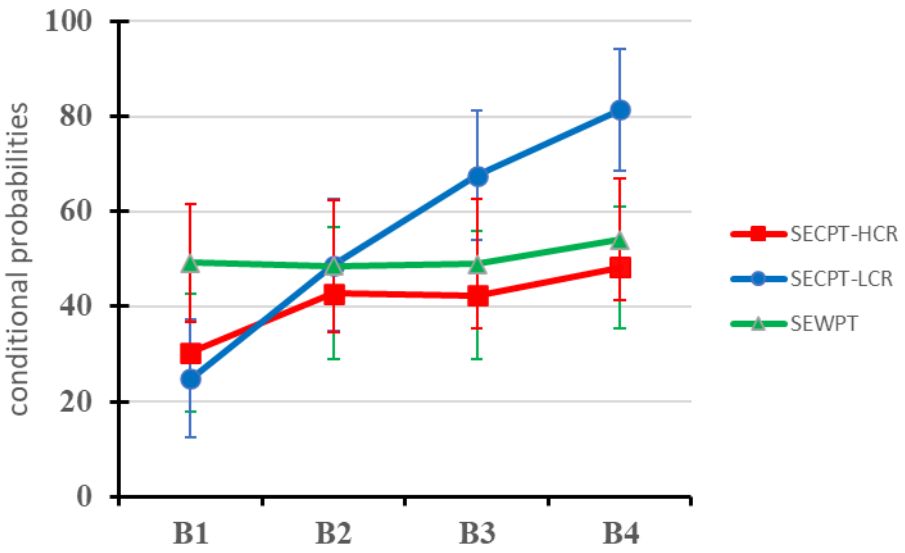

Figure 3.8: Conditional risk measure (probabilities x 100) for each stress group in all 4 Blocks. Y-axes the probabilities of the conditional risk measure. Error bars indicate 1 SEM. High values indicate less risk.

A look at this interaction with emphasis on the differences between stress groups in each block ($\psi_{crit,\ C=12;\ df=90;\ MSE=.029} = .21$) revealed that at block 1 the SECPT-LCR group had lower values than the control group with the difference between the SECPT-HCR group and the control group just failing the significance level ($p = .06$). No difference between stress groups were observed in block 2, while in blocks 3 and 4 low cortisol responders had larger values than the other two groups.

This interaction was not further qualified by the relevant interactions STRESS GROUP by REPETITION by BLOCK [power($\Omega^2 \geq .10$, $\rho = .7$)>.95] or STRESS GROUP by REPETITION by PREVIOUS FEEDBACK by BLOCK [power($\Omega^2 \geq .10$. $\rho = .7$)>.95]. Thus, the error of falsely accepting these statistical null hypotheses is less than 5%.

The other relevant result was a significant STRESS GROUP by PREVIOUS FEEDBACK interaction [$F(2,30) = 4.23$; $p < .01$; $\eta^2 = .23$], depicted in Figure 3.9. Comparing the conditional probabilities after positive and negative feedback is only significant for the SECPT-LCR group ($\psi_{crit,\ C=3;\ df=30;\ MSE=.046} = .11$). After a positive feedback SECPT-LCR subjects exhibited more risky behavior than the other two groups, whereas after a negative feedback SECPT-HCR subjects made less risky decisions than the warm water control group, with the remaining comparisons being not significant ($\psi_{crit,\ C=6;\ df=30;\ MSE=.046} = .12$).

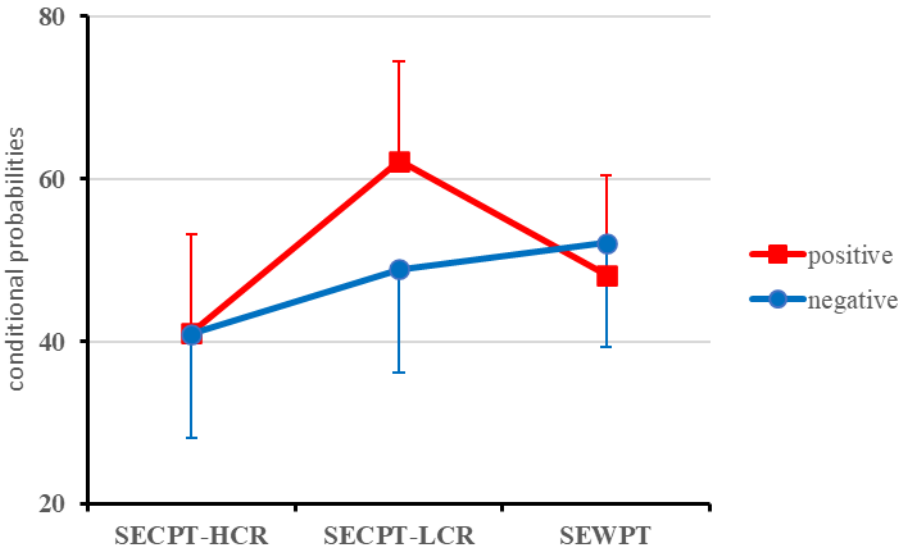

Figure 3.9: Conditional risk measure (probabilities x 100) after positive feedback s (red) and losses (blue) for each stress group. Error bars indicate 1 SEM.

This interaction was not further qualified by BLOCK (power for the STRESS GROUP by PREVIOUS FEEDBACK by BLOCK interaction >.95) or by REPETITION (power for the STRESS GROUP by REPETITION by PREVIOUS FEEDBACK >.81).

3.3.2.3 Feedback Related Negativity

Figure 3.10 shows the grand averages for positive feedback, negative feedback and the differences between both, for each stress group.

The latency of the FRN was submitted to a STRESS GROUP by REPETITION by BLOCK ANOVA. The only significant effect was a main effect of BLOCK [$F(3,90)=3.48$; $p<.05$;$\varepsilon=.73$;$\eta^2=.10$]. Post-hoc tests revealed ($\psi_{crit,\ C=6;\ df=90;\ MSE=453} =13.54$) that the latency in block 1 (281 ms) was later than in blocks 2 (267ms) and 3 (268ms). Block 4 (274 ms) did not differ from any other block.

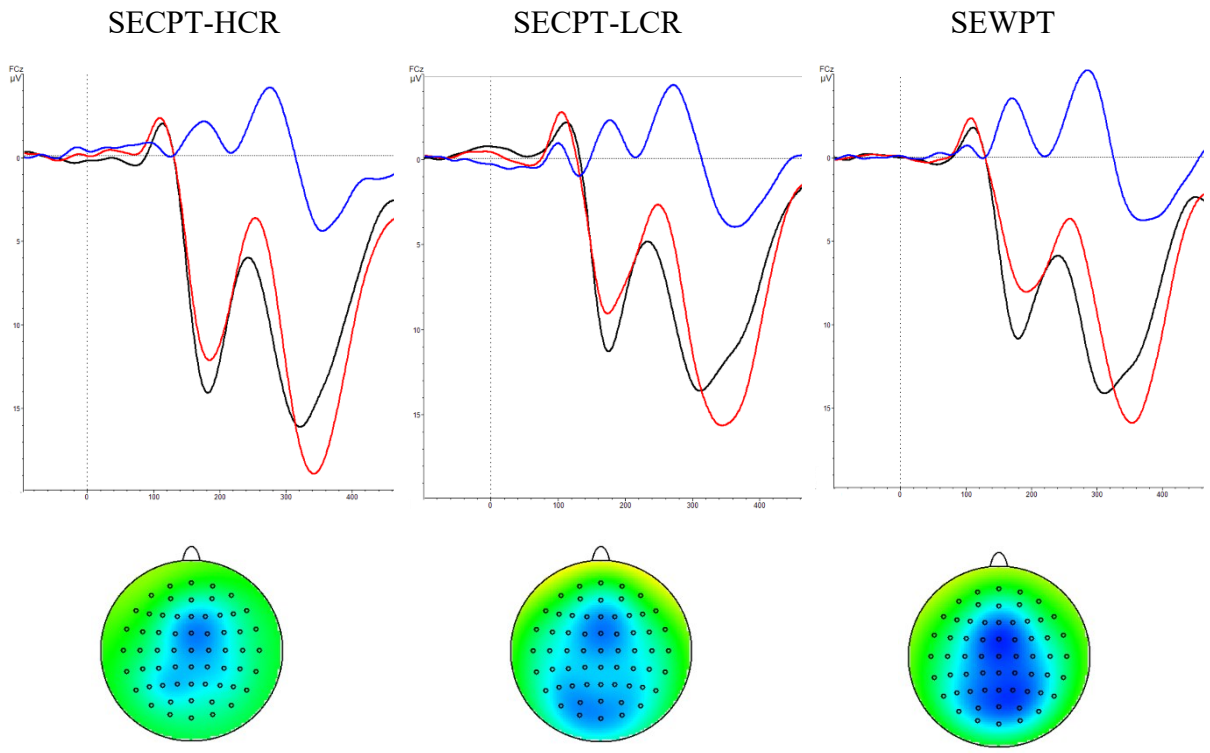

Figure 3.10: Grand averages at FCz for all subjects (first row) and for SECPT-HCR, SECPT-LCR and SEWPT subjects (1st row). Plotted together are the positive feedback stimulus (black), negative feedback stimulus (red) and the difference potential negative minus positive feedback (blue). Time axes from -100 to 500 ms; y-axes from -5 to 20 µV. Row 2 represents the topographies of the average amplitude (from 260 to 290 ms) of the difference potential for each stress group. All topographies are scaled from -5 to +5 µV.

The average FRN amplitude at FCz (± 15 ms around the peak) was submitted to STRESS GROUP by REPETITION by BLOCK ANOVA. The only significant result was a STRESS GROUP by BLOCK interaction [$F(6,90)=2.82$; $p<.05$;$\varepsilon=.93$;$\eta^2=.16$] shown in Figure 3.11.

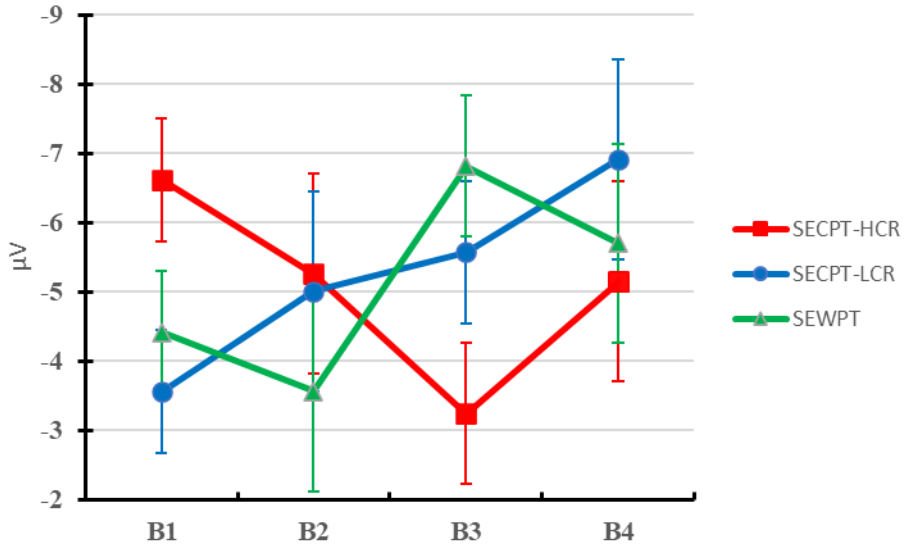

Figure 3.11: FRN amplitudes in µV (negative upwards) at FCz for each stress group in each block. Error bars indicate ± 1SEM. More details see text.

Post-hoc tests, comparing the block profile within each stress group ($\psi_{crit,\ C=18;\ df=90;\ MSE=6.12}$=2.16), showed a complex picture. For cold water high cortisol responders (SECPT-HCR), FRN amplitude was less negative in blocks 2 and 3 compared to block 1. Block 4 showed more negative amplitudes than block 3. The difference between block 4 and block 1 approached significance (p=.07). Nearly the opposite picture was obtained for SECPT-LCR subjects. FRN amplitudes successively got more negative over blocks with blocks 3 and 4, showing more negative amplitudes than block 1. For the control group (SEWPT) blocks 1, 2 and 4 did not differ. Block 3 was more negative than blocks 1 and 2, with the difference between blocks 3 and 4 only approaching significance (p=.09).

A look at this interaction for differences in groups in each block ($\psi_{crit,\ C=12;\ df=90;\ MSE=6.12}$ =2.21) showed the following results:

- Block 1: SECPT_HCR < (SECPT-LCR = SEWPT)
- Block 2: SECPT_HCR = (SECPT-LCR = SEWPT
- Block 3: SECPT_HCR > (SECPT-LCR = SEWPT)
- Block 4: SECPT_HCR = (SECPT-LCR = SEWPT

3.3.3 Influence of hair cortisol concentration

Mean hair cortisol concentration was 4.67 pg/ml (sd=2.30).

IGT: To explore the influence of chronic stress level, as measured by hair cortisol concentration (HCC), the above reported STRESS GROUP by REPETITION by PREVIOUS FEEDBACK by BLOCK ANOVA (see 3.3.2.1 Hand 3.3.2.2) for the reaction times and the conditional risk measured, was repeated by adding HCC as a continuous predictor. The results reported there were not further qualified by HCC. Power for the HCC by STRESS GROUP by BLOCK interaction is > .95, whereas power for the HCC by STRESS GROUP by PREVIOUS FEEDBACK is .82 (both for $\Omega^2 \geq .10$ and ρ=.7). All other interactions have the same power as the analysis without HCC.

FRN: To explore the influence of chronic stress level, as measured by hair cortisol concentration (HCC), the STRESS GROUP by REPETITION by PREVIOUS FEEDBACK by BLOCK ANOVA for the FRN amplitude measure was repeated, by adding HCC as a continuous predictor. The above reported interaction STRESS GROUP by BLOCK (see 3.3.1.3) was not further qualified by HCC. Power for the HCC by STRESS GROUP by BLOCK interaction is > .95. All other interactions have the same power as the analysis without HCC.

Thus, no influence of hair cortisol concentration on IGT scorers or FRN amplitudes were found.

3.4 Discussion.

The second experiment was designed as a more rigorous test of the hypothesis developed in the general introduction which stated:

Acute stress leads to faster, riskier decisions under ambiguity only in subjects who show a clear cortisol increase in response to the acute stressor. The mechanism behind this cortisol induced change is a switch in feedback processing, preferring positive over negative feedback, resulting in a decrease in FRN amplitudes.

The changes compared to the first study were

a) use of a different decision-making task, namely the IGT
b) only male subjects participated in the experiment,
c) a repetition of the SECPT or SEWPT was introduced and
d) the first block of the decision task was performed immediately after the SECPT or SEWPT.

All these steps were introduced to achieve a more rigorous test of the above hypothesis.

Though some interesting results were obtained for the conditional risk measure and for the FRN amplitudes, these results are again not in line with the hypothesis under test. Hence, firstly the question has to be asked, whether the experiment was properly conducted. This question will be answered in the following paragraphs which look at the outcome of the manipulation checks.

The SECPT and SEWPT worked as expected. On the hormonal level, a maximum increase in cortisol secretion was observed 20 minutes after the SECPT, only in those subjects which were categorized as high cortisol responders. This is completely in line with the published literature, where the largest increase in cortisol is measured between 20 and 30 minutes after an acute stressor (see the meta-analysis of Dickerson & Kemeny, 2004; figure1 on page 369). Also, the high cortisol responder group, with repetitions, showed their maximum cortisol response 45 minutes after the stressor, whereas the cortisol level of no-repetition high cortisol responders declined 30 minutes post stressor. This showed that the repetition worked as expected on the hormonal level (see Figure 3.3).

On the psychological level, SECPT subjects experienced more pain and less pleasantness after the SECPT. This effect held on for the repetition condition. Here, subjects were also more stressed after the SECPT. These results demonstrate a strong negative psychological response to the acute stressor and to the repetition of the SECPT. Finally, the fast, adrenergic reaction to

the stressor appeared as expected and can be seen from the observed acceleration of heart rate in the two minutes after the stressor (see Figure 3.4).

The IGT also functioned as expected. Subjects learned very fast, that cards 1 and 2 were much more favorable than cards 3 and 4. The use of the most favorable card1 successively increased from 28% in block 1 to nearly 46% in block 4, whereas the use of the least favorable card 4 decreased from nearly 14% in block 1 to 7% in block 4 (see Table 3.1). This is the expected course across time (Bechara, 2007) and shows, that the subjects in this experiment learned from experience.

Finally, the FRN was observed in the expected latency range with an average latency of 272 ms, showing the common fronto-central maximum on the scalp (see Figure 3.7).

In summary, all the manipulation checks showed convincing results and there is no reason to assume that the results discussed in the following paragraphs are due to problems with the operationalizations of the acute stressor, the decision task or the electrophysiological measurement.

The probability of falsely interpreting relevant statistical null hypotheses is nearly always below 5% in experiment 2 (see the results section for details), which is the same as in experiment 1. Thus, the nonsignificant results can be interpreted with confidence.

As we can conclude that the manipulation checks hold true and interpretations of statistical null hypotheses were appropriate, the following paragraphs turn now to the discussion of those results, relevant to the general hypothesis.

Regarding the FRN, the hypothesis relies on the argument that cortisol secretion activates the dopaminergic system, which is crucially involved in reward processing. More dopamine available in the frontal cortex (more specifically in the anterior cingulum) should result in reward signals (positive feedback) which become more important. This again should diminish the difference between electrocortical responses to positive and negative feedback, in the time range of the FRN, consequently resulting in a less negative FRN amplitude.

At the first glance, the experiment showed results which support the hypothesis for the FRN (see Figure 3.11). The high cortisol responder group had the most negative FRN amplitude in block 1, where relatively little cortisol was available. Then the amplitude became less negative in blocks 3 and 4, where the cortisol secretion was at its maximum and negativity was enhanced in block 4. The low cortisol responder group showed an opposite pattern. For these subjects,

the FRN amplitude was less negative in block 1 and successively enhanced its negativity across time.

In functional terms, this could be interpreted that high cortisol responders decreased their quality of feedback processing over time, whereas low cortisol responders increased the quality of their feedback processing over time. However, the problem with this interpretation is that high cortisol responders showed a more negative FRN immediately after the SECPT in block 1. The FRN amplitudes of the low cortisol responder group and the warm-water control group were significantly smaller.

There is no good explanation for this result, as one would expect the SECPT groups and SEWPT control group to be equal in FRN amplitude at this measurement point. The cortisol levels should not yet be affected by the acute stressor.

The comparison of stress-groups for blocks 2 to 4 are also puzzling. From the hypothesis, one would have expected less negative FRN amplitudes in these blocks only for the cortisol-high responder group. However, there was no difference between groups in blocks 2 and 4, but the expected difference was observed in block 3. The result of the group comparison in block 3 was due to the fact that the FRN amplitude of the warm-water control group was more negative than in the other blocks. This increase in negativity in block 3 for this group cannot be explained by any of the manipulated independent variables. Would this amplitude been on the same level as in the other three blocks, quite likely, no differences between groups would have occurred in block 3.

In sum, the results for the FRN are puzzling and difficult to interpret, but they are not in line with the hypothesis.

On the behavioral level, the hypothesis predicted that high cortisol responders make faster and more risky decisions at the time when the cortisol response is at his maximum, as cortisol influences feedback processing, such that positive feedback becomes more important than negative feedback. The results of the reaction times (see 3.3.2.1) contradict the prediction that reaction times should be faster for high cortisol responders. Neither the stressor, nor the intensity of the cortisol secretion, nor the feedback obtained prior to the actual reaction influenced reaction times.

The hypothesis also predicted that the high cortisol responders should increase their risk over time. This is not the case at all. All subjects developed some kind of risk aversion, as their balance got more positive from blocks 1 to 4. Whereas their balance was near zero in blocks 1 to 3 (block 1: -49.53 €; block 2: -7.17 €; block 3: 12.08 €). The balance in block 4 increased on

average to 111.86 €. This effect was not modified in any way by cortisol secretion, repetition, or previous feedback. This contradicts again the expectations derived from the hypothesis. From there, it would have been expected that high cortisol responders increase their risk across blocks, whereas low cortisol responders and the warm-water control group stay on the same risk levels or even decrease their risk levels across the experiment.

The same expectation was made for the conditional risk measure, which considered the quality of the feedback (positive or negative) in the preceding trial (see Figure 3.8). The interesting result was the decision behavior of the low cortisol responders. This group continuously decreased their risk from blocks 1 to 4, showing higher values (remember: high values indicate less risk) than the other two groups in blocks 3 and 4. Here, the acute stressor led to more cautious behavior for subjects not showing a strong hormonal response to the acute stressor, again a result not expected by the hypothesis. The prediction from the hypothesis was, that only high cortisol responders increase their risk, whereas low cortisol responders and control group should not do so.

In sum, also on the behavioral level, the data from the present experiment is not in line with predictions derived from the general hypothesis.

Furthermore, both SECPT groups made riskier decisions than the warm-water control group in block 1, where the expectation was, that here no difference between groups should be observed due to relatively comparable and low cortisol levels immediately after the SECPT or SEWPT. That is, immediately after the cold-pressure test, these subjects showed riskier decisions, perhaps as a fast consequence of the adrenergic physiological response. Then the high cortisol responders return to homeostasis and behaviorally act like the control group, whereas those subjects who showed no strong cortisol reaction after the stressor made more and more cautious decisions.

Despite the experiment being properly conducted, as validated by the manipulation checks, these results are clearly not in line with the hypothesis. A speculative interpretation might be, that the acute stressor is a signal for cautiousness and that the secretion of cortisol leads to the expected homeostasis by reactivation of the HPA axis via a negative feedback loop (see 1.3.2). However, it is always possible that this is a random result and only further research can lead to valid interpretations.

There is a noteworthy parallel between the Feedback Related Negativity and the decision behavior for the low cortisol responders (compare the blue lines in Figure 3.8 and Figure 3.11). This group became more and more cautious from blocks 1 to 4 and at the same time FRN

amplitudes became more negative. That is, optimal feedback processing, indicated by a more negative FRN, leads to more rational behavior. A nice result, but not in line with the general hypothesis.

In summary, the general hypothesis, that acute stress leads to riskier decision making in ambiguous decision situations is not supported by the present experiment. Moreover, the commonly assumed mechanism that stress influences feedback learning, via an influence of the stress hormone cortisol on the dopaminergic reward system, is also not supported. Though this experiment did not identify any impact of the dopaminergic reward system, it directly measured the activity of feedback processing by means of the FRN. As acute stress did not influence feedback processing in ambiguous decisions making, the whole argument chain is obsolete. Though there exist some consistent findings that acute stress leads to riskier decisions in ambiguous situations (Mather & Lighthall, 2012; Starcke & Brand, 2012, 2016), these effects are quite likely not due to a change in fast and automatic feedback processing.

The exploratory analysis of the influence of chronic stress, as measured by hair cortisol concentration (Stalder et al., 2017) on decision making under uncertainty, revealed no significant results. I could not find a single paper or report studying the influence of chronic stress on decisions under uncertainty in the literature.

One study (Ceccato, Kudielka, & Schwieren, 2016) investigated the influence of chronic stress, measured by hair cortisol concentration, in binary lottery decisions. This is a risk paradigm where outcome probabilities are known to the decision maker. With a large sample (n=195) they report no correlation between hair cortisol concentration and decision making under risk and a significant but very small positive correlation (r=.118) between subjectively experienced chronic stress and risky decision making. Shields, Ivory, and Telzer (2019) report a negative correlation between HCC and risky decision making (r=-.393) for an adolescent sample (average 13.39 years old). Their decision task was the yellow light game where subjects could cross or stop at a yellow light. The relation of this decision task to economic decision making is not clear, as is the comparability of their adolescent sample to the sample in this study.

In sum, the results reported in this experiment and the few published research papers point to none or minimal influence of chronic stress on decision making. However, much more research is needed to come up with an unambiguous answer.

4 General Discussion

The general discussion first compares in detail the behavioral and electrophysiological results, relevant to the hypothesis under test. I will then return to the example of the portfolio manager, and change the prediction of his decision behavior in light of the current results. Then a general conclusion is drawn, followed by a discussion of some possible objections which might be raised against this conclusion. Finally, a possible direction for future research is developed.

4.1 Overview over the convergent and divergent results in both studies

In both experiments, acute stress did not confirm that high cortisol responders make riskier decisions than low cortisol responders and the warm-water control group. Figure 4.1A depicts the conditional probabilities for male and female subjects in experiment 1. Here, the conditional probability is the percentage of making a risky decision in a trial under the condition that the previous trial was a positive or negative feedback. Large values in this measure indicate high risk.

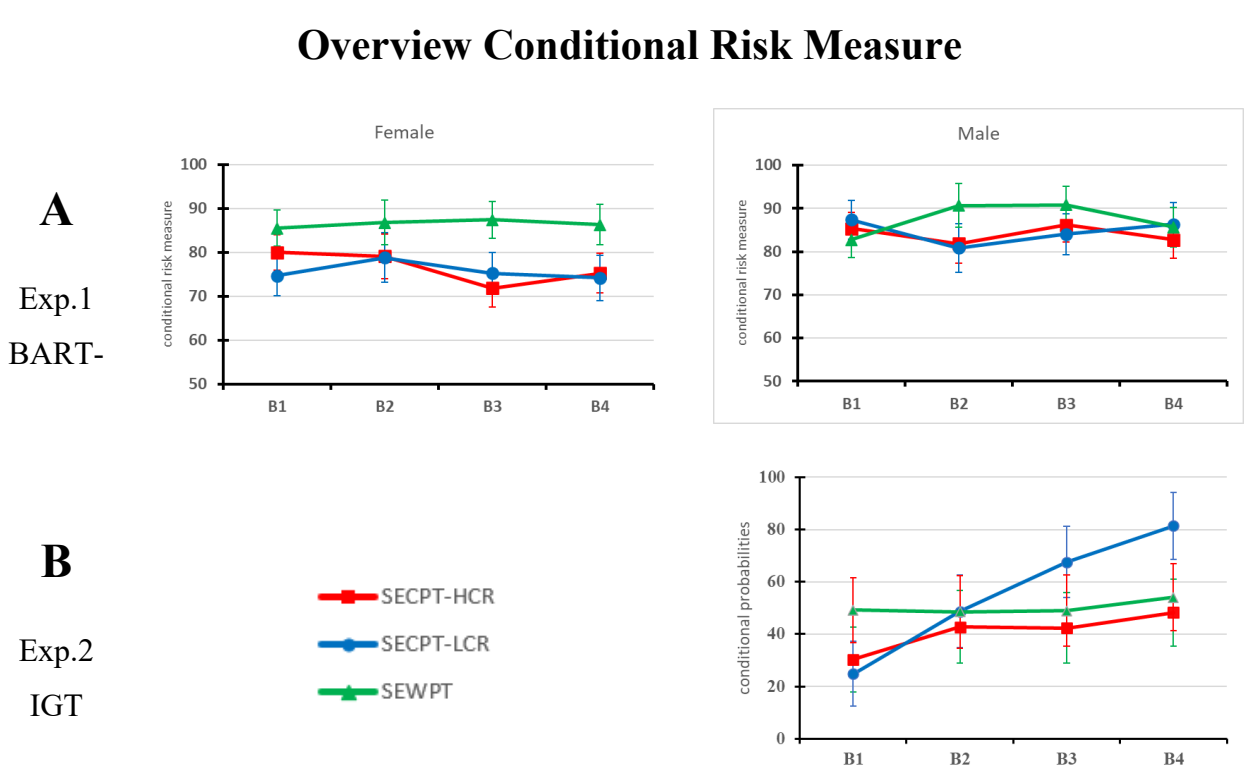

Figure 4.1: Profile of conditional risk measures (probabilities x 100) separate for each block in experiment 1 (A for female and male subjects) and experiment 2(B. only male subjects). Experiment 1: The probability is the percentage of a level chosen in an actual decision trial, under the condition that the previous trial was a positive or negative feedback. As this independent variable exhibited no influence on the risk measure the probabilities are averaged over the two levels of this independent variable. *Large values indicate high risk* Experiment 2: The conditional risk measure was calculated separately for previous wins and losses as the difference of the conditional probabilities for cards 1and 2 minus cards 3 and 4. Large values in this measure indicate low risk. As previous feedback showed no influence on the risk measure data were averaged over the levels of this independent variable. Error bars are 1 SEM.

No prediction derived from the hypothesis could be confirmed statistically. Moreover, descriptively. Female control subjects always showed less risky behavior, whereas male subjects showed this effect only in blocks 2 and 3. Hence, on the behavioral level there is not the slightest indication that acute stress negatively affects decision-making in an ambiguous decision situation.

In spite of the measures used to strengthen the operationalizations of the paradigms, the same holds true in experiment 2 (see Figure 4.1 B), in which the Iowa Gambling Task was used as an experimental decision paradigm. The conditional risk measure is somewhat different to the one in the BART task. The conditional risk measure was calculated separately for previous wins and losses as the difference of the conditional probabilities for cards 1and 2 (favorable desks) minus cards 3 and 4 (less favorable desks). Large values in this measure indicate low risk. Though some expected interactions became statistically significant, their structure contradicted the hypothesis.

Immediately before the acute stressor, subjects which passed through the SECPT, act riskier than the control group. This cannot be caused by cortisol, as at baseline there was no difference in the cortisol measures between these groups.

When cortisol became available, the high cortisol responders showed the same decision-making behavior as the non-stressed warm-water control group. Again, this contradicts the hypothesis, more so, as the stressed group, which showed only a small activation of the HPA-axes, turned more and more cautious (risk averse) over the experiment. That is, the acute stressor led 20 minutes after its experience to less risky decision behavior.

Both decision paradigms produced behavioral results that are not in line with the hypothesis under test. Moreover, their general outcome is not convergent, which is mostly caused by the very different decision-making behavior of the SECPT-LCR groups in both experiments. This leads to the assumption, that the paradigms might measure different aspects of the decision-making process. This is suggested by a recent publication of Buelow and Barnhart (2018). They reported that the correlation between the BART task and the IGT is very low (r=.02). Additionally, results from factor analysis (Buelow & Blaine, 2015) revealed that BART and IGT load on different orthogonal factors. This suggests that the IGT and BART measure different types of decision-making. Obviously, more research is needed to characterize these different types of decision making under acute stress. This might also reflect a possible explanation why the two experiments did not show convergent results. Whatever these possible

types of decision making look like, the present results indicate that they are not influenced by acute stress.

In summary, neither the statistical level, nor the descriptive level allows for any conclusion that, building upon the behavioral decision-making data of both experiments, acute stress leads to riskier decisions in ambiguous decision-making situations.

Nearly the same conclusion can be drawn for the FRN results in both experiments. The hypothesis predicted, that the larger the risk, the smaller the FRN amplitude. Figure 4.2 depicts the intensity of the FRN in each block of the experiment.

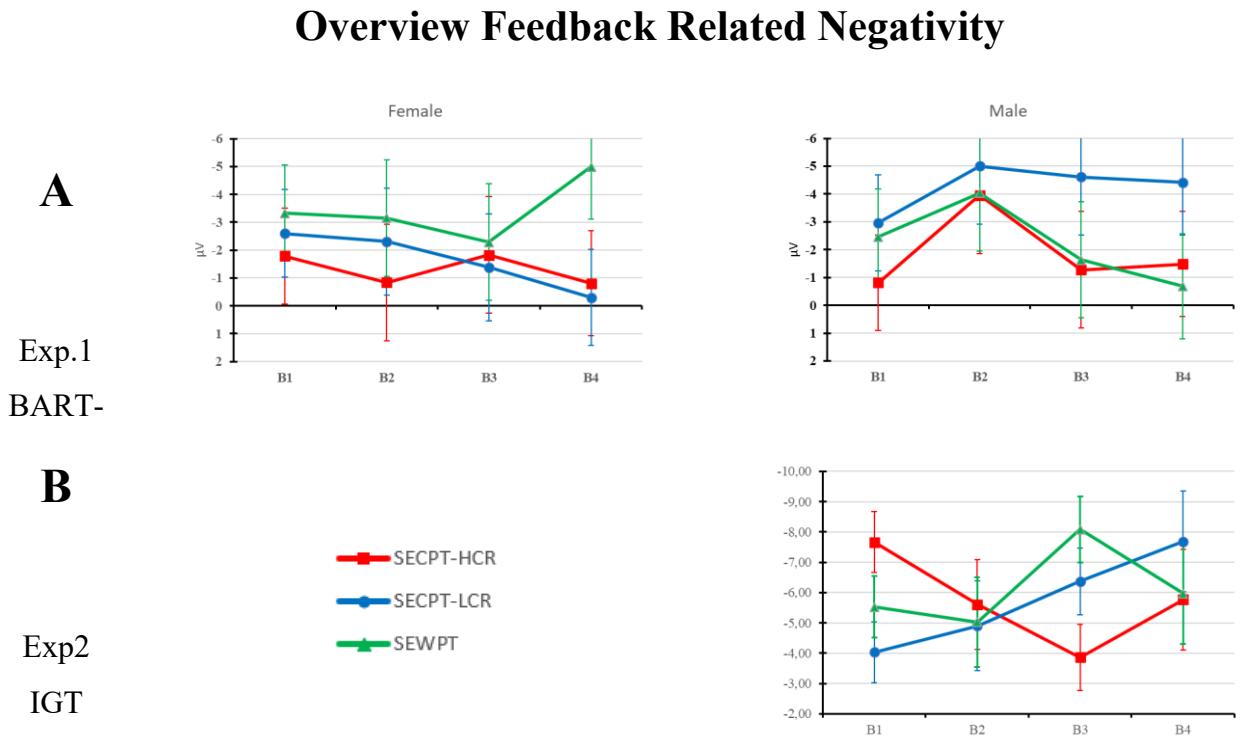

Figure 4.2: Profile of FRN amplitudes in experiment 1 (A) and experiment 2 (B) at FCz in each block for each stress group, separate for each block in experiment 1 (A) and 2(B).

Descriptively, none of the profiles followed the prediction with one exception: The low cortisol responders in experiment 2 showed an increase in risk aversion across blocks 1 to 4, 1 to block 4, see Figure 4.2 B. Completely in line with this finding, their FRN amplitude is less negative in block 1 and gets linearly more negative up to block 4. For this group, less risk is associated with more negative FRN amplitudes, that is, the better the feedback processing, the less risk one takes. This may support the idea, developed in the general discussion, that optimal feedback processing leads to better decisions under uncertainty. But this observation is clearly not in line

with the prediction that the FRN should be less negative after an acute stressor, especially for those subjects who showed a strong activation of the HPA-axes.

Thus, the overall conclusion for the behavioral and electrophysiological results is that the predictions were not fulfilled, in consequence the hypothesis under test has to be rejected. The data presented in this thesis suggest, that acute stress does not negatively influence decision making under uncertainty.

4.2 General conclusion

This thesis started with a fictitious story of a portfolio manager who had to make a financial decision half an hour after he experienced an acute stressor, because his wife threatened to leave him with their two children. At thetime he made his choices, he was in a very bad mood. It turned out that the decisions he made under the influence of the acute stressor were suboptimal. Not only did he make his decisions too fast, but he ignored nearly all negative information he has gathered beforehand about the potential buys, relying mostly on the positive ones.

From the hypothesis developed in the general introduction which read "*Acute stress leads to faster, riskier decisions under ambiguity only in subjects who show a clear cortisol increase in response to the acute stressor. The mechanism behind this cortisol induced change is a switch in feedback processing, preferring positive over negative feedback, resulting in a decrease of FRN amplitudes"* the behavior of our portfolio manager was interpreted as follows:

He felt bad, his first physiological reaction (sweating, strong cardiac activation), which appeared immediately after the threatening announcement of his wife to leave him and take the children with her, had faded away. This fast physiological reaction calmed down after he had left the house. Twenty minutes after the stressful event he arrived at the office and in the next half hour he had to structure the portfolio for his customer. Without his knowledge the activation of the HPA- axis had produced an unusually high amount of the stress hormone cortisol. This activation reached its maximum at the time he made his decisions. The stress hormone led to an increase in the activity of the reward (dopaminergic) system. This unconsciously biased his information processing towards previously rewarding aspects and led to a non-consideration of previously negative outcomes. Thus, he chose those companies which received positive feedbacks in his previous prepared analysis and paid much less attention to the negative feedbacks. This could have led to suboptimal decisions.

Given the results of the two experiments reported here the prediction, derived from the above hypothesis about the portfolio manager's decision, was wrong. The data presented here suggest that he might have been in a bad mood and that he showed a strong HPA-axis reaction, however, this did not lead to bad decisions, nor did it influence his fast, unconscious and automatic feedback processing. The behavioral data even suggest that he might act a bit more cautious than usual.

Going beyond our fictitious example, it can only be stated that the hypothesis failed in both experiments. Neither on the behavioral, nor on the biological observational level, a negative influence of acute stress on decision making under uncertainty could be observed.

Thus, the interpretation of the results is straightforward: Acute stress does not influence decision making under uncertainty and does not bias feedback towards a preference of positive feedback.

This conclusion contradicts the general result drawn from two reviews (Starcke & Brand, 2012, 2016) and the literature published after 2016. In section 1.4, the relevant literature was critically discussed. It was asserted that not a single of these studies fulfilled all of the first three desiderata (use a psychological stressor; use a validated decision paradigm; validate the acute stressor by measuring the adrenergic and HPA-axis activity). Other studies showed severe methodological shortcomings (Byrne et al., 2019; Kassam et al., 2009; Lighthall et al., 2013; Preston et al., 2007).

Only one study fulfilled (Van den Bos et al., 2009) desideratum 4 (categorize subjects into low and high cortisol responders). In all other studies subjects were not grouped according to the intensity of the production of the stress hormone cortisol, which is important, as the bias towards positive feedback should only occur when cortisol levels are high. Though most authors agreed that stress biases feedback processing towards positive feedback, none of these studies differentiated whether the previous experience (feedback) was positive or negative (desideratum 5: the paradigm should allow to make this categorization). Moreover, the experiments reported here are the first ones, which used a direct measure of feedback processing (desideratum 6: use a direct measure of feedback processing), namely the FRN.

To summarize, there are good reasons to accept the results presented here and to conclude that acute stress does not change feedback processing and consequently has no negative influence on decision making under uncertainty.

However, a scientist should be as critical as possible with his conclusions. Therefore, I will discuss in the following paragraphs possible objections to the general conclusion.

4.3 Possible objections to the general conclusion

4.3.1 Are the effect sizes used to calculate power values too optimistic?

One methodological objection might be that the population effect size ($\Omega^2 \geq .10$), chosen for the calculation of the probability of falsely accepting the null hypotheses, is too large. This objection is difficult to invalidate.

If the real population effect is smaller (for example 3%) then the power (probability to detect a given effect *if it really exists)* of detecting such effects is around 70% at best and all the nonsignificant results would have an error probability of around 30%. Consequently, they should not be interpreted. However, even if the population effect is in reality smaller than 10%, one would expect that on the pure descriptive level, results look like the predictions derived from the general hypothesis. In this case the argument that the power of the statistical tests is not sufficient is a strong one. However, as shown in chapter 4.1 this is clearly not the case.

Another critique might be that the overall effect reported in the meta-analytic review of Starcke and Brand (2016) is only d=.17, which is transformed to Ω^2 less than 1% (exactly .0072%). In my view, this effect is too small to be chased by laborious and expensive experiments. As argued in the general introduction (see chapter 1.4), there are some studies which show empirical effect sizes of around 10%. The present studies are optimized in procedure and design to detect such an effect statistically. However, due to the small number of studies showing effect sizes of around 10%, there is no meta-analytic statistical validation for this assumed population effect size. It is only an argument based on descriptive statistics. If the real population effect is much less than 10%, the results reported here are problematic, at least as far as they rely on the interpretation of statistical null hypotheses.

I do not dare to argue that a negative effect of acute stress on decision making under uncertainty of let's say 3 to 5% is too small to have any practical implication. This issue is very difficult to deal with. What is the critical effect size for aggregated effect sizes (ideally validated by meta-analytic statistics) to be of practical importance for economic decisions in everyday life? This could only be answered by a recommendation of an expert group of senior scientists. These recommendations then should be the basis to calculate sample sizes for experiments in this field.

4.3.2 The problem of post-hoc classification

The general problem of a classification into high cortisol responders and low cortisol responders by statistics (median-split) or by norm was raised in the discussion section of experiment 1. An even a more severe problem is that this categorization is always a post-hoc classification and

possibly confounding situational and/or individual variables cannot be controlled. Incongruent results in different experiments might be explained by this problem.

Also, it is not known whether the classification in high responders and low responders is dependent on the stress paradigm used. Is a cortisol responder in the SECPT also a responder in the TSST? Furthermore, it has not been studied if responders are consistent over time. Here basic research is urgently needed.

Thus, lacking published results about the stability of this classification, it cannot be excluded that in both experiments unknown confounds are responsible for the results. A possible, but extremely laborious and expensive alternative, mitigating these potentially confounding effects would be an a-priori measurement of a large group of subjects with different laboratory stressors accompanied by the measurement of possible confounds (such as sensitivity to reward, risk-taking propensity, arousability etc.) and based on such results forming high responder and low responder groups. This could make it possible, at least, to control for known confounds (i.e., by statistical matching).

Possible but unknown confounds, when post-hoc classifying the subject into high cortisol responders and low cortisol responders, might be responsible for incongruent results in between the two experiments.

4.3.3 Are the decision paradigms suitable for the research question?

BART: The Balloon Analogue Risk Task has acceptable psychometric qualities (see Buelow & Barnhart, 2018 and the literature cited there). However, in the introduction of Experiment 2 it was argued that the risk-taking behavior might change in the course of the experiment from risk seeking during the first trials to risk averse on later trials as the reference point on which decisions are based changed in the course of the experiment. According to Kahneman (2011), people change their decision behavior, when moving from very low monetary value to higher monetary values (see also Kahneman, 1992). This reference point could be changed in the course of experiment 1 due to the fact that subjects saw their balance after each trial. When experiencing negative feedback, the resulting loss was not deducted from their balance. Thus, the amount of money, to be won at the end of the experiment, grew continuously.

IGT: Only recently Schmitz, Kunina-Habenicht, Hildebrandt, Oberauer, and Wilhelm (2020) published data on the psychometrics of the Iowa Gambling Task, gained from a large sample (n=220) of healthy adults. They also measured risk-taking by using the German adaption of the Domain-Specific-Risk-Taking Scale (Weber, Blais, & Betz, 2002) Schmitz et al. (2020; p.8) conclude: “Correlations of the gambling scores with variables of the nomological network of

risk taking were low, inconsistent and mostly nonsignificant". Their conclusion is: "Taken together, both the IGT and the BGT[11] showed insufficient reliability, and we obtained no evidence for their validity either" (p.11).

These data seem to be very trustworthy because of the large sample size. If the conclusion of Schmitz et al. (2020) is correct, then the IGT is not a suitable decision-task to measure economic decision-making under uncertainty in Experiment 2.

Thus, to study the influence of acute stress on economic decision-making under uncertainty, it could make sense to develop new paradigms.

4.3.4 Is the general conclusion applicable to real world economic decisions?

An often-posed question is whether results obtained from highly controlled economic experimental studies can be applied to the real world. This question addresses one of four quality criteria for experiments as developed by Campbell and Stanley (2002). The types of quality criteria (or validities) are:

(a) statistical conclusion validity
refers to the appropriate use of statistics

(b) internal validity
refers to whether the covariation of independent and dependent variables resulted from a causal relationship

(c) construct validity
refers to whether the operationalizations measure the intended constructs

(d) external validity
refers to whether the cause-effect relationship holds over variations in person, setting, operationalizations and measurement variables

Possible problems with statistical validity were addressed in this thesis, when discussing the problem of falsely interpreted statistical null hypothesis (see 2.4.3). Aspects of internal validity were addressed, when emphasizing possible confounds, due to the post-hoc classification of subjects into low cortisol responders and high cortisol responders. In addition, aspects of construct validity were discussed, when questioning if the decision tasks really measure the construct "decision making under uncertainty".

The question in the heading of this chapter refers to the external validity or generalizability of the obtained results, defined by Campbell & Stanley as "the validity of inferences about whether the causal relationship holds over variations in persons, settings, treatment variables, and measurement variables" (2002, p. 507). More specific, can the results obtained here be

[11] BGT: Berlin Gambling Task is a variant of the IGT and was also used in the study of Schmitz et al. (2020)

transferred to any decision maker, who makes decisions under uncertainty in any financial real-world situation?

There is some debate in the economic literature about this issue (Al-Ubaydli, List, & Suskind, 2020; Levitt & List, 2007a, 2007b; List, 2020). Al-Ubaydli et al. (2020) proposed three criteria which should be fulfilled for acceptable external validity. The first they called "statistical inference" and is partly related to the problem of falsely interpreting statistical null hypothesis, as discussed in chapter 2.4.3. In addition, to fulfill the statistical inference criterion, exact or conceptual replications of results are mandatory (see also Maniadis, Tufano, & List, 2014).

Though the two experiments partly fulfill the replication criterion (experiment 2 is a conceptual replication of the results of males in experiment 1), more independent replications are desirable.

The second criterion is about the representativeness of the experimental sample. A sample is appropriate for a hypothesis under test, if the sample consists of subjects for whom the hypothesis claims to be applicable to. List (2020) formulated in a very interesting paper, dealing with the problem of generalizability in economics, "….theory should be universal, so tests of it can occur in any given setting with any given population - if the theory is correct, it should manifest itself everywhere goes the hypothesis" (p.38). The hypothesis here claims to be applicable to healthy adult subjects. In this sense the samples investigated here are representative for the hypothesis under test. In case there are doubts with respect to the generalizability to other persons, these should be decided empirically, for example by running experiments with different groups, which are theoretically or empirically identified as deviating in decision-behavior from the normal population. (Coates & Gurnell, 2017; Coates & Herbert, 2008; Maniadis et al., 2014).

Thus, the experiments fulfill the second criterion for external validity.

The final criterion is the representativeness of the experimental situation. In my view, this criterion is fulfilled here. The acute stressors and the decision paradigms, used in the experiments, are well validated and often used in stress and decision research, though some objections might be raised as discusses in the previous paragraph.

Overall, I am confident that the results can be transferred at least to healthy male adults, though some independent replications would increase my confidence.

4.4 What are possible directions for future research?

The results reported here are certainly not the final answer to the question, whether acute stress has an influence on decision making under uncertainty. Considering the critique formulated with respect to the validity of the decision paradigm (BART, IGT), future research should use new and valid paradigms, developed from well-established decision paradigms in behavioral economics.

The general idea for a new paradigm, to study the influence of acute stress on decision-making under uncertainty, is based on the well-known fourfold pattern of risk attitudes, as introduced by Tversky and Kahneman (1974). In general, their decision tasks consist of two options, each characterized by a payoff distribution (probabilities).

In the gain domain, risk averse choice behavior is observed when gain probabilities are low and risk seeking behavior is observed when gain probabilities are high. The following two examples are adopted Kahneman (2011)

Example 1: Option B, which is risk averse, is preferred by most subjects.

- Option A: win 32 € with a probability of 10 %, 0 otherwise
  vs
- Option B: win 3 € for sure (100%)

Example 2: Option A, which is risky, is preferred by most subjects.

- Option A: win 4 € with a probability of 80%, 0 otherwise
  vs
- Option B: win 3 € for sure (100%)

Just the opposite occurs in the loss domain. When loss probabilities are low, decision makers show risk seeking behavior, but make risk averse choices when loss probabilities are high.

Example 3 Option A, which is risky, is preferred by most subjects.

- Option A: lose 32 € with a probability of 10%, lose 0 otherwise
  vs
- Option B: lose 3 € for sure (100%)

Example 4: Option B, which is risk averse, is preferred by most subjects.

- Option A: lose 4 € with a probability of 80%, lose 0 otherwise
  vs
- Option B: lose 3 € for sure (100%)

The first proposal is to use these well-established tasks to study the influence of acute stress on decision making. This would lead to studies where DOMAIN (win, loss) and PROBABILITIES (low, high) are varied. Within these two levels of probabilities, a finer granularity can be introduced, for example low probabilities with levels .01, .05, .10 and .25 and high probabilities with levels 75, .90, .95 and .99. This allows to study the influence of rare outcomes which are, according to New Prospects Theory (Tversky & Kahneman, 1992), overweighted by decision makers for small probabilities and under weighted for high probabilities.

It is important to note that despite Tversky and Kahneman (1992) giving their famous publication the title "Advances in Prospect Theory: Cumulative Representation of Uncertainty", they use the word uncertainty in a different meaning than it was used throughout this thesis. For them uncertainty means 'not sure' or 'the probability of an outcome is less than 1'. In all of their decision tasks the outcome probabilities of all outcomes are known to the subjects. According to the nomenclature of Weber and Johnson (2009), which is used throughout this thesis, these are 'risky' decisions, where the outcome probabilities are known to the decision maker.

As shown by Hertwig and colleagues (Frey, Pedroni, Mata, Rieskamp, & Hertwig, 2017; Hertwig, Barron, Weber, & Erev, 2004; Hertwig & Erev, 2009; Hertwig, Hogarth, & Lejarraga, 2018; Hertwig, Wulff, & Mata, 2019; Mata, Frey, Richter, Schupp, & Hertwig, 2018) risk tendencies change, when outcome probabilities are not known. These authors use the term "decisions from description" for decisions for which outcome probabilities are known and "decision from experience" when outcome probabilities are unknown.

The paradigms to study decisions in the gain/loss domain, with low and high probabilities for the payoff distributions, are depicted in Figure 4.3.

In these paradigms, subjects see two buttons on a computer screen and their task is to explore the payoff distribution of each alternative. The left deck represents option A and the right one option B of the decision tasks described above. The example comes from the loss domain

1. Option A: lose 3 € with certainty
   or
   Option B: lose 32 € with a probability of .1, 0 € otherwise

In the "sampling paradigm" (Figure 4.3. a), subjects can explore each of the decks as often as they want. When they have finished their exploration, they see the choice screen (green screen) and they give their decision whether they choose option A or B. Here the exploration can be done with no costs (Figure 4.3b).

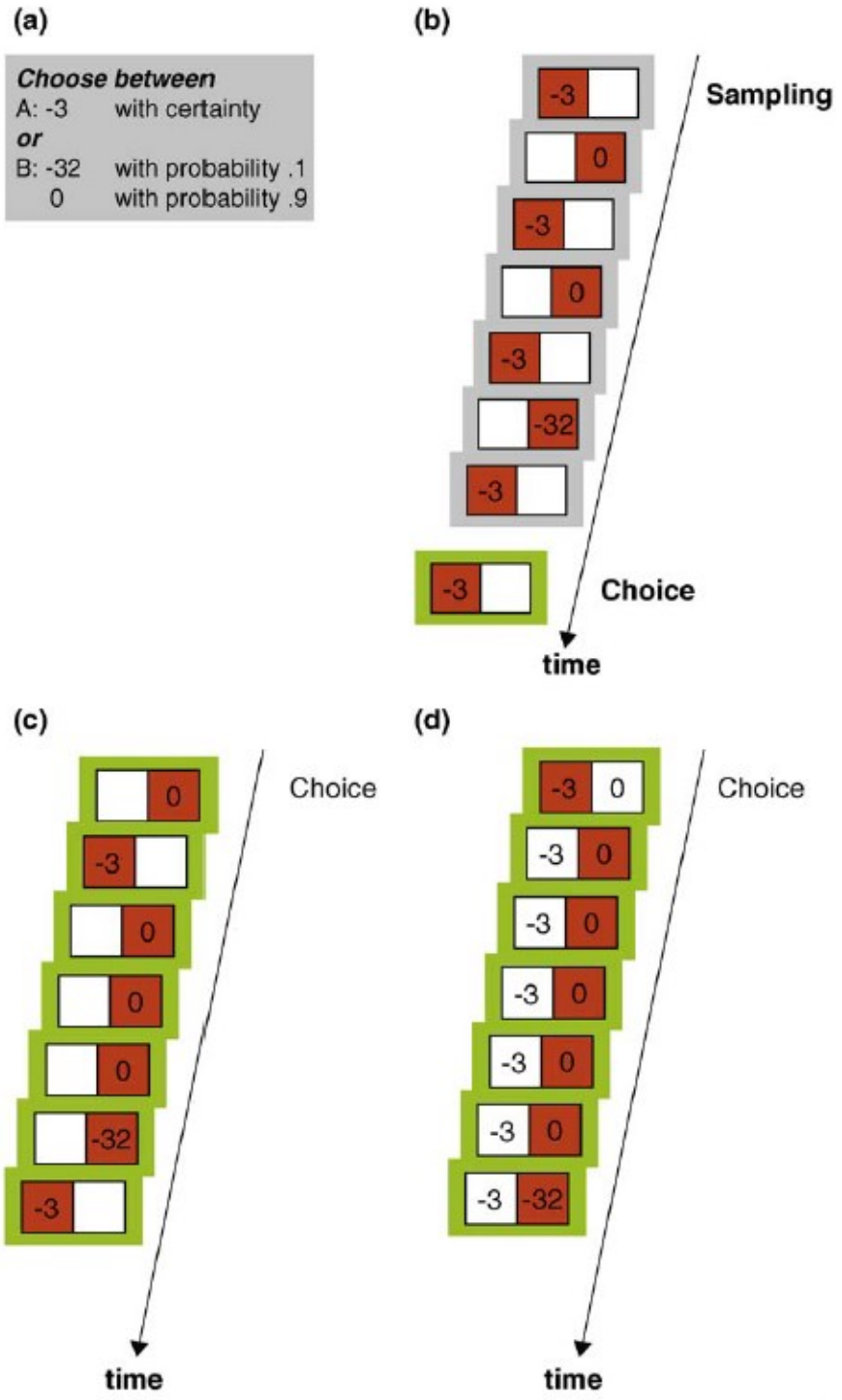

Figure 4.3: (a) Classical decision task as designed Tversky and Kahneman. (b) to (d) same task transformed to a situation where decision makers get no information about the probabilities of options. The buttons chosen by the subject are marked in red. A gray border means, no consequences of the choice. Green border means a consequence for the payoff. More details see text. [12]

[12] Figure 1 taken from Hertwig and Erev (2009). Used by permission of R. Hertwig.

The next two paradigms demand a choice in each trial, so the exploration can lead to wins or losses. They differ in the amount of feedback provided after the choice. Figure 4.3. (c) depicts the partial feedback paradigm where in each trial a choice has to be made which contributes to the subject's earnings. In the full feedback paradigm subjects not only see a value from the probability distribution of the chosen option, but additionally they get informed after their choice what would have been the result, had they drawn from the probability distribution of the other option (Figure 4.3 d).

These two paradigms have a fixed number of trials and are also suitable for electrophysiological measurements. Additionally the reference point, which is important for decisions made in the win/loss domain (Kahneman, 1992) can be manipulated by offering different monetary starting points within a decision task.

Table 4.1: Risk tendencies for decision tasks with known (cursive) and unknown outcome probabilities (bold). prob.: probability of the outcome distributions.

	gain domain		loss domain	
probability	*prob. known*	**prob. unknown**	*prob. known*	**prob. unknown**
low	*risk-seeking*	**risk-averse**	*risk-averse*	**risk-seeking**
high	*risk-averse*	**risk-seeking**	*risk-seeking*	**risk-averse**

Changing these decision tasks from knowledge of outcome probabilities to no information about these probabilities reverses the risk preferences of decision makers. This is summarized in Table 4.1 and is called "decision-experience gap" (Hertwig & Erev, 2009; Wulff, Mergenthaler-Canseco, & Hertwig, 2018).

For possible future research this is an interesting, but not a problematic result. From the hypothesis developed in the introduction of experiment 1 it was predicted that risk seeking is enhanced in those subjects, showing a strong HPA-axes activation (as measured by salivary cortisol) and this should be reflected in the quality of feedback processing, as indexed by the Feedback Related Negativity. Risk taking occurs in both decision paradigms, and it might be a good idea to vary the type of risk with the levels 'probabilities known' and 'probabilities unknown' in future studies.

Thus, a research program is proposed which ideally uses decision tasks in the win/loss domain, with decision problems consisting of two options (depicted in Figure 4.2 c and d) which vary in the probabilities of the outcome distributions. This cannot be done in a single experiment,

but only in a whole series of studies, as the effectiveness of the acute stressor lasts up to 30 minutes before cortisol levels return to baseline.

In these experiments different processive stressors such as the SECPT (Schwabe & Schaechinger, 2018), the TSST (Kirschbaum et al., 1993) or the Montreal Imaging Stress Tests (Dedovic et al., 2005) should be used. It would be desirable to establish a pool of subjects tested with the different processive stressors at different time points. This is expensive but doable, and would solve the problem of possible confounds, due to the post-hoc classification into high responders and low responders.

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6 Attachment

6.1 Experiment 1: Information and Declaration of Consent"

Probandeninformation und Einwilligungserklärung

Studie: „Psychophysiologische Untersuchungen zu Risikoverhalten"**"**

Sehr geehrte Teilnehmerin, sehr geehrter Teilnehmer,

vielen Dank für Ihr Interesse an unserer Studie. Die Studie wird von Universitätsprofessor Dr. Wolfgang Miltner (Lehrstuhl für Biologische und Klinische Psychologie des Psychologischen Instituts der Friedrich-Schiller-Universität) und von Dr. rer. nat. Ewald Nauman (Lehrbeauftragter an unserem Institut), gemeinsam geleitet.

1. Problemstellung und Ziel / Zweck des wissenschaftlichen Vorhabens

Ziel der Studie ist es, die Reaktionen des Gehirns auf riskante Entscheidungen zu untersuchen und heraus zu finden, wie diese Reaktionen von körperlichen Zuständen und hormonellen Veränderungen beeinflusst werden.

2. Studienablauf: Was wird an / mit mir getan? Was muss ich tun, wie hoch ist der Aufwand

Wenn Sie im Labor ankommen, werden wir sie zuerst bitten für eine Minute auf einem Wattebausch zu kauen. Aus diesem können wir später verschiedene Hormone bestimmen. Diese Messung wiederholt sich insgesamt siebenmal während der Studie.

Dann werden Sie für die Messung des Elektroenzephalogramms (EEG) vorbereitet. Das EEG wird von vielen Elektroden Ihres Kopfes erfasst, Sie ein Computerspiel spielen. Zur Erfassung des EEGs wird Ihnen eine Elektrodenkappe aufgesetzt, die 64 Elektroden enthält, die mit Gel gefüllt werden, um den Kontakt zwischen Kopfhaut und Elektroden herzustellen

Vor dem Computerspiel werden wir Sie bitten ihre rechte Hand für drei Minuten entweder in sehr kaltes (1-4 . Grad Celsius) oder in köperwarmes Wasser zu halten. In welche der beiden Bedingungen sie gelost werden, wird erst kurz vor dem Experiment festgelegt. Mit der Unterschrift unter diese Probandenaufklärung verpflichten Sie sich, für beide Bedingungen zur Verfügung zu stehen.

Danach spielen sie ein Computerspiel. Sie spielen die sogenannte Balloon Analogue Risk Task/Aufgabe (BART). Sie werden sich immer wieder entscheiden müssen, ob sie das Risiko eingehen wollen, einen Ballon weiter aufzupumpen, um einen erhöhten Geldbetrag zu gewinnen, oder ob Sie den aktuellen Wert vorziehen, den Sie durch die Größe des Ballons bislang erzielt haben. Platzt der Ballon, dann erhalten sie in diesem Durchgang nichts. Es werden vier Blöcke mit je 50 Durchgängen gespielt. Die Gewinnerwartung liegt zwischen vier und acht Euro.

Der zeitliche Aufwand der Teilnahme umfasst 100 bis 120 Minuten.

3. Vorteile und Nutzen für der Probanden

Die Teilnahme an der Studie ist nicht mit einem besonderen persönlichen Vorteil für den Teilnehmer/die Teilnehmerin verbunden. Die Teilnahme dient rein wissenschaftlichen Zwecken.

4. Risiken (Nebenwirkungen, Unannehmlichkeiten) für Probanden

Die Elektroenzephalografie zur Messung Ihrer Hirnprozesse ist schmerzfrei. Durch die Verwendung eines leicht abrasiven Elektrodengels zur Verbesserung des Hautwiderstandes zwischen Elektroden und Kopfhaut kann es an den Berührungsstellen der Elektroden mit der Haut gelegentlich zu lokalen Hautrötungen/-reizungen kommen, die aber schnell und unkompliziert wieder abklingen. Andere Nebenwirkungen/Gefährdungen sind nicht bekannt geworden.

Das zur Verbesserung der Messung benutzte Elektrodengel können Sie später in unserer Abteilung durch Duschen und Haarwäsche problemlos wieder entfernen.

Das Eintauchen der Hand in kaltes Wasser (Kaltwassertest) gilt als sehr risikoarm. Weltweit gibt es über 1000 publizierte Studien, die diese Prozedur zur Manipulation körperlicher Zustände genutzt haben, ohne dass irgendwelche Komplikationen bekannt geworden wären. Zwar kommt es zu einem deutlichen Blutdruckanstiege, diese liegt aber vergleichsweise ähnlich wie bei einer Anstrengung durch moderates Fahrradfahren. So führt eine moderate Arbeitsbelastung von 100 Watt, welche von jungen Gesunden bei Sport problemlos toleriert wird, zu deutlich höheren Anstiegen von Herzfrequenz und Blutdruck.

Jedoch treten bei der Durchführung des Kaltwassertests in allen Fällen Schmerzen im Bereich der Hände auf. Erfahrungsgemäß bleiben die Schmerzen bei sachgemäßer Durchführung des Tests im tolerierbaren Bereich. Ohnehin ist Ihnen der Abbruch des Tests bei Überschreiten einer subjektiv tolerierbaren Schmerzschwelle jederzeit erlaubt. Nach Beendigung des Tests sind bei Gesunden die Schmerzen innerhalb von Sekunden bis Minuten rückläufig. Anhaltende Komplikationen sind nicht zu erwarten. Der Kaltwassertest wird durch geschultes Personal durchgeführt. Auf Wunsch des Probanden oder bei Bedenken des Versuchsleiters wird der Test abgebrochen.

5. Vertraulichkeit und Handhabung der von Ihnen erfassten persönlichen Daten, Fragebogendaten und EEG-Daten

Alle Daten, die von Ihnen im Rahmen der Studie gesammelt werden, werden von uns nur anonymisiert gespeichert und ausgewertet. Weiterhin werden die Daten bei der Auswertung nur in anonymisierter Form verwendet. Alle Mitarbeiter an der Studie sind zur Verschwiegenheit verpflichtet.

6. Aufwandsentschädigung

Für die Teilnahme an der Studie erhalten Sie pro Stunde eine Entschädigung von 6,- Euro, die Ihnen von der Universitätskasse auf Ihr Bankkonto überwiesen wird. Alternativ können auch Versuchspersonenstunden vergeben werden. Der Gewinn des Risikospiels wird Ihnen immer ausbezahlt. Dazu benötigen wir von Ihnen Ihre Privatadresse und Ihre Bankverbindung sowie eine schriftliche Bestätigung, dass Sie an dieser Studie mit entsprechendem Zeitaufwand teilgenommen haben. Ein entsprechendes Formular wird Ihnen zu Versuchsbeginn überreicht, in das Sie auch die jeweils aufgewendeten Zeiten ihrer Beteiligung eintragen.

7. Verpflichtungen der Probanden

Als Teilnehmer/Teilnehmerin der Studie verpflichten Sie sich, alle Fragebögen wahrheitsgemäß auszufüllen und alle Fragen zu Ihrem Gesundheitszustand und Risikofaktoren wahrheitsgemäß zu beantworten.

Weiterhin verpflichten Sie sich:

- Am Vorabend der Untersuchung keinen Alkohol zu trinken
- Am Untersuchungstag vor dem Erscheinen zur Studie keinen extensiven Sport zu betreiben

Die letzteren Maßnahmen sind notwendig, damit die Hormonmessung über die Wattebällchen nicht verfälscht wird.

8. Verantwortlicher Ansprechpartner während der Teiluntersuchungen der Studie

Der verantwortliche Ansprechpartner während der der Studie ist der o.g. Studienleiter und in seiner Vertretung der/die jeweils vor Ort in dem jeweiligen Labor mit der Teiluntersuchung beauftragte Mitarbeiter/Mitarbeiterin, dessen/deren Name auf dem Formular zum Zeitaufwand ihrer Beteiligung an den Teiluntersuchungen dieser Studie handschriftlich und mit Unterschrift signiert eingetragen sein wird.

8. Erklärung des Teilnehmers, der Teilnehmerin

Für die Teilnahme an der Gesamtstudie ist Ihre schriftliche Zustimmung erforderlich.

Ihre Einwilligung können Sie jedoch zu jeder Zeit ohne Angabe von Gründen und ohne Nachteile z.B. hinsichtlich Ihrer Vergütung widerrufen.

Mit Ihrer Unterschrift bestätigen Sie Folgendes:

1. Ich nehme freiwillig an der Studie teil. Ich wurde über den Ablauf, den Zweck und die Risiken der Studie aufgeklärt und habe keine weiteren Fragen. Mir ist bekannt, dass ich meine Einwilligung zu jeder Zeit ohne Angaben von Gründen und ohne Nachteile zurückziehen und meine Teilnahme an der Studie jederzeit beenden kann. Auch der Studienleiter kann die Entscheidung treffen, die gesamte Studie abzubrechen oder Ihre Teilnahme vorzeitig zu beenden, wenn dies (etwa aus medizinischen Gründen) angezeigt sein sollte.

2. Datenschutzklausel: Ich erkläre, dass ich mit der im Rahmen der Studie erfolgenden Aufzeichnung von Daten zu meiner Person und ihrer pseudo- bzw. anonymisierten Form und für ihre anonyme Nutzung für wissenschaftliche Zwecke einverstanden bin.

3. **Für den Fall, dass durch die EEG-Untersuchungen Auffälligkeiten in meinem Gehirn oder bei den klinischen Eingangsuntersuchungen medizinische Krankheiten oder psychische Störungen entdeckt werden, die auf eine krankhafte Veränderung hinweisen, erkläre ich, dass (bitte kreuzen Sie einen der nachstehenden Kreise an)**

O ich darüber NICHT informiert werden möchte.

O ich darüber informiert werden möchte und zu diesem Zweck kontaktiert werden darf.

Name und Anschrift (wenn möglich mit Telefonnummer):

_____

_____

Datum, Ort: _____ Name (Druckschrift): _____

_____ _____

Unterschrift Teilnehmer/in Unterschrift Studienleiter

6.2 Experiment 2: Information and Declaration of Consent"

Probandeninformation

Studie: „Psychophysiologische Untersuchungen zu Risikoverhalten**"**

Sehr geehrter Teilnehmer,

vielen Dank für Ihr Interesse an unserer Studie. Die Studie wird von Universitätsprofessor Dr. Wolfgang Miltner (Lehrstuhl für Biologische und Klinische Psychologie des Psychologischen Instituts der Friedrich-Schiller-Universität) und von Dr. rer. nat. Ewald Nauman (Lehrbeauftragter an unserem Institut) gemeinsam geleitet.

1. Problemstellung und Ziel / Zweck des wissenschaftlichen Vorhabens

Ziel der Studie ist es, die Reaktionen des Gehirns von männlichen Individuen auf riskante Entscheidungen zu untersuchen und heraus zu finden, wie diese Reaktionen von körperlichen Zuständen und hormonellen Veränderungen beeinflusst werden.

2. Studienablauf: Was wird an / mit mir getan? Was muss ich tun, wie hoch ist der Aufwand

Wenn Sie im Labor ankommen, werden wir Sie zuerst bitten, für eine Minute auf einem Wattebausch zu kauen. Aus diesem können wir später verschiedene Hormone bestimmen. Diese Messung wiederholt sich insgesamt sechs Mal während der Studie. Zudem werden wir vom Hinterkopf einige wenige Haare nahe an der Kopfhaut entnehmen. Diese Prozedur ist absolut schmerzfrei und ungefährlich und hinterlässt auch keine sichtbaren Haarlücken. Über das im Haar gespeicherte Hormon lässt sich die Alltagsbelastung während der letzten Wochen bestimmen.

Dann werden Sie für die Messung des Elektroenzephalogramms (EEG) vorbereitet. Das EEG wird von vielen Elektroden Ihres Kopfes erfasst, während Sie ein Computerspiel spielen. Zur Erfassung des EEGs wird Ihnen eine Elektrodenkappe aufgesetzt, die 64 Elektroden enthält, die mit Gel gefüllt werden, um den Kontakt zwischen Kopfhaut und Elektroden herzustellen.

Nach Anlegung der Elektrodenhaube üben Sie das Computerspiel, das Sie während des Experiments spielen sollen. Das Ziel ist eine möglichst hohe Gewinnsumme zu erzielen. Sie sehen dabei in vier nebeneinanderstehenden Kästchen vier Alternativen mit unterschiedlichen Geldbeträgen. Der Geldbetrag in den Kästchen wird von links nach rechts höher, das Risiko zu verlieren ebenfalls. Die Gewinn- bzw. Verlustwahrscheinlichkeiten der Alternativen werden Sie beim Spielen selbst herausfinden. Gewinne und Verluste während des Spiels werden addiert*. Die fünf Versuchsteilnehmer mit den höchsten*

Gewinnen erhalten nach Abschluss des gesamten Experimentes neben der Entschädigung für Ihre Teilnahme an unserem Experiment je 100,00 Euro. Sie erhalten am Ende des Experimentes eine Aufstellung über den Kontoverlauf und den Endkontostand. Nach Beendigung der Studie (voraussichtlich Mitte Juli 2018) erhalten Sie eine anonymisierte Aufstellung der Endkontostände aller Versuchsteilnehmer, wobei ihr Kontostand ersichtlich gemacht wird. Sollten Sie zu den besten fünf Spielern gehören, wird Ihnen der Betrag von 100,00 Euro unmittelbar auf Ihr Girokonto überwiesen.

Vor dem Computerspiel werden wir Sie bitten, Ihre rechte Hand für drei Minuten entweder in sehr kaltes (1-4 Grad Celsius) oder in körperwarmes Wasser zu halten. Zu welchen der beiden Bedingungen Sie zugelost werden, wird erst kurz vor dem Experiment festgelegt. Mit der Unterschrift unter diese Probandeninformation erklären Sie sich bereit, für beide Bedingungen zur Verfügung zu stehen.

Nach dem eintauchen Ihrer Hand ins Wasser, spielen Sie in einem anschließenden Teil der Untersuchung ein Risikospiel in insgesamt vier Blöcken von je ca. 10 Minuten. Während der Spielpausen werden Sie nochmals aufgefordert, Ihre Hand für 45 Sekunden in kaltes oder warmes Wasser zu tauchen. Auch hier wird erst kurz vor dem Experiment festgelegt, welcher Bedingung sie zugeordnet werden.

Der zeitliche Aufwand der Teilnahme umfasst ca. 100 bis 120 Minuten.

3. Vorteile und Nutzen für der Probanden

Die Teilnahme an der Studie ist nicht mit einem besonderen persönlichen Vorteil für Sie verbunden. Die Teilnahme dient ausschließlich wissenschaftlichen Zwecken.

4. Risiken (Nebenwirkungen, Unannehmlichkeiten) für Probanden

Die Elektroenzephalografie zur Messung Ihrer Hirnprozesse ist schmerzfrei. Durch die Verwendung eines leicht abrasiven Elektrodengels zur Verbesserung des Hautwiderstandes zwischen Elektroden und Kopfhaut kann es an den Berührungsstellen der Elektroden mit der Haut gelegentlich zu lokalen Hautrötungen/-reizungen kommen, die aber schnell und unkompliziert wieder abklingen. Andere Nebenwirkungen/Gefährdungen dieser EEG-Untersuchung sind nicht bekannt geworden.

Das zur Verbesserungen der EEG-Messung benutzte Elektrodengel können Sie später in unserer Abteilung durch Duschen und Haarwäsche problemlos wieder entfernen.

Das Eintauchen der Hand in kaltes Wasser (Kaltwassertest) gilt als sehr risikoarm. Weltweit gibt es über 1000 publizierte Studien, die diese Prozedur zur Manipulation körperlicher Zustände genutzt haben, ohne dass irgendwelche Komplikationen bekannt geworden wären. Zwar kommt es dadurch zu einem Blutdruckanstieg, dieser ist aber bei gesunden Personen vergleichsweise dem Anstieg bei moderatem Fahrradfahren. So führt eine moderate Arbeitsbelastung von 100 Watt, welche von jungen Gesunden beim Sport problemlos toleriert wird, zu deutlich höheren Anstiegen der Herzfrequenz und des Blutdrucks als durch diesen Kaltwassertest.

Jedoch treten bei der Durchführung des Kaltwassertests in allen Fällen leichte Kaltschmerzempfindungen in der Hand auf, die aber nach Herausnehmen der Hand aus dem kalten Wasser innerhalb weniger Sekunden wieder restlos abklingen. Ohnehin ist Ihnen der Abbruch des Tests jederzeit erlaubt, so Ihnen die Kälte persönlich zu unangenehm erscheint. Anhaltende

Komplikationen sind nicht zu erwarten. Der Kaltwassertest wird durch geschultes Personal durchgeführt. Auf Ihren Wunsch oder bei Bedenken des Versuchsleiters wird der Test jederzeit abgebrochen.

5. Vertraulichkeit und Handhabung der von Ihnen erfassten persönlichen Daten, Fragebogendaten, Speicheldaten und EEG-Daten

Alle Daten, die von Ihnen im Rahmen der Studie gesammelt werden, werden von nur in anonymisierter Form gespeichert und ausgewertet, so dass zu keiner Zeit aus den Daten Rückschlüsse auf Ihre Person gezogen werden können. Weiterhin werden die Daten bei Publikationen oder Vorträgen der Studie nur in anonymisierter Form verwendet. Alle Mitarbeiter an der Studie sind zur Verschwiegenheit verpflichtet. Aus den Speichel- und Haarproben wird ausschließlich der Hormonspiegel bestimmt. Nach dessen Bestimmung werden die Speichelproben vernichtet.

6. Aufwandsentschädigung

Für die Teilnahme an der Studie erhalten Sie pro Stunde eine Entschädigung von 10,- Euro, die Ihnen von der Universitätskasse auf Ihr Bankkonto überwiesen wird. Alternativ können auch Versuchspersonenstunden vergeben werden. Den fünf Spielern mit den höchsten Gewinnen beim Risikospiel werden nach Beendigung der Studie (voraussichtlich Mitte Juli) jeweils 100 Euro überwiesen. Dazu benötigen wir von Ihnen Ihre Privatadresse und Ihre Bankverbindung sowie eine schriftliche Bestätigung, dass Sie an dieser Studie mit entsprechendem Zeitaufwand teilgenommen haben. Ein entsprechendes Formular wird Ihnen zu Versuchsbeginn überreicht, in das Sie auch die jeweils aufgewendeten Zeiten ihrer Beteiligung eintragen.

7. Verpflichtungen der Probanden

Als Teilnehmer der Studie verpflichten Sie sich, alle Fragebögen wahrheitsgemäß auszufüllen und alle Fragen zu Ihrem Gesundheitszustand und Risikofaktoren wahrheitsgemäß zu beantworten.

Weiterhin verpflichten Sie sich:

- Am Vorabend der Untersuchung keinen Alkohol zu trinken
- Am Untersuchungstag vor dem Erscheinen zur Studie keinen extensiven Sport zu betreiben

Die letzteren Maßnahmen sind notwendig, damit die Hormonmessung über die Wattebällchen nicht verfälscht wird.

8. Verantwortlicher Ansprechpartner während der Teiluntersuchungen der Studie

Der verantwortliche Ansprechpartner während der Studie ist der o.g. Studienleiter und in seiner Vertretung der/die jeweils vor Ort in dem jeweiligen Labor mit der Teiluntersuchung beauftragte Mitarbeiter/Mitarbeiterin, dessen/deren Name auf dem Formular zum Zeitaufwand ihrer Beteiligung an den Teiluntersuchungen dieser Studie handschriftlich und mit Unterschrift signiert eingetragen sein wird.

Erklärung gemäß & 4 Absatz 1 der Promotionsordnung

Hiermit erkläre ich,

1. dass mir die geltende Promotionsordnung bekannt ist;

2. dass ich die Dissertation selbst angefertigt, keine Textabschnitte eines Dritten oder eigener Prüfungsarbeiten ohne Kennzeichnung übernommen und alle von mir benutzten Hilfsmittel, persönlichen Mitteilungen und Quellen in meiner Arbeit angegeben habe;

3. dass ich bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskriptes keine unzulässige Hilfe in Anspruch genommen habe;

4. dass ich nicht die Hilfe einer kommerziellen Promotionsvermittlung in Anspruch genommen habe und dass Dritte weder unmittelbar noch mittelbar geldwerte Leistungen von mir für Arbeiten erhalten haben, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen;

5. dass ich die Dissertation noch nicht als Prüfungsarbeit für eine staatliche oder andere wissenschaftliche Prüfung eingereicht habe;

6. dass ich nicht die gleiche, eine in wesentlichen Teilen ähnliche oder eine andere Abhandlung bei einer anderen Hochschule bzw. anderen Fakultät als Dissertation eingereicht habe.

Bad, Vilbel im Mai 2021

Peter Naumann