# Judgments and Decisions about Risk: The Influence of Affect and Stress

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# Summary


This dissertation presents three papers on judgments and decisions about risk. Specifically, it explores how affect and particularly stress influence risk-related judgment and decision processes.

The first paper is based on research on the monetary-medical gap, also referred to as affect gap. This research suggests that people tend to neglect probabilities and rely on heuristic decision processes when making affect-rich medical choices compared to affect-poor monetary choices. Research paper 1 demonstrates that the medical-monetary gap extends to decisions that are made for another person – decision situations that are presumably relatively affect-poor. One of the conclusions from this paper is that affect might not be the main driver of the difference between medical and monetary choices.

The second and third paper investigate the influence of stress on the individual and social dynamics of risk perception. In both studies, stress was induced with the Trier Social Stress Test prior to the behavioral task. Stress reactions were measured by participants' subjective stress reports as well as their cortisol levels through saliva samples. The second paper explores how stress influences the social dynamics of risk perception. Risk perceptions are rarely formed in isolation from other individuals but are part of a wider context and communication process. Risk-related information is passed on from one person to another. Each person can filter out information and amplify or attenuate the risk signal. Results from this paper suggest that acute stress exposure leads to an attenuation of the risk signal: participants who were exposed to the stressor prior to the task were less influenced by negative risk information and transmitted a less negative risk signal to others. In contrast, people who reported higher subjective stress levels reported to feel more concerned about the risk. This suggests that an acute stress reaction, but not a subjective feeling of stress, can reduce the social amplification of risk.

Findings from the second paper indicate that acute stress decreases updating of risk perceptions in response to risk-related information. The third paper explores whether acute stress also influences updating of probability estimates of a risk in response to information about the probability. The paper tested the hypothesis that stress increases the optimistic update bias – a finding that people update their beliefs more readily in response to good news than in response to bas news. Acute stress did not influence how participants updated their probability estimates of a risk. But the more participants perceived their life as stressful, the less likely they were to update their risk-related probability estimates. Together, findings from the second and third paper suggest the following: First, effects of stress on integration of risk information depend on the type of the risk information. Second, subjective feelings of stress can have a different effect on risk perception than the physiological reaction to a stressor.

# Zusammenfassung

In dieser Dissertation werden drei Projekte zu risikobezogenem Urteils- und Entscheidungsverhalten vorgestellt. Insbesondere wird untersucht, wie sich Affekt und vor allem Stress auf risikobezogene Beurteilungs- und Entscheidungsprozesse auswirken.

Das erste Projekt basiert auf Forschung zum Unterschied zwischen medizinischen und monetären Entscheidung, der auch als *affect gap* bezeichnet wird. Im Vergleich zu affekt-armen monetären Entscheidungen basieren affekt-reiche medizinische Entscheidungen oft auf heuritischen Entscheidungsprozessen, die Wahrscheinlichkeiten außer Acht lassen. Ergebnisse des ersten Projekts zeigen, dass sich der Unterschied zwischen medizinischen und monetären Entscheidungen auch auf Situaitonen überträgt, in denen für eine andere Person entschieden wird – also auf Entscheidungssituationen, die relativ affekt-arm sind. Eine der Schlussfolgerungen aus diesem Projekt ist, dass Affekt möglicherweise nicht der Hauptfaktor für den Unterschied zwischen medizinischen und monetären Entscheidungen ist.

Das zweite und dritte Projekt untersuchen den Einfluss von Stress auf individuelle und soziale Dynamiken der Risikowahrnehmung. In beiden Projekten wurde Stress vor der eigentlichen Entscheidungsaufgabe mit dem Trier Social Stress Test induziert. Um die Stressreaktion zu messen, wurden die Teilnehmer zu mehreren Zeitpunkten nach ihrem subjektiven Stressempfinden gefragt und ihr Cortisolspiegel anhand von Speichelproben gemessen. Das zweite Projekt untersucht, wie Stress die soziale Dynamik von Risikowahrnehmungen beeinflusst. Risikowahrnehmungen werden selten isoliert von anderen Individuen geformt, sondern sie sind vielmehr Teil eines breiteren Kontexts und Kommunikationsprozesses. Risikobezogene Informationen werden von einer Person an die nächste weitergegeben. Dabei kann jede Person bestimmte Informationen über das Risiko herausfiltern und damit das Risikosignal verstärken oder abschwächen. Die Ergebnisse dieses Projekts deuten darauf hin, dass eine akute Stressbelastung zu einer Abschwächung des Risikosignals führt: Gestresste Teilnehmer wurden weniger von negativen Risikoinformationen beeinflusst und übermittelten ein weniger negatives Risikosignal an andere. Im Gegensatz dazu berichteten Menschen, die über höhere subjektive Stressniveaus berichteten, dass sie beunruhigter über das Risiko seien. Das deutet darauf hin, dass eine akute Stressreaktion, nicht aber ein subjektives Stressempfinden, die soziale Amplifikation von Risiken reduzieren kann.

Die Ergebnisse aus dem zweiten Projekt deuten darauf hin, dass Menschen nach akutem Stress ihre Risikowahrnehmung weniger an neue Informationen anpassen. Das dritte Projekt untersucht, ob akuter Stress auch beeinflusst, wie stark Menschen ihre Wahrscheinlichkeitsschätzungen über ein Risiko abändern, sobald sie Informationen über diese Wahrscheinlichkeit erhalten. In dem Projekt wurde die Hypothese getestet, dass Stress den *optimistic update bias* erhöht - ein Befund, dass Menschen ihre Einschätzungen eher an gute als an schlechte Neuigkeiten anpassen. Akuter Stress hatte keinen Einfluss darauf, wie die Teilnehmer ihre Wahrscheinlichkeitsschätzungen anpassten. Aber je stressiger die Teilnehmer ihr aktuelles Leben empfanden, desto weniger haben sie ihre Wahrscheinlichkeitsschätzungen angepasst. Die Befunde aus dem ersten und zweiten Projekt deuten insgesamt auf Folgendes hin: Erstens hängen die Auswirkungen von Stress auf die Einbindung von Risikoinformationen von der Art der Risikoinformation ab. Zweitens kann subjektives Stressgempfinden einen anderen Einfluss auf die Risikowahrnehmung haben als die physiologische Reaktion auf einen Stressor.

# Contents

# Chapter 1

## Synopsis

## 1.1 Introduction

Should I choose the medication that was found to lead to diarrhea in 29% of the cases, or rather the one that might cause nausea with a probability of 10%? Should I worry about chemical substances in cosmetic products? What is the risk of being involved in a car accident? We constantly have to make judgements and decisions involving risks. Wrong assessments of risk and misinterpretation or neglect of statistical information can lead to harmful behavior, even on a societal level: Underestimation of a risk can increase incautious actions such as risky driving or practicing unsafe sex. Overestimation of a risk can lead to unnecessary anxiety and dangerous behavior, such as not getting vaccinated. Understanding how people form their judgments and decide when faced with risks is therefore not only relevant from an individual but also from a policy perspective.

The three research papers presented in this dissertation all contribute to a better understanding of how people make decisions and judgments about risk. Specifically, I investigate how affect and, in particular, stress can influence these judgment and decision processes. Affect and stress seem to play an important role in risk-related judgements and decisions: Information about a potential risk such as a severe medical side effect can trigger an affective or stressful reaction (Loewenstein, Weber, Hsee, & Welch, 2001; Traczyk, Sobkow, & Zaleskiewicz, 2015). And even when affective states and stress are unrelated to the decision and the potential risk, they can alter the decision process (Lerner, Li, Valdesolo, & Kassam, 2015; Starcke & Brand, 2016).

Although there are by now numerous studies that investigated the role of affect in decision making, it remains unclear how exactly affect can influence decision processes (Volz & Hertwig, 2016). A promising attempt has been to compare existing cognitive models among affect-rich and affect-poor decision situations (Lejarraga, Pachur, Frey, & Hertwig, 2016; Pachur & Galesic, 2013; Pachur, Hertwig, & Wolkewitz, 2014; Suter, Pachur, & Hertwig, 2016). In research paper 1, I extend findings of these studies to decisions that are made for another person – decision situations in which people are usually less affectively involved.

Stress has been neglected in the decision sciences for a long time (Starcke & Brand, 2012, 2016). Most of the studies focus on the effect of stress on decisions under risk. But there is practically no research on how stress can influence risk perception. I investigated this question in research paper 2 and 3. I was especially interested in the effect of stress on social dynamics of risk perception and on how people update their belief about a risk in response to new evidence.

To explore the role of affect and stress in decisions and judgments about risks, I used experimental methods, computational modeling and assessed biomarkers such as the hormone cortisol. This dissertation hence combines methods and theories from social psychology, cognitive psychology and endocrinology which makes it an interdisciplinary approach to research on decision making and risk perception.

In this general introduction, I provide an overview of my three research papers presented in chapters 2, 3 and 4. To motivate the research questions and set a common ground, I first review relevant concepts and findings on risk-related judgments and decisions and on the influence of affect and stress. This review section is not exhaustive, it rather serves as a framework for this dissertation. After shortly presenting each of the research papers separately, I close with a general discussion of their findings and implications for future research.

## 1.2 Theoretical Background

### 1.2.1 Judgments and Decisions about Risks

*"The ability to sense and avoid harmful conditions is necessary for the survival of all living organisms" (Slovic, 1987, p.280).*

How humans sense and avoid harmful conditions is a core question in the behavioral decision sciences. Research dealing with this question can be divided in mainly two fields: Research on decisions under risk and research on risk perception. Both approaches have in common that they attribute two components to risk: the probability of a harmful event and the magnitude of the harm (Bodemer & Gaissmaier, 2015). In research paper 1, I investigate decisions under risk. In research paper 2 and 3, I study how risk judgments are formed and mainly refer to the literature on risk perception.

Decisions under risk have been defined traditionally as situations in which the potential outcomes of a decision and their corresponding probabilities are known, in contrast to decisions under uncertainty in which people have no information about the probabilities of the outcomes (Knight, 1921). To understand how people make decisions under risk, researchers have often made use of lottery choices (Wulff, Mergenthaler-Canseco, & Hertwig, 2018). In such lottery choices, people choose between two options that can lead to different outcomes with specific probabilities. These outcomes are usually monetary gains or losses. Recent studies have found that decision processes substantially differ when people face medical outcomes (e.g., side effects) rather than monetary outcomes (Lejarraga et al., 2016; Pachur & Galesic, 2013; Pachur et al., 2014; Suter et al., 2016; Suter, Pachur, Hertwig, Endestad, & Biele, 2015). Medical outcomes are assumed to trigger stronger affective reactions than monetary outcomes, which has been provided as an explanation for this difference (see next section). Medical and monetary decisions under risk are the focus of research paper 1.

Research on risk perception is mainly concerned with how lay people perceive a risk and how that influences behavior (e.g. Kasperson et al., 1988; Slovic, 1987; Slovic & Peters, 2006; Weinstein, 2009). Risk perception has been defined as the "subjective assessment of the probability" of an event and "how concerned we are with the consequences" of the event (Sjöberg, Moen, & Rundmo, 2004, p. 8). As such, people are usually asked about their subjective assessment of the severity of the risk (e.g., Moussaïd, Brighton, & Gaissmaier, 2015), about their subjective assessment of the probability of the risk (e.g., Schapira, Davids, McAuliffe, & Nattinger, 2004), or about both (e.g., Renner & Reuter, 2012). In research paper 2, risk perception is measured by asking people how concerned they are about a specific topic. In research paper 3, risk perception refers to people's subjective assessment of the probability of a risk.

### 1.2.2 The Influence of Affect

It is now largely undisputed that our judgments and decisions concerning risk are not solely based on a deliberative, reason-based processes, but that they are often influenced by some "hot processes and states" (Peters, Västfjäll, Gärling, & Slovic, 2006, p. 79) According to the affect heuristic hypothesis, for example, people's risk assessment is influenced by how they feel about it (Slovic, Finucane, Peters, & MacGregor, 2007; Slovic & Peters, 2006). In a similar vein, the risk-as-feelings hypothesis states that people's decisions under risk depend on the anticipated emotions experienced during the decision (Loewenstein et al., 2001). But the concept of "hot processes and states" (Peters et al., 2006, p. 79) as well as its concrete effect on the decision and judgment forming process often still remain vague (Volz & Hertwig, 2016). For this reason, Volz & Hertwig (2016) claim that researchers studying the role of emotions in decision making should make use of existing cognitive models to analyze how exactly emotions impact the decision-making processes. As an example for good practice, the authors state the research on the monetary-medical gap in decisions under risk, also referred to as *affect gap* (Pachur et al., 2014; Suter et al., 2016, 2015)

This research on the monetary-medical gap was based on an often raised hypothesis that people become insensitive to or neglect probability information in decision situations that evoke relatively strong emotional reactions (e.g., Rottenstreich & Hsee, 2001; Sunstein, 2002). To investigate this hypothesis, the authors compared choices between medications that could potentially lead to side effects, and lotteries that could potentially lead to monetary losses (Lejarraga et al., 2016; Pachur & Galesic, 2013; Pachur et al., 2014; Suter et al., 2016, 2015). Participants associated stronger affective reactions to the medical side effects than to the monetary losses. Choices between medications were hence treated as affect-rich decisions, whereas choices between monetary lotteries were treated as affect-poor decisions. The authors then used cognitive modelling to compare decision strategies in both domains (Lejarraga et al., 2016; Pachur & Galesic, 2013; Pachur et al., 2014; Suter et al., 2016). They also studied how people search for probability information in both domains using a sampling paradigm and a process tracing method (Lejarraga et al., 2016; Pachur et al., 2014). Their findings were seen as support for the hypothesis on probability neglect in affect-rich decisions: when making affect-rich medical choices compared to affect-poor monetary choices, participants searched less for probability information and relied more often on a heuristic decision strategy that only focuses on the outcome of the decision. In research paper 1, I extended these findings and tested whether this monetary-medical gap, or *affect gap*, persists in decisions that are made for another person, which presumably are less affective.

### 1.2.3 The Influence of Stress

The research on the monetary-medical gap dealt with *integral* affect that is directly elicited by the potential outcome of a decision. *Incidental* affect refers to affective states that are independent of the stimulus (Lerner et al., 2015; Peters et al., 2006). Here, research has mainly focused on mood, such as fear and anger (e.g., Frey, Hertwig, & Rieskamp, 2014; Lerner & Keltner, 2001) or anxiety (e.g., Eysenck, 1992). Although one of the probably most present affective states in our daily lives, acute stress has long been neglected in the research on decision making (Starcke & Brand, 2012, 2016). Many decisions and judgments are made under stress. The Stress in AmericaTM survey by the American Psychological Association (2017) suggests that 75 percent of Americans experience at least one stress symptom per month.

Stress has been initially defined as a bodily reaction to a stressor (Selye, 1956). The concept of psychological stress added the notion of appraisal. That means, a situation is seen as stressful when the demands of the situation exceed the resources of the individual (Lazarus & Folkman, 1984). Stressors (stimuli that induce a stress reaction) share the characteristics of being unpredictable and uncontrollable (Dickerson & Kemeny, 2004). Stress triggers two paths of bodily reactions (Starcke & Brand, 2012): First, the fast-reacting sympathetic adrenomedullary system (SAM-system) leads to a release of adrenaline and noradrenaline and the classical "fight-or-flight" reaction. Second, the slower-reacting hypothalamic–pituitary–adrenal (HPA) axis initiates the release of the stress hormone cortisol which peaks around 21-40 minutes after exposure to the stressor (Dickerson & Kemeny, 2004). Cortisol can bind to receptors in the limbic system (especially hippocampus) and prefrontal cortex (Starcke & Brand, 2016). Acute stress and an increased cortisol level have been found to influence memory processes (Schwabe, Roozendaal, Wolf, & Oitzl, 2012; Wolf, Atsak, de Quervain, Roozendaal, & Wingenfeld, 2016; Wolf, 2009), cognitive functions (Shields, Sazma, & Yonelinas, 2016) and recently also decision making under risk and uncertainty (Starcke & Brand, 2012, 2016). Research on the effect of stress on decision making has mainly focused on risk behavior, reward sensitivity and cognitive reflection (Starcke & Brand, 2012, 2016).

Studies investigating the effect of stress on risk judgments or risk perception remain an exception (Sobkow, Traczyk, & Zaleskiewicz, 2016). To the best of my knowledge, only one study has looked at the relation between acute stress and risk perception so far (Sobkow, Traczyk, & Zaleskiewicz, 2016). In this study, participants were asked to imagine consequences of different risky situations and to indicate their risk perception of each situation. Before the task, participants were exposed to the Trier Social Stress Test (TSST), a well-established procedure to elicit a pronounced stress reaction (Dickerson & Kemeny, 2004; Kirschbaum, Pirke, & Hellhammer, 1993). The authors found no direct but an indirect effect of the stress manipulation on risk perception: Participants who were exposed to the TSST rated the situations as more stressful and hence also as more risky.

Whereas Sobkow et al. (2016) investigated individual risk perceptions, I emphasized in research paper 2 the importance to understand risk perception as a social, dynamic process (Moussaïd et al., 2015). Research paper 3 was built on findings from research paper 2 and investigated whether stress influences how people update *probabilistic* risk perceptions in response to evidence.

## 1.3 Overview of Research Papers

### 1.3.1 Research Paper 1: Monetary-Medical Gap in Choices for Others

In two experimental studies, I investigated to what extent the discrepancy in medical and monetary choices and their underlying cognitive processes also emerges when decisions are made for another person. In both domains (medical and monetary), people often provide recommendations or make a decision for somebody else. Financial managers, for example, choose investment options for their clients; doctors recommend treatment options to their patients. When the decision outcomes affect another person rather than oneself, people have been found to be less emotionally engaged in the decision (Albrecht, Volz, Sutter, Laibson, & Cramon, 2010; Andersson, Holm, Tyran, & Wengström, 2013; Zhang et al., 2017). Additionally, differences in self-other decision making seem to increase the greater the affective involvement of the participant (Albrecht et al., 2010). If the gap between medical and monetary gambles is indeed due to the medical gambles being more affective (affect gap), then this gap could decrease in decisions for others: The affective impact of medical side effects should be smaller when people decide for others compared to when they decide for themselves, which in turn could make medical decisions for others more similar to monetary decisions.

I investigated this question by applying a similar paradigm as previously used to study the monetary-medical gap (Lejarraga et al., 2016). Participants made hypothetical decisions for themselves or they made either a hypothetical decision for somebody else (Study 1) or gave a recommendation (Study 2). In the choice task, participants made binary choices between monetary gambles (that could each lead to a monetary loss with some probability) and monetarily equivalent medical gambles (two equally effective treatment options, each involving a different side effect with a specific probability). To make both types of gambles comparable, participants indicated in an initial monetary evaluation task the amount they (or the person they make the decision for) would be willing to pay to avoid each side effect of the medical gambles. This monetary evaluation task revealed the monetary equivalents for each side effect for every participant. The monetary gambles that participants encountered later in the task were the same as the medical gambles but with the medical side effects replaced by each participants' monetary equivalent.

Monetary and medical gambles were either presented as *decisions from description* (i.e., where the characteristics of the gambles' payoff distributions are conveniently summarized) or *decisions from experience* (i.e., where the characteristics of the gambles' payoff distributions have to be learned from experiential sampling), similar to Lejarraga et al. (2016). Studying both, decisions from description (DfD) and decisions from experience (DfE), allowed to explore two ways of how people can learn about the probabilistic outcomes of their choices: either by receiving a description of the potential outcomes and their probabilities (as for example in a patient information leaflet), or by relying on their own experience and that of others (e.g. in the case of homeopathy where no concrete information about potential outcomes and their probabilities is available) (Lejarraga et al., 2016; Wulff et al., 2018). Additionally, behavior in the DfE-framework can give further insights into how people deal with probability information. In the DfE-framework, participants initially do not have any information about the payoff distribution of each option; they only see two buttons on the screen representing the two different options. Participants can, however, learn about the outcomes and probabilities by sampling from each of the options without any cost. Clicking on option A, for example, triggers a random draw of an outcome from option A's outcome distribution. The more people sample (click on one option), the more precise their knowledge about the probability of each outcome. People who mostly care about the outcomes of the options are hence expected to draw smaller samples than people who also care about the probabilities of the outcomes.

Results from the two studies suggested that the gap between medical and monetary decisions persists when decision outcomes affect another person rather than oneself. Participants, who were asked to make a choice or provide a recommendation for somebody else, applied very similar decision strategies and demonstrated similar sampling behavior in the DfE framework as participants who made the decision for themselves. Independent of who the decision was made for, participants relied more on a heuristic decision strategy that tries to avoid the worst outcome, while neglecting its probability when making medical rather than monetary decisions. The findings suggest that decisions under risk and their underlying processes are more influenced by the type of prospect of the decision, such as monetary losses versus medical side effects, than by who is affected by this prospect.

Another conclusion I drew from this research was that affect might not be the main driver for the difference between medical and monetary choices. Participants who decided for others overall associated less negative affect with the outcomes than participants deciding for themselves. But this difference in affective value of the outcomes did not translate into a difference in choice and search behavior between decisions for self and other. I additionally tested whether sample size was smaller in affect-rich compared to affect-poor gambles of the same domain. This would have been an indicator that probability information is treated as less important in affect-rich compared to affect-poor decisions. I did not find evidence for this assumption. Other potential factors that might have driven the difference in decision behavior in the medical and monetary domain are, for example, the information format of the outcomes (verbal vs. numerical) and differences in their fungible nature. The gap between medical and monetary decisions hence does not seem to be an *affect gap*.

### 1.3.2 Research Paper 2: Stress and the Social Dynamics of Risk Perception

Risk perceptions are rarely formed in isolation from other individuals but are part of a wider context and communication process. According to the social amplification of risk framework (Kasperson et al., 1988), information about a risk is transmitted from one station to the next in a communication chain. At each station (which can be an individual, media outlet, or an institution), the signal of the risk may be amplified or attenuated. And people tend to transmit information that is in line with their initial risk perception, neglecting opposing information (Moussaïd et al., 2015). On the aggregated level, this can lead to a social amplification of risk perception and fuel polarization (Moussaïd et al., 2015).

In research paper 2, I studied whether acute stress influences the social amplification of risk perception. I analyzed whether stress influences 1) how participants perceive a risk, 2) how they change this risk perception in response to information about the risk, and 3) what they tell others about the risk. To explore this question, I applied a similar decision task as used by research on the social dynamics of risk perception (Moussaïd et al., 2015). In this task, participants were asked to read articles about Triclosan, a controversial chemical substance, and to subsequently pass on information about this substance to another person. Participants reported their risk perception of Triclosan (how concerned they felt about Triclosan) before and after reading the articles.

To induce stress, half of the participants performed a group-version of the Trier Social Stress Test (TSST) whereas the other half completed a control task (von Dawans, Kirschbaum, & Heinrichs, 2011). As most other studies on stress and decision making, I induced stress before the decision task to ensure a maximal stress response during the task and especially a high cortisol response (Starcke & Brand, 2012). To check whether the stress manipulation worked, I assessed participants' salivary alpha-amylase and cortisol levels as biomarkers for a response of the autonomic nervous system and the HPA activation, respectively. I also assessed participants' subjective feeling of stress. For the main research questions, I compared the variable of interest among the stress group and control group. To get a better understanding of the mechanisms underlying the effect of stress, I also explored to what extent increases in cortisol and subjective stress could explain the effect of the acute stress exposure. Before the stress induction, participants responded to the Perceived Stress Scale (Cohen et al., 1983) which measures the extent to which participants appraise their life within the last month as stressful.

The results suggested that acute stress does not directly influence how people initially perceive a risk, but it influenced how participants altered their risk perception in response to new evidence: Through an increase in cortisol, acute stress led to a smaller increase in concern after reading the overall worrying articles. Participants in the stress group also transmitted less negative information to others. This suggest that after acute stress people are less responsive to negative risk information, which could be an adaptive strategy to reduce anxiety and restore homeostasis.

In contrast to the effect of our stress manipulation and the effect of cortisol, subjective stress was related to higher levels of concern. It is important to mention here that during the TSST, participants reported significantly increased levels of subjective stress. But these subjective stress levels quickly returned to baseline after conclusion of the TSST. Cortisol had its peak right after the TSST and remained above the level of the control group throughout the experiment. The physiological reaction to a stressor can hence still have an influence on behavior although people do not feel subjectively stressed anymore. At the same time, people's subjective feelings of stress and the physiological reaction to a stressor can have different effects on risk judgments.

Finally, independent of the experimental condition (stress vs. control) and subjective stress levels, participants were significantly biased by their initial risk perception when communicating the potential risk: The more concerned participants were initially about the chemical substance, the more negative the information they transmitted to another person. Overall, the results suggest that the biological reaction to a stressor that involves elevated cortisol levels can reduce the social amplification of risk perception. But it also suggests that subjective feelings of stress might increase the social amplification of risk perception.

### 1.3.3 Research Paper 3: Stress and Probabilistic Belief Updating

In research paper 2, participants updated their beliefs about the risk of Triclosan less strongly after receiving information than participants who have not been stressed. This finding motivated me to further investigate the effect of stress on belief updating. One widely-used psychological paradigm to study belief updating is a paradigm to test for the optimistic belief updating bias (Sharot, Korn, & Dolan, 2011). This bias states that people tend to adapt their beliefs about personal risk more in response to better-than-expected information (e.g. when they realize that they overestimated the probability for the negative event) than in response to worse-than-expected-information (e.g. when they underestimated the probability for the negative event) (e.g. Chowdhury, Sharot, Wolfe, Düzel, & Dolan, 2014; Garrett & Sharot, 2017; Kuzmanovic & Rigoux, 2017; Sharot, Kanai, et al., 2012; Sharot, Korn, & Dolan, 2011).

There are several reasons to assume that acute stress through the release of cortisol actually increases the optimistic update bias. First, stress has been found to improve learning from positive and to impair learning from negative feedback in a reinforcement learning task (Lighthall, Gorlick, Schoeke, Frank, & Mather, 2013; Petzold, Plessow, Goschke, & Kirschbaum, 2010). And those processes underlying reinforcement learning are assumed to be similar to the processes underlying probabilistic belief updating (Lefebvre, Lebreton, Meyniel, Bourgeois-Gironde, & Palminteri, 2017). Second, stress through the release of cortisol can increase dopaminergic activity which in turn has been found to increase the optimistic update bias (Sharot, Guitart-Masip, Korn, Chowdhury, & Dolan, 2012).

I experimentally tested the hypothesis that stress leads to a stronger optimistic update bias with an adapted version of the belief updating paradigm (Kuzmanovic & Rigoux, 2017). Participants encountered several different negative life events (e.g., getting lung cancer) and were asked to provide an estimate of the probability that this event happens to the average person in the society and an estimate of the probability that this event happens to themselves. Afterwards, participants received the actual average probability and were asked to provide a second estimate of their personal probability. Stress induction and measurement were the same as in research paper 2.

I replicated the findings from past studies on the optimistic update bias: People updated their probability estimates more readily when receiving good news (when they overestimated the average probability in the population) than when receiving bad news (when they underestimated the average probability in the population). Similarly, update scores deviated more from the rational Bayesian benchmark after receiving bad news than after receiving good news, independently of the stress manipulation. But the results did not provide any evidence that the optimistic update bias is increased by acute stress. The findings rather suggested that acute stress has no influence on how people update probability estimates of a personal risk. In contrast, participants' responses in the Perceived Stress scale influenced updating behavior: The more participants appraised their last month as stressful the less likely they were to adapt their personal risk assessment to new evidence.

## 1.4 General Discussion

The aim of this dissertation was to contribute to a better understanding of how people make risk-related judgments and decisions. As part of this question, I investigated how these processes can be influenced by affect and especially stress. Findings from the three research papers replicated already published effects and generalized them to other situations, namely decisions for others and decisions under stress. The findings also provide new evidence on how stress can influence risk perception and the underlying processes. In what follows, I discuss what these results imply for research on the role of affect and stress in decision making and for research dealing with risk-related decision processes, in general.

### 1.4.1 Affect is Difficult to Grasp

When studying the role of affect in decisions and judgments about risks, it is useful to make a distinction between incidental and integral affect (Lerner et al., 2015). In research paper 2 and 3, I studied acute stress as incidental affect that is unrelated to the decision situation. Research on the role of incidental affect on decision making typically investigates mood states (e.g., Frey et al., 2014; Lerner et al., 2015; Scheibehenne & Helversen, 2015). Note that stress itself can induce mood states such as fear and anger (Strelau, 1995). But similar to other studies investigating the effect of acute stress on decision making, I did not test for such specific emotions (Sobkow et al., 2016). Future studies could test for potential interactions between stress exposure and the type of emotion experienced in response to stress exposure.

Whereas acute stress can be induced with a standardized procedure and its well-known physiological effects can be clearly measured, the integral affect of a decision seems much more difficult to manipulate. From research paper 1 I concluded that there is still no clear definition of what affect-rich actually means and how one could disentangle affective load of a stimuli from other factors such as the information format of the outcome or the degree to which outcomes are fungible. One possible approach could be to describe outcomes from the same domain either in vivid or in neutral terms. Sunstein (2003, p. 125), for example, created an affect-rich condition by describing the outcome, cancer, as "very gruesome and intensely painful, as the cancer eats away at the internal organs of the body". In the affect-poor condition, cancer was not further described. But more research is needed to better understand what exactly makes a decision affect-rich and how that influences decision making. Future research should take two useful approaches from research on the monetary-medical gap: to investigate affect-rich and affect-poor decision *within* rather than *between* participants and to apply cognitive modelling to better understand how exactly affect can influence decision processes.

### 1.4.2 Stress Influences Risk Judgments in Different Ways

Results of research paper 2 and 3 suggest that stress might influence risk perception and the underlying processes in different ways: Findings of research paper 2 suggested that stress reduces the social amplification of risk. Acute stress led to a smaller increase in concern about the risk after participants received information with an overall negative signal about the risk. The higher the increase in cortisol, the smaller the increase in concern. In line with this finding, stressed participants transmitted less negative information about the risk to others. Overall, these findings suggest that people who have been acutely stressed are less responsive to negative risk information – a potentially adaptive process to restore homeostasis. I believe that this considerable finding should be examined in further investigations in-depth. For example, one could test whether acute stress decreases attention towards the harms of a potential risk but increases attention towards the benefits of a potential risk. Here, process tracing methods giving insights to attention allocation could be useful, such as mouse-tracking and eye-tracking.

The goal of research paper 3 was to further investigate the effect of acute stress on updating of beliefs about risk. Note that in research paper 2, participants in the stress group updated their risk perceptions to a smaller degree than participants in the control group. In research paper 3, I tested whether stress would also influence updating of probability estimates of a personal risk. I applied a well-established paradigm that has been previously used to test for the optimistic update bias: a finding that people update their beliefs more in response to bad news than in response to good news. Different from what I expected, acute stress did not influence updating behavior in this task (that is, updating of probability estimates).

Taken together, findings from research paper 2 and 3 suggest that the effects of acute stress on how people form risk judgments depends on the *type* of risk information. In research paper 2, information that participants received about the risk were six different articles that described the potential benefits and harms of the risk (the antibacterial agent Triclosan) relatively detailed. In research paper 3, the risk information received was only numerical information about the probability of a risk. It is possible that acute stress only affects how people process risk information when this information is relatively concrete and descriptive and not when it is of abstract numerical nature. For the case of descriptive or concrete risk information, future studies could investigate how people under acute stress adapt their risk perception when receiving neutral or reassuring risk information. If people indeed attend selectively to positive and negative information to regulate emotions after acute stress, stressed participants (compared to unstressed participants) should be more influenced by risk information if this information is reassuring.

Another important conclusion derived from both research papers: The physiological response to a stressor can have other effects on decision processes than people's subjective feeling of stress. In research paper 2, people in the stress and control group were equally concerned about the risk before receiving any information. At the same time, participants' subjective feelings of stress had a positive effect on risk perception: The more participants reported to *feel* stressed at the moment of the risk perception question, the more they reported to be concerned about the risk. In research paper 3, subjective feelings of stress also played a role, but not the extent to which participants appraised the *current situation* as stressful but rather the extent to which participants perceived their *life* within the last month as stressful. Here I found that scores of the Perceived Stress Scale were negatively linked with overall updating scores. That means that the more participants appraised their last month as stressful, the less they would adapt their probability estimates of a risk to new information. Future research is needed to understand the differential effects of the psychological and biological aspect of stress on judgment and decision making.

In the research papers of this dissertation, I only studied the effect of psychosocial stress induced by the TSST. Other stressors include, for example, physiological challenges such as putting ones hand in ice-cold water as done in the Cold Pressor Test (Hines & Brown, 1932). Future studies could investigate whether such different types of stressors have different effects on how people process risk related information. To better understand how a physiological stress reaction influences decision processes, it could also be interesting to directly administer stress hormones such as cortisol. This could help, for example, to test for a causal relation between elevated cortisol levels and a decreased focus on negative risk information.

### 1.4.3 Implications and Future Directions

Correctly assessing risks is a prerequisite to avoid harm and make smart and balanced decisions. In this dissertation, I replicated three important findings on how people make risk-related judgments and decisions: First, we base our decision more on a heuristic process that neglects probability information when making affect-rich medical compared to more neutral monetary decisions (research paper 1). Second, what we tell others about a risk is strongly influenced by our prior beliefs – a mechanism that, on a social level, can lead to amplification or attenuation of a risk and to polarization (research paper 2). And third, when we learn about the probability of a risk, we adjust our beliefs more when this probability has been good news to us as when it has been bad news (research paper 3). These effects have already been reported in the literature. However, in the face of the recently discussed replication crisis in psychology and the social sciences (Camerer et al., 2018; Open Science Collaboration, 2015), it is valuable to replicate already published effects before extending them in a careful manner.

Furthermore, this dissertation suggests that these three effects (neglect of probabilities in medical decisions, transmission of risk information supporting one's beliefs, and optimistic updating of beliefs about probabilities) generalize to decisions for others (paper 1) and to situations of acute stress (papers 2 and 3). Research paper 2 and 3 demonstrate that when we have been acutely stressed, our decision behavior does not necessarily become more biased. Although stressed participants transmitted risk information confirming their prior beliefs and updated their beliefs about probabilities in an optimistic manner, they did so to a similar degree as unstressed participants. Research paper 1 indicates that even when the outcomes of a medical decision (e.g., side effects of a medication) do not affect ourselves but rather another person, we tend to rely on heuristic decision strategies and put little attention to the probability of the outcome. This implies that decision processes are more influenced by the type of prospect of the decision, such as monetary losses versus medical side effects, than by who is affected by this prospect. Researchers studying decisions under risk with monetary lotteries should hence be cautious when generalizing findings to other decision contexts.

A fruitful attempt to help people understand risk information is to develop simple but effective tools such as visual aids and tabular representations of the risk (e.g., Arkes & Gaissmaier, 2012; Galesic, Garcia-Retamero, & Gigerenzer, 2009; Garcia-Retamero & Cokely, 2013). Existing research indicates that individual differences in graph-literacy and numeracy can influence how well people understand such different representations (Gaissmaier et al., 2012; Garcia-Retamero & Galesic, 2010). Future research could address the question how stress and negative affect influence people's understanding of risk information presented in these different formats. For example, are people who perceive their life as stressful also more reluctant to evidence about probabilities when it is presented graphically?

From the conclusions derived above, it might seem that people act constantly irrational when facing risks. Especially in research paper 1 and 3, I related observed decision processes to a rational benchmark (expected value maximization and Bayesian updating) and showed that there is often quite some deviation. However, I want to emphasize the importance of evaluating a decision and the underlying process not only by its fit with logical models, but rather by its fit with the environment (Gigerenzer & Todd, 1999; Todd, Gigerenzer, & ABC Research Group, 2012). For example, the use of a heuristic decision strategy such as minimax (described in research paper 1) disregards probability information that is relevant to assess the full potential of a threat. However, such a strategy that focuses on avoiding the worst possible outcome can be adaptive when we face irreversible, high-cost dangers and do not have enough time or cognitive resources available for a trade-off process between outcomes and probabilities (Volz & Hertwig, 2016). Similarly, unrealistic optimism (a potential result of optimistic belief updating studied in research paper 3) can lead to underestimation of the risk and hence to harmful behavior. But optimism has also been found to be beneficial under some circumstances where it can increase success rates (Johnson & Fowler, 2011; Sharot & Garrett, 2016). This perspective of ecological rationality could also very useful when studying the influence of affect and stress on judgment and decision making. As such, affect and stress also do not lead to more rational or more irrational behavior per se. Such an evaluation should rather be based on the circumstances. Future research could focus more on the structure of the environment to test under which circumstances affect and stress lead to more or less functional behavior (see also Starcke & Brand, 2016; Volz & Hertwig, 2016).

# Chapter 2

## The Gap Between Medical and Monetary Choices Under Risk Persists in Decisions for Others

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**Abstract**

Decisions under risk in the medical domain have been found to systematically diverge from decisions in the monetary domain. When making choices between monetary options, people commonly rely on a decision strategy that trades off outcomes with their probabilities; when making choices between medical options, people tend to neglect probability information. In two experimental studies we test to what extent a difference between medical and monetary decisions also emerges when the decision outcomes affect another person. Using a well-established risky choice paradigm for medical and monetary decisions, we ask participants to make hypothetical decisions for themselves as well as either a socially distant other (Study 1) or to give a recommendation as financial advisor or doctor (Study 2). In addition, we examined people's information search in a condition in which information about the options' payoff distributions had to be learned from sequential sampling. Computational modeling and analyses of people's search behavior indicated a similarly pronounced gap between medical and monetary decisions in decisions for others than in decisions for oneself. Our results suggest that when making medical rather than monetary decisions, people try to avoid the worst outcome while neglecting its probability — even when the outcomes affect others rather than themselves.

**Keywords:** decisions for others, risky choice, medical choices, monetary choices, decisions from experience

## 2.1 Introduction

For a patient suffering from diabetes, several different medications are available. One of them leads to diarrhea in 29% of the cases. The other medication, equally effective as the first, leads to nausea in around 10% of the cases. How do patients and doctors make such choices between treatments, of which outcomes cannot be predicted with certainty and are, therefore, decisions under risk? Traditionally, decisions under risk have been studied with choices between gambles involving monetary gains or losses. A common assumption arising from studies using such monetary stimuli is the one of maximization of expectation (Bernoulli, 1738/1954): People weight the outcomes with their corresponding probabilities and choose the option that maximizes the resulting expected outcome. When faced with medical rather than monetary prospects, however, people seem to rely on a substantially different mechanism. Specifically, people often seem to neglect probability information in such decisions and to rely on simpler, heuristic decision strategies (Lejarraga et al., 2016; Pachur & Galesic, 2013; Pachur et al., 2014; Suter et al., 2016, 2015).

Research on medical decisions under risk and how it diverges from decisions with monetary stimuli has so far been exclusively focused on decisions that people make for themselves. Note that in everyday decision making, both for medical and monetary decisions, people often choose on behalf of somebody else. Financial managers, for example, choose investment options for their clients and the anticipated gains and losses do not directly affect their own income but that of their client. Doctors recommend treatment options to their patients but they themselves do not have to deal with the potential side effects of the treatment. Although patients are increasingly encouraged and enabled to play an active role in medical decisions, it is still the case that the decision is effectively made by the doctors. Even if the doctor only provides a recommendation, this recommendation often determines the final decision of the patient (Gurmankin, Baron, Hershey, & Ubel, 2002).

In two studies, we investigate to what extent a discrepancy in choice and in its underlying cognitive processes between medical and monetary contexts also occurs in decisions that affect another person. Is the monetary-medical gap reduced in decisions for others relative to decisions for oneself? Or are medical decisions for others also more heuristic compared to monetary decisions, as has been found in decisions for oneself? Such a finding would be especially relevant for medical decision making, where doctors are usually expected to act as rational agents who make objective decisions by adequately weighing the risks and benefits of the treatment with the corresponding probabilities.

### 2.1.1 Discrepancies between Medical and Monetary Choices

Differences in decision strategies and cognitive processes between choices with medical and monetary prospects have been systematically studied in a series of studies (Lejarraga et al., 2016; Pachur & Galesic, 2013; Pachur et al., 2014; Suter et al., 2016). These studies show that in the medical compared to the monetary domain people focus more on avoiding the worst outcome, disregarding the probability of the outcomes. Typically investigated with a within-subjects design, participants make binary choices between monetary gambles (that could each lead to a monetary loss with some probability) and monetarily equivalent medical gambles (two equally effective treatment options, each involving a different side effect with a specific probability). To equate the outcomes in both tasks monetarily, participants are asked in an initial evaluation task to indicate the amount they would be willing to pay to avoid each side effect of the medical gambles. This monetary evaluation task determines the monetary equivalents for each side effect for every participant. For every medical gamble, there exists then a corresponding monetary gamble with the same probabilities in both options but with the side effects replaced by participants' willingness to pay to avoid the specific side effect. A medical gamble would be, for example, a choice between medication A that could lead to memory loss with a probability of 19% and medication B that could lead to fever with a probability of 98%. If the participant had indicated a willingness to pay of €150 to avoid memory loss and a willingness to pay of €37.50 to avoid fever, the same choice problem in the monetary domain would, hence, be a choice between monetary gamble A that could lead to a loss of €150 with a probability of 19% and gamble B that could lead to a loss of €37.50 with a probability of 98%.

Computational modeling and process data have shown that when choosing between options with medical outcomes, people's choices are often best described by the *minimax heuristic* (Savage, 1951). According to this heuristic, the option with the more attractive worst outcome is chosen – disregarding the probabilities. In the example above, the minimax heuristic would result in choosing option B, as probabilities would be ignored and as fever is less bad than memory loss (as indicated by the participant's willingness to pay to avoid each of the outcomes). In choices involving monetary losses, in contrast, people have been found to rely more often on the expected-value maximization strategy

(EV), which weights outcomes by their specific probabilities (Pachur et al., 2014). According to this strategy, one would choose option A in the example above, as the expected value would be higher (-€150*0.19 = -€28.50 > -€37.50*0.98 = -€36.75). These differences in decision strategies have been shown to lead to a systematic preference reversal between the same choice problems of the medical and monetary domain (e.g. to choose option B in the medical domain but choose option A in the same choice problem of the monetary domain) (Pachur et al., 2014).

To obtain a better understanding of how people search for information in both domains and how important it is for them to get a precise knowledge about the probability of a specific outcome, Lejarraga et al. (2016) tested participants' search and decision behavior in a decisions from experience (DfE) paradigm. In this paradigm, participants initially do not have any information about the payoff distribution of each option; they only see two buttons on the screen representing the two different options. Participants can, however, learn about the outcomes and probabilities by sampling from each of the options without any cost. Clicking on option A, for example, triggers a random draw of an outcome from option A's outcome distribution. Participants are told that they can sample as often as they like from each option before making their decision. As such, people who mostly care about the outcomes are expected to sample much less often compared to people who are also interested in the probabilities of each outcome. In line with conclusions based on people's choice behavior, the authors found that people sample less frequently for medical than for monetary gambles. This finding is supported with data from a process tracing study that show that people distribute their search effort equally among outcome information and probability information in the monetary domain, but look significantly less at probability information than at outcome information in the medical domain (Pachur et al., 2014).

One explanation provided for the discrepancy between medical and monetary decisions is the affective content of the different prospects: Compared to monetary outcomes, medical side effects have been associated with a stronger affective evaluation which could be an explanation for a stronger focus on outcomes in the medical domain (Pachur et al., 2014). Also other studies have suggested that affect-rich outcomes lead to a neglect of the corresponding probability (Petrova, van der Pligt, & Garcia-Retamero, 2014; Rottenstreich & Hsee, 2001; Sunstein, 2003). The discrepancy in decision behavior between monetary and medical decisions has therefore been referred to as the *affect gap* (Pachur et al., 2014).

### 2.1.2 Decisions for Another Person

To date, the research on the monetary-medical gap has been exclusively conducted in the context of decisions for oneself. Will medical and monetary decisions also differ when the choices are made for others, and will decision strategies and search behavior diverge? Although we do not know about any study investigating decision processes in risky choices made for others in the medical and monetary domain, we can derive at least three possible scenarios from the existing literature: 1) people make more defensive decisions for others, independent of choice domain, 2) people make more rational decisions for others, independent of choice domain, 3) the gap between medical and monetary choices decreases in decisions for others.

#### *2.1.2.1 More defensive decisions for others*

Participants who make a decision for another person may decide more defensively and focus on avoiding the worst possible outcome than people who decide for themselves. Such a decision behavior has been observed in studies in the medical as well as the monetary domain: both actual physicians (Garcia-Retamero & Galesic, 2012, 2014; Heesen et al., 2017; Ubel, Angott, & Zikmund-Fisher, 2011) and hypothetical physicians (i.e., participants imagining themselves in the role of a physician; Zikmund-Fisher, Sarr, Fagerlin, & Ubel, 2006) have been found to make more conservative, less risky choices for their patients compared to when patients choose the treatment for themselves. A similar tendency was reported by Roszkowski and Snelbecker (1990), who showed that professional financial planners made more risk averse investment choices when dealing with their clients' than with their own money. Findings from Kray and Gonzalez (1999) and Kray (2000) also support the assumption that participants deciding for others choose more according to the minimax heuristic than participants deciding for themselves. In their study, people giving advice took fewer decision attributes into account than people deciding for themselves. Decisions made for oneself seemed to be based more often on a trade-off strategy, whereas the decisions from an advisor perspective seemed to be based more often on a simple heuristic.

#### *2.1.2.2 More rational decisions for others*

There is also evidence showing that decisions made for others deviate less from rational choice behavior (i.e., expected utility theory) than decisions made for oneself. This has been demonstrated in studies on risk aversion (Sun, Liu, Zhang, & Lu, 2017; Zhang, Liu, Chen, Shang, & Liu, 2017), loss aversion (Andersson et al., 2013; Mengarelli, Moretti, Faralla, Vindras, & Sirigu, 2014; Pahlke, Strasser, & Vieider, 2012; Zhang et al., 2017), and intertemporal choice (Albrecht, Volz, Sutter, Laibson, & Cramon, 2010). One frequent explanation for this finding is that decisions for someone else are emotionally less engaging than decisions for oneself, which would allow for a more rational approach to the choice problem (Albrecht et al., 2010; Andersson et al., 2013; Mengarelli et al., 2014; Polman, 2012a; Zhang et al., 2017). In the context of our study, this would predict that people deciding for others will more often follow an expected-value maximizing strategy.

*2.1.2.3 Decreased monetary-medical gap in choices for others*

If the gap between medical and monetary gambles is indeed due to the medical gambles being more affective ('affect gap'), then this gap may decrease in decisions for others. Differences in decisions for others and for the self have been attributed to a decreased emotional engagement when outcomes affect another person. This assumption of decreased emotional engagement is supported by neuroimaging studies showing a decreased activation of reward-related brain areas in choices for others compared to choices for the self (Albrecht et al., 2010; Krigolson, Hassall, Balcom, & Turk, 2013). Additionally, differences in self-other decision making seem to increase the greater the affective involvement of the participant (Albrecht et al., 2010). Following this line of reasoning, the affective impact of medical side effects may be smaller when people decide for others compared to when they decide for themselves, which in turn could make medical decisions for others more similar to monetary decisions. This would decrease the gap between medical and monetary decisions when made for others.

### 2.1.3 Present Research

We conducted two experiments to address the following questions: To what extent do medical and monetary decisions for another person differ from decisions for oneself in terms of decision strategies and search behavior? Does the gap between medical and monetary decisions persist or does it decrease? The two experiments cover two important perspectives in decisions for others: In Study 1, participants act as proxy decision makers and are asked to make a (hypothetical) decision for another student. In Study 2, we ask participants to imagine themselves as a physician or financial planner and to give a recommendation to a patient or client, respectively.

The paradigm in both experiments is based on Lejarraga et al. (2016), where people make either decisions from description (DfD) (i.e., where the characteristics of the gambles' payoff distributions are conveniently summarized) or decisions from experience (DfE) (i.e., where the characteristics of the gambles' payoff distributions have to be learned from experiential sampling) between several monetary and medical gambles. Studying both, decisions from description and decisions from experience, allows us to explore two ways of how people can learn about the probabilistic outcomes of their choices: either by receiving a description of the potential outcomes and their probabilities (as for example in a patient information leaflet), or by relying on their own experience and that of others (e.g. in the case of homeopathy where no concrete information about potential outcomes and their probabilities is available) (Lejarraga et al., 2016; Wulff et al., 2018). Additionally, search effort in the DfE framework gives an insight into how important it is for participants to reduce uncertainty and get a precise knowledge about outcomes and their corresponding probabilities.

We expect to replicate past findings on the monetary-medical gap, namely that participants choose more often according to EV maximization and draw larger samples in the monetary compared to the medical domain when making decisions for themselves. Regarding the emergence of a gap between medical and monetary choices made for others, the existing literature gives rise to opposing predictions. If people make more defensive decisions for others, participants in the OTHER condition should choose more often according to the minimax heuristic in both domains than participants in the SELF condition. In Lejarraga et al. (2016), choosing with the goal of avoiding the worst outcome was linked with a reliance on relatively small samples. We, hence, expect that choosing according to the minimax heuristic will come along with decreased search effort in the DfE paradigm. If people decide more rationally for others, participants in the OTHER condition should choose more often according to EV maximization strategy. We again assume that choice behavior is strongly linked to search behavior: People who choose with the goal of maximizing the EV are expected to draw larger samples to get an accurate representation of the true underlying probability. Finally, if the monetary-medical gap is mainly driven by differences in the affective load of the prospects, choice and search behavior in the medical domain should become more similar to the monetary domain in choices for others compared to choices for oneself. More specifically, that would mean that particularly in the medical domain, choices for others would follow more often EV maximization and rely on larger samples than choices for oneself.

Since the amount of negative affect related to the outcomes might be an important driver for differences in decision processes between domains and decision perspectives (self vs. other), we additionally elicit participants' affective evaluation of each outcome. Based on past research we expect that the stronger the affective evaluation of a prospect, the more people neglect probabilities. This would imply less choices following EV maximization and smaller samples in affect-rich compared to affect-poor decision problems[1].

Our two studies do not only allows us to test the generalizability of the medical-monetary discrepancy to decisions for others, they also contributes to a better understanding of decisions for others in general. To the best of our knowledge, we are the first to apply cognitive modeling to self-other decision making. This allows us to get a better understanding of the cognitive processes underlying decisions made for one self versus for another person. Moreover, it is unclear so far how people sample information in a decision from experience paradigm when the outcomes do not affect themselves but another person.

## 2.2 Method

To a large extent, the two studies reported follow the same design. The only difference between the studies are the instructions in the OTHER condition, which were framed in terms of a decision for someone else in Study 1 and in terms of a recommendation for someone else in Study 2. We will, hence, report methods and results from both studies in parallel.

### 2.2.1 Participants

For Study 1, we recruited 164 participants (139 female; (85%), age: *M* = 21.92, *SD* = 4.60). Study 2 included 155 participants (130 female (84%), age: *M* = 22.25, *SD* = 4.10). Two participants from Study 1 were excluded from the analysis because of unreliable values in the monetary evaluation task (one participant entered the same WTP for every side effect, another participant reported a WTP of €1,000,000,000 which was more than ten thousand times the interquartile range of the participant's WTP). In both studies,

[1] We refer here to "integral affect" (Lerner, Li, Valdesolo, & Kassam, 2015) that is directly elicited by the potential outcome of a decision. For a study that investigates the effect of incidental affect on sampling, see Frey, Hertwig, & Rieskamp (2014).

participants were recruited at the University of Konstanz and received either course credit or €6 as a compensation for their participation. Overall, the study took around thirty minutes to complete.

### 2.2.2 Design

The experimental design of both studies involved the two between-subjects factors *decision perspective* (self vs. other) and *decision format* (DfD vs. DfE) and the within-subjects factor *domain* (medical vs. monetary). Participants in both studies were approximately equally distributed across the four different experimental condition (see Table A1.2 in the Appendix).

### 2.2.3 Materials

Participants made twenty binary choices between monetary gambles involving different potential losses and twenty choices between medical gambles, that is, drugs that lead to different side effects with a specific probability. We used the same nine choice problems as in Lejarraga et al. (2016) and additionally selected eleven choice problems from Pachur et al. (2014) and Suter et al. (2016). The choice problems were selected such that they included a balanced representation of each of the twelve side effects used before and a well distributed range of probabilities of the side effects from 5% to 100%. Choice problems with very rare side effects (< 5%) were not considered as they are very unlikely to be sampled in the decisions from experience paradigm (where people usually do not draw very large samples; e.g., Hertwig et al., 2004). The choice problems of Pachur et al. (2014) and Suter et al. (2016) were constructed such that EV maximization strategy and minimax heuristic often would make opposing predictions. For participants in our studies, EV maximization strategy and minimax heuristic made opposing predictions in on average 58% (Study 1) and 53% (Study 2) of the choice problems. Only 9% (Study 1) and 8% (Study 2) of the choice problems included one clearly dominating option. A complete list of the choice problems used in both studies can be found in Table A1.1 in the Appendix.

### 2.2.4 Procedure

#### *2.2.4.1 Monetary evaluation task*

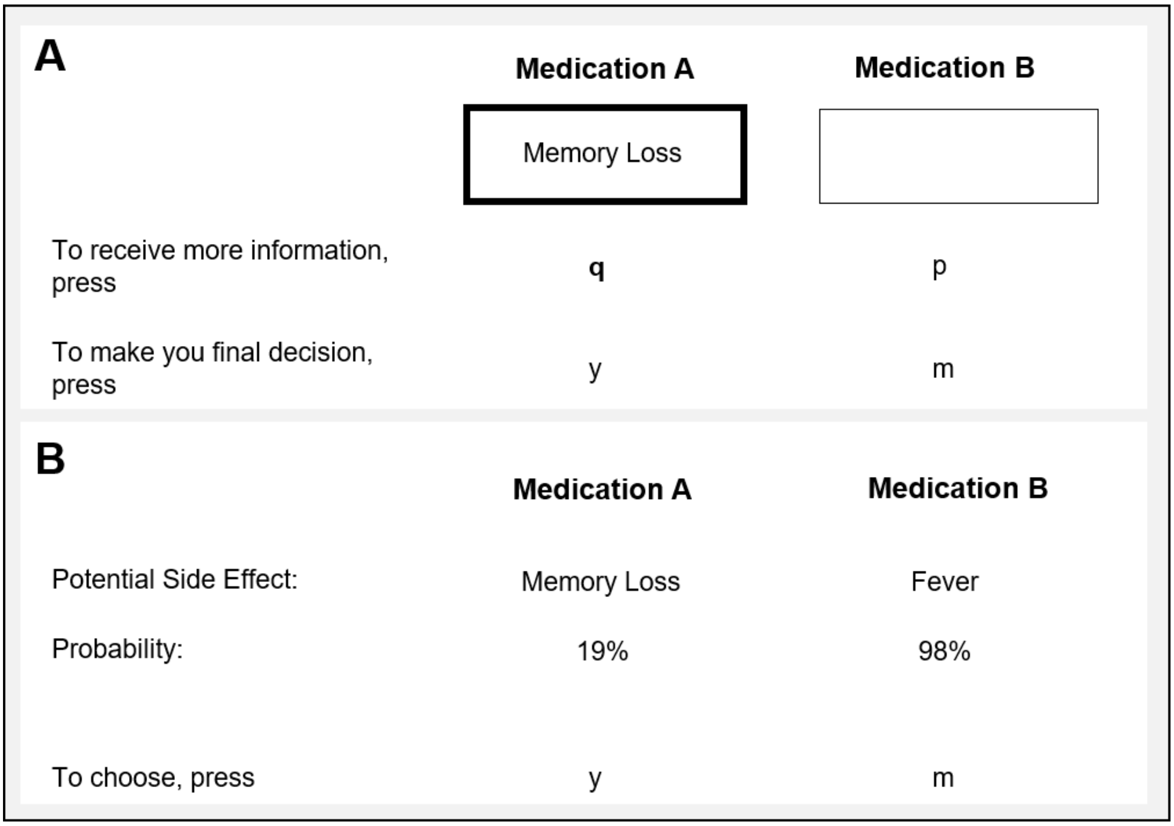
At the beginning of the experiment, participants were asked to indicate their willingness to pay (WTP) to avoid each of the twelve side effects (see Table A1.3 in the Appendix for median WTPs for each side effect). These monetary evaluations were later used to construct the monetary gambles for each participant. More specifically, participants were instructed to imagine that they were suffering from a severe disease and that there existed different medications to treat the disease that were all equally effective but could lead to different side effects. In the SELF condition, participants were then asked how much more they would be willing to pay for a new medication that is as effective as an existing medication but would not lead to the same side effect. They then first ranked the side effects by the amount they would be willing to pay to avoid them and then in a next step reported the exact amount of their WTP. In the OTHER condition, participants were doing the same task but were asked to estimate the amount that another student would be willing to pay to avoid the side effect. In order to test the reliability of the measure, the monetary evaluation task was presented again at the end of the experiment.

#### *2.2.4.2 Choice task*

After the monetary evaluation task, participants were presented with the medical and the monetary choice tasks, with the order of both tasks being counterbalanced across participants. In the medical choice task, participants encountered twenty choice problems where they had to choose between two different medications. Both medications were described as being equally effective but potentially leading to different side effects with different probabilities. In the monetary choice task, participants were faced with the same choice problems, but with the side effects replaced by their monetary equivalents reported in the monetary evaluation task (their WTP). As in Lejarraga et al. (2016), choices were either presented in a decisions from description (DfD) condition or a decision from experience (DfE) condition. In the DfD condition, outcomes and their probabilities were fully disclosed to participants (see Figure 2.1 B). In the DfE condition, however, participants had no prior information about the two options. They could draw a random sample of the binary outcome distribution of each option by pressing a corresponding key on the keyboard. The drawn outcome (either the specific side effect or "No Side Effect", or the specific loss or "€0") would then be presented on the screen under the respective option (see Figure 2.1 A) until the next sample is drawn. Participants could sample in every order and as often as they liked before making a choice.

In the SELF condition, participants made choices as described above; in the OTHER condition, participants were asked how they would choose for another person. Instructions in the OTHER condition differed between Study 1 and Study 2. In Study 1, participants were told to imagine that a student who they did not know well but who is also in one of their courses asks them to buy a lottery ticket (monetary domain) or a medication (medical domain) for him/her. In Study 2, participants were asked to imagine that they were either a physician (in the medical condition) or a financial advisor (in the monetary condition) and should give a recommendation to a student.

*Figure 2.1:* Schema of choice tasks in the medical domain and how they was presented to participants on the screen; (A) in the Decisions from Experience (DfE) condition where a participant just clicked on “q”, and (B) in the Decisions from Description condition (DfD).




*2.2.4.3 Affective evaluation task*

To examine the extent to which the side effects and monetary amounts triggered different amounts of affect, and also whether the decision perspective played a role, participants were asked at the end of the experiment to indicate on a 1-10 scale for each of the medical and monetary outcomes how upset they would feel if they (or the person they made the decision for) actually lost the specific amount or got the specific side effect.[2]

### 2.2.5 Measures

*2.2.5.1 Choice behavior: choice reversals and strategy classification*

To examine the extent to which participants’ choices were affected by outcome domain and decision perspective, we first computed how often participants reversed their choices

[2] Specifically, we used the German term „verärgert“.

within the same choice problem from the medical to the monetary domain. Second, we modeled choices with the EV maximization strategy and the minimax heuristic in each condition (similar to Pachur et al., 2014). The EV-strategy weights the outcome of an option with its probability (calculates its expected value) and chooses the option with the highest expected value. The minimax heuristic minimizes the maximal loss and hence chooses the option with the lowest potential loss, disregarding the corresponding probabilities. In the medical domain, the WTPs are used to define the value for the medical side effects for each participant. To estimate the expected value of an option in the DfE condition, we used participants experienced probabilities, that is, the proportion of times the participant actually encountered the specific outcome. Participants were classified to the strategy with the best fit, using a maximum likelihood approach, similar to Pachur and Galesic (2013), Pachur et al. (2014), and Pachur and Marinello (2013). The goodness of fit of strategy $k$ was determined for each participant as

$$G_{i,k}^2 = -2\sum_{j=1}^{N} \ln[f_j(y)] \tag{1}$$

where $f_j(y)$ represents the probability with which a strategy predicts an individual choice $y$ at choice problem $j$. If option A was chosen, $f_j(y)$ was the probability that the strategy predicted the choice of option A over option B, $P_j(A,B)$. If option B was chosen, $f_j(y)$ was the probability that the strategy predicted the choice of option B, 1 – $P_j(A,B)$. As in Pachur et al. (2014), we defined the probability that the strategy predicted the choice of gamble A ($P_j(A,B)$) with an exponential version of Luce's choice rule (softmax):

$$P_j(A,B) = \frac{e^{\varphi V(A)}}{e^{\varphi V(A)} + e^{\varphi V(B)}} \tag{2}$$

For the EV strategy, the valuations of options A and B were defined as: $V(A) = x_A * p_A$ and $V(B) = x_B * p_B$ ($x$ is the outcome of the option and $p$ its corresponding probability). For the minimax heuristic, these valuations were defined as $V(A) = x_A$ and $V(B) = x_B$. The parameter $\varphi$ in Eq. 2 represents the sensitivity towards differences in the subjective valuations of the choice problems. It was estimated using a grid search and subsequent optimization with the Nelder-Mead algorithm (using the first best solution from the grid search as starting point). If the goodness of fit $G^2$ of the best fitting strategy was equal to or bigger than the goodness of fit $G^2$ of a random choice ($P_j(A,B)$ = 0.5), participants were classified as "guessing or using another strategy" (Pachur et al., 2014).

#### *2.2.5.2 Search effort*

Search effort in the DfE condition was measured by the total number of draws (sample size) from both options per choice problem.

### 2.2.6 Analyses

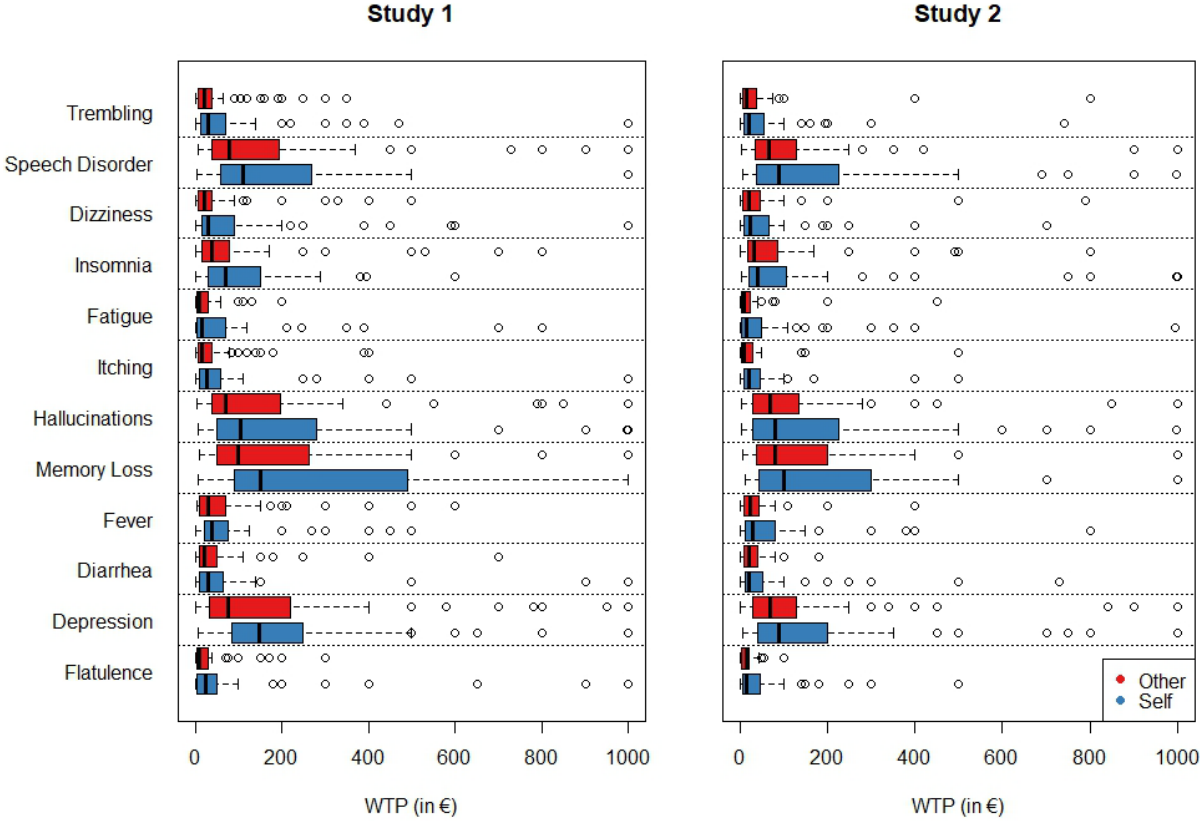
For all the analyses we applied mixed-effects regression analyses using the lme4 package in R (Bates, Mächler, Bolker, & Walker, 2014; R Core Team, 2017). Effects of our factors of interest were examined in a step-wise approach, first estimating the full model and then testing the effect of excluding the relevant factor on model fit using a chi-squared test. For readability, the details of the models will be provided in the Results section.

## 2.3 Results

### 2.3.1 Monetary Evaluation of the Side Effects

The WTPs reported in the beginning and in the end of the experiment were highly correlated (mean correlation across participants: Study 1: $r$ = .975; Study 2: $r$ = .959), indicating that they are a reliable measure over time. Figure 2.2 displays the reported WTPs to avoid each of the twelve side effects (monetary equivalents) across participants in both conditions (SELF and OTHER). The amounts that participants reported ranged from 0 up to 1,000,000 € (Study 1: *Mdn* = 40 €, *M* = 1887 €; Study 2: *Mdn* = 30 €, *M* = 3782 €). In the OTHER condition, participants were asked to report how much they thought the other student would be willing to pay to avoid each of the side effects. Although WTPs in the OTHER condition seem to be generally lower than in the SELF condition, excluding the dummy coding of decision perspective from the model does not lead to a significantly poorer model fit (Study 1: $\chi^2(1) = 2.31$, $p$ = .128 ; Study 2: $\chi^2(1) = 1.81$, $p$ = .179). As the values of the WTP variable are highly right-skewed, we reran the model using log-transformed WTPs. In this analysis, decision perspective predicted the (log-transformed) WTP (Study 1: $\chi^2(1) = 6.29$, $p$ = .012; Study 2: $\chi^2(1) = 5.90$, $p$ = .015), with WTPs being higher in the SELF than in the OTHER condition.

*Figure 2.2*. Reported willingness to pay (WTP) in € to avoid the specific side effect. In the OTHER condition, participants were asked to report how much they think the other student would be willing to pay to avoid the specific side effect. The right and left limits of the boxes denote the first and third quartile. The whiskers denote the lowest datum within 1.5 interquartile range (IQR) of the 1st quartile, and the highest datum within 1.5 IQR of the 3rd quartile. Not shown are values above a WTP of 1,000€ (but they are included in the boxplots).




## 2.3.2 Choice Behavior

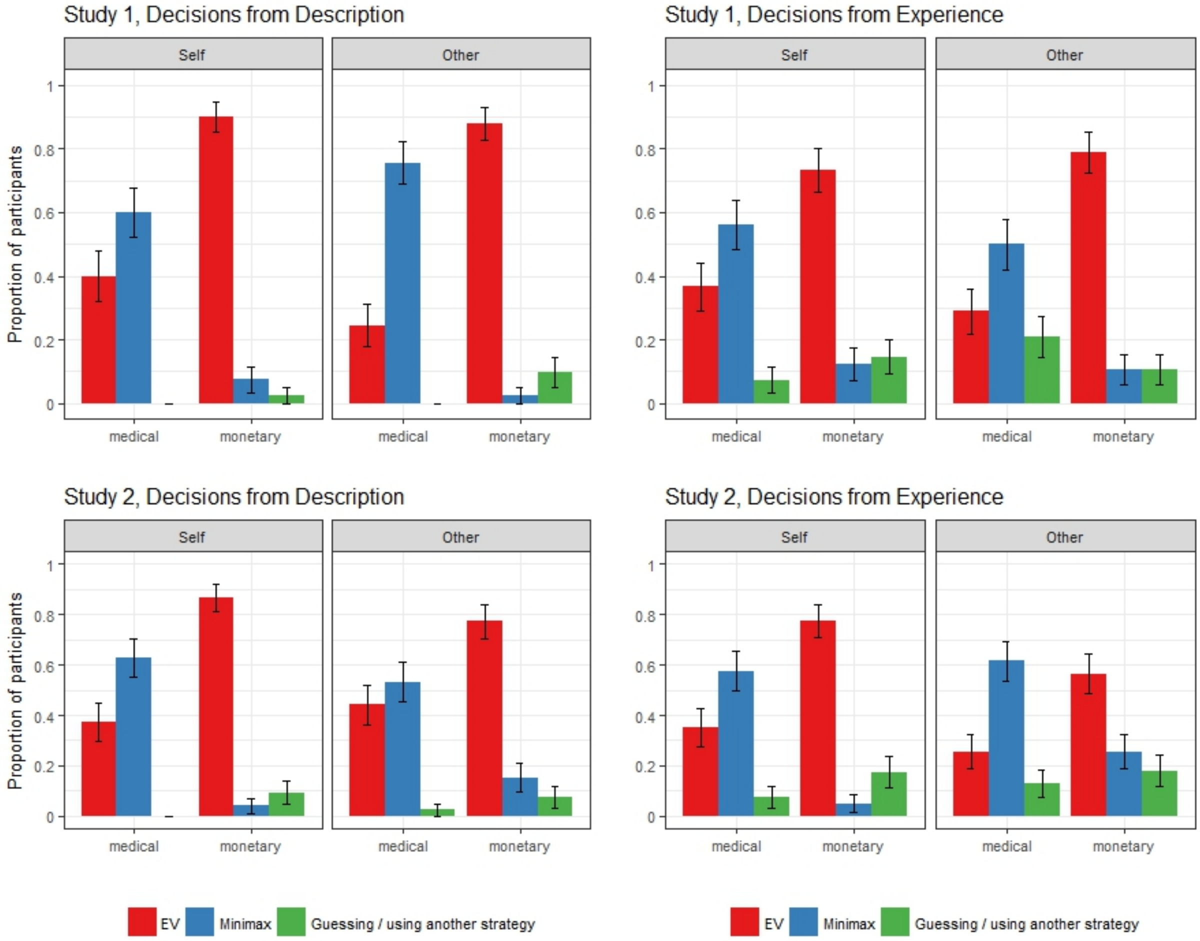
### *2.3.2.1 Choice reversals*

Do people choose differently in the medical than in the monetary task? As in Pachur et al. (2014), participants reversed their choices between the medical and the corresponding monetary choice problem more than two fifth of the time (with M = 40% and M = 44% in Study 1 and Study 2, respectively). In both studies, a mixed-effects logistic regression analysis, with participants and choice problem as random effects and decision perspective (SELF vs. OTHER) and decision format (DfD vs. DfE) as fixed effects, did not show a difference between the SELF and OTHER conditions (Study 1: $\chi^2(1) = 0.72$, p = .396 ; Study 2: $\chi^2(1) = 1.14$, p = .285). Choice reversals, however, differed between the decision format in Study 2 ($\chi^2(1) = 7.79$, p = .005), but only slightly so in Study 1 ($\chi^2(1) = 2.35$, p = .125). In the DfE condition, participants were somewhat more consistent in their choices across the two domains than in the DfD condition (percentage of choice reversals: Study 1 DfD: 42%, Study 1 DfE: 38%; Study 2 DfD: 47%, Study 2 DfE: 40%).

#### *2.3.2.2 Strategy classification*

Results of the strategy classification can be found in Figure 2.3. Consistently over the four conditions of our two studies, participants were more often classified as following an EV maximization strategy in the monetary domain than in the medical domain and following a minimax heuristic more often in the medical compared to the monetary domain. To test the effect of choice domain, decision format and decision perspective on strategy use, we created a dummy variable for whether participants were classified as following the EV strategy or not and run a mixed logistic regression analysis with the above-mentioned variables as fixed effects and participants as random effect. Additionally, we tested whether adding interaction terms would improve model fit. In both studies, more participants were classified as following the EV strategy in the monetary than in the medical domain (Study 1: $\chi^2(1) = 86.9$, $p < .001$; Study 2: $\chi^2(1) = 95.2$, $p < .001$), but there was no main effect of the decision perspective (Study 1: $\chi^2(1) = 1.09$, $p = .296$; Study 2: $\chi^2(1) = 1.13$, $p = .288$). However, there was an interaction between domain and decision perspective in Study 2 ($\chi^2(1) = 4.59$, $p = .032$), with fewer participants being classified as following the EV strategy in the monetary domain and the OTHER condition than in the SELF condition. Furthermore, there was a main effect of decision format in Study 2 with more participants classified as following EV maximization and less as following the minimax heuristic in the DfD compared to the DfE condition (EV maximization: DfD: 61.36%, DfE: 48.73%; minimax: DfD: 33.77%, DfE: 37.34%). This is consistent with results from Lejarraga et al. (2016) where minimax predicted slightly more choices in the DfE condition than in the DfD condition.

*Figure 2.3.* Proportion of participants classified as following the expected-value (EV) strategy, the minimax heuristic, and as guessing / using another strategy in the four conditions of our two studies, respectively. Error bars denote ± standard error of the proportion.




### 2.3.3 Search Effort

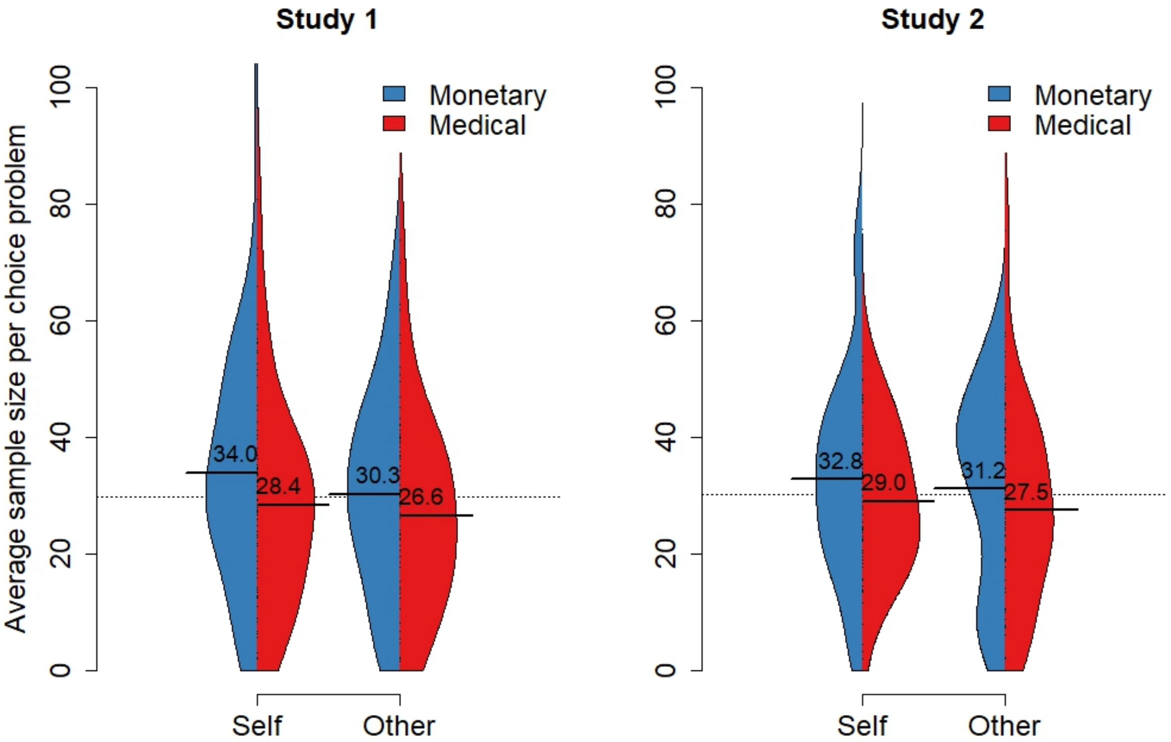
In the DfE condition, participants drew a relatively large number of samples, with an average number of draws per choice problem of $M$ = 33.2 ($SD$ = 35.1; $Mdn$ = 26) and $M$ = 30.1 ($SD$ = 21.7; $Mdn$ = 26) in Study 1 and Study 2, respectively.[3] To predict the effect of choice domain and decision perspective on the sample size, we ran a mixed-effects linear regression, additionally controlling for the difficulty of the choice problem, *EVdiff* (measured as relative difference of the expected values of both options). Domain, decision perspective and *EVdiff* where treated as fixed effects and participant and choice problem

[3] These numbers are relatively large compared to a mean of 19.4 draws in Lejarraga et al. (2016) and a median of 22 for choices with two risky options reported in a meta-analytic review by (Wulff, Mergenthaler-Canseco, & Hertwig, 2018). One reason for this relatively high number of draws might be that sampling in our experimental paradigm was made very easy: In order to sample from an option, participants did not first have to select an option with the mouse but they just had to press a certain key on the keyboard ("y" to sample from option A and "m" to sample form option B). The feedback would then directly appear on the screen. Moreover, our choice problems involved only negative outcomes which also has been found to increase search effort (Lejarraga, Hertwig, & Gonzalez, 2012; Wulff et al., 2018).

as random effects. Moreover, we added individual-specific random slopes for domain and an interaction between domain and decision perspective. The number of draws per choice problem was lower in the medical than in the monetary domain in both studies (Study 1: $\chi^2$ (1) = 12.5, $p$ < .001; Study 2: $\chi^2$ (1) = 8.73, $p$ = .003).[4] As can be seen in Figure 2.4, this difference held regardless of whether participants were making decisions for themselves or for another student. Although participants took slightly smaller samples in both domains across both studies in the OTHER condition compared to the SELF condition (see Figure 3), decision perspective did not predict sample size (Study 1: $\chi^2$ (1) = 0.36, $p$ = .546, Study 2: $\chi^2$ (1) = 0.25, $p$ = .616). There was also no interaction between decision perspective and domain (Study 1: $\chi^2$ (1) = 1.63, $p$ = .201, Study 1: $\chi^2$ (1) = 0.56, $p$ = .455, Study 2: $\chi^2$ (1) = 0.00, $p$ = .969). These findings are in line with the results on participants' choice behavior where those deciding for /giving a recommendation to another student followed similar decision strategies in both domains as participants deciding for themselves. Indeed, choice behavior seems to be linked to sample size: those classified as following an EV strategy sample on average more than those classified as following a minimax heuristic (Study 1: sample size EV strategy: 34.96, sample size minimax heuristic: 27.95, $t$(114.7) = 2.42, $p$ = .017; Study 2: sample size EV strategy: 34.70, sample size minimax heuristic: 26.48, $t$(125.03) = 3.26, $p$ = .001). Participants who were classified as guessing or following another strategy overall drew the smallest samples (Study 1: 13.55, Study 2: 23.92).

[4] This effect was disturbed by an outlier in Study 1 who drew substantially more samples in the OTHER condition than the other participants ($M$ = 167.6, maximum = 399, $SD$ = 101, see Figure A1.2 in the Appendix). We excluded this outlier from the analyses reported here. Results on search effort including the outlier are shown in Figure A1.1 in the Appendix.

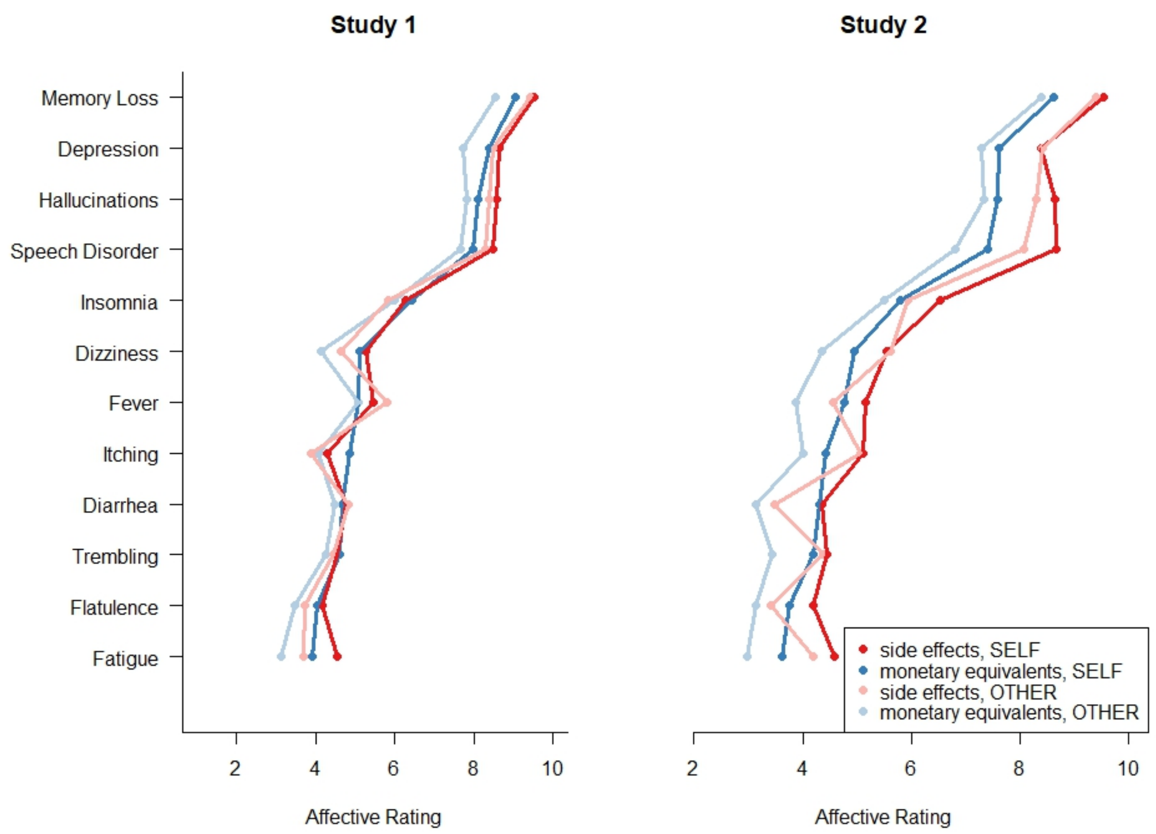
*Figure 2.4.* Average sample size per choice problem in the DfE condition. Whereas decision domain (monetary vs. medical) predicted sample size (Study 1: $\chi^2$ (1) = 12.5, $p$ < .001; Study 2: $\chi^2$ (1) = 8.73, $p$ = .003), decision perspective (self vs. other) does not influence how much participants sample from an option (Study 1: $\chi^2$ (1) = .352, $p$ = .553, Study 2: $\chi^2$ (1) = .240, $p$ = .624).




### 2.3.4 Affective Evaluation

Mean affective ratings for each side effect and its monetary equivalent in the SELF and OTHER condition are displayed in Figure 2.5. In the OTHER condition, participants were asked to report how upset they would feel if the person they made the decision / recommendation for actually lost the specific amount or got the specific side effect. Affective ratings were higher for medical side effects than for monetary losses (mixed-effects linear regression with participants as random effects and side effects, domain, decision perspective and decision format as fixed effects: Study 1: $\chi^2(1) = 30.8$, $p < .001$ ; Study 2: $\chi^2(1) = 192.7$, $p < .001$), which is consistent with past studies on discrepancies in medical and monetary decisions (Pachur & Galesic, 2013; Pachur et al., 2014). There was no effect of decision format on affective rating (Study 1: $\chi^2(1) = 0.13$, $p = .716$; Study 2: $\chi^2(1) = 0.05$, $p = .821$) but of decision perspective: Participants reported to feel less upset when somebody else would experience the outcome as when they themselves would experience it (Study 1: $\chi^2(1) = 4.42$, $p < .036$; Study 2: $\chi^2(1) = 8.14$, $p < .004$). However, as reported above, participants indicated lower WTPs when they had to estimate what the other person would pay to avoid the specific side effect than when reporting the WTPs for themselves. They were therefore also presented with, on average, lower monetary values in the affective evaluation task than participants in the SELF condition. These lower values might have driven the effect of the OTHER condition on affective rating. To control for this difference in monetary amounts, we conducted a mixed-effects regression analysis separately for the medical and the monetary domain, using the type of side effect in the medical domain and the amount of WTP in the monetary domain as covariates. This analysis showed that only for medical side effects in Study 2, decision perspective was a significant predictor of affective rating ($\chi^2(1) = 5.24$, $p = .022$). The lower affective rating in the OTHER condition can, hence, partly be explained by the lower estimated valuation of the side effects by others in terms of WTP.

*Figure 2.5.* Mean affective ratings (ranging from 0-10) for side effects and their monetary equivalents (WTPs) in the SELF and OTHER condition of both studies.




## 2.4 Discussion

Results from both our studies demonstrate that the gap between medical and monetary decisions is a robust phenomenon that persists when decision outcomes affect another person rather than oneself. Participants who were asked to make a choice or a give a recommendation for somebody else systematically reversed their choices between monetary and medical gambles just as often as participants making choices for themselves. Computational modeling revealed that choices for others could be described in a very similar way as choices for oneself: In both conditions, monetary choices were better modeled with the compensatory EV strategy that weights outcomes with their corresponding probabilities than with minimax. Medical choices were better modeled with the simple minimax heuristic that neglects probabilities and minimizes the worst possible outcome. These patterns in choice behavior were also reflected in participants' search effort in the decision from experience paradigm: When making medical choices for oneself and for others, participants relied on much smaller samples than when making monetary choices.

### 2.4.1 Implications for the Gap between Medical and Monetary Decisions

Our results closely replicate the results by Lejarraga et al. (2016) and Pachur et al. (2014) and support their finding that choice and search behavior differ between decisions involving medical and monetary prospects. Specifically, probability information tends to be neglected in medical decisions. Such a replication of previous findings seems especially valuable considering the recently discussed replication crisis in psychology and the social sciences (Camerer et al., 2018; Collaboration, 2015). As a new contribution, our results show that the gap between medical and monetary decisions generalizes to choices for others: Choice behavior and information search in medical decisions differ from monetary decisions independent of who is affected by the outcome.

The difference between medical and monetary decisions has various important implications: First, it demonstrates that decision behavior is highly context dependent and seems to be more influenced by the type of prospect (in our case monetary losses vs. medical side effects) than by who is affected by these prospects. Caution is thus due when generalizing findings from lab experiments on risky choices involving monetary outcomes to other decision contexts. Second, demonstrating that people seem to disregard probabilities in medical decisions, and that this also holds true for decisions and recommendations for others, implies a challenge for informed medical decision making. To overcome this challenge, effective risk communication tools that help patients as well as doctors to adequately take into account probability information have been developed. Such tools include, for example, well-designed visual aids such as icon arrays or bar graphs which have been found to significantly improve comprehension of risk information (Garcia-Retamero & Cokely, 2013).

Zhang et al. (2017) argue that physicians may make better medical decisions if they make it for a socially distant person instead of making the decision for a friend or themselves. Our findings suggest that even when the patient is a stranger, this may not be the case. However, whether these findings from hypothetical laboratory medical decisions also generalize to decision processes of actual physicians still has to be investigated by future research.

### 2.4.2 Implications for Self-Other Decision Making

In both our studies, choice behavior, decision strategies and sampling behavior of participants deciding for others were very similar to the ones of participants deciding for themselves. These findings indicate that the decision processes applied by participants making risky choices on behalf of somebody else were similar to the decision processes applied by participants asked to decide for themselves. The only difference we found occurred in the monetary domain of Study 2, where decisions for oneself were following the EV strategy more often, whereas recommendations for other were slightly more defensive and less in accordance with the EV strategy. Note, however, that this effect is small, and the overall pattern of strategy classifications is largely comparable.

In contrast to our findings, most published studies on self-other decision making have found differences between the two decision perspectives. There are various reasons for why we did not find a systematic self-other discrepancy in decision making in our two studies although they have been reported in the past: First, due to publication bias studies with statistically nonsignificant results may have been less likely to be published than studies that report significant results (Ioannidis, Munafò, Fusar-Poli, Nosek, & David, 2014; Sterling, 1959). Second, decision task and research question in our study are different from most of the past studies on decisions for others. To the best of our knowledge, we are the first to examine decision strategies in choices between gambles made for others. The studies that used similar tasks as we did, however, also find similar results. One study on decisions from experience for others that has not (yet) been published in a scientific journal has found – similar to us – no difference in search effort between situations when outcomes affected participants themselves or another participant (Olschewski, Dietsch, & Ludvig; 2017). Sun et al. (2017) have investigated choices for self and other in daily-life decision scenarios involving either monetary gains or losses and found differences in risky choices for self vs. other only in the gain domain but not in the loss domain. They explain this finding by an asymmetry in emphasizing with others positive and negative experiences: Empathizing with others' losses seems to be easier than empathizing with other's gains (Martínez-Jauand et al., 2012; Nahum et al., 2011). In our studies, gambles include solely negative outcomes and, additionally, these negative outcomes are relatively high in value. To better understand decisions for others, future research should systematically vary not only the type of decision (e.g. proxy decision making vs. providing a recommendation) and social distance to the other person, but also the value of the decision outcome and whether it is a gain or loss, and the accountability or need for justification of the decision maker.

A limitation of our study is that we asked participants to decide for an abstract "other student". Such a decision might be quite different from real-world decisions for others where we usually know the other person and her preferences. Instructions to imagine an abstract other are quite common in research on decisions for others (L. Kray & Gonzalez, 1999; Polman, 2010, 2012b; Sun et al., 2017). This can produce a lot of heterogeneity in who people imagine, from a close friend to a complete stranger. We tried to reduce this heterogeneity by asking participants to imagine another student who they don't know well but who is in one of their courses. They, hence, were all supposed to imagine a socially distant other from the same peer group. A next step would be to study monetary and medical decisions for others with actual dyads.

### 2.4.3 The Role of Affect

Similar to past studies on the gap between medical and monetary decisions, participants in our study overall indicated that they would feel more upset when experiencing the medical side effect than when experiencing the monetarily equivalent loss. This gap in affective valuation was also found for participants who affectively evaluated outcomes that would be experienced by the person they made the decision for. Overall, participants in the OTHER condition of both studies report lower affect than participants in the SELF condition. Participants deciding for others, hence, faced gambles in which they associated less negative affect with the outcomes than participants deciding for themselves. This difference in affective value of the outcomes did, however, not translate into a difference in choice and search behavior, suggesting that affect might not be the main driver for the discrepancy between medical and monetary decisions. In additional analyses reported in the Appendix, we test whether search effort differs between affect-rich and affect-poor gambles of the same domain. We do not find any evidence for this assumption.

Another factor that is likely to have influenced the use of different decision processes in the two domains is the format or the *evaluability* of the outcomes: Monetary losses have a clearly defined, numerical value that can easily be weighted with probabilities. Medical side effects, on the other side, do usually not have such a clearly defined value that can be expressed by a number. Their evaluation is relatively difficult and rather represents a feeling that can hardly be weighted by a numerical probability. Medical gains and losses can also not compensate each other in contrast to monetary outcomes. For example, a sprained ankle does not improve when vision is treated. This holds true regardless of whether the outcome affects oneself or another person.

### 2.4.4 Predicted Willingness to Pay

To obtain monetary equivalents for the medical side effects, we asked participants how much they would be willing to pay to avoid the specific side effect. In the OTHER condition, participants reported the amount they predicted another person to be willing to pay to avoid the side effect. In both studies, this predicted willingness to pay was on average lower than the willingness to pay participants reported for themselves. In a number of studies, Frederick (2012) found increased predicted WTP of others. However, this was only the case when asked about the WTP to experience positive events. When asked about a compensation for experiencing a negative event (such as shaving the head), which is very similar to asking for the WTP to avoid a negative event, participants predicted that others would demand a smaller amount than themselves (see Appendix J in Frederick, 2012). Similarly, Hsee and Weber (1997) showed that people predict others to be more willing to take risks than themselves. As explanation for these findings authors of both studies suggested that people have difficulties empathizing with the feelings of socially distant others and tend to underestimate how others evaluate negative events. Our results on the lower predicted WTP and lower affective ratings in the OTHER condition support this notion.

## 2.5 Conclusion

In two studies, we extended findings on the gap between medical and monetary decisions under risk to decisions made for others. In decisions with monetary prospects, people generally trade-off outcomes with their probabilities. In decisions with medical prospects, people tend to rely more on a heuristic strategy that focuses on the outcome of the decision while ignoring its respective probability. Our results indicate that this gap between medical and monetary decisions persists when decision makers are not affected by the outcome themselves, but rather make a decision or recommendation for another person. Cognitive modelling of decision strategies and an analysis of sampling behavior in a decision from experience paradigm indicated that decisions made for others and decisions made for the self follow similar processes in risky choices. Taken together, these findings suggest that decisions under risk and their underlying processes are more influenced by the type of prospect of the decision, such as monetary losses versus medical side effects, than by who is affected by this prospect.

# Chapter 3

## Acute Stress Reduces the Social Amplification of Risk Perception

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**Abstract**

Risk perceptions typically underlie a social dynamic: Risk-related information is exchanged between individuals, this information influences risk perceptions, and risk perceptions influence which information is transmitted. This can lead to a social amplification of the risk. We test how stress, a widespread affective state, influences the social dynamics of risk perception. Participants (N = 146) read articles about the controversial antibacterial agent Triclosan and were then asked to inform another person about Triclosan. Before and after reading the articles, participants reported their concern about Triclosan. Stress exposure before the task led to a smaller increase in concern in response to the articles. The stronger the increase in cortisol, the smaller the increase in concern. Furthermore, participants in the stress group transmitted less negative information about Triclosan to others. In contrast, participants' subjective feelings of stress were associated with higher concern and more alarming risk communication. We conclude an acute stress reaction, but not a subjective feeling of stress, can reduce the social amplification of risk.

**Keywords:** Stress, risk perception, social amplification of risk, cortisol, information transmission

## 3.1 Introduction

Within the context of growing mass media and social networks, understanding the social dynamics behind the formation of risk perceptions becomes an increasingly important task. People's perceptions of a potential threat are often not in line with scientific evidence and can be based on misinformation (Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012; Slovic, 1987). Information about a particular risk received through media sources or social networks is likely to influence these perceptions (Moussaïd, 2013). When this risk-related information is passed on to other individuals through means of social media or verbal communication, parts of the information typically gets altered or even lost (Moussaïd, Brighton, & Gaissmaier, 2015). People tend to convey information that is in line with their initial risk perception, neglecting opposing information. This, in turn, can lead to an amplification of the initial risk perception of the group, even if the original information supported the opposite view; it also fuels polarization between different groups (Moussaïd et al., 2015).

Little is known about how acute stress, a widespread affective state, influences the individual and social dynamics of risk perception. Through the activation of the hypothalamic–pituitary–adrenal (HPA) axis and the subsequent release of the stress hormone cortisol (Dedovic, Duchesne, Andrews, Engert, & Pruessner, 2009), stress is known to influence memory processes (Schwabe, Joëls, Roozendaal, Wolf, & Oitzl, 2012; Wolf, Atsak, de Quervain, Roozendaal, & Wingenfeld, 2016; Wolf, 2009) and decision making under risk and uncertainty (Starcke & Brand, 2012, 2016). To the best of our knowledge, only one study has looked at the relation between acute stress and risk perception so far (Sobkow, Traczyk, & Zaleskiewicz, 2016). In this study, participants were asked to imagine consequences of different risky situations (e.g., "Ignoring persistent medical problems") and to indicate their risk perception of each situation. The authors found no direct but an indirect effect of acute stress on risk perception: Participants who were exposed to a stressor prior to the task rated the situations as more stressful and, consequently, also as more risky.

Whereas Sobkow et al. (2016) investigated individual risk perceptions, we emphasize the importance to understand risk perception as a social, dynamic process (Moussaïd et al., 2015). Risk perceptions are rarely formed in isolation from others, but rather they are part of a wider context and communication process. According to the social amplification of risk framework (Kasperson et al., 1988), information about a risk is transmitted from one station to the next in a communication chain. At each station (which can be an individual, media outlet, or an institution), the signal of the risk may be amplified or attenuated. In the current study, we investigated how acute stress influences this amplification or attenuation process. This implies asking whether stress influences how individuals perceive a risk, how they change this risk perception when receiving information about the risk, and what kind of information about the risk they transmit to the next individual. Since we are often under acute stress in our everyday lives and information about a risk itself might already trigger a stress reaction (Traczyk, Sobkow, & Zaleskiewicz, 2015), it seems highly relevant to better understand this relation.

We used a slightly adapted version of a previously developed paradigm for studying the social dynamics of risk perception (Moussaïd et al., 2015). In this paradigm, participants are asked to read articles about a controversial chemical substance, the antibacterial agent Triclosan, and subsequently pass on information to another participant informing him or her about Triclosan. Participants report their risk perception of Triclosan before and after reading the articles. Whereas Moussaïd et al. (2015) studied transmission of risk information in social diffusion chains of ten participants, we explore the effect of stress on the attenuation or amplification process at *one* chain position, that is, of one participant. In contrast to Moussaïd et al. (2015), each participant received the same risk information and passed on this information by writing a message to another person. Just prior to this task, half of the group was exposed to a group-version of the Trier Social Stress Test (von Dawans, Kirschbaum, & Heinrichs, 2011) (TSST; involving public speaking and mental arithmetic in front of an audience), while the other half completed a control task. The TSST is a well validated stressor which leads to reliable increases in subjective stress perception, cortisol release, and activation of the sympathetic nervous system (Dickerson & Kemeny, 2004). To validate the induction of stress, we measured participants' subjective stress as well as their cortisol and alpha-amylase levels through saliva samples in twelve- to fifteen-minute intervals throughout the experiment.

Our analyses focused on understanding the influence of acute stress on 1) initial risk perception, 2) change in risk perception and the influence of the presented information, and 3) the signal of the transmitted risk information. For the main research questions, we compared the variables of interest (risk perception, change in risk perception and influence of risk information, message signal) among the stress group and control group. To get a better understanding of the mechanisms underlying the effects of stress, we additionally explored associations between hormonal stress responses and the variables of the risk task. Based on the findings from Sobkow et al. (2016), we also tested for indirect effects of acute stress on risk perception through higher subjective stress ratings.

## 3.2 Methods

### 3.2.1 Participants

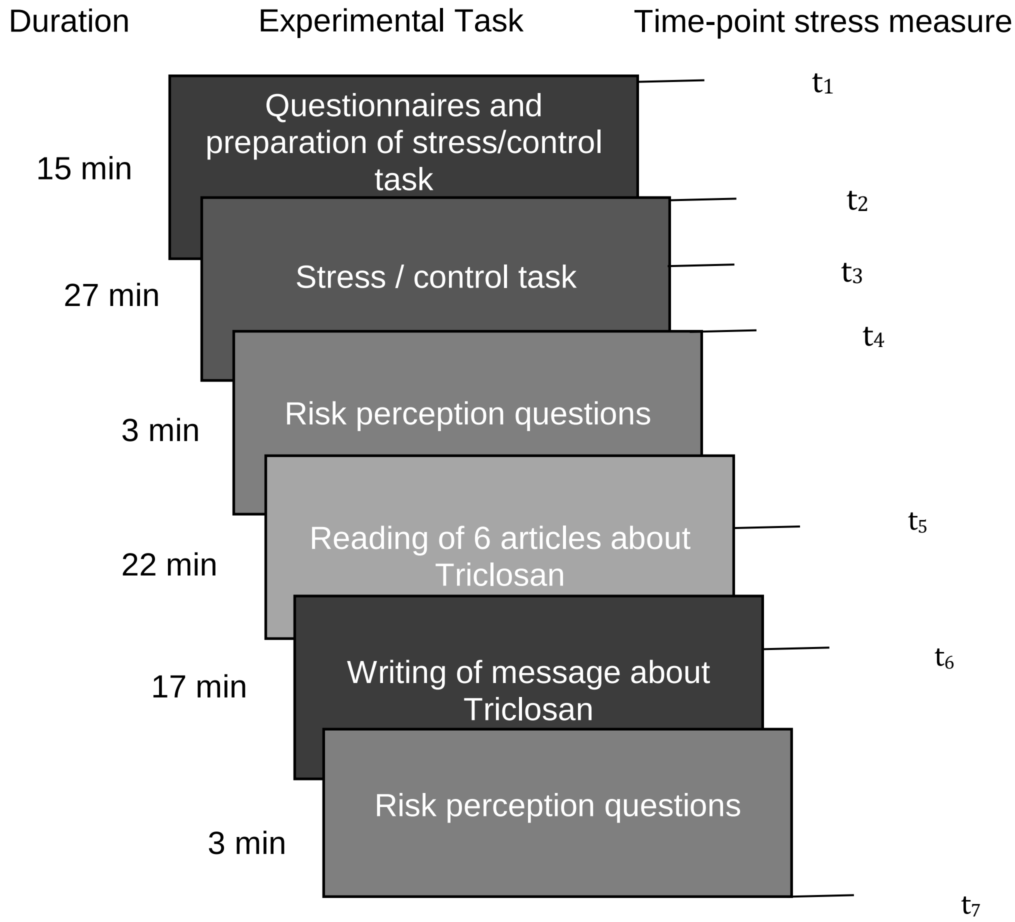
We recruited 146 young healthy subjects through electronic and paper advertisements at the University of Konstanz. Participants either received 15€ or course credit as a compensation. Four participants were excluded because of very high baseline cortisol levels (larger than 3 standard deviations from the mean) and one because she showed a strong increase of cortisol in the control group with a cortisol level larger than 3 standard deviations from the mean at the third measurement (see Figure A2.1 in the Appendix for individual cortisol levels over the course of the experiment for both groups). The remaining 141 participants were included in our final analysis [73 male, mean age = 23.29 (*SD* = 3.94)].

### 3.2.2 Design and Procedure

After participants were informed about the procedure of the study and gave their informed consent, they filled out a demographic questionnaire, the Rosenberg Self-Esteem Scale (Rosenberg, 2015), and the Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983). These measures served to control for potentially confounding factors.[5] Participants were then randomly assigned to receive either the stress induction or the control task in another room, which is described in detail below. Finally, participants went into a third room in which they performed the main task concerned with risk perception, which is also described in detail below.

[5] All analyses presented in the Results section were additionally performed controlling for perceived stress and self-esteem. Neither scores of the Perceived Stress Scale nor scores of the Rosenberg Self-Esteem Scale were found to influence stress reactions and behavior in the risk perception task. They are, hence, not included in the results reported here.

*Figure 3.1.* Schematic of experimental procedure. Stress measures included saliva samples and subjective stress reports.




#### 3.2.2.1 *Stress induction and control task*

We conducted a slightly modified version of the Trier Social Stress Test (TSST) for groups (von Dawans et al., 2011). During a 5-minute preparation period in a first room, participants had to first identify a job they would want to apply for, and then identify arguments of why they were a good fit for this position. At the end of the preparation period, participants were invited to enter a test room, and asked to perform a video-taped public speaking task and a mental arithmetic task in front of two confederate interviewers (one male and one female both wearing white laboratory coats). In the public speaking portion, participants had three minutes to deliver an oral presentation of why they thought they were the right candidates for the hypothetical job. Up to four participants were scheduled to participate in the TSST for groups, thus the public speaking went on for a total of twelve minutes. The order among the four participants was randomized, and participants were prevented from seeing each other by poster boards set up between them. All participants could however see the interviewers, who were instructed to refrain from any emotional facial expression and to prompt participants to continue speaking if they stopped before the end of the three minutes. After each participant had finished their speech, they continued with a 3-minute arithmetic task each. In this portion of the test, participants were asked to count down from a 4-digit number in steps of 17 and were told to start over if a mistake was made. The order of the arithmetic task was randomized across participants. Experiments were scheduled in groups of four, but due to late cancellations or no-shows sessions took place in groups of four in 37.5% of cases, in groups of three in 37.5% of cases, and with two participants in 25% of cases. To adjust the time of overall stress exposure, in the instances of three or two participant sessions the individual speaking and math time was adjusted to result in overall identical length of the TSST.

In the control group, participants were asked to identify a job they would want to apply for, and prepare arguments for their choice during the preparation time, and to write down those facts on a piece of paper in the testing room with no interviewers present, but with otherwise identical configuration (poster boards, number of people etc.), as well as to (silently) count down from a 4-digit number in steps of 1. They were explicitly told that their notes are solely for themselves and would not be used by the experimenter. The control task was, hence, similar to the task in the treatment condition with respect to paradigm and procedure, but lacked social evaluation, social interaction, and social threat.

#### *3.2.2.2 Main task on the social dynamics of risk perception*

The main task initially assessed prior knowledge about the chemical substance of interest, Triclosan[6]. Participants were then asked to report their risk perception of chemical substances in general and Triclosan specifically. Subsequently, participants read six articles stating different views about Triclosan. The articles were already used by Moussaïd et al. (2015) and represent a selection from the first page of google search results on "Triclosan". Sources of the articles were Wikipedia, Focus Online (a German online news magazine), Greenpeace, the German Environment Agency ("Umweltbundesamt"), The Cosmetic, Toiletry and Perfumery Association (CTPA), and a report of Environmental Defense (a Canadian environmental organization). All articles were presented in a random order and each one was displayed for three minutes to the participants. After having read the articles, each participant had 17 minutes to write a message to another participant informing him or her about Triclosan. We told

[6] "Have you heard about Triclosan before?", "Do you know how you could be exposed to Triclosan in your daily life? If yes, please specify."

participants that their messages would be shown to another participant later on. At the end of the study, participants were asked once again to report their concern about chemical substances in general and about Triclosan.

### 3.2.3 Measures

#### *3.2.3.1 Stress measures*

Cortisol and salivary alpha-amylase (sAA) were analyzed from saliva samples (Sarstedt AG & Co, Nümbrecht, Germany). Cortisol levels (nmol/l) were measured using a time-resolved fluorescence immunoassay (Dressendörfer, Kirschbaum, Rohde, Stahl, & Strasburger, 1992). Salivary alpha-amylase (U/ml) levels were determined using the enzyme kinetic method (Engert et al., 2011). Participants' subjective stress levels were measured on a visual analogue scale ranging from 0 to 10. All measures were anchored to 7 time-points, in twelve- to fifteen-minute intervals, throughout the experiment from 0' to 90' minutes. Missing values of a single time-point were replaced with the mean value of the measurement between the time-point before and after the time-point of the missing value. If the missing value occurred at the overall peak of the measurement, it was replaced with the group mean of the corresponding experimental group. In total, there were 7 values of six participants missing and replaced.

#### *3.2.3.2 Risk perception*

To measure participants' risk perception, we asked how concerned they feel about chemicals in daily products in general and about Triclosan specifically. Concern as a measure of affective risk perception has been found to be strongly linked to intentions for risk reducing behavior such as getting vaccinated (Renner & Reuter, 2012). Answers were given on a visual analogue scale ranging from 0 (not concerned at all) to 100 (extremely concerned). As the risk information provided to participants was specifically about Triclosan, we focused in the analysis on initial concern and change in concern about Triclosan and not on reported concern about chemicals in general.[7] Changes in risk

[7] Although the majority of participants hasn't heard about Triclosan before the experiment (138 out of 146 participants), we still think that their reported concern about Triclosan before having read the articles is a valid measure of their initial risk perception. First of all, participants were told that Triclosan is a chemical substance used in daily products before being asked about their risk perception of Triclosan. Second of all, initially reported concern about Triclosan and reported concern about chemical substances was significantly correlated ($r(144) = .574$, $p < .001$). We find very similar patterns on the effect of stress on risk perception when looking at participants' reported concern about chemicals in general (see Figure A2.2 in the Appendix).

perception were calculated by subtracting concern reported before the articles from concern reported after the articles.

*3.2.3.3 Message Signal*

Participants' written messages were coded with respect to the signal about Triclosan they conveyed. Three independent coders labeled each sentence in the messages of participants as either positive, negative or neutral with respect to Triclosan. Sentences explicitly stating benefits of Triclosan or suggesting that the use of Triclosan is safe or under control were coded as positive, sentences expressing real or suspected harms of the chemical were labeled as negative. Sentences that neither expressed a positive or negative statement about Triclosan, or that expressed both simultaneously, were coded as neutral. Inter-coder reliability was high ($\alpha$ = 0.878, Krippendorff, 2011). The final amount of positive, negative and neutral statements per participant was determined by calculating the mean response of the three coders. The message signal, meaning the degree to which the text transferred a negative signal about Triclosan, was defined by the number of negative statements relative to the total number of positive and negative statements [$s = n^{+}/(n^{+}+n^{-})$], as in Moussaïd et al. (2015).

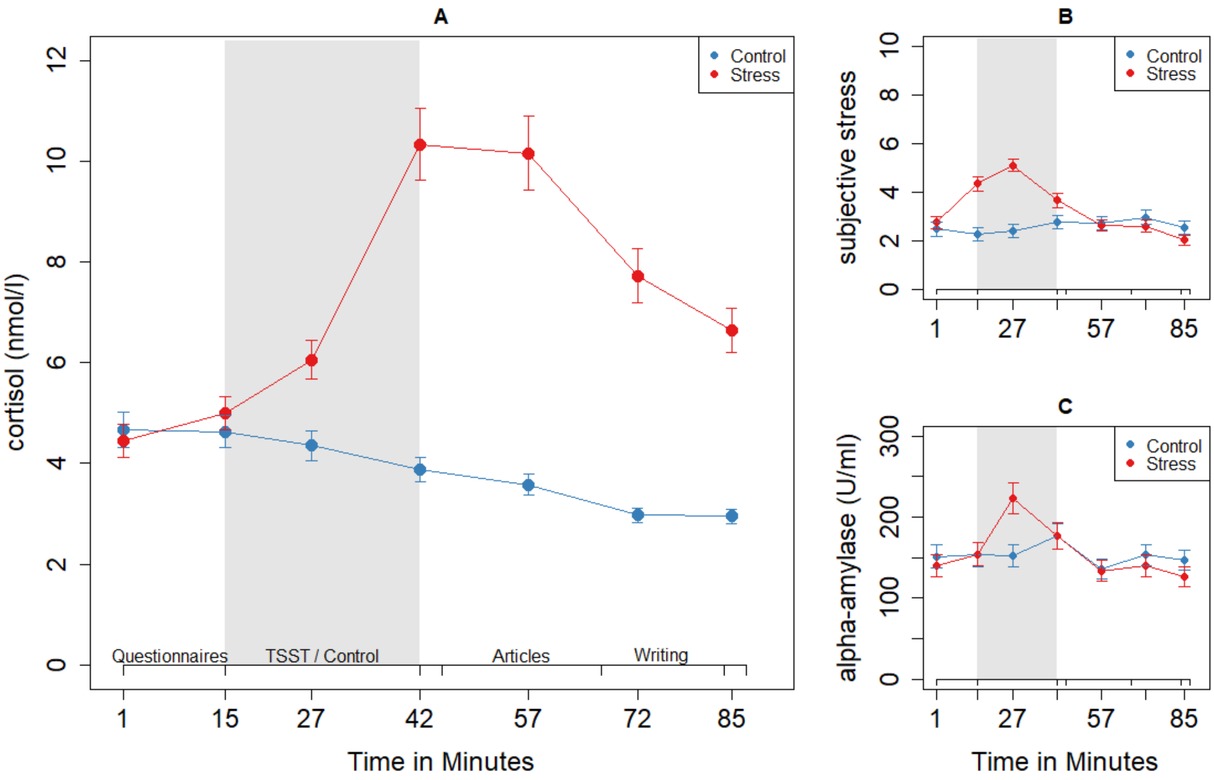
## 3.3 Results

### 3.3.1 Manipulation Check

The stress manipulation successfully increased participants' cortisol levels. [Figure 3.2 A, two factor mixed design ANOVA with group (control or stress) as the between subject factor, time (seven levels) as the within subject factor and gender as a covariate: $F_{stress}(1, 138) = 48.90$, $p < .001$; $F_{stress*time}(6, 834) = 54.70$, $p < .001$]. We could not observe gender differences in cortisol release [$F_{gender}(1, 138) = 1.55$, $p = .215$]. Initial cortisol levels measured at the beginning of the experiment did not significantly differ between the two groups [$M_{\text{control}} = 4.67$ ($SD = 2.88$), $M_{\text{stress}} = 4.45$ ($SD = 2.77$), $t(137.34) = 0.45$, $p = .650$, $d = 0.08$]. As displayed in Figure 3.2 C, we found a corresponding activation of the autonomic nervous system in the stress group as indicated by participants' increased salivary α-amylase levels during the TSST compared to the control task [$M_{\text{control}} = 152.57$ ($SD = 110.61$), $M_{\text{stress}} = 223.26$ ($SD = 159.42$), two-sample t-test: $t(128.7) = -3.08$, $p = .003$, $d = -0.51$].

These findings are in line with participants' self-reported stress levels: participants in the stress group reported higher values than participants in the control group (two factor mixed design ANOVA with experimental group as the between subject factor, time (seven levels) as the within subject factor and gender as covariate, $F_{stress}(1, 138)=5.64$, $p = .019$). As can be seen in Figure 3.2 B, this difference was driven by clearly higher levels of subjective stress during the TSST than during the control task. Moreover, there was a gender effect on subjective stress [$F_{gender}(1, 138) = 14.07$, $p < .001$] with female participants reporting overall higher subjective stress levels than male participants [$M_{\text{female}} = 3.53$ ($SD = 1.94$), $M_{\text{male}} = 2.42$ ($SD = 1.65$), $t(132.05) = 3.65$, $p < .001$, $d = 0.62$]. In subsequent analyses, we thus added gender as a control variable to our models.

*Figure 3.2.* Mean values across participants for the seven time points during the experiment for cortisol levels (A), self-reported subjective stress (B), and alpha-amylase levels (C). Bars denote ± one standard error of the mean.




### 3.3.2 Effects of Stress on Risk Perception and Change in Risk Perception

Risk perception was assessed before and after reading the articles. Participants reported how concerned they were about Triclosan on a scale from 0 (not concerned at all) to 100 (extremely concerned). Results are displayed in Figure 3.3 A. Overall, the majority of participants was initially not very concerned about Triclosan [$M = 29.62$ ($SD = 21.76$), $Mdn = 25$]. Participants in the stress group were slightly more concerned about Triclosan before reading the articles than participants in the control group [$M_{\text{control}} = 26.41$ ($SD = 21.23$), $M_{\text{stress}} = 32.62$ ($SD = 21.96$), $t(138.81) = -1.71$, $p = .090$, $d = -0.29$]. Interestingly, participants in the stress group changed their reported concern to a substantially smaller degree in response to the articles compared to participants in the control group [change in concern: $M_{\text{control}}$ = 23.35 ($SD$ = 21.89), $M_{\text{stress}}$ = 11.34 ($SD$ = 21.37), $t$(137.75) = 3.29, $p$ = .001, $d$ = 0.56]. This is also reflected in an interaction effect in a two factor mixed design ANOVA with experimental group (stress or control) as the between subject factor, time point (before articles or after articles) as the within subject factor, and gender as a covariate [$F_{stress*time\_point}(1, 139) = 10.86$, $p$ = .001]. Whether the effect of acute stress on change in concern can be (partly) explained by an increase in the stress hormone cortisol is explored further below.

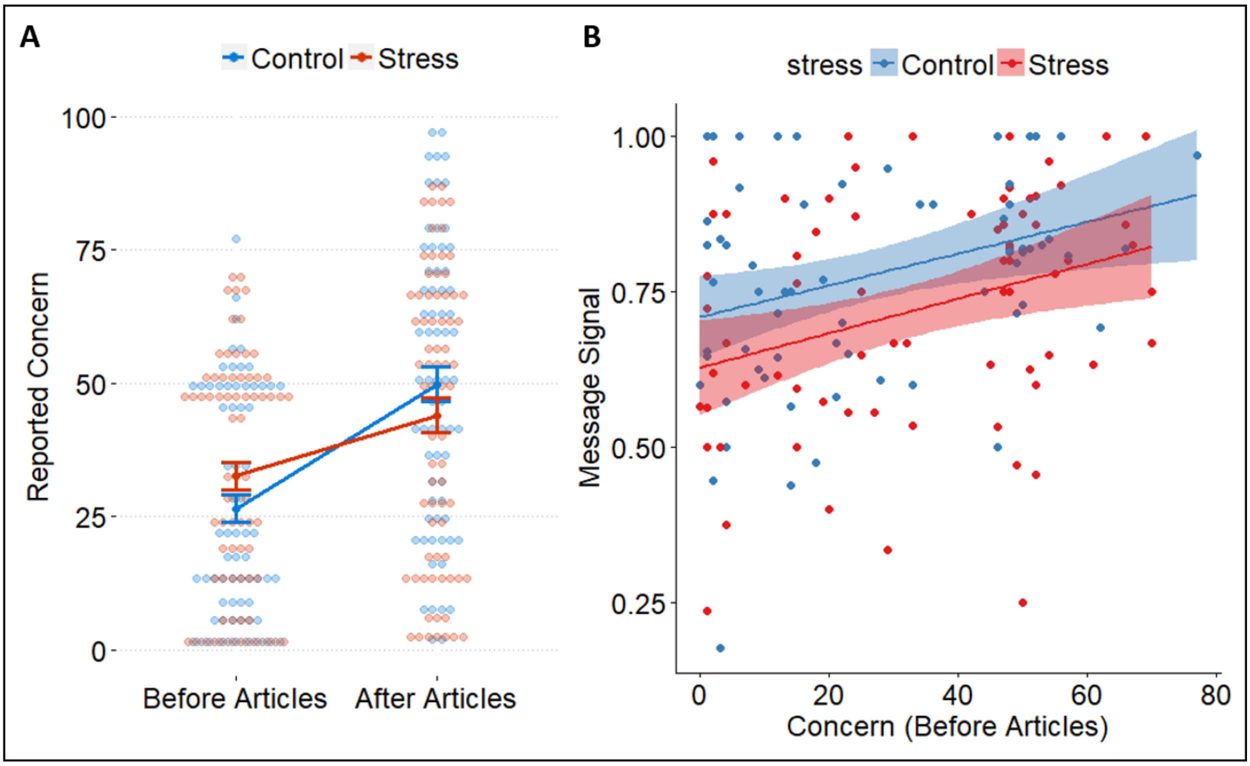
### 3.3.3 Effects of Stress on the Influence of Risk Information

As described in Moussaïd et al. (2015), change in risk perception can be modeled as a combination of one's initial risk perception, the signal of the message received and an influence factor that describes the extent to which the received information actually influences one's risk perception:

$$C_i - C_i^0 = \alpha(s - C_i^0), \quad (1)$$

where $C_i^0$ is a participants' initially reported concern divided by 100 to lie between 0 (not concerned at all) and 1 (extremely concerned), $C_i$ is the reported concern after having received information on the risk divided by 100, $s$ is the signal of the information received, and $\alpha$ is the influence factor with values between 0 (no influence) and 1 (complete adoption). The message signal $s$, meaning the degree to which the information transferred a negative signal about Triclosan, was defined by the number of negative statements relative to the total number of positive and negative statements in the articles or participants' messages, respectively [$s = n^+/(n^+ + n^-)$]. Moussaïd et al. (2015) estimated the influence factor in their experiment to take the value of $\alpha = 0.45$. Entering the mean values for $C_i$ and $C_i^0$ for both groups of our experiment separately and the signal of the articles ($s_{articles} = 0.81$) into the formula above, we get a very similar value for the influence factor of the control group ($\alpha_{control} = 0.43$). This value is, however, much lower for the stress group ($\alpha_{stress} = 0.23$). This suggests that after acute psychosocial stress, people are less influenced in their risk perception by new information.

*Figure 3.3.* (A) Participants' reported concern about Triclosan for both experimental groups (control and stress) asked before and after reading the articles about Triclosan. Despite large inter-individual variation, stressed participants changed their reported concern to a substantially lower degree in response to the articles than participants in the control group. Dots represent single individuals, bars denote ± 1 standard error of the mean. (B) Message signal as a function of experimental group and reported concern about Triclosan before reading the articles. Higher values in message signal indicate a more negative evaluation of Triclosan.




### 3.3.4 Effects of Stress on Message Signal

The messages that participants wrote to inform another person about Triclosan were on average 214 words long, and length did not differ between the groups [$M_{control}$ = 208 (*SD* = 86), $M_{stress}$ = 219 (*SD* = 77), $t(134.5) = -0.78$, $p = .439$, $d = -0.13$]. Participants' messages contained a smaller proportion of neutral statements about Triclosan than the original articles, whereas the proportion of positive and negative statements was higher in participants' messages compared to the articles (see Table 3.1). In the control group, the proportion of negative statements increased more than the proportion of positive statements. The opposite is the case for participants in the stress group, where the proportion of positive statements increased more than the proportion of negative statements. As a result, the messages of the control group contained a significantly higher proportion of negative statements than messages of the stress group [proportion of negative statements: $M_{control}$ = 43% (*SD* = 14%), $M_{stress}$ = 37% (*SD* = 15%), $t(138.93) = 2.74$, $p = .007$, $d = 0.46$].

*Table 3.1:* Percentage of neutral, positive and negative statements about Triclosan in the articles, and in messages of participants in the control and stress group.

| Valence of Statements | Articles | Control Group (Difference to Articles) | Stress Group (Difference to Articles) |
|---|---|---|---|
| neutral | 55% | 44% (- 11%) | 49% (- 6%) |
| positive | 9% | 13% (+ 4%) | 14% (+ 5%) |
| negative | 36% | 43% (+7%) | 37% (+1%) |

As in Moussaïd et al. (2015), the message signal *s* was positively correlated with participants' initially reported concern about Triclosan [$r(139) = .287$, $p < .001$, see Figure 3B], indicating that participants were biased by their initial risk perception when transmitting information. To test whether stress leads to an increased bias of transmitting information in line with one's own risk perception, we ran a linear regression analysis with the message signal (ranging from 0 to 1, with higher values indicating a more negative signal) as dependent variable, and the experimental manipulation (stress or. control), initial concern and an interaction between both variables as independent variables, additionally controlling for gender. Results are reported in Table 3.2 (Model 1). We did not find an interaction effect between initial concern and our stress manipulation on the message signal, indicating that acute stress does not increase the bias to transmit information corresponding to one's risk perception. Excluding the interaction term from the model improved model quality (as indicated by a lower AIC) and showed again a negative effect of stress on the message signal (see Table 3.2, Model 2): Participants' message signal in the stress group was less negative with respect to Triclosan than the message signal in the control group. This finding is well in line with the finding that participants in the stress group reported a smaller change in their risk perception about Triclosan in response to the articles. Overall, these results suggest that under acute stress, people focus less on negative aspects of risk-related information and get less worried by negative information.

*Table 3.2.* Regression analyses on the effect of stress manipulation and initial concern on participants' message signal.

| *Predictors* | *Message Signal* | | | |
|---|---|---|---|---|
| | Model 1 | | Model 2 | |
| | *B (CI)* | *p* | *B (CI)* | *p* |
| (Intercept) | 0.730 (0.657 – 0.802) | **<.001** | 0.728 (0.666 – 0.790) | **<.001** |
| Initial Concern | 0.003 (0.001 – 0.005) | **.010** | 0.003 (0.001 – 0.004) | **<.001** |
| Stress Manipulation | -0.079 (-0.177 – 0.020) | .116 | -0.075 (-0.133 – -0.016) | **.012** |
| Gender | -0.044 (-0.102 – 0.014) | .135 | -0.044 (-0.101 – 0.013) | .133 |
| Stress Manipulation*Initial Concern | 0.000 (-0.003 – 0.003) | .920 | | |
| Observations | 141 | | 141 | |
| $R^2$ / adj. $R^2$ | .138 / .112 | | .138 / .119 | |
| F-statistics | 5.431*** | | 7.291*** | |
| AIC | -87.512 | | -89.502 | |

### 3.3.5 Effects of Individual Stress Responses

#### *3.3.5.1 Hormonal stress responses*

So far, all of the analyses were concerned with mean differences between the stress and the control group. An important next step is to analyze whether these mean differences are mediated by individual hormonal stress responses. In other words, is the effect of acute stress on changes in risk perception and on the signal of the transmitted message associated with an increased release of the hormone cortisol? To test this, we computed for each participant the area under the curve with respect to increase (AUC_I) of the cortisol measures (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003) and tested its correlation with our variables of interest, change in risk perception and message signal.

Participants' change in risk perception was linked to their hormonal stress response: the higher the cortisol increase over the course of the study, the smaller the increase in risk perception [$r(140) = -.298$, $p < .001$]. To further analyze this effect, we conducted a mediation analysis using quasi-Bayesian Monte Carlo method for variance estimation based on 10,000 simulations. In both, mediator and outcome model, we controlled for gender. Results confirmed that the effect of the stress manipulation on change in concern was mediated by increases in cortisol (a*b = –5.18, $p = .036$; see Figure 3.4 A).

For message signal, however, we did not find a corresponding correlation with cortisol increase [$r(140) = -.087$, $p = .500$]. Additionally, we ran a similar mediation analysis as before but with the outcome model predicting message signal based on the stress manipulation, increase in cortisol ($AUC_I$), initial concern, and gender. The effect of the stress manipulation on message signal was not related to an increased release of cortisol (a*b = –0.02, $p = .231$, Figure 3.4 B).

#### *3.3.5.2 Subjective stress reports*

Past research has found that exposure to a stressor indirectly influences risk perception through increased ratings of the stressfulness of the risky event (Sobkow et al., 2016). Based on this finding, we tested for the possibility that stress exposure indirectly influenced risk perception in our study through increased ratings of subjective stress.

First, we analyzed whether there was a link between how people rated their current feeling of stress and how concerned they were about the risk. Reported concern about Triclosan before as well as after the articles significantly correlated with participants' subjective stress reports at the time of the question, that means at $t_4$ and $t_7$ [before articles ($t_4$): $r(139) = .193$, $p = .022$, after articles ($t_7$): $r(139) = .275$, $p = .001$]. At the same time, subjective stress reports at $t_4$ were higher for participants in the stress group compared to participants in the control group [$M_{control} = 2.75$, $M_{stress} = 3.65$, $t(138.94) = -2.24$, $p = .026$]. Mediation analyses using quasi-Bayesian Monte Carlo method for variance estimation based on 10,000 simulations also demonstrated a small indirect effect of the stress manipulation on reported concern through subjective stress (a*b = 1.498, $p = .056$, controlling for gender in both, mediator and outcome model, Figure 3.5). This indicates that, on an individual level, acute feelings of subjective stress are linked to an increased concern about a potential risk. Moreover, we found that a higher baseline level in subjective stress (as measured directly in the beginning of the study) was positively related to the proportion of negative statements in participants' messages [$r(139) = .205$, $p = .015$].

How do these findings fit with the findings from the group comparison and individual cortisol analyses? Note that during the TSST, participants reported significantly increased levels of subjective stress but these subjective stress levels quickly returned to baseline after conclusion of the TSST (see Figure 3.2 B). Cortisol had its peak right after the TSST and remained above the level of the control group throughout the experiment (see Figure 3.2 A). The physiological reaction to a stressor can hence still have an influence on behavior although people overall do not feel subjectively stressed anymore.

*Figure 3.4.* Mediation models with unstandardized coefficients for the indirect effect of the stress manipulation on participants' change in concern (A) and message signal (B) through the increase in cortisol.

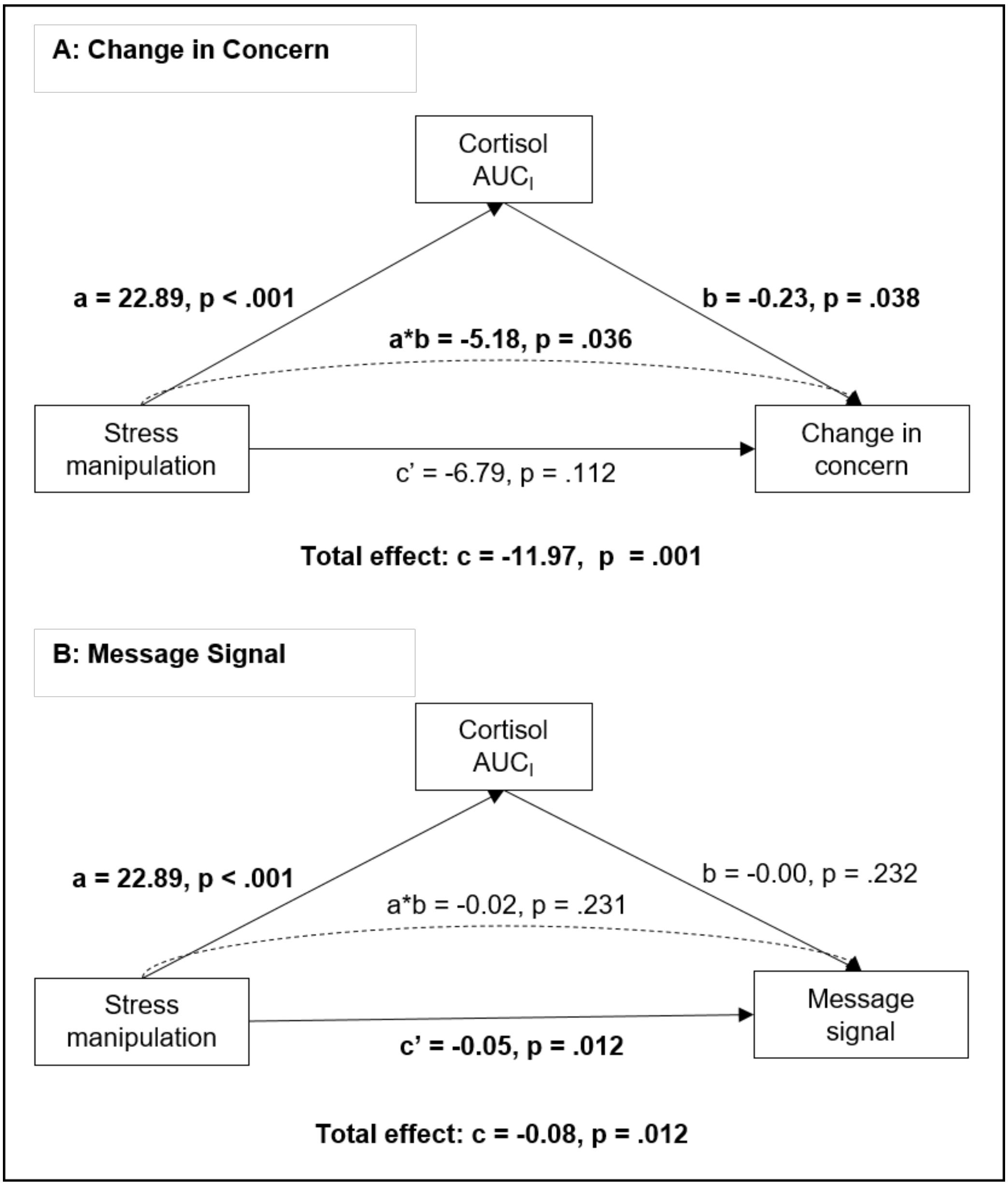
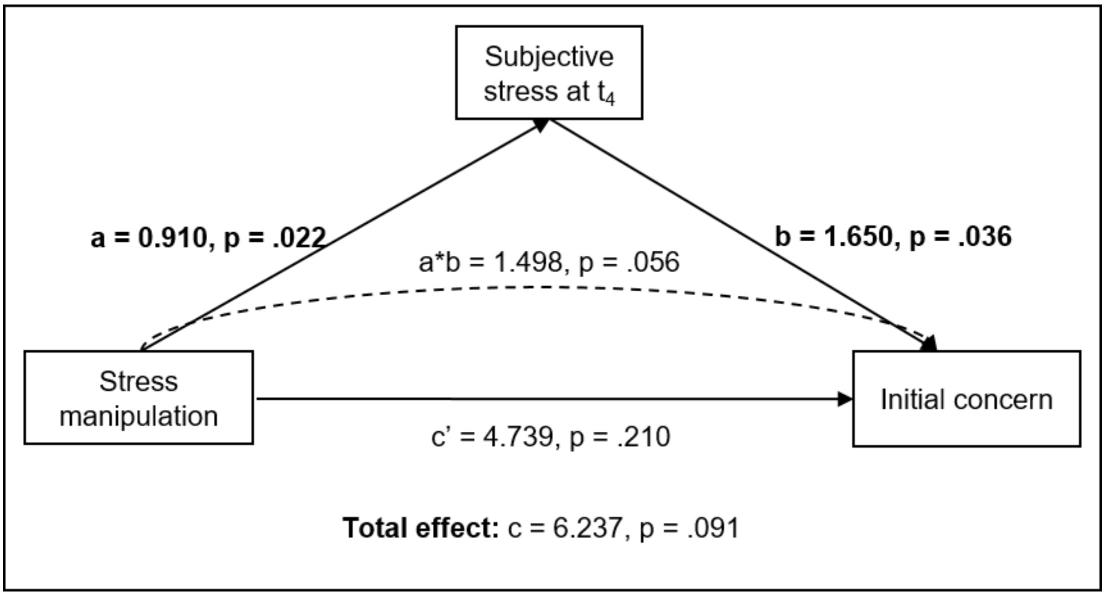


*Figure 3.5:* Mediation model for the indirect effect of the stress manipulation on participants' initial concern about Triclosan through the increase in subjective stress with unstandardized coefficients.




## 3.4 Discussion

The presented study investigated the effect of acute stress on the social dynamics of risk perception. More specifically, we tested whether stress influences how people perceive a risk, how they update this risk perception in response to relevant information and what kind of risk information they transmit to another person. The potential risk in our study was the antibacterial agent Triclosan and the information presented to participants were real-world articles with an overall rather concerning message about the substance. Most participants initially reported not to be very concerned about Triclosan. After having read the articles, participants' reported increased concern overall. Importantly, we found a substantial difference between participants who were acutely stressed compared to participants who performed a control task in the beginning of the study: Participants in the stress group were less influenced by the articles and increased their reported concern to a much smaller degree. Interestingly, this effect was mediated by increases in the stress hormone cortisol: the stronger the increase in cortisol, the smaller the increase in concern. In line with this finding, participants who were acutely stressed passed on information with a less negative signal about Triclosan than participants who were not acutely stressed, even though this effect was not mediated by increases in cortisol.

These findings suggest that acute stress causing an increase in cortisol renders people to be less responsive to negative risk information. Studies from different domains have shown that acute stress and an elevated cortisol level can lead to a subsequent avoidance of negative information. In a study by Ellenbogen, Schwartzman, Stewart, & Walker,(2002) participants who completed a stressful task were subsequently faster in shifting attention away from negative words compared to positive and neutral words in a spatial cueing task. Similarly, acute stress and elevated cortisol levels have been found to reduce selective attention to threat in an emotional stroop task (Putman, Hermans, & van Honk, 2007; Roelofs, Bakvis, Hermans, van Pelt, & van Honk, 2007). Research on the effects of acute stress on reinforcement learning have shown that after acute stress people show enhanced learning from positive feedback (Lighthall, Gorlick, Schoeke, Frank, & Mather, 2013) but impaired learning from negative feedback (Petzold, Plessow, Goschke, & Kirschbaum, 2010). There is even evidence that an elevated cortisol level reduces phobic fear (Soravia et al., 2006) and activity of the amygdala, a brain region known to play a key role in processing of emotions such as fear and anxiety (Henckens, Wingen, Joëls, & Fernández, 2010). Whereas the immediate stress response activates the amygdala to increase vigilance (Kloet, Joëls, & Holsboer, 2005), cortisol then seems to reduce this vigilant and anxious state again by desensitizing the amygdala (Henckens et al., 2010). These findings indicate that adaptive processes are at play after acute stress to regulate emotions and restore homeostasis and that cortisol plays a crucial role in terminating the stress response. Our study suggests that a similar process might be involved when people are faced with risk-related information while experiencing acute stress. Neglecting negative information about a potential risk could be a natural defense mechanism to reduce anxiety after an acute threat.

Note that in our study, the risk information presented to participants was completely unrelated to the social threat encountered by the stress group. This may be a crucial point. Roelofs et al. (2007) suggest that when information is relevant to the stress context, attention towards negative information increases. In a case where the risk itself triggers the stress response (such as, for example, the information about the outbreak of an epidemic), people might become more vigilant to the negative aspect of risk information and become more concerned by the risk information.

The articles in our study had an overall negative signal about Triclosan. We chose those articles because they represent a naturalistic sample of information about a risk (namely real-world online articles found when searching for “Triclosan”) and because they were used in previous research (Moussaïd et al., 2015). A remaining question is how stress influences the social dynamics of risk perception in response to information with an overall neutral or positive signal. If people indeed attend selectively to positive and negative information in order to regulate emotions after acute stress, participants who have been acutely stressed should be influenced more strongly by risk information if this information is reassuring.

Our findings imply that there is a substantial difference in how people deal with risk information just after they have been exposed to a stressor that is not present anymore but still has an influence on HPA axis activation, and in how people deal with risk information when they currently feel subjectively stressed. The more people reported to feel stressed at the moment of the risk perception question, the more they also reported to be concerned about Triclosan. Similar to Sobkow et al. (2016), we did not find a direct effect of acute stress on initial risk perception (reported by participants before reading articles about the risk) but an *indirect* effect through elevated subjective stress. In Sobkow et al. (2016), participants were presented with different hypothetical situation and were asked as how risky they rated this situation. Subjective stress was measured by asking participants how stressful they would rate the presented situation. In their study, the subjective stress measure was, hence, directly associated with the potential risk. Our results show that even when the subjective stress measure is completely unrelated to the risk (the fourth stress measurement happened just shortly before the first risk perception question about Triclosan and before participants have gotten any information about the chemical), it still influences how people perceive the risk. We also found that participants with higher baseline levels of subjective stress passed on a higher proportion of negative information in their messages.

What do our findings reveal about the influence of stress on the social amplification or attenuation process of risk perception? Moussaïd et al. (2015) show that people tend to transmit risk information that is consistent with their preconceptions. Our results replicated this finding: Participants' message signal was positively associated with their initially reported concern, irrespective of the stress manipulation. Although stress in our study did not influence this bias to transmit information consistent with one's beliefs, participants in the stress group were less influenced by the received information and transmitted an overall less negative message signal to others. This suggests that acute stress can make the communication about a risk less alarming and hence reduce social amplification of risk. At the same time, subjective stress seems to make a social amplification of the risk signal more likely. Both an amplification and attenuation of the risk can be harmful: Underestimation of a risk can increase incautious actions such as risky driving or practicing unsafe sex. Overestimation of a risk can lead to unnecessary anxiety and dangerous behavior, such as not getting vaccinated. Further research to better understand the differential effects of stress on the social dynamics of risk perception hence seem relevant not only from an individual but also from a policy perspective.

# Chapter 4

# Stressed but More Optimistic? The Effect of Acute Stress on Belief Updating About Personal Risks

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**Abstract**

People update their beliefs about future outcomes in an optimistic manner: They take into account good news but neglect bad news. This optimistic update bias has been found to become stronger through enhanced dopaminergic activity. Acute stress can increase dopaminergic activity together with the release of the hormone cortisol. In the current study, we test whether acute stress also influences belief updating and increases the optimistic update bias through the release of the stress hormone cortisol. Seventy-six participants completed an adapted version of a well-established belief updating paradigm. Prior to the task, half of the group was randomly assigned to stress induction by the Trier Social Stress Test, while the other half completed a control task. During the study, we measured stress induction in twelve- to fifteen-minute intervals by measuring participants' cortisol levels through saliva samples. Our results suggest that acute psychosocial stress and significant cortisol increase have no effect on valence-dependent belief updating.

**Keywords:** Stress, belief updating, optimism, cortisol, bias, probability estimates

## 4.1 Introduction

Beliefs about the future strongly influence our decisions and actions. Our belief about the probability of catching the flu influences our decision to get vaccinated, our belief about the risk of losing money on the stock market influences our decision to invest, and our belief about the likelihood of becoming occupationally disabled influences our decision to get occupational disability insurance. Often these beliefs are unrealistically optimistic as we tend to underestimate our probability of experiencing negative events (Rose, Suls, & Windschitl, 2011; Sharot et al., 2011; Weinstein, 1980, 1982). A process that explains why optimism is maintained despite information challenging this belief is valence-dependent belief updating (Sharot et al., 2011): We adjust our beliefs more in response to better-than-expected information than in response to worse-than expected information. This phenomena is called the optimistic update bias.

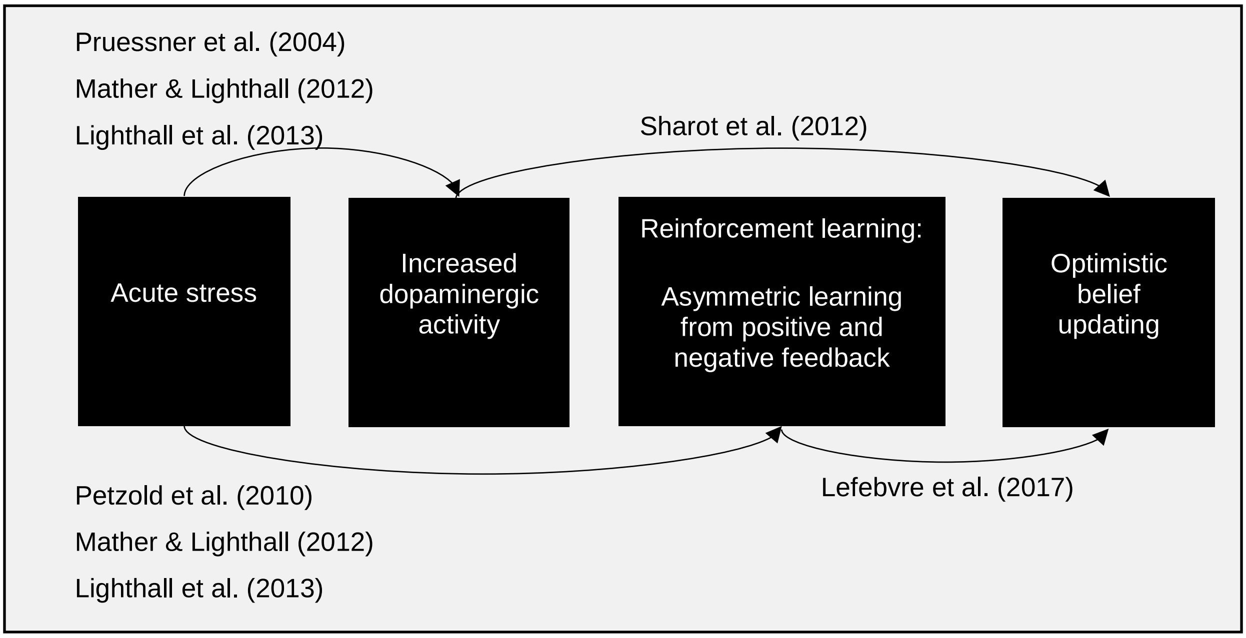
In the professional as well as in the private domain, beliefs are often formed and updated under stress. The Stress in America™ survey by the American Psychological Association (2017) suggests that 75 percent of Americans experience at least one stress symptom per month. Physicians, police officers, politicians, or stock brokers frequently form and update risk assessments in stressful situations as part of their profession. A recent study further indicates that acute stress may affect our risk perception (Sobkow, Traczyk, & Zaleskiewicz, 2016). It is unknown so far, however, whether acute stress also influences the way we update beliefs about personal risks.

In the current study, we tested whether acute stress affects how people update their probability estimates about a personal risk in an adapted version of the belief updating task (Kuzmanovic & Rigoux, 2017). In this task, participants first estimate the base rate (the average probability in the population) and their personal probability of experiencing a negative life event (e.g. breast cancer). They next receive the actual base rate of the event and are then asked to provide a second estimate of their personal probability. Good news in this task are defined as trials where participants overestimated the base rate (the average risk in the population is actually smaller than expected). Bad news are defined as trials where participants underestimated the base rate. Optimistic belief updating refers to the finding that people update their personal risk estimate more in response to such good news than in response to bad news.

We assumed that acute stress *increases* the optimistic update bias for the following reasons. First, acute stress might increase the optimistic update bias through the increase of dopaminergic activity. Several studies suggest that stress increases dopamine firing rates and that stress-induced cortisol levels correlate with dopamine activity (Lighthall et al., 2013; Mather & Lighthall, 2012; Pruessner, Champagne, Meaney, & Dagher, 2004; Scott, Heitzeg, Koeppe, Stohler, & Zubieta, 2006; Starcke & Brand, 2016; Ungless, Argilli, & Bonci, 2010). At the same time, Sharot, Guitart-Masip, Korn, Chowdhury, & Dolan (2012) have shown that enhanced dopaminergic activity increases the optimistic update bias: Participants who received a dopamine-enhancing drug showed impaired updating of their beliefs in response to worse-than-expected news compared to participants who received a placebo.

Second, studies on probabilistic reinforcement learning show that acute stress improves learning from positive feedback but impairs learning from negative feedback (Lighthall et al., 2013; Mather & Lighthall, 2012; Petzold, Plessow, Goschke, & Kirschbaum, 2010). These studies used a task in which participants learn which of two options is the more favorable one (Frank, Seeberger, & O'Reilly, 2004). Clicking on an option in the learning phase either yields a positive feedback (e.g. "correct") or a negative feedback (e.g. "incorrect") with a specific probability. The more favorable options are the ones that lead to positive feedback with a higher probability. From in total six options, there is one "worst" option (with overall lowest probability of positive feedback) and one "best" option. In the test phase, participants face several trials with two options and are asked to choose the more favorable one. Participants can accomplish the task by either learning from positive feedback and developing a preference for the more favorable option or by learning from negative feedback and avoiding the unfavorable option. Learning from positive feedback is hence measured by the accuracy in trials including the "best" option, learning from negative feedback is measured by accuracy in trials including the "worst" option. People who have been exposed to a stressor prior to this task showed decreased accuracy in avoiding the worst option but increased accuracy in choosing the best option (Lighthall et al., 2013; Petzold et al., 2010). Although learning which of two options has a higher chance of positive feedback is a different task than updating beliefs about probabilities, Lefebvre, Lebreton, Meyniel, Bourgeois-Gironde, & Palminteri (2017) argue that the process involved in reinforcement learning is similar to the one in probabilistic belief updating. Behavior in a reinforcement learning task and in the probabilistic belief updating task can be best described with very similar cognitive models (Kuzmanovic & Rigoux, 2017; Lefebvre et al., 2017) and in  in both tasks, individual differences in behavior are associated in a similar way with differences in the activation of the brain's reward system (Kuzmanovic, Jefferson, & Vogeley, 2016; Lefebvre et al., 2017; Sharot, Kanai, et al., 2012). Since acute stress seems to improve learning from positive feedback but to impair learning from negative feedback in probabilistic reinforcement learning tasks, it is hence also likely that stress leads to more optimistic updating in a probabilistic belief updating task.

*Figure 4.1:* Logic behind research question based on past research.




To test whether acute stress increases the optimistic update bias, we randomly assigned half of the participants to the Trier Social Stress Test (von Dawans, Kirschbaum, & Heinrichs, 2011), while the other half completed a control task before performing the belief updating task. We validated induction of stress by measuring participants' cortisol levels through saliva samples throughout the task. Updating scores in good news and bad news trials as well as their deviations from the normative benchmark of Bayesian updating were then compared among the two groups.

## 4.2 Method

### 4.2.1 Participants

Seventy-five healthy participants (34 males and 41 females) completed the study at the University of Konstanz. We excluded seven participants because of the following reasons:

Three participants were classified as potentially depressive according to the four-item Beck Depression Inventory (Jenny, Pachur, Lloyd Williams, Becker, & Margraf, 2013) which has been an exclusion criteria in past studies on belief updating (Garrett & Sharot, 2014, 2017; Moutsiana, Charpentier, Garrett, Cohen, & Sharot, 2015; Moutsiana et al., 2013). One person answered unreliably in the rating task (same rating for all 43 items), two participants did not update their probability estimate in more than 40 of the 43 items, and one participant had to be excluded due to technical issues with the tablet on which we presented the questionnaires. After excluding these seven participants, our sample consisted of 68 participants (39 female (57.4%); age: $M$ = 21.71, $SD$ = 3.27, range = 18 - 34) who we randomly assigned to the stress group ($n$ = 34) and control group ($n$ = 34). The completion of the study took 1.5 hours. Participants received course credits or a 15 € payment as a compensation for their participation.

### 4.2.2 Procedure

At the beginning of the experiment, participants received information about the procedure of the study, gave their informed consent and responded to different questionnaires that assessed demographics and aspects of personality to control for potentially confounding factors (see section 4.2.4.3). After having completed the questionnaires, which took about 10 minutes, participants received information either about the stress or the control task and had five minutes to prepare for the task. Then they were brought to another room to complete the assigned task (as described in the following section). After the stress or control task (26 minutes), the participants performed the updating task individually on computers in a third room (45 minutes). At the end, we debriefed participants and provided them with their compensations.

#### *4.2.2.1 Stress induction and control task.*

We conducted a slightly modified version of the Trier Social Stress Test (TSST) for groups (von Dawans et al., 2011). During the five-minute preparation period in a first room, participants first had to choose a job they would want to apply for, and then identify arguments of why they were a good fit for this position. At the end of the preparation period, participants entered a test room, and performed a public speaking task and a mental arithmetic task in front of a video camera and two confederate interviewers (one male and one female both wearing white laboratory coats). In the public speaking portion, participants had 3 minutes to deliver an oral presentation of why they thought to be the right candidates for their ideal job. In each group of the TSST there were up to four participants, thus the public speaking went on for a total of twelve minutes. We randomized the order among the four participants and prevented them from seeing each other by setting up poster boards between them. All participants could however see the interviewers, who refrained from making any emotional facial expression and prompted participants to continue speaking if they stopped before the end of the 3 minutes. After each participant had finished their speech, they continued with the 3-minutes arithmetic task. In this portion of the test, participants were asked to count down from a 4-digit number in steps of 17 and were told to start over if a mistake was made. We scheduled experiments in groups of four, but due to late cancellations or no-shows they did take place in groups of three in 43% of cases, and with two participants in 13% of cases. To adjust the time of testing, in these instances we adjusted the individual speaking and math time to result in overall identical length of the TSST.

In the control group, participants were asked to identify their ideal job and prepare arguments for the choice during the preparation. They were asked to write down their arguments on a piece of paper in the testing room with no interviewers present, but with otherwise identical configuration. They were also asked to (silently) count down from a 4-digit number in steps of 1 and to write down these numbers on a piece of paper. They were explicitly told that their notes were solely for themselves and would not be used by the experimenter. The control task was, hence, similar to the task in the treatment condition with respect to procedure and paradigm, but lacked social evaluation, social interaction, and threat.

#### *4.2.2.2 Updating task*

Each trial of the updating task had the following structure (Figure 4.2 B): First, a negative life event was presented on the screen. After four seconds, participants were asked to estimate how likely this event is to occur to an average person in the population once or more often during his/her lifetime. Afterwards, they estimated the probability of the event happening to themselves. If the participants had already experienced the event, we instructed them to provide the probability of the event happening to them again. In the next step, we presented the actual base rate for four seconds. In the introductions, we explained that the base rates were based on research of online resources like the Office for National Statistics and PubMed, and on a scientific study with a representative sample of people who were asked if the life event had already happened to them (Schönfelder, Langer, Schneider, & Wessa, 2017). After receiving the information, participants were asked to re-estimate the probability of the event occurring to themselves once or more often in their lifetimes, independently on their prior estimate. In total, there were 43 trials. For each estimation, an integer between 0 and 100 had to be typed in within 10 seconds. Afterwards, the program proceeded automatically. To avoid omissions, participants received a warning if they were too slow and they got 10 additional seconds to type in their estimation. In the beginning of the task, participants answered to two test items to get familiar with the task and the timing.

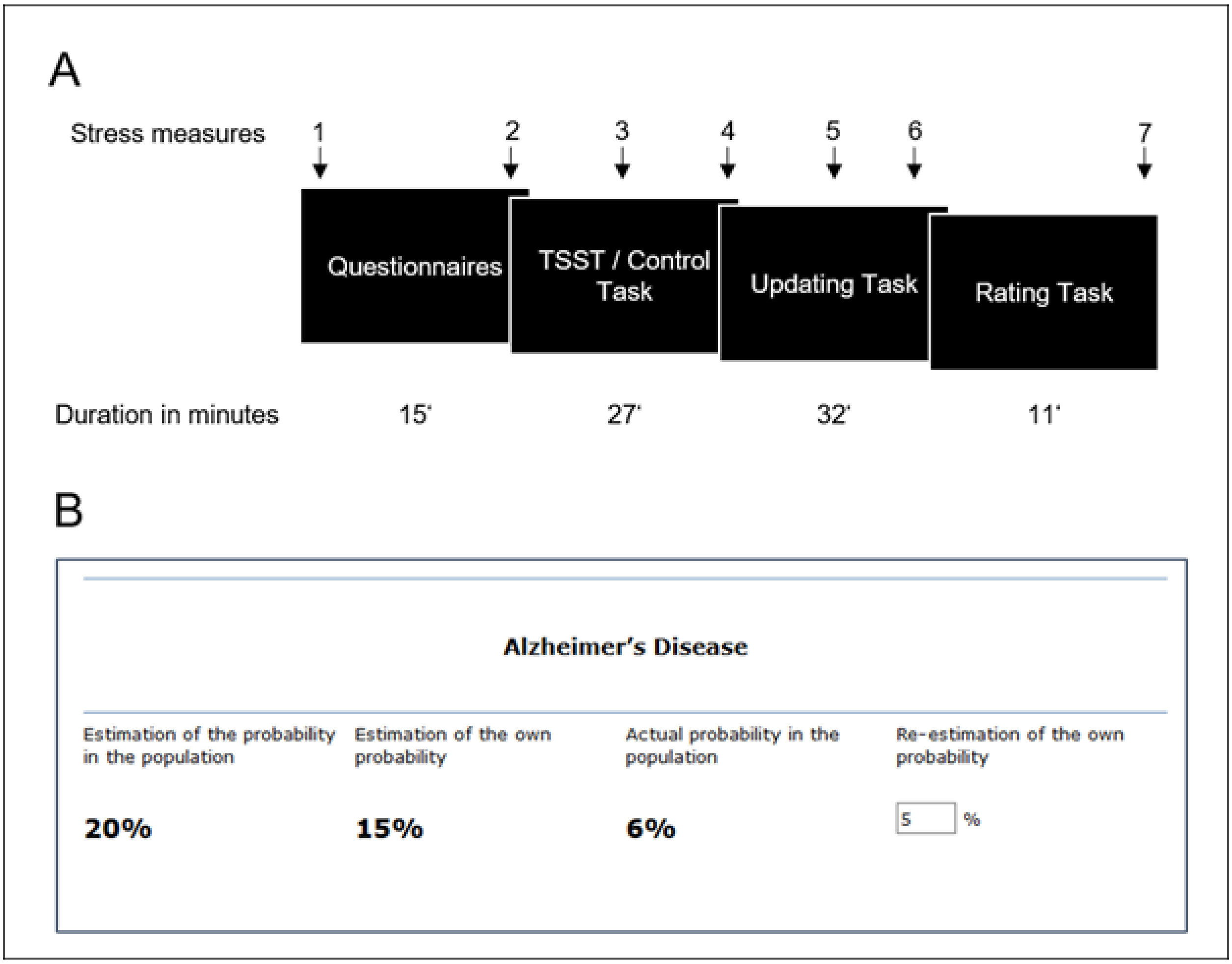
#### *4.2.2.3 Rating task*

After the updating task, participants rated each of the events with respect to controllability, vividness, negativity and trustworthiness of the provided base rate. For every rating, we used a six-point Likert scale. During all rating tasks, we randomized the order of the items. Participants could perform the rating task at their own pace.

### 4.2.3 Materials

Our study included 43 items. We had to exclude two items from the analysis because of wrong presentation of the base rates. Also, answers of one participant for two items were missing. We took items and corresponding base rates from Schönfelder et al. (2017) and from Shah, Harris, Bird, Catmur, & Hahn (2016). Base rates from Shah et al. (2016) came from the Office of National Statistics and PubMed, base rates from Schönfelder et al. (2017) were based on an online-sample of 294 participants. From an initial list of 83 negative life events we selected the 43 final items using an online pre-study with 63 participants with a similar design as described above. We excluded items that received low ratings in trustworthiness of the base rate (trustworthiness scores lower than 1 *SD* from the mean), items with low variance in updating (standard deviations of updating scores lower than 1 *SD* from the mean), and items with no updating for over one third of participants. Table A3.1 in the Appendix provides a list of all the items used in the final analysis.

*Figure 4.2.* (A) Experimental Procedure. Stress measures included salivary samples and subjective stress reports on a visual analogue scale. (B) Example of an item in the updating task. For the estimation of the probability in the population (eBR), estimation of the own probability (PE1) and re-estimation of the own probability (PE2), participants were asked to enter an integer between 0 and 100.




### 4.2.4 Measures

#### *4.2.4.1 Stress measures*

We analyzed cortisol, as a marker of hypothalamic–pituitary–adrenal (HPA) axis activation, and salivary alpha-amylase (sAA), as a marker for the activation of the autonomic nervous system, from saliva samples (Sarstedt AG & Co, Nümbrecht, Germany). Cortisol levels (nmol/l) were measured using a time-resolved fluorescence immunoassay (Dressendörfer, Kirschbaum, Rohde, Stahl, & Strasburger, 1992). Salivary alpha-amylase (U/ml) levels were determined using the enzyme kinetic method (Engert et al., 2011). Participants' subjective stress levels were measured on a visual analogue scale ranging from 0 (not stressed at all) to 10 (extremely stressed). All measures were anchored to 7 points in time, in twelve- to fifteen-minute intervals, throughout the experiment (see Figure 4.2 A). We replaced missing values of a single measurement with the mean value of the measurements directly before and after the missing value. In one case, two values of subsequent measurements were missing which we replaced with the overall mean of the subject. As a measure for cortisol increase over the course of the study, we calculated for each participant the area under the curve with respect to increase (AUC_I) for cortisol (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003)

#### *4.2.4.2 Variables of the updating task*

For each trial and each participant, we calculated participants' personal knowledge (PK) (the difference between participants' estimated base rate of the event (eBR) and participants' first personal estimate of encountering the event him- or herself (PE1)), the estimation error (EE), and the updating score (U). Table 4.1 provides details on how we computed these parameters. Note that we follow a recently applied method to calculate these variables (Kuzmanovic & Rigoux, 2017), but good and bad news trials originally have been defined differently (see, for example, Sharot, Guitart-Masip, et al., 2012; Sharot, Kanai, et al., 2012; Sharot et al., 2011). We report results on updating scores in good news and bad news trials calculated the original way in the Appendix together with a short discussion on the differences between the methods and a justification for choosing the current one (see also Kuzmanovic & Rigoux, 2017 and Shah et al., 2016). Following Kuzmanovic & Rigoux (2017), we additionally calculated for each trial the rational Bayesian updating score bU based on the likelihood ratio LR and computed the deviation from this rational benchmark dU as difference between Bayesian updating and actual updating.

#### *4.2.4.3 Questionnaires and control variables*

The questionnaires included the *Rosenberg Self-Esteem Scale* (Rosenberg, 2015), the *Perceived Stress Scale* (Cohen, Kamarck, & Mermelstein, 1983), the *Life Orientation Test – Revised* as a measure for optimism (Glaesmer, Hoyer, Klotsche, & Herzberg, 2008), and the four-item *Beck Depression Inventory* (Jenny et al., 2013). Depression scores were assessed to exclude participants classified as potentially depressive (see section 2.1). The Rosenberg Self-Esteem Scale and Perceived Stress Scale were included because self-esteem as well as perceived stress have been found to be associated with cortisol regulation (Pruessner et al., 2005; Pruessner, Hellhammer, & Kirschbaum, 1999). In our study, neither perceived stress nor self-esteem scores influenced stress reactions (results related to the questionnaire scores and their effect on stress reactions can be found in the Appendix). We still decided to include perceived stress (PSS) as a control variable into our analyses because perceived stress scores significantly differed between stress and control group (see Appendix). The *Life Orientation Test – Revised* as a measure of trait optimism was assessed because it has been found to be linked to neural correlates of the optimistic update bias (Sharot et al., 2011). All the analyses were hence additionally conducted controlling for trait optimism. As it did not influence neither stress reactions nor answers in the updating task, we did not include trait optimism in the results reported here. Gender (coded as dummy variable *female* that is 1 for female participants and 0 otherwise) was included in all the analyses because in past studies it has been found to influence stress reactions (e.g., Kirschbaum, Wüst, & Hellhammer, 1992), which was also the case in the current study (see section 4.3.1).

*Table 4.1:* Variables of the updating task and how they were obtained.

| Variable | Source |
|---|---|
| Estimated base rate (eBR) | *Entered by participant* |
| 1. Personal Estimate (PE1) | *Entered by participant* |
| Personal Knowledge (PK) | PK = eBR – PE1 |
| Actual base rate (BR) | *Presented to participant* |
| 2. Personal Estimate (PE2) | *Entered by participant* |
| Estimation error (EE) | EE = \|BR – eBR\| |
| Valence of trials | "good news" if eBR > BR<br>"bad news" if eBR < BR |
| Updating (U) | |
| For good news trials: | $U_{good}$ = PE1 – PE2 |
| For bad news trials: | $U_{bad}$ = PE2 – PE1 |
| Likelihood Ratio (LR) | $LR = \frac{PE1}{1 - PE1} / \frac{eBR}{1 - eBR}$ |
| Bayesian 2. Estimate (bE2) | $bE2 = \frac{BR * LR}{BR * LR + (1 - BR)}$ |
| Bayesian Updating (bU) | |
| For good news trials: | bU = PE1 – bE2 |
| For bad news trials: | bU = bE2 – PE1 |
| Deviation from Bayesian Updating (dU) | dU = bU – U |

### 4.2.5 Analysis

*4.2.5.1 Manipulation check*

To test whether our stress manipulation worked, we compared cortisol levels, salivary α-amylase, and subjective stress reports across the stress and control group using a two factor mixed design ANOVA with group (control / stress) as the between-subjects factor, time of measurement (seven levels) as the within-subjects factor; gender and scores of the Perceived Stress Scale were included as control variables.

*4.2.5.2 Updating*

We analyzed the data trial-by-trial by applying mixed-effects regression analyses using the lmerTest package in R (Kuznetsova, Brockhoff, & Christensen, 2018; R Core Team, 2017). Valence of the news (good news / bad news) and group (stress / control) as well as an interaction between the two variables were treated as fixed effects. Participants and events were treated as random effects and we entered participant-specific random slopes for the valence of the event. Additionally, we controlled for gender, scores of the Perceived Stress Score, event characteristics, personal knowledge, and estimation error. Note that the overall findings did not change when excluding these control variables from the analysis. As done by previous studies, trials in which participants' correctly estimated the base rate (EE = 0, 1.6% of trials), did not enter the analysis on updating behavior (e.g., Kuzmanovic & Rigoux, 2017).

To make our results comparable to previous studies on the optimistic update bias, we also analyzed updating behavior in an aggregated way by computing mean update scores for good and bad news trials for each participant and entering them into a 2 (stress / control) by 2 (good news / bad news) mixed-design ANOVA (e.g. Garrett & Sharot, 2017; Shah et al., 2016; Sharot, Guitart-Masip, et al., 2012). Results of this aggregated method are reported in the Appendix. With our given experimental design and sample size ($N$ = 68) we have a power of $\beta$ = .98 to detect a within-between interaction effect of medium size ($f$ = 0.25[8], correlation between repeated measures of 0.5 as in Kuzmanovic & Rigoux (2017) in a two-factor mixed design ANOVA with group as between-subjects factor (stress /

[8] Lighthall et al. (2013) have reported even larger effect sizes partial $\eta^2$ = 0.1 for the interaction effect of stress condition and valence of feedback on learning accuracy which is equivalent to $f$ = 0.33.

control) and valence of the news as within-subjects factor (good / bad). With the trial-by-trial mixed-effects regression analysis our statistical power even increases.

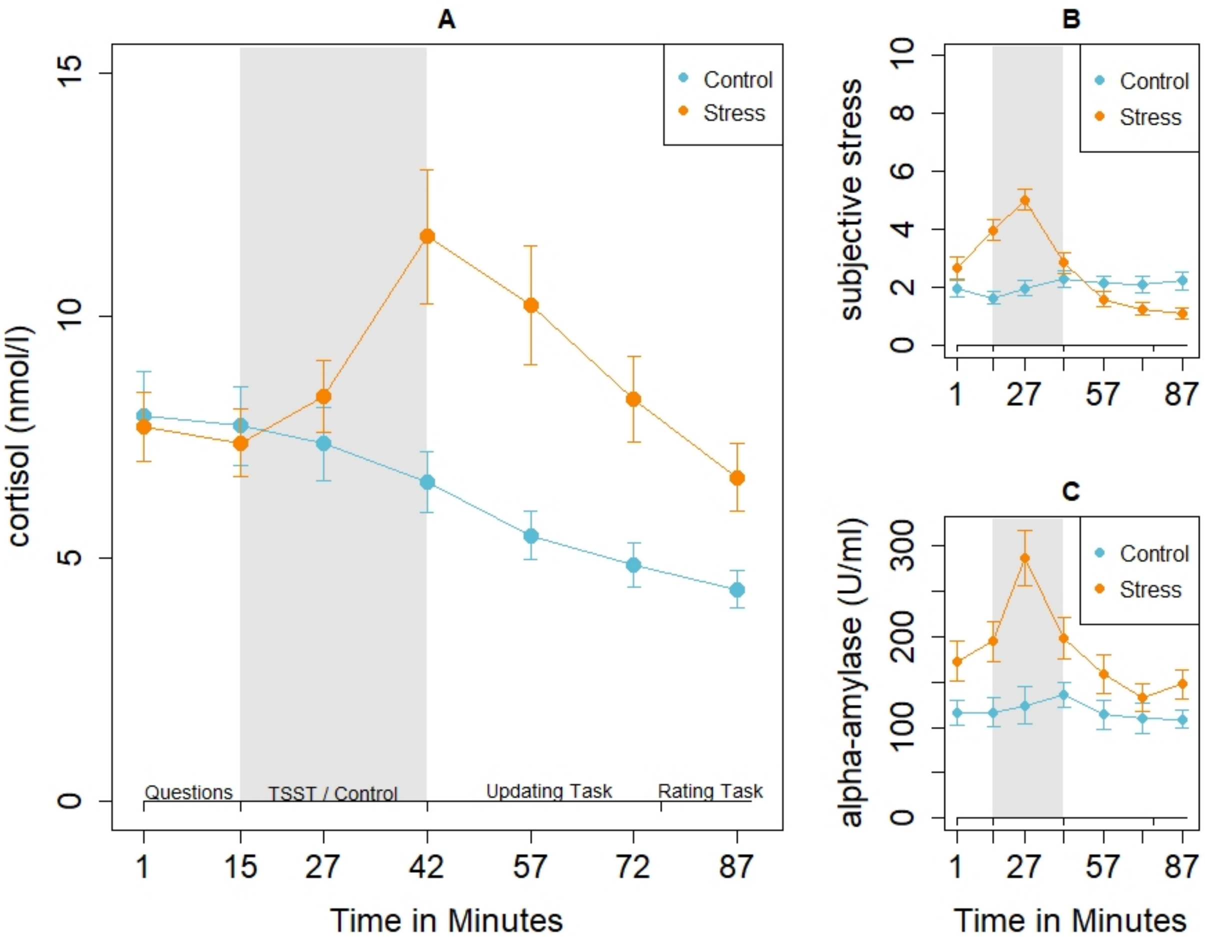
## 4.3 Results

### 4.3.1 Manipulation Check

As Figure 4.3 illustrates, our stress manipulation successfully induced acute stress: Participants in the stress group showed increasing cortisol levels over the course of the study ($F_{stress}(1, 64) = 6.00$, $p = .017$; $F_{stress*time}(6, 396) = 11.64$, $p < .001$). Initial cortisol levels did not differ between the two experimental groups ($M_{control} = 7.93$ ($SD = 5.37$), $M_{stress} = 7.70$ ($SD = 4.14$), $t(62.0) = 0.20$, $p = .844$, 95% CI [-2.09, 2.56], $d = 0.05$). These findings indicate an increased activation of the HPA axis in the stress group. Similarly, participants in the stress group showed an increased activation of the autonomic nervous system compared to participants in the control group as indicated by a main effect of stress on salivary alpha-amylase levels and a time*stress interaction ($F_{stress}(1, 64) = 7.98$, $p = .006$, $F_{stress*time}(6, 396) = 10.04$, $p < .001$). Our stress manipulation also increased participants' subjective stress reports ($F_{stress}(1, 64) = 3.65$, $p = .061$; $F_{stress*time}(6, 396) = 34.3$, $p < .001$). During the TSST, participants reported to be significantly more stressed than participants performing the control task ($M_{control} = 1.99$ ($SD = 1.47$), $M_{stress} = 5.02$ ($SD = 2.07$), $t(59.5) = -7.00$, $p < .001$, 95% CI [-3.91, -2.17], $d = - 1.69$).

We found significant gender effects on our stress reactions: As reported by other studies, male participants' cortisol levels were more elevated than cortisol levels of female participants ($F_{female}(1, 64) = 8.52$, $p = .005$) (Kirschbaum et al., 1992). At the same time, female participants overall reported higher subjective stress values ($F_{female}(1, 64) = 6.25$, $p = .015$).

*Figure 4.3:* Mean cortisol (A), self-reported subjective stress (B), and alpha-amylase levels (C) across participants for the seven measurements during the experiment. Bars denote ± one standard error of the mean.




## 4.3.2 Updating

### *4.3.2.1 Optimistic update bias*

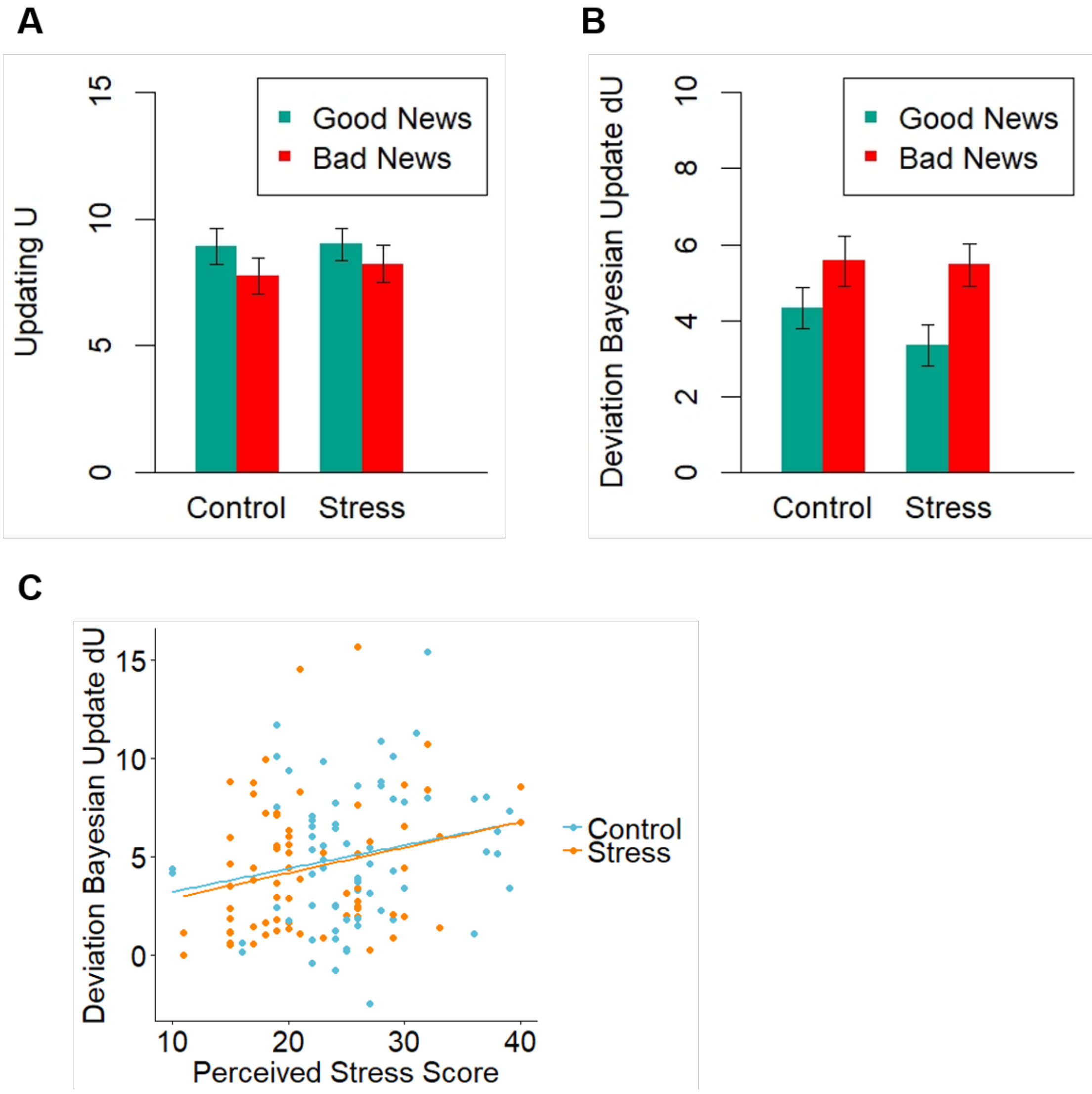
As displayed in Figure 4.4 A, participants alter their probability estimates more in response to good than in response to bad news ($\beta_{valence}$ = 1.06, $t(93.9)$ = 2.47, $p$ = .015, 95% CI [0.21, 1.91]). The effect is well comparable to previous studies on the optimistic update bias (see Appendix for the respective analyses). Our data do not provide any evidence that acute stress influences belief updating. Stress did not affect overall updating ($\beta_{stress}$ = -0.19, $t(66.7)$ = -0.28, $p$ = .783, 95% CI [-1.59, 1.21]), nor did stress affect the optimistic update bias in the sense of larger updating scores after good news than after bad news ($\beta_{stress*valence}$ = 0.22, $t(65.3)$ = 0.28, $p$ = .778, 95% CI [-1.33, 1.76]). We find the same pattern of results when using the original method to classify good and bad news trials (see Appendix). We additionally divided the stress group into stress-responders (cortisol AUC_I > 0, $n$ = 20) and non-responders (cortisol AUC_I ≤ 0, $n$ = 14). This allowed us to check whether only participants with a clear stressor-induced HPA axis activation showed a different updating behavior than participants in the control group. This was not the case: Participants with the expected endocrine response to the stressor, i.e. positive cortisol increase, showed similar updating scores than participants of the control group ($\beta_{stress\_reactors}$ = 0.28, $t$(61.9) = 0.34, $p$ = .736, 95% CI [-1.30, 1.86]). We also did not find a link between cortisol increase (AUC_I) and updating scores in good and bad news trials (good news trials: r(66) = .08, p = .535, 95% CI [-.16, .31], bad news trials: r(66) = .01, p = .962, 95% CI [-.23, .24]).

In contrast to our stress manipulation, the perceived stress score, which we added as a control variable, negatively affected updating ($\beta_{PSS}$ = -0.13, $t$(68.8) = -2.43, $p$ = .018, 95% CI [-0.25, -0.02]). Although perceived stress decreased overall updating, it did not influence the optimistic update bias ($\beta_{PSS*valence}$ = -0.09, $t$(63.4) = -1.46, $p$ = .149, 95% CI [-0.21, 0.03]). We also found a gender effect on updating: female participants updated their probability estimates overall more than male participants ($\beta_{female}$ = 1.49, $t$(67.9) = 2.16, $p$ = .034, 95% CI [0.12, 2.86]). There was however no gender-specific effect of stress on updating ($\beta_{female*stress}$ = -2.14, $t$(62.1) = -1.54, $p$ = .128, 95% CI [-4.79, 0.52]; $\beta_{female*stress*valence}$ = 0.41, $t$(61.6) = 0.26, $p$ = .800, 95% CI [-2.71, -3.57]).

#### *4.3.2.2 Deviation from Bayesian updating*

As can be seen in Figure 4.4 B, participants' updating behavior deviated from the Bayesian benchmark but to a smaller degree in good news than in bad news trials (difference in dU between good and bad news trials, paired t-test: $t$(67) = -3.5, $p$ = .001, $M$ = -1.69, 95% CI [-2.64, -0.73], $d$ = -0.43; mixed effects linear regression: $\beta_{valence}$ = -1.53, $t$(78.4) = -3.47, $p$ < .001, 95% CI [-2.40, -0.66]). These deviations are very similar to the ones found in Kuzmanovic & Rigoux (2017). Similar to participants' raw updating scores, we did not find an effect of our stress manipulation on the deviation from Bayesian updating ($\beta_{stress}$ = 0.04, $t$(63.2) = 0.06, $p$ = .950, 95% CI [-1.15, 1.22]). Perceived stress scores, however, appear to have an influence on deviation from Bayesian updating: people with higher perceived stress levels update their beliefs in a less "rational" manner (see Figure 4.4C; $\beta_{PSS}$ = 0.13, $t$(65.6) = 2.61, $p$ = .011, 95% CI [0.03, 0.22]). There is no effect of gender on deviations from Bayesian updating ($\beta_{female}$ = -0.34, $t$(64.7) = -1.57, $p$ = .121, 95% CI [-2.11, 0.22]).

*Figure 4.4.* (A) Mean updating Scores U in good news trials and bad news trials in the control and stress group. Bars indicate ± one standard error of the mean. Trial-by-trial mixed-effects linear regression shows an effect of valence of trials on updating but no effect of the stress manipulation. (B) Mean deviation from Bayesian updating dU in good news trials and bad news trials in the control and stress group. Bars indicate ± one standard error of the mean. Trial-by-trial mixed-effects linear regression shows an effect of valence of trials on updating but no effect of the stress manipulation. (C) Participants' mean deviations from Bayesian updating dU as a function of their perceived stress scores in the control and stress group.




## 4.4 Discussion

We assumed that acute stress increases the optimistic update bias because past research has found that acute stress 1) improves learning from positive and impairs learning from negative feedback, 2) can increase dopaminergic activity which in turn has been found to increase the optimistic update bias. We did not find any support for our hypothesis:

Participants who were exposed to the TSST before the updating task showed similar updating behavior than participants in the control group. Both groups updated their beliefs in a valence-dependent manner with higher updating scores in response to good news than in response to bad news. These updating scores deviated more from the “rational” Bayesian benchmark in bad news trials than in good news trials, independent of the stress manipulation. Overall these results indicate that acute stress does not influence how people integrate probability information into their personal risk estimate. They suggest that optimistic belief updating – i.e. updating one’s belief more readily in response to better-than-expected information than in response to worse-than-expected information – is a robust phenomenon that is not influenced by acute stress.

We do not find evidence for the expected effect although we replicated the findings from past studies on the optimistic update bias and although we successfully induced a subjective and biological stress reaction. It is possible that the link between acute stress and increased dopamine firing rates is not as strong and clear as postulated in research on stress and decision making (Mather & Lighthall, 2012; Starcke & Brand, 2016; Yu, 2016). There is indeed strong evidence for a positive relation between elevated cortisol levels after acute stress and dopamine activity (Pruessner et al., 2004; Scott et al., 2006; Ungless et al., 2010). Still some studies argue that acute stress and elevated cortisol levels have differential effects on reward sensitivity and dopamine activation dependent on sex (Kinner, Wolf, & Merz, 2016) and the brain region of the dopamine neuron (Ungless et al., 2010). Other studies even report a negative effect of acute stress and cortisol on the brain’s reward circuitry (Montoya, Bos, Terburg, Rosenberger, & van Honk, 2014). Further research seems to be needed to fully understand to what extend acute stress can increase dopaminergic activity.

Independent of the role of dopamine, we hypothesized that stress increases the optimistic update bias because of findings on the effect of stress on probabilistic reinforcement learning. Our results demonstrate that effects found in probabilistic reinforcement learning tasks do not directly translate to similar effects in the probabilistic belief updating task. Whereas acute stress seems to improve learning from positive but to impair learning from negative feedback (Lighthall et al., 2013; Petzold et al., 2010), it does not increase belief updating in response to good news and decrease belief updating in response to bad news. Future studies should further investigate how processes involved in reinforcement learning and in probabilistic belief updating actually relate to each other.

Recent studies using cognitive modeling and functional imaging seem to be a promising attempt to better understand this relation (Kuzmanovic & Rigoux, 2017; Lefebvre et al., 2017).

Although we did not find an effect of our stress manipulation on belief updating, we found a negative effect of participants' reported perceived stress scores. The more participants perceived their current life within in the last month as stressful, the less they adjusted their probability estimates in response to new information and the more they deviated from rational Bayesian updating – independent of the valence of the news. Our two stress measures – acute stress induced by the TSST and perceived stress measured by the Perceived Stress Scale – hence have different effects on behavior in our updating task. This might seem counterintuitive at first. However, they both refer to two different kinds of stress: The TSST simulates a naturalistic stressor that induces an acute psychobiological stress response which is considered to be adaptive (Starcke & Brand, 2016). The Perceived Stress Scale, on the other hand, measures the extent to which participants appraise situations within the last month as stressful (Cohen et al., 1983). Differently from acute stress induced by the TSST, perceived stress is not clearly linked to an elevated cortisol level (Pruessner et al., 1999; van Eck, Berkhof, Nicolson, & Sulon, 1996). It rather indicates the degree to which participants find their lives "unpredictable, uncontrollable and overloading" (Cohen et al., 1983). Whereas participants can forget about the stress experienced during the TSST as soon as the task is over, perceived stress in the daily life of participants is likely to still be on the mind during the whole study. Participants with high levels of perceived stress might, hence, have less cognitive resources available to integrate new information and adapt their beliefs to it. Future research should further investigate the relation between perceived stress and belief updating.

Research on the effect of acute stress on judgement and decision processes is still in its beginning and the majority of these studies has focused on reward seeking and risk taking (Starcke & Brand, 2012, 2016). To the best of our knowledge, we are the first to study the effect of acute stress on probability estimates and belief updating. Nearly all the published studies in this field report significant effects of acute stress or cortisol on decision making. We only know from one other study that reports to find no effect of acute stress on, in their case, intertemporal choice (Haushofer et al., 2013). It is possible that the number of studies finding null effects of acute stress or cortisol on decision making is actually much higher but didn't get published and that the published effects of acute stress on decision making are inflated due to publication bias (Ioannidis, Munafò, Fusar-Poli, Nosek, & David, 2014; Sterling, 1959) – a problem that recently got increasing attention in the behavioral sciences (Camerer et al., 2018; Open Science Collaboration, 2015). To better understand which decision processes are prone to be influenced by stress *and which are not* it is, hence, crucial to publish well-designed studies independent of their results.

In conclusion, our study demonstrates that acute stress does not influence how people update their probabilistic beliefs about future life events. Independent of stress, people are biased in an optimistic manner: they estimate to be less likely than the average person to experience a negative event and they change this estimate more in response to better-than-expected than in response to worse-than-expected information

# Appendix

## Chapter 2

### Choice Problems

*Table A1.1:* Medical Choice Problems

| | Gamble A | | Gamble B | |
|---|---|---|---|---|
| | Side effect | Probability | Side effect | Probability |
| 1 | Flatulence | 1.00 | Hallucinations | .25 |
| 2 | Fatigue | .90 | Memory loss | .25 |
| 3 | Itching | .70 | Depression | .25 |
| 4 | Fever | .40 | Hallucinations | .20 |
| 5 | Insomnia | .55 | Depression | .30 |
| 6 | Speech disorder | .30 | Memory loss | .20 |
| 7 | Fatigue | .70 | Dizziness | .30 |
| 8 | Itching | .60 | Trembling | .50 |
| 9 | Flatulence | .70 | Diarrhea | .40 |
| 10 | Depression | .50 | Memory loss | .10 |
| 11 | Memory loss | .10 | Insomnia | .20 |
| 12 | Hallucinations | .71 | Insomnia | .96 |
| 13 | Hallucinations | .30 | Diarrhea | .98 |
| 14 | Fatigue | .99 | Insomnia | .70 |
| 15 | Speech Disorder | .05 | Trembling | .94 |
| 16 | Itching | .54 | Depression | .05 |
| 17 | Memory loss | .19 | Fever | .98 |
| 18 | Itching | .60 | Trembling | .50 |
| 19 | Speech Disorder | .56 | Insomnia | .98 |
| 20 | Dizziness | .98 | Memory Loss | .55 |

*Note.* In the monetary domain, side effects were replaced by each participants' monetary evaluation of the specific side effect.

## Descriptive Statistics of Experimental Conditions

*Table A1.2*: Number of Participants and Descriptive Statistics in Each of the Four Experimental Conditions

| | DfD | | | | | | DfE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SELF | | | OTHER | | | SELF | | | OTHER | | |
| | *n* | % female | $M_{age}$ (*SD*) | *n* | % female | $M_{age}$ (*SD*) | *n* | % female | $M_{age}$ (*SD*) | *n* | % female | $M_{age}$ (*SD*) |
| Study 1 | 40 | 90 | 22.2 (4.9) | 41 | 88 | 23.0 (5.8) | 41 | 83 | 20.7 (2.1) | 40 | 83 | 21.8 (4.4) |
| Study 2 | 36 | 86 | 21.8 (2.7) | 40 | 83 | 22.0 (3.1) | 40 | 83 | 22.8 (5.9) | 39 | 85 | 22.4 (3.8) |

*Note*. In both studies, participants made the decisions either for themselves (SELF) or for another person (OTHER) and either in a decision from description (DfD) or a decision from experience (DfE) condition.

## Monetary Equivalents of Side Effects and Affective Evaluations of both Prospects

*Table A1.3:* Median Monetary Equivalents of Side Effects and Mean Affective Ratings of the Side Effects and Their Monetary Equivalents

| | | | Affective ratings | | | |
|---|---|---|---|---|---|---|
| | Monetary equivalents in € (Median) | | Side Effects (Mean) | | Monetary Equivalents (Mean) | |
| Side Effects | SELF | OTHER | SELF | OTHER | SELF | OTHER |
| Study 1 | | | | | | |
| Memory Loss | -150 | -100 | 9.52 | 9.41 | 9.05 | 8.46 |
| Depression | -147 | -77 | 8.65 | 8.52 | 8.37 | 7.68 |
| Hallucination | -105 | -70 | 8.56 | 8.35 | 8.09 | 7.76 |
| Speech Disorder | -110 | -80 | 8.46 | 8.3 | 7.98 | 7.61 |
| Insomnia | -70 | -39 | 6.27 | 5.9 | 6.41 | 5.98 |
| Fever | -37.5 | -30 | 5.45 | 5.84 | 5.07 | 5.11 |
| Dizziness | -30 | -20 | 5.28 | 4.7 | 5.12 | 4.17 |
| Diarrhea | -30 | -21 | 4.76 | 4.89 | 4.68 | 4.5 |
| Trembling | -30 | -21.5 | 4.55 | 4.46 | 4.6 | 4.28 |
| Itching | -27 | -15 | 4.28 | 3.91 | 4.87 | 4.1 |
| Flatulence | -25 | -10 | 4.16 | 3.78 | 4.05 | 3.52 |
| Fatigue | -15 | -10 | 4.55 | 3.74 | 3.93 | 3.2 |
| Study 2 | | | | | | |
| Memory Loss | -100 | -80 | 9.52 | 9.4 | 8.61 | 8.38 |
| Depression | -90 | -68.5 | 8.65 | 8.07 | 7.4 | 6.8 |
| Hallucination | -80 | -70 | 8.39 | 8.41 | 7.61 | 7.29 |
| Speech Disorder | -90 | -67 | 8.63 | 8.29 | 7.57 | 7.34 |
| Insomnia | -40 | -32.5 | 6.53 | 5.92 | 5.79 | 5.49 |
| Fever | -30 | -25 | 5.55 | 5.6 | 4.95 | 4.35 |
| Dizziness | -25 | -20 | 5.11 | 5.05 | 4.43 | 4 |
| Diarrhea | -20 | -20 | 5.15 | 4.56 | 4.77 | 3.88 |
| Trembling | -20 | -15 | 4.45 | 4.36 | 4.19 | 3.44 |
| Itching | -20 | -10 | 4.36 | 3.48 | 4.31 | 3.14 |
| Flatulence | -15 | -14 | 4.19 | 3.41 | 3.75 | 3.12 |
| Fatigue | -15 | -10 | 4.59 | 4.2 | 3.61 | 2.98 |

## Plots of Search Effort when Including the Outlier

*Figure A1.1.* Average sample size per choice problem in the DfE condition before excluding the outlier in the OTHER condition of Study 1. With the outlier in the data set, the OTHER condition in Study 1 is the only condition where the difference in sample size between the monetary and medical domain disappears ($\chi^2$ (1) = 1.66, $p$ = .197).

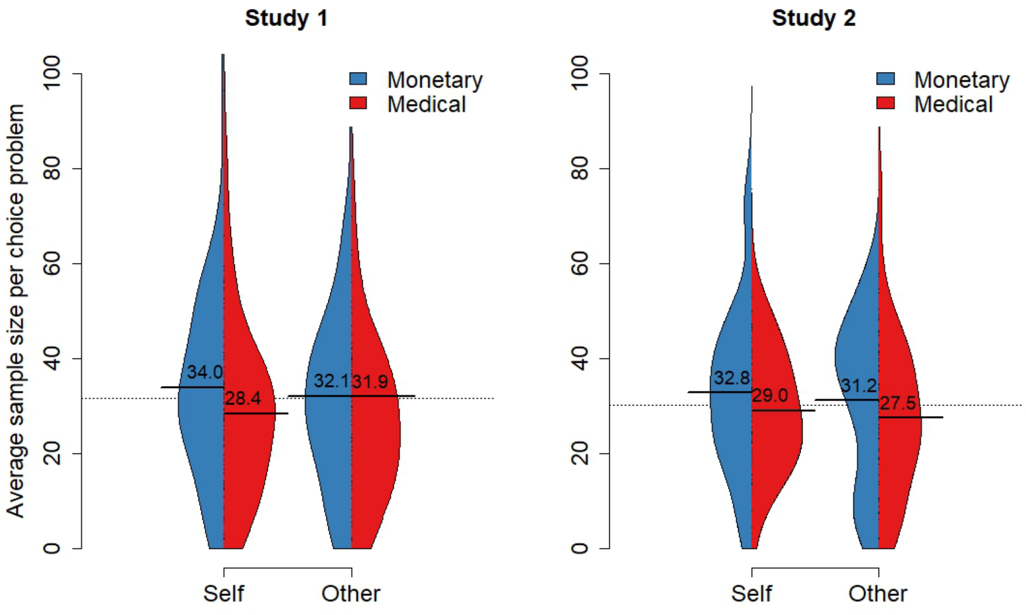
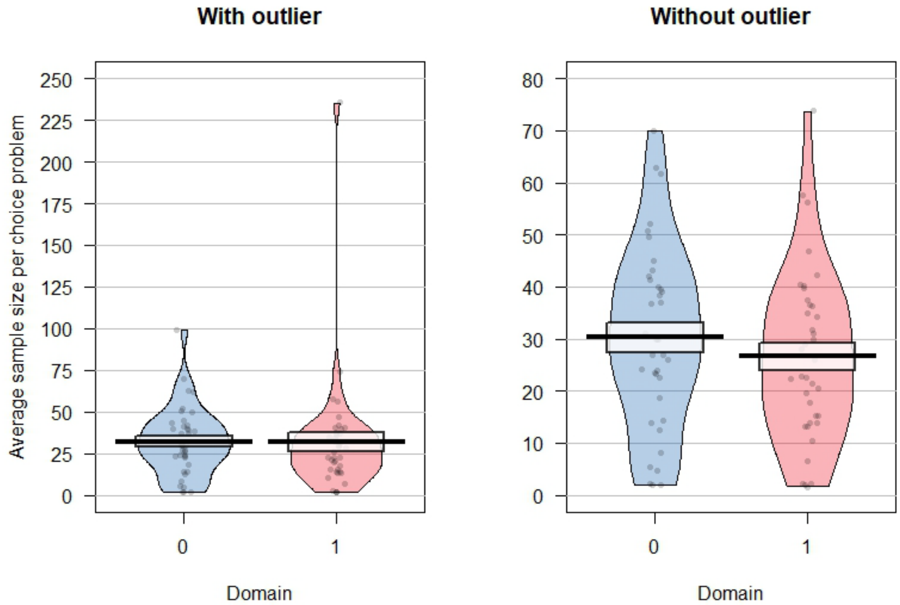



*Figure A1.2.* Average sample size per choice problem in the OTHER condition of Study 1 before excluding the outlier (left) and after excluding the outlier (right). Each point represents one participant, the upper and lower boarders of the box denote ± 1 standard error from the mean (black line). Domain of 0 refers to the monetary, domain of 1 to the medical domain.



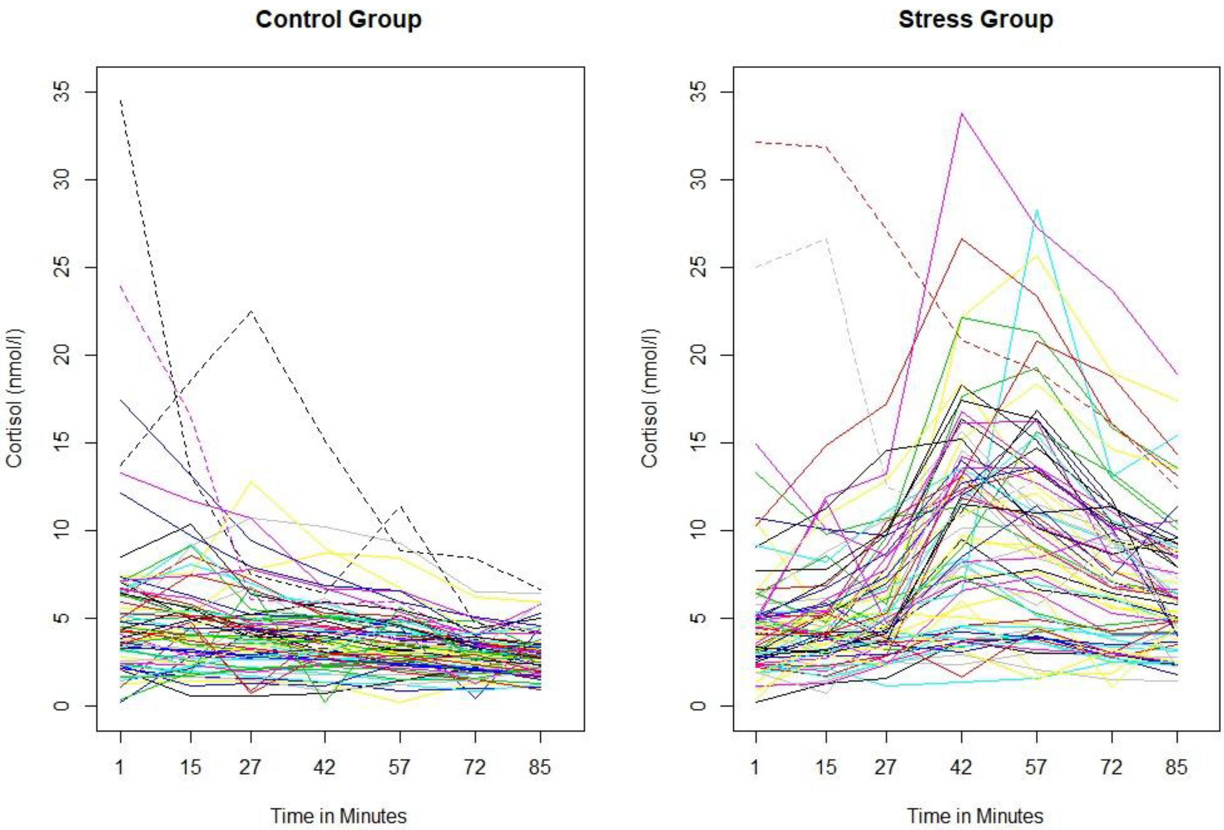
## The Effect of Affective Rating of Gambles on Search Effort

We classified each gamble as being either affect-poor (mean affective rating below or equal to 5) or affect-rich (mean affective rating above 5). We then entered the dummy coded variable into a mixed effects linear regression to test whether it predicts sample size, separately for the medical and monetary domain. As in the other analyses, we treated participants and choice problems as random effects and added decision perspective as control variable. Only in the monetary domain of study 2, the affective value of the gambles predicted sample size (Study 1 monetary domain: $\chi^2$ (1) = 1.52, $p$ = .218; Study 1 medical domain: $\chi^2$ (1) = 0.08, $p$ = .773; Study 2 monetary domain: $\chi^2$ (1) = 8.02, $p$ = .005; Study 2 medical domain: $\chi^2$ (1) = 0.53, $p$ = .467) but showed a positive effect of affective rating on search effort ($\beta$ = 3.10). This does not support the assumption that people rely on smaller samples when making affect-rich decisions.

# Chapter 3

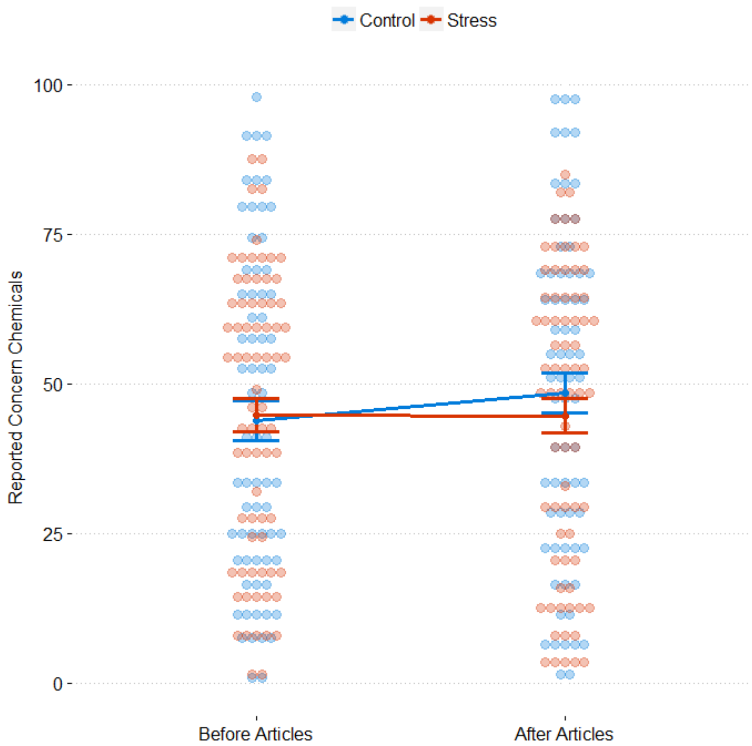
## Individual Cortisol Paths

*Figure A2.1:* Individual cortisol levels over the course of the experiment in the control and stress group. Participants with a baseline cortisol level larger than 3 SD plus the mean were excluded from the analysis as well as one participant who showed a strong increase in cortisol in the control group with a cortisol level larger than 3 SD plus the mean at minute 27 (dashed lines).



## Reported Concern about Chemicals in Daily Products

*Figure A2.2:* Reported concern about chemicals in daily products in general for both experimental groups (control and stress) asked before and after reading the articles. Similar to findings on reported concern about Triclosan, initially reported concern about chemicals in general did not differ between stress and control group [$M_{control}$ = 43.87 (SD = 27.29), $M_{stress}$ = 44.78 (SD = 23.48), t(132.6) = −0.21, p = .832, d = 0.04]. After reading the articles about Triclosan, concern about chemicals in general increases slightly in the control group but not in the stress group [change in concern: $M_{control}$ = 4.60 (SD = 18.44), $M_{stress}$ = −0.10 (SD = 18.08), t(137.86) = 1.53, p = .130, d = 0.26]. Dots represent single individuals, bars denote ± 1 standard error of the mean.



# Chapter 4

## Items Used in the Study

*Table A3.1:* Items used in the experiment and the source they were taken from. Events were presented in German.

| Event (English translation) | Event (German) | Base Rate | Source |
|---|---|---|---|
| Dying before 80 | Tod vor dem 80. Lebensjahr | 41 | Shah et al. (2016) |
| Liver disease | Lebererkrankung | 8 | Shah et al. (2016) |
| Heart failure | Herzversagen | 31 | Shah et al. (2016) |
| Kidney stones | Nierensteine | 10 | Shah et al. (2016) |
| Chronic high blood pressure | Chronischer hoher Blutdruck | 20 | Shah et al. (2016) |
| Type II diabetes | Typ II Diabetes | 27 | Shah et al. (2016) |
| Dying before 70 | Tod vor dem 70. Lebensjahr | 18 | Shah et al. (2016) |
| Stroke | Schlaganfall | 17 | Shah et al. (2016) |
| Prostate / breast cancer | Prostata / Brustkrebs | 5 | Shah et al. (2016) |
| Serious hearing problem | Starke Hörprobleme | 14 | Shah et al. (2016) |
| Hepatitis A/B | Hepatitis A/B | 36 | Shah et al. (2016) |
| Dying before 60 | Tod vor dem 60. Lebensjahr | 8 | Shah et al. (2016) |
| Sports injury | Sportverletzung | 59 | Schönfelder et al. (2017) |
| Treatment in an intensive care unit | Behandlung auf einer Intensivstation | 17 | Schönfelder et al. (2017) |
| Bone fracture | Knochenbruch | 38 | Schönfelder et al. (2017) |
| Root canal treatment | Zahnwurzelbehandlung | 49 | Schönfelder et al. (2017) |
| Abnormal heart rhythm | Herzrhythmusstörungen | 24 | Schönfelder et al. (2017) |
| Gastrointestinal ulcer | Magen-Darm-Geschwür | 6 | Schönfelder et al. (2017) |
| Develop a mental illness (e.g. depression, schizophrenia) | An einer psychischen Erkrankungen (z.B. Depression, Schizophrenie) erkranken | 32 | Schönfelder et al. (2017) |
| Cancer | Krebserkrankung | 40 | Schönfelder et al. (2017) |
| Athlete's foot | Fußpilz | 38 | Schönfelder et al. (2017) |
| Chronic obstructive bronchitis | Chronisch-obstruktive Bronchitis | 6 | Schönfelder et al. (2017) |
| Acute appendicitis | Akute Blinddarmentzündung | 17 | Schönfelder et al. (2017) |

| | | | |
|---|---|---|---|
| Sexual dysfunction (e.g. loss of libido, impotence) | Sexuelle Schwierigkeiten (z.B. Lustlosigkeit / Libidoverlust, Impotenz) | 36 | Schönfelder et al. (2017) |
| Receiving a dog bite | Von einem Hund gebissen werden | 28 | Schönfelder et al. (2017) |
| Household accident (requiring medical treatment) | Unfall im Haushalt (mit erforderlicher ärztlicher Behandlung) | 32 | Schönfelder et al. (2017) |
| Getting severely sunburnt | Extremer Sonnenbrand | 53 | Schönfelder et al. (2017) |
| Theft from a vehicle | Diebstahl aus Fahrzeug | 76 | Shah et al. (2016) |
| Law suit against own person | Gerichtsverfahren gegen die eigene Person | 19 | Schönfelder et al. (2017) |
| Being pickpocketed | Taschendiebstahl | 27 | Schönfelder et al. (2017) |
| Loss of data due to computer virus | Durch einen PC-Virus wichtige Daten verlieren | 22 | Schönfelder et al. (2017) |
| Domestic burglary | Einbruch in die eigene Wohnung / ins eigene Haus | 13 | Schönfelder et al. (2017) |
| Long-term unemployment (more than one year) | Langzeitarbeitslosigkeit (mehr als ein Jahr) | 12 | Schönfelder et al. (2017) |
| Fail at an important exam | Bei einer wichtigen Prüfung durchfallen | 43 | Schönfelder et al. (2017) |
| Unfulfilled desire for a child | Unerfüllter Kinderwunsch | 12 | Schönfelder et al. (2017) |
| Severe conflicts with parents-in-law | Ernste Konflikte mit den Schwiegereltern | 23 | Schönfelder et al. (2017) |
| Divorce | Ehescheidung | 45 | Schönfelder et al. (2017) |
| Having vermin in the house / apartment (e.g. ants, mice) | Schädlinge im Haus bzw. in der Wohnung (z.B. Ameisen, Mäuse) | 65 | Schönfelder et al. (2017) |
| Water pipe burst in one's own flat/house | Wasserrohrbruch im Haus bzw. in der Wohnung | 32 | Schönfelder et al. (2017) |
| Mold in one's own house or flat | Schimmel im Haus bzw. in der Wohnung | 69 | Schönfelder et al. (2017) |
| Missing a flight | Einen Flug verpassen | 12 | Schönfelder et al. (2017) |

## Questionnaire Scores and Their Effect on Stress Measures

### *Rosenberg Self-Esteem Scale*

Possible scores on the Rosenberg Self-Esteem Scale could range from 1 to 40 with higher values indicating higher self-esteem. With a mean value of 32.12 (*SD* = 4.59), self-esteem score in our sample were very similar to scores found in the past on another German sample (Schmitt & Allik, 2005). There was no difference in assessed self-esteem between the stress and control group ($M_{control}$ = 32.15 ($SD$ = 3.47), $M_{stress}$ = 32.15 ($SD$ = 5.55), $t$(55.4) = 0, $p$ = 1, 95% CI [-2.25, 2.25], $d$ = 0). Self-esteem did neither affect cortisol levels ($F$(1, 62) = 0.60, $p$ = .441), alpha-amylase levels ($F$(1, 62) = 0.31, $p$ = .579), nor subjective stress reports ($F$(1, 62) = 0.24, $p$ = .627).

*Life Orientation Test*

Possible scores on the LOT-R range from 0 to 24 with higher values indicating higher dispositional optimism. On average, our participants seem to be rather optimistic with mean LOT-R scores of 16.6 ($SD$ = 3.63) which is very similar to what has been found in the past with a sample of the same age group and country (Glaesmer et al., 2012). LOT-R scores did not significantly differ between the two experimental groups ($M_{control}$ = 16.32 ($SD$ = 3.29), $M_{stress}$ = 16.94 ($SD$ = 3.97), $t$(63.8) = -0.70, $p$ = .487, 95% CI [-2.38, 1.15], $d$ = -0.17). Trait optimism did neither affect cortisol levels ($F$(1, 62) = 0.09, $p$ = .772), alpha-amylase levels ($F$(1, 62) = 1.53, $p$ = .221), nor subjective stress reports ($F$(1, 62) = 0.72, $p$ = .401).

*Perceived Stress Scale*

Perceived stress scores could range from 0 to 56 with higher scores indicating higher levels of perceived stress. In the control group, scores of the Perceived Stress Scale (reported before the experimental manipulation) were higher than the stress group ($M_{control}$ = 25.65 ($SD$ = 6.12), $M_{stress}$ = 21.88 ($SD$ = 6.39), $t$(65.9) = 2.48, $p$ = .016, 95% CI [0.74, 6.79], $d$ = 0.60). Overall, however, perceived stress scores of our participants are similar to results from other samples (Cohen et al., 1983). Perceived stress did neither affect cortisol levels ($F$(1, 62) = 0.76, $p$ = .387), alpha-amylase levels ($F$(1, 62) = 0.19, $p$ = .661), nor subjective stress reports ($F$(1, 62) = 3.27, $p$ = .075).

**Aggregated Analysis of Updating and Comparison with Effects of Previous Studies**

To compare our results on the optimistic update bias with previous studies, we also analyzed updating behavior by computing mean update scores for good and bad news trials for each participant (e.g. Garrett & Sharot, 2017; Shah et al., 2016; Sharot, Guitart-Masip, et al., 2012). We then entered these mean update scores into a 2 (stress / control) by 2 (good news / bad news) mixed-design ANOVA and added the following control variables to the model besides our usual control variables (scores of the Perceived Stress Scale and gender): The difference in average estimation error between good and bad news trials, the difference in the number of good and bad news trials (e.g., Garrett & Sharot, 2017).

With the aggregated analysis, the effect of the optimistic update bias becomes less pronounced but we still found larger updating scores in good news compared to bad news trials (difference in U between good and bad news trials, paired t-test: $t(67) = 1.9$, $p = .062$, $M = 0.98$, 95% CI [-0.05, 2.00], $d = .23$; main effect of valence of news in the mixed design ANOVA: $F(1, 66) = 3.67$, $p = .063$). Although Kuzmanovic & Rigoux (2017), for example, did find a larger effect of valence of the news on updating ($d = 0.48$, N = 27), they report a very similar 95% CI of the difference in updating between good and bad news ([0.16, 1.99]). When calculating updating scores by defining the valence of trials as done with the original method (Korn, Sharot, Walter, Heekeren, & Dolan, 2014; Moutsiana et al., 2013; Sharot, Guitart-Masip, et al., 2012; Sharot et al., 2011), the difference in updating scores between good and bad news becomes substantially larger and similar to the effects reported in studies applying this method (see section 6.4).

**Updating in Good and Bad News Trails: The "Original" Method**

*Background*

In the original version of the belief updating paradigm as used, for example, in Korn et al. (2014), Moutsiana et al. (2013), Shah et al. (2016), Sharot, Guitart-Masip, et al. (2012), Sharot, Kanai, et al. (2012), Sharot, Korn, & Dolan (2011), participants are not asked to provide an estimate of the base rate. Good news trials are defined as trials where participants' first personal estimate is larger than the average probability, whereas bad news trials are defined as trials where the personal estimate is smaller than the average probability. One concern with this method is that researchers do not know participants' belief about the average probability of the event (Garrett & Sharot, 2014; Shah et al., 2016). When estimating one's personal risk, people might estimate their risk as being the same as for the average population. But they might also have diagnostic information specific to themselves that provide a good reason to estimate the own risk to be different from the base rate. For example, I might think that the base rate of getting breast cancer is about 5% but I know that there have been cases of breast cancer in my family. That is why I estimate my personal risk of getting breast cancer as being slightly higher than the risk in the average population. To be able to judge whether participants receive better- or worse-than expected news, researchers, hence, need to know participants' estimate of the base rate. Asking participants to provide an estimate of the base rate has an additional advantage: With information on participants' estimated base rate and their personal risk estimate, it is possible to calculate how a rational agent would update her beliefs according to Bayes theorem and compare participants' behavior to this normative benchmark (Kuzmanovic & Rigoux, 2017; Shah et al., 2016).

*Results*

Overall, results from the original method to define good and bad news trials are very similar to the results we report above, although the optimistic updating bias becomes much more pronounced with the original method ($t(67) = 9.01$, $p < .001$, $M = 6.61$, 95% CI [5.14, 8.07], $d = 1.09$; $F_{valence}(1, 66) = 80.86$, $p < .001$). Stress does not influence updating ($F_{stress}(1, 62) = 0.06$, $p = .806$, $F_{stress*valence}(1, 66) = 0.75$, $p = .390$). Analyzing the data trial-by-trial with the mixed-effects linear regression analysis, we also find increased updating in response to good news compared to bad news trials ($\beta_{valence} = 6.94$, $t(74.6) = 8.58$, $p < .001$) but no effect of acute stress ($\beta_{stress} = -0.79$, $t(62.8) = -1.03$, $p = .308$). Also when only analyzing those with the expected endocrine response to the stressor, i.e. an elevated cortisol level, we do not find an effect of stress on updating ($\beta_{stress\_reactors} = -0.43$, $t(58.8) = -0.48$, $p = .635$). Again perceived stress leads to overall lower updating scores ($\beta_{PSS} = -0.22$, $t(65.9) = -3.55$, $p < .001$). Although it decreases overall updating, perceived stress does not seem to influence the optimistic update bias as there is no interaction effect between scores in the Perceived Stress Scale and valence of the trials ($\beta_{PSS*valence} = -0.18$, $t(68) = -1.46$, $p = .150$).

*Figure A3.1.* Mean updating scores in bad news trials and good news trials for the control and stress group when good news and bad news are defined as done "originally" by the difference between participants' personal estimate PE1 and the actual base rate BR (Sharot et al., 2011).

# List of Contributions

**Chapter 2**

Popovic, N. F., Pachur, T. & Gaissmaier, W. (2018). The Gap Between Medical and Monetary Choices Under Risk Persists in Decisions for Others. (submitted)

- Idea and study design: NP, TP, WG
- Data collection: NP
- Data analysis: NP
- First draft manuscript: NP
- Edited manuscript and approved final draft: NP, TP, WG

**Chapter 3**

Popovic, N. F., Pruessner, J. C., Moussaïd, M. & Gaissmaier, W. (2018). Acute Stress Reduces the Amplification Process of Risk Perception.

- Idea and study design: WG, JP, NP, MM
- Data collection: NP
- Data analysis: NP
- First draft manuscript: NP
- Edited manuscript and approved final draft: NP, JP, WG, MM

**Chapter 4**

Popovic, N. F., Gaissmaier, W., Baer, L. & Pruessner, J. C. (2018). Stressed but More Optimistic? The Effect of Acute Stress on Belief Updating About Personal Risks.

- Idea and study design: NP, LB, WG, JP
- Data collection: NP, LB
- Data analysis: NP
- First draft manuscript: NP
- Edited manuscript and approved final draft: NP, JP, WG

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