Effects of stress on decisions under uncertainty: A meta-analysis

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Abstract

The purpose of the present meta-analysis is to quantify the effects that stress has on decisions made under uncertainty. We hypothesized that stress increases reward seeking and risk taking through alterations of dopamine firing rates and reduces executive control by hindering optimal prefrontal cortex functioning. In certain decision situations, increased reward seeking and risk taking is dysfunctional, while in others, this is not the case. We also assumed that the type of stressor plays a role. Additionally, moderating variables are analyzed, such as the hormonal stress response, the time between stress onset and decisions, and the participants' age and gender. Studies that investigated decision making after a laboratory stress induction versus a control condition are included in the meta-analysis (k = 32 datasets, N = 1829 participants). A random effects model reveals that overall, stress leads to decisions that can be described as more disadvantageous, more reward seeking and more risk taking compared with a non-stress condition (d = .17). In those situations in which increased reward seeking and risk taking is disadvantageous, stress leads to significant effects (d = .26), whereas in other situations, no effects were observed (d = .01). Effects were observed under processive stressors (d = .19), but not under systemic ones (d = .09). Moderation analyses did not reveal any significant results. We conclude that stress deteriorates overall decision-making performance through the mechanisms proposed. The effects differ depending on the decision situation and the type of stressor but not on the characteristics of the individuals.

Keywords: stress, decision making, meta-analysis, ambiguity, risk

Introduction

Many decisions must be made under stress. Choosing the correct answers on an exam or doing the right thing in an emergency are prominent examples. These examples also indicate that many decision situations are stress eliciting in and of themselves. Thus, if stress alters decision-making abilities, then difficult decision situations are prone to stress-induced changes. Some jobs expose workers to stressful situations in which important decisions must be made (Kälvemark, Höglund, Hansson, Westerholm, & Arnetz, 2004; Larsson & Sanner, 2010). Therefore, the influence that stress has on the quality of decisions receives growing scientific and public attention. Poor decision making due to stress is also discussed as a potential link between stress and an unhealthy lifestyle, e.g., by indicting smoking, drinking, or unhealthy diet (McEwen, 2008).

In a recent narrative review, Starcke and Brand (2012) summarized studies that examined the influence of acute stress on subsequent decisions in humans, particularly from a neuroscientific perspective. Studies included in this review were published between 1985 and 2011. Since then, numerous new studies have been published. In this study, we attempt to quantify a portion of the data with the help of a meta-analysis. The studies that are included in the meta-analytical calculations are preceded by an asterisk when they appear in the text.

Theoretical Background

Decision Making under Uncertainty

According to Balleine (2007), decision making is defined as the "ability of humans and other animals to choose between competing courses of action based on their relative value of consequences." The courses of action cover a wide array of phenomena, such as for example monetary, culinary, social, or moral decisions. Despite this phenomenological heterogeneity, decisions can be differentiated on a conceptual level; the degree of uncertainty that is associated with the expected outcome varies among decision situations (Weber & Johnson, 2009). Thus, some decision situations offer more information about the expected outcome than others do. They can be placed on a

continuum from complete ignorance (not even the possible outcomes are known), through ambiguity (the possible outcomes, or at least their dimensions, but not their probabilities are known), through risk (the outcome probabilities are known), and finally to certainty (only a single outcome is known to result). The placement on this continuum of uncertainty influences which mechanisms are particularly involved in a decision (see below). In decision-making research, many tasks reflect decisions under ambiguity or risk (Brand, Labudda, & Markowitsch, 2006; Schiebener & Brand, 2015). The categorization of these tasks is described below.

Decisions under ambiguity. In ambiguous situations, contingencies between options and potential outcomes are initially unknown to the person who faces the decision. Therefore, it is not possible to use any calculations that weigh options against one another. In these situations, learning from feedback is a particularly important mechanism. Thus, when the probability of an outcome is unknown, people must infer the probabilities through feedback from previous decisions. Feedback can be utilized to develop strategies in the course of the decision-making task such as reinforcement learning (inferring the expected reward values of each option on the basis of their previous outcomes and choosing the options with the highest expected value), or the win-stay/lose-shift strategy (choosing the same option if the outcome was a gain, and switching to a different option if the outcome was a loss). Worthy et al. (2013) compared different strategies that are based on feedback processing. Receiving feedback does not necessarily result in the development of strategies, but feedback can also be processed implicitly (Damasio, 1996). Thus, the decider relies on feelings and hunches that he or she experiences after the receipt of feedback (Bechara, Damasio, Tranel, & Damasio, 1997). The sensitivity to reward and punishment plays an important role in these situations. For example, a high sensitivity to immediate rewards can lead to a preference for current reward options that are disadvantageous in the long term (Bechara, 2003) or to the choice of immediate rewards instead of delayed rewards, although delayed rewards could be higher (Chabris, Laibson, & Schuldt, 2007). A prominent task that simulates decisions under ambiguity is the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Tranel, & Damasio, 2000). In this task, participants are exposed to four card decks (A, B, C, and D) and can choose one card at a time. The task has 100 trials, but this is unknown to the participants. Each card is associated with a financial gain, but in between, money is lost. Card decks differ in net gains: Decks A and B are disadvantageous, whereas decks C and D are advantageous. This must be discovered by the participants through the processing of the given feedback. Importantly, the disadvantageous decks A and B are initially associated with high gains and are only disadvantageous in the long term, which makes learning of contingencies more complicated. The processing of reward and punishment through feedback learning is involved in decision making under ambiguity.

On a neural level, decisions under ambiguity should rely particularly on brain regions associated with feedback learning and reward and punishment sensitivity, such as the ventromedial prefrontal/orbitofrontal cortex, the amygdala, and the striatum. Patients with lesions or dysfunctions in the ventromedial prefrontal/orbitofrontal cortex or the amygdala often choose the disadvantageous options in the IGT (Bechara, et al., 1994; Bechara, Damasio, Damasio, & Lee, 1999; Brand, Grabenhorst, Starcke, Vandekerckhove, & Markowitsch, 2007). Healthy participants show brain activations in the ventromedial prefrontal/orbitofrontal cortex (Bolla, Eldreth, Matochik, & Cadet, 2004; Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005; Thiel et al., 2003), the anterior cingulate cortex, and the dorsolateral prefrontal cortex (Adinoff *et al.*, 2003) during IGT performance. Patients with striatal or amygdala dysfunctions have difficulties in balancing reward and punishment or show flattened emotional response to punishment (Bechara, Damasio, & Damasio, 2003; Kobayakawa, Tsuruya, & Kawamura, 2010). Healthy participants show activations when exposed to reward and punishment in the ventral striatum, amygdala, ventromedial prefrontal/orbitofrontal cortex, and anterior and posterior cingulate gyrus (review in Liu, Hairston, Schrier, & Fan, 2011). On a neurotransmitter level, dopamine neurons in the basal ganglia are crucially involved in feedback learning (review in Shohamy, Myers, Kalanithi, & Gluck, 2008). Dopamine firing rates increase when the cues predict an upcoming reward. However, when a reward is expected and not received, dopamine firing rates decrease. Learning reward contingencies through feedback processing does not

rely on the absolute level of dopamine, but on the relative level and the exact timing of dopamine release. Dopaminergic neurons respond more strongly towards stimuli that predict rewards with large compared with small magnitudes (G. Morris, Nevet, Arkadir, Vaadia, & Bergman, 2006) and towards stimuli that predict immediate compared with delayed rewards (Kobayashi & Schultz, 2008). A complex neural network is involved in decisions made under ambiguity. It includes the firing rate of dopaminergic neurons in the basal ganglia and further processing steps in the limbic and prefrontal regions.

Decisions under risk. In situations of risk, probabilities of outcomes are known to the person who faces a decision. Therefore, it is possible to evaluate the outcomes and to choose options with the most preferred outcome considering the probabilities independent of previous decision outcomes (Brand, et al., 2006). In this process, decision-making strategies are involved, such as weighing the options against one another concerning their outcome valence and probability (Schiebener & Brand, 2015; Schiebener, Zamarian, Delazer, & Brand, 2011). Prominent strategies are maximization (choosing the option with the highest winning probability in each trial) and probability matching (choosing the options proportional to their winning probability). Stanovic and West (2003) described these strategies in detail. Prominent tasks that simulate decisions under risk are the Game of Dice Task (GDT; Brand *et al.*, 2005), lotteries (e.g., Putman, Antypa, Crysovergi, & van der Does, 2010) or wheels of fortune, such as the Risky Choice Task (Rogers et al., 2003). In the GDT, participants choose in 18 trials between a single die and a combination of two, three or four dice. A single die and the combination of two dice are associated with a low winning probability and a high potential gain or loss. The combinations of three or four dice are associated with a high winning probability and moderate potential gains or losses. Then, a single die is thrown. If the thrown number matches a chosen number, the participant receives a gain; otherwise, money is lost. Thus, the GDT has explicit and stable rules for gains and losses and their associated probabilities. In lotteries or wheel of fortune gambles, participants can also choose between options that have explicit rules for gains/losses and their respective probabilities. However, in these tasks, those rules are mostly unstable and a new strategy must be established for each trial. It must be stated that in situations of risk, strategies play an important role, but feedback processing also influences decisions. If a strategic decision is made, the feedback of the decisions' outcome can modulate the strategy for upcoming decisions (Schiebener & Brand, 2015). For example, participants can apply an advantageous strategy (maximization) and nevertheless receive a loss, and then switch to another option (lose-shift). Notably, people differ on to what degree they rely on strategies versus intuitions for decisions made under risk (Brand, Heinze, Labudda, & Markowitsch, 2008). Decisions made under risk conditions rely on the application of decision strategies and executive functioning, but the processing of feedback and the reliance on immediate and potential high rewards also plays a role.

On a neural level, decision making under risk conditions relies on brain regions that are involved in executive functioning, working memory, and the estimation of magnitudes but also on regions that are involved in feedback processing and reward sensitivity (Brand, et al., 2006). A key region for executive functioning and working memory is the dorsolateral prefrontal cortex (review in Nee *et al.*, 2013), which therefore plays an important role in strategy use, such as weighing options against one another. Patients who possess lesions of the dorsolateral prefrontal cortex show a tendency towards poorer decisions compared with patients who possess lesions of the orbitofrontal cortex in decisions made under risk (Manes et al., 2002). A single case study in a patient who possesses dysfunctions of the dorsolateral prefrontal cortex demonstrated that she made disadvantageous decisions under explicit risk conditions (Brand, Kalbe et al., 2004). Patients who potentially possess dysfunctions of the dorsolateral prefrontal cortex due to Parkinson's disease show similar results (Brand, Labudda et al., 2004; Euteneuer et al., 2009). Healthy participants who make decisions under risk while their brain activity is measured show activations in the dorsolateral prefrontal cortex, the ventral prefrontal cortex, the anterior cingulate gyrus and the anterior cingulate cortex, the orbitofrontal cortex, and the parietal cortex (e.g. Demanuele et al., 2015; Hsu, et al., 2005; Labudda et al., 2010; Labudda et al., 2008; Rogers et al., 2004; Rudorf & Hare, 2014). The latter is considered to be involved in the estimation and integration of magnitudes of gains and losses (Labudda, et al., 2008).

A very recent study demonstrated that the stimulation of the dorsolateral prefrontal cortex with transcranial direct current stimulation leads to alterations in decision making under risk conditions (Ye, Chen, Huang, Wang, & Luo, 2015). Brain regions involved in feedback and reward processing also show increased activation in decisions made under risk. For example, Xue et al. (2009) found ventral striatum and ventral medial prefrontal cortex activity during the processing of gains. During a risky decision, they found activation in the dorsal medial prefrontal cortex. Their results demonstrate the interplay of brain regions that are involved in cognitive processes and feedback and reward processing in decision making under risk.

Reward seeking and risk taking. As outlined above, in situations of ambiguity and situations of risk, the processing of rewards and punishments plays a crucial role for upcoming decisions because the anticipation of future rewards and punishments guides the current decision-making process. In most of the decision-making tasks described above (e.g., IGT and GDT), it is most advantageous to make risk averse decisions because potential high rewards are associated with likely high punishments. Participants who focus on the potential high rewards and ignore the potential punishments make decisions with a poor outcome because they are very likely to receive a great loss. However, this is not the case for all decision-making paradigms. In some situations, it is advantageous to rely on the potential high rewards a situation offers and to take some risk to receive the high reward. Thus, reward seeking and the associated risk taking is advantageous, at least to a certain degree, in these situations. A prominent example is the Balloon Analogue Risk Task (BART; Lejuez et al., 2002). In this task, participants have to pump up a balloon, and every pump is associated with a monetary reward. However, the balloon explodes at a random point, and if the balloon explodes, all money collected in the current trial is lost. The participants can stop pumping at any point they wish. When they stop pumping at a very early stage this leads to a small monetary gain, but when they continue pumping too long, the risk of an explosion (leading to zero money) increases. Thus, a balance between a certain degree of reward seeking and the associated risk taking versus risk avoidance leads to optimal results. On a neural level, risk taking in the BART is associated with increased activity in the striatum, the insula, the anterior cingulate cortex and the dorsolateral prefrontal cortex (Rao, Korczykowski, Pluta, Hoang, & Detre, 2008). A recent study used positron emission tomography and results demonstrated that dopaminergic neurotransmission modulates risk taking in the BART (Kohno et al., 2015). In some other tasks, for example some lottery tasks and wheel of fortune gambles, reward seeking behavior, which is associated with taking a risk, also leads to advantageous outcomes. In sum, decision situations cannot only be categorized as decisions made under ambiguity versus risk but also according to whether reward seeking and the associated risk taking are mainly detrimental or advantageous in a given situation.

Stress

Stress induction. Stress is assumed to occur whenever a demand exceeds the regulatory capacity of an organism, particularly in situations that are unpredictable and uncontrollable (Dickerson & Kemeny, 2004; Koolhaas et al., 2011). Stress elicits psychological, physiological, and behavioral reactions that differ substantially across individuals (Kudielka, Hellhammer, & Wüst, 2009). In the short term, they are considered adaptive, although in the long term, negative consequences emerge (Ellis & Del Giudice, 2014). Laboratory stressors simulate natural stressors. They consist of a socio-evaluative threat, a cognitive or physical demand or a combination of more than one of these components (Dickerson & Kemeny, 2004). Prominent laboratory stressors are public speaking tasks in combination with a cognitive demand such as the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993), in which a speech must be delivered and an arithmetic task must be performed. A child version (Buske-Kirschbaum *et al.*, 1997) and a group version of the TSST have been developed (von Dawans, Kirschbaum, & Heinrichs, 2011). Additionally, the pure announcement of a required public speech is used as a stressor (*Starcke, Wolf, Markowitsch, & Brand, 2008). Another common possibility to induce stress as a physical demand is the Cold Pressor Test (CPT; Hines &

Brown, 1936), in which participants must immerse a hand in ice water. A recent modification of this procedure combines the CPT with a social evaluative threat. While participants perform the CPT, their facial expression is recorded by a video camera (Schwabe, Haddad, & Schachinger, 2008). Another common physical threat is the announcement (*Keinan, 1987) or actual application (Clark *et al.*, 2012) of electric shocks during task performance. A cognitive and physical stressor, specifically designed for adolescents, is the Behavior Indicator of Resiliency to Distress (BIRD; Lejuez, Doughters, Danielson, & Ruggiero, 2006). In this task, participants must perform correct number selections to free a bird from its cage. Failure results in the bird staying in the cage and an aversive loud sound. Laboratory stressors differ in terms of whether they include physiological stress (also called systemic stressors) or consist of stress that results from interpreting a situation (also called processive stressors). Furthermore, laboratory stressors differ in their duration and timing. Some stressors are ongoing (e.g., announcement of shocks in case of a wrong reaction); others are completed prior to other tasks and substantially differ in duration from about three minutes (CPT) to 15 minutes (TSST). The type of the stressor as well as its timing and duration influence the height and exact nature of stress reactions that are described in the upcoming section.

Stress reactions. Methods for measuring stress reactions are manifold. It is essential to ensure that stress induction was successful when examining (decision-making) performance after stress exposure. Acute psychological stress reactions are frequently measured via questionnaires such as the State Trait Anxiety Inventory (STAI; Spielberger, 1972), which measures acute anxiety, or the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) or the Profile of Mood States (POMS; Shacham, 1983), which measure positive and negative affect.

However, most common in stress research is the assessment of biological reactions such as physiological, endocrine and, recently, neural reactions. Stress triggers two biological systems: the fast-reacting neural path, also known as the sympathetic adrenomedullary system (SAM-system; Cannon, 1914), and the slower-reacting hypothalamus pituitary adrenal axis (HPA-axis; Selye, 1956). The fast-reacting system originates in the hypothalamus, stimulates sympathetic nuclei in the medulla and triggers the release of adrenaline and noradrenaline from the adrenal medulla. They can be measured in the blood but also in saliva via the enzyme alpha-amylase (Nater & Rohleder, 2009). The release of adrenaline and noradrenaline leads to an increase in heart rate, blood pressure and electrodermal activity, which can be measured directly. Reactions of the SAM-system start immediately after the onset of stress and return to baseline approximately 10 minutes after the stressor stops (e.g., Het, Rohleder, Schoofs, Kirschbaum, & Wolf, 2009; Kirschbaum, et al., 1993). These fast reactions allow a fast fight-or-flight response towards stressors (Cannon, 1914). Laboratory stressors that include a physical or cognitive demand reliably elicit reactions of the SAM-system, while reactions of the HPA-axis are less pronounced (e.g., Lejuez, Kahler, & Brown, 2003; Schwabe, et al., 2008). Therefore, social evaluative components have been added to physical stressors (Schwabe, et al., 2008) and further potentially stressful elements, such as aversive pictures, have been added to cognitive stressors (Reinhardt, Schmahl, Wüst, & Bohus, 2012). A stimulation of the HPA-axis leads to the secretion of the corticotropin-releasing hormone from the peri-paraventricular nucleus of the hypothalamus and adrenocorticotropic hormone from the anterior pituitary, finally triggering the release of cortisol from the adrenal cortex (Sapolsky, 2000). Cortisol mobilizes energy resources through an elevation of blood glucose levels and can be measured in the blood, urine and saliva. In the central nervous system, limbic and prefrontal loops regulate HPA-axis activity (De Kloet, Joëls, & Holsboer, 2005; Herman, Ostrander, Mueller, & Figueiredo, 2005). In these regions, many receptors exist to which cortisol can bind. The peak cortisol secretion occurs approximately 21-40 minutes after the onset of a stressor (Dickerson & Kemeny, 2004). If the peak is high, an elevation of cortisol can be measured for more than one hour after cessation of the stressor; otherwise, cortisol levels return to baseline within 41-60 minutes after the stressor stops. This timeline is due to rapid non-genomic cortisol responses. In the aftermath of stress, genomic cortisol stress responses also occur and can last for several hours (Hermans, Henckens, Joëls, & Fernandez, 2014). Genomic cortisol responses induce changes in gene transcription that alter protein expression, structure and functioning of cells (de Kloet, Vreugdenhil, Oitzl, & Joëls, 1998). Rapid non-genomic cortisol responses affect cell functioning

without changes in gene transcription. They affect membrane lipids and membrane and cytoplasmic proteins (Haller, Mikics, & Makara, 2008). Laboratory stressors that include a social-evaluative threat in combination with a cognitive demand (such as the TSST) elicit the highest cortisol reactions in addition to reactions of the SAM-system (Dickerson & Kemeny, 2004).

Neural stress reactions of systemic and processive stressors. Stress potentiates dopaminergic activity (review in Ungless, Argilli, & Bonci, 2010). Acute painful stress increases striatal dopamine in healthy humans (Scott, Heitzeg, Koeppe, Stohler, & Zubieta, 2006), and the cortisol increase correlates with striatal dopamine (Pruessner, Champagne, Meaney, & Dagher, 2004). Thus, there is interdependence between endocrine and neurotransmitter reactions towards stress. Recent neuroimaging studies show that stress leads to metabolic changes in brain regions that have receptors for stress hormones such as the orbitofrontal cortex, the dorsolateral prefrontal cortex, the anterior cingulate cortex, the hippocampus, the thalamus, the hypothalamus, the amygdala, the basal ganglia, the ventral striatum, and the insular cortex (reviews in Dedovic, D'Aguiar, & Pruessner, 2009; Pruessner et al., 2010). Some studies indicate a decrease in activity in the orbitofrontal cortex, the hypothalamus and the hippocampus (Pruessner et al., 2008), and an increase in activity in the dorsolateral prefrontal cortex, the anterior cingulate cortex, the basal ganglia and the ventral striatum during stress (Pruessner, et al., 2004). Mixed results were reported for the amygdala, the thalamus and the insular cortex (Dedovic et al., 2009; Pruessner, et al., 2008; Wang et al., 2005). Inconsistent results may be explained by different hormonal reactions towards stress. Some individuals do not respond with a cortisol reaction towards stress while others do so. Those persons who do not show this hormonal stress response also do not show deactivations of the limbic system (Pruessner, et al., 2008).

Another reason for mixed results might be that different stressors engage different neural pathways. Physiologic stressors (i.e., systemic stressors) particularly trigger brainstem systems that project directly to the paraventricular nucleus of the hypothalamus. Stressors that include an interpretation of a situation (i.e., processive stressors) particularly engage limbic pathways prior to projecting to the hypothalamic paraventricular nucleus (Herman, Prewitt, & Cullinan, 1996). This is an established finding in animal literature, but evidence in humans is sparse thus far. Nevertheless, the distinction between those two types of stressors is proposed to exist in humans as well (Dedovic, Duchesne, Andrews, Engert, & Pruessner, 2009). An example of a systemic stressor applicable to humans is the CPT, and an example of a processive stressor applicable to humans is the TSST.

Decision Making under Stress

Main effects. As outlined above, stress and decision making are not only related on a behavioral level (many decisions must be made under stress or are stressful by themselves) but also share neurobiological substrates. The brain regions that are involved in decision making, such as limbic, basal ganglia and prefrontal cortex regions (review in Vorhold, 2008), show alterations under acute stress (review in Dedovic, D'Aguiar, et al., 2009). These regions possess numerous receptors to which stress hormones can bind.

Two mechanisms are proposed to explain how acute stress may influence subsequent decision making under uncertainty: First, acute stress should increase the reliance on immediate and potentially high rewards. Stress leads to an increase in dopaminergic activity via the stress hormone cortisol (Ungless, et al., 2010), and the dopamine firing rate is crucially involved in reward prediction and feedback learning (Shohamy, et al., 2008). Dopaminergic neurons respond strongly towards stimuli that predict rewards with large magnitudes (G. Morris, et al., 2006) and towards stimuli that predict immediate rewards (Kobayashi & Schultz, 2008). Thus, an elevated dopamine response can lead to focusing on immediate and potentially high rewards. As dopamine firing rates increase under acute stress, Mather and Lighthall note that “stress triggers additional reward salience (STARS),” or, more poetically, “Seeing STARS: Stress can make rewards gleam more brightly”(Mather & Lighthall, 2012, page 2). At the same time, the willingness to avoid potential losses is diminished. While a focus on

potential high and immediate rewards can be beneficial in some decision-making tasks (such as the BART), other tasks (such as the IGT or the GDT) profit from a careful consideration of the potential losses that are associated with each option. Thus, a heightened reward and lowered punishment sensitivity could lead to changes in decision making under stress, which are beneficial in some situations, but dysfunctional in others. Feedback learning and reward processing are essential for decisions made under ambiguity because no clues other than the feedback of a previous outcome are provided. Empirically, studies indicate that stress influences decisions made under ambiguity (e.g., *Lighthall, Mather, & Gorlick, 2009; *van den Bos, Harteveld, & Stoop, 2009).

Second, stress may lead to hurried and unsystematic decision making without considering all options (review in Janis & Mann, 1977). Recent studies also suggest that stress impairs executive control (review in Hermans, et al., 2014). According to Hermans et al., executive control is suppressed under acute stress because the excessive release of dopamine, noradrenaline, and cortisol impairs the normal functioning of the prefrontal cortex. Neurons of the prefrontal cortex cannot maintain persistent patterns of spiking activity under these circumstances. Executive functioning and systematic consideration of options is crucial for decision making under risk. Empirical evidence suggests that acute stress influences decision making under risk (e.g., *Keinan, 1987; *Leder, Häusser, & Mojzisch, 2013; *Starcke, et al., 2008).

Moderating effects. Several moderators may influence the exact nature of stress effects on subsequent decision making. They concern the stressor and associated stress responses as well as characteristics of the individual. Regarding the reactions towards a certain stressor, it is frequently observed that stress induction does not affect decisions per se, but the individual stress reaction does (e.g., Starcke, Polzer, Wolf, & Brand, 2011). In particular, the release of stress hormones is thought to cause alterations in decision making. As outlined above, a heightened release of adrenaline, noradrenaline and cortisol increases dopaminergic activation in certain brain regions, which in turn is considered to lead to heightened reward salience and reduced executive control. Therefore, persons who do not respond with a release of stress hormones after being exposed to a stressor should be less affected by stress when making a decision. Empirical studies show a relationship between individual stress responses and decision-making performance in decisions made under uncertainty (e.g., *Leder, et al., 2013; *Starcke, et al., 2008). Notably, not only were linear relationships observed, but a recent study suggests an inverted u-shaped relationship between cortisol responses and decision-making performance in males (*van den Bos, et al., 2009). These authors suggest that an optimal stress level for decision-making performance might exist. Another moderator that is closely related to the individual's stress hormone release is the timing of stressors. Neuroendocrine reactions towards stressors vary over time (Hermans, et al., 2014): First, noradrenaline and dopamine are secreted directly after stress onset and return to baseline soon after cessation of the stressor; second, non-genomic cortisol responses occur sometime after stress onset and overlap with noradrenergic and dopaminergic reactions, potentiating the effects of stress on dopamine release; finally, genomic cortisol reactions occur at least one hour after stress onset. The genomic actions of cortisol may reverse the initial effects of noradrenergic, dopaminergic and non-genomic cortisol responses. Thus, early stress responses should increase reward salience and decrease executive control, while late stress responses (at least one hour after stress onset) might have opposite effects. Therefore, timing of the stress induction relative to the subsequent decision-making task should be an important moderator of how stress affects decisions. Laboratory stressors differ in their timing and also in their duration, which should be taken into account when interpreting the effects of stress on decisions. Recent empirical studies also indicate that the timing between stress onset and the decision-making task is important (*Pabst, Brand, & Wolf, 2013a). The authors conclude that stress effects are particularly detrimental when the release of noradrenaline, dopamine and non-genomic cortisol responses overlap.

Concerning the characteristics of the individual, demographic variables such as gender and age may influence the effects of stress on decisions. The participants' gender influences stress reactions (Kudielka, et al., 2009) and partly affects decision-making performance under conditions of initial ambiguity (van den Bos, Homberg, & de Visser, 2013). Males show a higher response to laboratory

stress than females. However, females' stress response depends on the phase of their menstrual cycle and their intake of oral contraceptives. Females who use oral contraceptives or who are in the follicular phase of the menstrual cycle show blunted hormonal stress responses. In the absence of stress, some studies report differences in decision making between males and females. For example, van den Bos et al. (2013) suggest that males outperform females in the IGT. However, no gender effects were observed in the GDT, even in a very large sample (Brand & Schiebener, 2013). In studies that examined the interaction between stress and gender on decision making, males took more risks under stress, while females became more conservative under stress (*Daughters, Gorka, Matusiewicz, & Anderson, 2013; *Lighthall, et al., 2009; *Preston, Buchanan, Stansfield, & Bechara, 2007; *van den Bos, et al., 2009). This enhanced the performance of males when risk taking was advantageous in a certain task, but decreased their performance when risk taking was disadvantageous. In a recent study (*Lighthall et al., 2012), brain activation during the BART after stress exposure were measured. The results indicate that the activation of the insula and putamen was increased in males, but not in females. Activation of the dorsal striatum was related with increased reward-seeking behavior in stressed males, but not in stressed females. Thus, an interaction between stress and gender on decision making might exist on a behavioral, endocrine and neural level.

The participants' age might also moderate the effects of stress on decision making. However, the effects of age on stress responses appear to be minor. Only a few studies have reported elevated cortisol responses in elderly participants, and only in males (Kudielka, et al., 2009). De Kloet and colleagues (1998) suggest that even with older age, homeostatic control can be maintained, which results in similar endocrine stress responses in older and younger persons. However, age influences decision making in the absence of stress (Mata, Josef, Samanez-Larkin, & Hertwig, 2011). In decisions made under risk conditions, old and young participants show similar decision-making behavior aside from older adults who have impaired executive functions (Brand & Schiebener, 2013). In decisions made under ambiguity, age differences emerged as a function of learning. Older adults' learning was poorer compared with younger adults' learning. Therefore, older adults sought risk when learning usually lead to risk-avoidant behavior, and they were risk-averse when learning usually lead to risk-seeking behavior. It has been suggested that dopaminergic systems are less responsive to reward processing at higher ages (review in Bäckman, Lindenberger, Li, & Nyberg, 2010). A recent study that examined the interaction between stress and age on decision making found that stressed older adults became most risk averse, which led to a disadvantageous outcome in the task used (*Mather, Gorlick, & Lighthall, 2009). However, another study by the same workgroup could not demonstrate a stress-age interaction in decision making (*Lighthall, Gorlick, Schoeke, Frank, & Mather, 2013). Thus, age appears to influence decision making in the absence of stress, while results concerning a stress-age interaction in decision making are inconclusive to date.

Hypotheses

As outlined above, stress leads to a strong reliance on immediate and potentially high rewards. This effect is caused by an increased firing rate of dopaminergic neurons, which is modulated by the stress hormone cortisol. Furthermore, stress impairs executive control because the secretion of stress hormones hinders the functioning of the prefrontal cortex. Reward processing is involved in both decisions made under ambiguity and decisions made under risk. Executive functioning is particularly involved in decisions made under risk. We therefore hypothesize that:

H1) Stress influences subsequent decision making in situations of ambiguity and risk.

As stress leads to a focus on potential high and immediate rewards, stress increases the willingness to take risks and to ignore potential negative outcomes. This is beneficial in some situations, but disadvantageous in others. Decisions made under ambiguity and risk can be impaired or unimpaired by increased reward seeking and risk taking. We therefore hypothesize that:

H2) The specific reward contingencies of a decision situation differentially affect decisions made under stress.

Different types of stressors elicit different neural stress responses. Systemic stressors trigger brain stem responses and processive stressors trigger limbic responses. We therefore hypothesize that:

H3) The specific stressors differentially affect decisions made under stress.

One underlying mechanism for stress affecting subsequent decisions is the release of stress hormones that affects numerous neuroendocrine processes. An elevated stress response strongly affects subsequent behavior. We therefore hypothesize that:

H4a) The peak cortisol stress response in the stress condition moderates the influence of stress on subsequent decisions. An elevated response predicts poor performance in situations in which heightened reward seeking is dysfunctional.

H4b) The peak alpha-amylase stress response in the stress condition moderates the influence of stress on subsequent decisions. An elevated response predicts poor performance in situations in which heightened reward seeking is dysfunctional.

The neuroendocrine stress responses after stress exposure vary over time. Adrenaline, noradrenaline and dopamine are released first, then non-genomic cortisol responses, and finally genomic cortisol responses occur. On a functional level, early stress responses should increase reward salience and decrease executive control, while late stress responses (at least one hour after stress onset) can have opposite effects. However, studies published thus far on the effects of stress on decisions made under uncertainty published so far used time intervals smaller than one hour after stress onset. Therefore, the effects should be the highest when the release of adrenaline, noradrenaline, dopamine and non-genomic cortisol responses overlap. We therefore hypothesize that:

H5) The time between stress onset and decision making moderates the influence of stress on subsequent decisions. A long interval predicts poor performance in situations in which heightened reward seeking is dysfunctional.

Males and females differ in their reactions towards stress and partially in their decision-making performance in the absence of stress. After stress exposure, males show more reward seeking and take more risks under stress, while females become more conservative under stress. Preliminary results indicate that the activation of the insula, the putamen and the dorsal striatum differ between males and females when making decisions made under stress. We therefore hypothesize that:

H6) The proportion of female participants in a sample moderates the influence of stress on subsequent decisions. A low proportion of females predicts poor performance in situations in which heightened reward seeking is dysfunctional.

The effects of age on decisions after stress exposure have rarely been studied, and the existing results are inconsistent. While older and younger adults appear not to differ substantially in their stress reactions, older adults have lower performance in the absence of stress in decisions made under ambiguity and partially in decisions made under risk. The underlying mechanisms are that learning might be reduced due to dopaminergic systems responding less to reward processing, and older adults are more prone to reduced executive functioning. We therefore hypothesize that:

H7) The participants' age in a sample moderates the influence of stress on subsequent decisions. High age predicts poor performance.

In addition to our hypotheses that are based on previous findings, we aim to address some exploratory questions with limited empirical evidence thus far: As we expect differential effects concerning the decision situation and the type of stressor, we calculate whether there are interactions between the type of decision situation and the type of stressor. We therefore ask:

Exploratory question 1) Is there an interaction between the type of decision situation and the type of stressor in predicting stress effects on decision-making performance?

One recent study (*van den Bos, et al., 2009) reported an inverted u-shaped relationship between the cortisol stress response and decision-making performance in males. This could be interpreted as reflecting the Yerkes-Dodson law (Yerkes & Dodson, 1908), which suggests an optimal level of arousal for performance. We therefore ask:

Exploratory question 2) Is the relationship between stress responses and decision-making performance non-linear but quadratic (inverted u-shaped)?

Recent research suggests that stress responses of the HPA-axis and those of the SAM-system are interdependent. We therefore ask:

Exploratory question 3) Do cortisol stress responses and alpha-amylase stress responses interact to predict the effects of stress on decision-making performance?

Method of Meta-Analysis

Literature Search

Inclusion criteria. The present meta-analysis includes studies investigating the influence of acutely induced laboratory stress on laboratory decisions in healthy humans that were published between 1985 and August 2015. Stress reactions and decision-making performance had to be quantified and only original data were included. We restricted our search to studies that investigated decision making in a narrower sense, which means that decisions must be made between at least two options in more or less complex situations. Tasks in which participants must react or choose not to react (as Go/No-Go tasks) or other tasks that measure basic perceptual and attentional processes (as signal detection tasks) were not included in this analysis. Additionally, only decision-making paradigms were included that investigated decisions under uncertainty that can be clearly identified as advantageous/disadvantageous, safe/risky, or patient/impatient. Tasks that examine social or moral decisions (such as moral dilemmas) were not included.

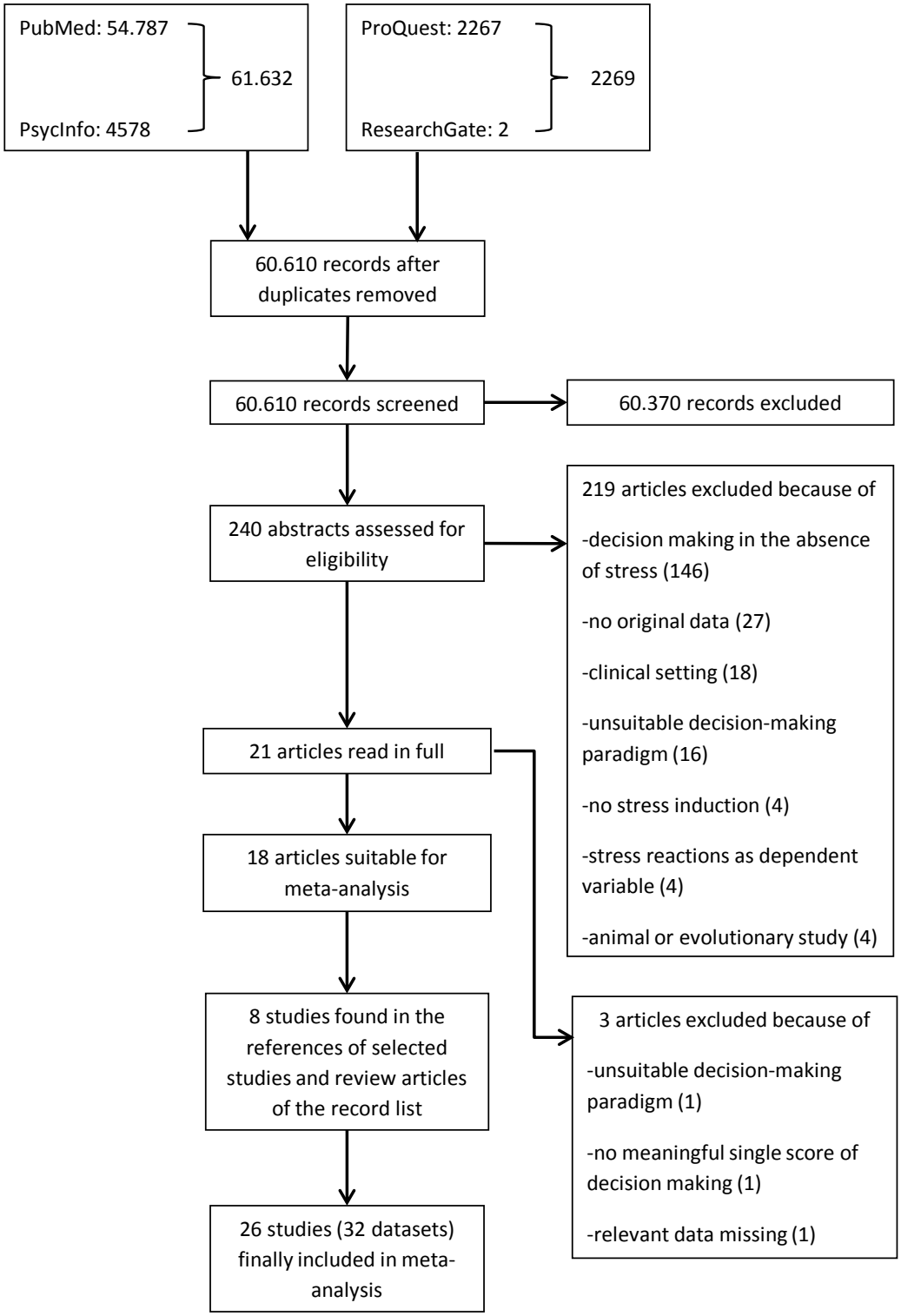
Searching procedure. Two databases were searched for suitable articles that were published in peer-reviewed journals: PubMed and PsycInfo. We used the search terms ‘stress’ and ‘decision making’ and also used a synonym finder to find suitable synonyms for the terms ‘stress’, ‘decision’ and ‘decision making’ (www.synonym-finder.com). Suitable synonyms for stress were ‘strain,’ ‘tension,’ and ‘tenseness’; suitable synonyms for decision were ‘selection,’ ‘choice,’ ‘judgment,’ and ‘judgement’; a suitable synonym for ‘decision making’ was ‘deciding.’ We added search terms that are common in the operationalization of stress and decision making, such as ‘social evaluation,’ ‘pressure,’ and ‘pressor’ for stress; and ‘risk taking’ and ‘gambling task’ for decision making. In PubMed and PsycInfo, a search according to Boolean logic was performed: Each search term reflecting stress (using the conjunction OR) and each search term reflecting decision making (using the conjunction OR) were combined using the conjunction AND.

We searched for unpublished data using the databases ProQuest to search for dissertations (www.proquest.com) and posted a request to send unpublished data on Research Gate (https://www.researchgate.net/home). The request was posted on October 10th and we asked to send potential data until November 3rd.

Search results. From the search of PubMed, 54.787 hits were retrieved. From the search of PsycInfo, 4.578 hits were retrieved. The ProQuest search led to 2.267 hits and two studies were sent via ResearchGate. The 63.901 hits were exported into one excel list. Two judges worked on this excel list, and each judge screened half of the headlines. The hits were sorted according to the headlines of the study, so it was possible to recognize duplicates. After the removal of duplicates, 60.610 hits

remained in the list. Keywords that led to the exclusion of studies were cancer (2759), disorder (509), HIV (747), food choice (284), hospital (727), heart failure (144), surgical decision making (107), treatment selection (186), decision support system (792), genetic (796), and genes (473). This procedure resulted in the exclusion of 7524 articles. All other headlines were read carefully and articles were excluded if the headline signaled that the topic was not related to our research question. For example, articles with patient groups as participants, or animals as subjects. After this procedure, 240 articles remained. One judge read the abstracts of those articles and excluded further 219 articles that were unrelated to the research topic. Reasons for exclusion at this stage were that the studies investigated decision making in the absence of stress (146); that the articles were no original articles, but reviews, commentaries etc. (27); that studies investigated patients or dealt with medical topics such as pharmacological interventions (18); that decision-making paradigms were not suitable, because they assessed social, moral, perceptual, or motor decisions (16); that studies utilized natural stress levels instead of stress induction (4); that decisions were the factor and stress reactions the dependent variable (4); or that studies included animal or evolutionary investigations (4). The remaining 21 articles were read in full which led to the further exclusion of three articles. One used an unsuited decision-making paradigm, one did not allow to create a meaningful single score of decision making performance (as also discussed with the corresponding author), and from one, relevant data were missing and could not be provided by the authors anymore. Thus, 18 articles remained. They were read again to look for potentially relevant articles that were cited in there. The same was done with review articles on stress and decision making. This led to a detection of 8 further articles meeting our inclusion criteria. Overall, 26 articles (containing 32 datasets) could be included in the meta-analytical calculations. Three of the studies were unpublished at the time of the literature search, as also indicated in Table 1. After the selection process, two further independent judges received the abstracts of the 26 articles that were included and in addition abstracts of 26 randomly selected articles that were excluded for the meta-analysis on the basis of the described criteria. The 52 abstracts were presented in random order. The judges were asked to decide with Yes/No whether or not each of the abstracts fulfills the inclusion criteria described. The results of this post-hoc evaluation were: Judge 1: Hit rate included studies: 22 of 26 (84.6%), hit rate excluded studies: 26 of 26 (100%), hit rate overall: 48 of 52 (92.3%); Judge 2: hit rate included studies: 26 of 26 (100%), hit rate excluded studies: 26 of 26 (100%), hit rate overall: 52 of 52 (100%). The inter-rater reliability was $r = .856$ ($p < .001$). The four included studies, which were not detected by the first judge, were again inspected by both authors and were considered clearly matching the inclusion criteria. Even more important in order to not overlooking relevant articles is the result that both judges considered 100% of the excluded abstracts as not matching the inclusion criteria. Given the clear definition of inclusion and exclusion criteria, the carefully performed selection process, and the high hit rate of the two additional judges in the post-hoc evaluation design, we think that defining the sample of studies included in the meta-analysis is reliable. The selection procedure can be observed in Figure 1.

Figure 1. Flow diagram of the literature search.



Studies included. Thus, in the final meta-analysis, 26 studies (32 datasets, n = 1829) were included (the studies are preceded by an asterisk when they appear in the text). Out of the 26 studies, 22 used a between-subjects design (participants were either stressed or not stressed), and four used a within-subjects design (participants were tested under stress conditions and under rest conditions). In each of the studies, participants performed a decision-making task after the experimental manipulation. Most of the studies that used a between-subjects design reported randomization of the participants to either the stress or the control condition; most of the within-subjects studies reported that the order of the stress versus the control condition was counterbalanced or potential order effects were controlled for afterwards. In most of the studies that assessed hormonal stress reactions, exclusion criteria that are common in stress research were applied; for example, the participants were not allowed to have any chronic or acute diseases, to smoke, to take medications, etc. Both procedures are suited to reduce the risk of biases for the individual studies. Studies were subdivided into those assessing decisions made under ambiguity and those assessing decisions made under risk. A further subdivision is made into decision-making paradigms in which decision making is impaired by increased reward seeking and risk taking and those in which this is not the case.

Calculations

Data acquisition and coding. The following variables were coded (if assessed): N; mean and standard deviation of decision-making performance in the stress condition and the control condition; minutes between stress onset and decision-making task; cortisol increase (nmole/l) in the stress condition; alpha-amylase increase (u/ml) in the stress condition; age; and gender. If the data were not reported in the paper, the authors were asked to provide the relevant data.

Effect size calculation. *N*, means, and standard deviations of decision-making performance were used to calculate Cohen's *d* as effect size. For the studies that used a between-subjects design, Cohen's *d* was calculated as (mean control group - mean stress group)/pooled *SD* (Cohen, 1988). For the studies that used a within-subjects design, Cohen's *d* was calculated as (mean control condition - mean stress condition)/*SD* control condition (Becker, 1988). We used this formula for within-subjects designs because it uses the raw score of the control condition and does not the change score of the experimental condition compared with control condition as denominator. Therefore, an analysis of the correlations between experimental and control conditions is not necessary. By doing so, we also solve the problem of combining the effect sizes of studies that use a between-subjects design and studies that use a within-subjects design. When using the raw-score formula by Becker, one can combine the effect sizes of between-subjects and within-subjects designs without additional calculations (Looney, Feltz, & VanVleet, 1994; S. B. Morris & DeShon, 2002). In studies that use a between-group design, it can be useful to correct *d*-scores for potential biases resulting from small sample size (Hedges, 1982). In order to provide the readers with these corrected effect size measures, we included Hedges' *g* in addition to Cohen's *d* for those studies that used a between-group design (see Table 1).

Meta-analytical calculations. A random effect size model (Hunter & Schmidt, 2004) was used for significance testing, confidence intervals, and Chi-square tests of homogeneity according to Hedges and Vevea (1998). Significant Chi-square tests indicate heterogeneity of the results. *D*-scores were utilized to consider the effects' directions. Thus, positive values represent a performance of the unstressed condition that is defined as more right, more advantageous, safer, less risky or more patient compared with the stress condition. Conversely, negative values represent a performance of the stress condition that is defined as more right, more advantageous, safer, less risky or more patient compared with the control condition. In this analysis, we perform the analyses a) for all datasets, b) separated by decision situation (ambiguity versus risk, and reward seeking disadvantageous versus not), and c) separated for the type of stressor (systemic versus processive).

Test for potential publication bias. As a first rough indicator of publication bias, the fail-safe *N* procedure by Rosenthal (Rosenthal, 1979) was used. This procedure estimates the number of unpublished studies needed to turn a significant effect size into a non-significant one. Then, Begg and Mazumdar's rank correlation test was applied (Begg & Mazumdar, 1994). This test quantifies the relationship between effect size and sample size, and a significant result indicates potential publication bias. However, in meta-analyses with few studies included, a non-significant result does not guarantee unbiased data. Therefore, we created funnel plots as proposed by Vevea and Woods (2005). Funnel plots indicate visual asymmetries that may arise from publication biases. The effect size of each single study is shown on the x-axis and the standard error (summarizing sample size and standard deviation) on the y-axis. If there is no bias, the plot should resemble a symmetrical inverted funnel. In case of bias, the funnel plot can show asymmetries because small studies with no significant results remain unpublished. A triangle within which 95% of studies would be expected to lie in case of no biases can be plotted. Examples of hypothetical funnel plots are provided in Higgins and Green (2011). The method by Vevea and Woods (2005) allows for estimating the effect sizes corrected for those biases. It determines a priori a set of fixed weights that represent a specific form and severity of biased selection and calculates the corrected effect sizes. Typical estimated weight functions are moderate one-tailed selection, severe one-tailed selection, moderate two-tailed selection, and severe two-tailed selection. One-tailed selection means that nonsignificant results with large one-tailed *p*-values remain unpublished. Then, the plot becomes skewed. Two-tailed selection means that selection is based on two-tailed *p*-values and studies with small sample sizes and effects around zero remain unpublished (Vevea & Hedges, 1995). This method is suitable for meta-analyses with fewer than 100 studies included. However, at least ten studies should be included for such a funnel plot (Higgins & Green, 2011), so we do not apply them for each subcategory of decision situations and stressors.

Moderator analysis. The cortisol stress response in the stress condition (peak minus baseline), the alpha-amylase stress response in the stress condition (peak minus baseline), the minutes between stress onset and the decision-making task, age, and gender distribution were included as continuous moderators. Moderator analyses were also performed a) for all datasets, b) separated by decisions situation (ambiguity versus risk, and reward seeking disadvantageous versus not), and c) separated by type of stressor (systemic versus processive).

Results

Main Results for Each Study

The basic study parameters and the main results for each study are shown in Table 1. The table is subdivided into decisions made under ambiguity and risk and further subdivided into those decision-making paradigms in which heightened reward seeking and risk taking is dysfunctional, and those in which this is not the case.

Table 1

Studies examining the effect of acutely induced laboratory stress on decisions made under ambiguity and in which increased reward seeking and risk taking were disadvantageous

Study	Participants	Decision-making task	Stressor	Time between stress onset and decision making[a]	Stress measures	Main result (Cohen's *d* and Hedges' *g*)
Kassam et al. (2009)	32 m/71 f	Anchoring and Adjustment	Modified TSST (processive)	15 min	heart rate, blood pressure	CC made better decisions than SC (*d* = .60, *g* = .60).
Lighthall et al. (2013)	48m/48f	Probabilistic selection task	CPT (systemic)	17 min	Cortisol	CC made better decisions than SC (*d* = 1.00, *g* = .99).
Otto et al. (2013)	26 m/30 f	Model based learning Model free learning	CPT (systemic)	5 min	Cortisol	In model based decisions, CC performed better than SC (*d* = .26, *g* = .26). In model free decisions, SC performed better than CC (*d* = .03, *g* = .03).
Preston et al. (2007)	Students and university	IGT	Anticipated speech (processive)	Immediately/ongoing	Heart rate	CC made more advantageous decisions than

	staff 20 m/20 f					SC (*d* = .06, *g* = .06).
Van den Bos et al. (2009)	Students and university staff 30 m/34 f	IGT	TSST (processive)	15 min	Cortisol	CC made more advantageous decisions than SC (*d* = .37, *g* = .37).
Wemm (2014)[c]	Students 24 m/32 f	IGT	TSST (processive)	13 min	Heart rate SCL PANAS	CC made more advantageous decisions than SC (*d* = .59, *g* = .59).

Studies examining the effect of acutely induced laboratory stress on decisions made under ambiguity and in which increased reward seeking and risk taking were not disadvantageous

Study	Participants	Decision-making task	Stressor	Time between stress onset and decision making[a]	Stress measures	Main result (*d*)
Buckert et al. (2014)	Mainly students 36m/39f	Lotterie tasks with hidden probabilities	TSST for groups (processive)	30 min	Heart rate Cortisol MDBF	CG has a higher ambiguity aversion than SC (*d* = .05, *g* = .05).
Daughters et al. (2013)[b]	Adolescents 59m/73f	BART	BIRD (processive)	20 min	Cortisol	SC made more unsafe decisions than CC (*d* = .06).

Finy et al. (2014)	Adolescents 88	BART	TSST for children (processive)	40 min	Cortisol VAS	CC made more unsafe decisions than SC (*d* = .10, *g* = .10).
Lighthall et al. (2009)	22 m/23 f	BART	CPT (systemic)	18 min	Cortisol	CC made more unsafe decisions than SC (*d* = .07, *g* = .07).
Lighthall et al. (2012)	24 m/23 f	BART	CPT (systemic)	24 min	Cortisol	SC made more unsafe decisions than CC (*d* = .18, *g* = .17).
Mather et al. (2009)	Younger and older adults 43 m/42 f	Driving Task	CPT (systemic)	18 min	Cortisol	CC made more unsafe decisions than SC (*d* = .62, *g* = .61).
Reynolds et al. (2013)[b]	Adolescents Ca. 11m/23f	BART	Anticipated speech (processive)	Immediately/ongoing	Short PANAS	SC made more unsafe decisions than CC (*d* = .12).

Studies examining the effect of acutely induced laboratory stress on decisions made under risk and in which increased reward seeking and risk taking were disadvantageous

Study	Participants	Decision-making task	Stressor	Time between stress onset and decision	Stress measures	Main results (*d*)

				making[a]		
Chipman & Morrisson (2015)[c]	Students 63f	Delay discounting	SECPT (systemic with one processive element)	5 min	Heart rate Blood pressure Subjective ratings	CC made more impatient decisions than SC (*d* = .26, *g* = .26).
Gathmann et al. (2014)	Mainly students 17 m/16f	Modified GDT	TSST (processive)	30 min	Cortisol Alpha-amylase PANAS	CC made more advantageous decisions than SC (*d* = .48, *g* = .47).
Haushofer et al. (2013)	Students 142 m	Delay discounting	TSST for groups (processive)	35 min 55 min	Cortisol Alpha-amylase PANAS VAS	35 minutes after stress onset, no differences between SC and CC were observed (*d* = .00, *g* = .00). 55 minutes after stress onset, CC made more patient decisions than SC (*d* = .17, *g* = .16).
Keinan (1987)	Students 42 m/59 f	Analogies Task	Threat of electric shock	Immediately/ongoing	STAI	CC made better decisions than SC (*d* =

			(processive)			1.25, *g* = 1.24).
Leder et al. (2013)	Students 60m	Beauty contest game	TSST for groups (processive)	16 min	Cortisol	CC made better decisions than SC (*d* = .34, *g* = .34).
Lempert et al. (2012)	113m	Delay discounting	Anticipated speech (processive)	5 min	Cortisol PANAS	CC made more patient decisions than SC (*d* = .14, g = .14).
Pabst et al. (2013)	Students 62m/64f	GDT	TSST (processive)	25 min	Cortisol Alpha-amylase PANAS	CC made more advantageous decisions than SC (*d* = .25, *g* = .25).
Pabst et al. (2013a)	Students 40m	GDT	TSST (processive)	5 min 18 min 28 min	Cortisol Alpha-amylase PANAS	5 and 18 minutes after stress onset, SC made more advantageous decisions than CC (*d* = .97, *g* = .93, *d* = .88, *g* = .85). 28 minutes after stress onset, CC made more advantageous decisions than

						SC (*d* = .58, *g* = .55).
Pabst et al. (2013b)	Students 40m/40f	Modified GDT	TSST (processive)	25 min	Cortisol Alpha-amylase	SC made more advantageous decisions than CC (*d* = .34, *g* = .34).
Starcke et al. (2008)	Students 18 m/22 f	GDT	Anticipated speech (processive)	30 min/ongoing	Cortisol Alpha-amylase STAI PANAS	CC made more advantageous decisions than SC (*d* = .94, *g* = .92).

Studies examining the effect of acutely induced laboratory stress on decisions made under risk and in which increased reward seeking and risk taking were not disadvantageous

Study	Participants	Decision-making task	Stressor	Time between stress onset and decision making[a]	Stress measures	Main results (*d*)
Buckert et al. (2014)	Mainly students 36m/39f	Lotterie tasks	TSST for groups (processive)	30 min	Heart rate Cortisol MDBF	SC made more risky decisions than CC (*d* = .33, *g* = .32).
Lempert et al. (2012)	113m	Lottery task	Anticipated speech (processive)	5 min	Cortisol PANAS	CC made more risky decisions than SC (*d* = .30, *g* = .30).
Neuwirth	Students	WaTr Sim	TSST	32	Cortisol	SC made

(2013)[c]	29m/24f		(processive)		PANAS PASA STAI	more risky decisions than CC (d = .56, g = .55).
Porcelli & Delgado (2009)[b]	Students 14 m/13 f	Lotteries	CPT (systemic)	2 min	SCL	SC made more risky decisions than CC (d = .27).
Richards et al. (2015)[b]	Adolescents 11m/24f	Wheel of Fortune Gambles	Anticipated speech (processive)	Immediately/ongoing	Short PANAS	CC made more risky decisions than SC (d = .03).

Note. BART = Balloon Analogue Risk Task; BIRD = Behavior Indicator of Resiliency to Distress; CC = Control Condition; CPT = Cold Pressor Test; GDT = Game of Dice Task; MDBF = Mehrdimensionaler Befindlichkeitsfragebogen (German mood scale); PANAS = Positive and Negative Affect Schedule; PASA = Primary Appraisal Secondary Appraisal questionnaire; POMS = Profile of Mood States questionnaire; SC = Stress Condition; SCL = Skin Conductance Level; SCR = Skin Conductance Response; SECPT = Socially Evaluated Cold Pressor Test; STAI = State Trait Anxiety Inventory; TSST = Trier Social Stress Test; VAS = Visual Analog Scale; WaTr Sim = Waste Water Treatment Simulation Task.

[a]Approximate time in minutes. [b]Within-subjects design. [c]Unpublished data (at the time of the literature search).

Effects of Stress Induction

Overall effects. We analyzed the *d*-values according to the effects' directions. Thus, whether unstressed participants achieved results that were better (or more advantageous, safer, less risky or more patient) compared with stressed participants was analyzed. Positive *d*-values represent a better performance of the unstressed participants, whereas negative *d*-values represent a better performance of the stressed participants. For all 32 datasets, an effect size d of .17 was observed (lower d = -.02, upper d = .32, standard error = .08, z = 2.17, $p < .05$). The test for homogeneity was not significant (X^2 = 33.59, df = 31, p = .34). Rosenthal's fail-safe N was 126. Begg and Mazumdar's rank correlation test was not significant (r = .15, p = .24). However, the funnel plot revealed a moderate two-tailed selection. Thus, selection based on two-tailed p-values might have led to a censorship of studies with small sample sizes and effects around zero. The corrected effect size d would be .15. The results are shown in Figures 2 and 3.

Effects of the decision situation. For those 14 datasets that examined decisions made under ambiguity, an effect size *d* of .18 was observed (lower *d* = -.04, upper *d* = .39, standard error = .11, *z* = 1.60, *p* = .11). The test for homogeneity was not significant (X^2 = 12.26, *df* = 13, *p* = .51). Rosenthal's fail-safe *N* was 24. Begg and Mazumdar's rank correlation test was not significant (*r* = -.01, *p* = .96). However, the funnel plot revealed a moderate one-tailed selection because it was skewed. Thus, selection based on one-tailed *p*-values might have led to a censorship of nonsignificant results or results in the unanticipated direction. The corrected effect size would be *d* = .07. For those 18 datasets that examined decisions made under risk, an effect size *d* of .16 was observed (lower *d* = -.06, upper *d* = .38, standard error = .11, *z* = 1.43, *p* = .15). The test for homogeneity was not significant (X^2 = 19.80, *df* = 17, *p* = .29). Rosenthal's fail-safe *N* was 23. Begg and Mazumdar's rank correlation test was not significant (*r* = .26, *p* = .14). However, the funnel plot showed a moderate two-tailed selection. Thus, selection based on two-tailed *p*-values might have led to a censorship of studies with small sample sizes and effects around zero. The corrected effect size *d* would be .15.

For those 20 datasets in which reward seeking and risk taking were disadvantageous (ambiguity and risk together), an effect size *d* of .26 was observed (lower *d* = .04, upper *d* = .48, standard error = .11, *z* = 2.35, *p* < .05). The test for homogeneity was not significant (X^2 = 20.96, *df* = 19, *p* = .34). Rosenthal's fail-safe *N* was 126. Begg and Mazumdar's rank correlation test was not significant (*r* = -.01, *p* = .95). However, the funnel plot revealed a moderate two-tailed selection. Thus, selection based on two-tailed *p*-values might have led to a censorship of studies with small sample sizes and effects around zero. The corrected effect size *d* would be .24. For those 12 datasets in which reward seeking and risk taking were not disadvantageous (ambiguity and risk together), an effect size *d* of .01 was observed (lower *d* = -.16, upper *d* = .18, standard error = .09, *z* =.10, *p* = .92). The test for homogeneity was not significant (X^2 = 11.32, *df* = 11, *p* = .42). Rosenthal's fail-safe *N* was -12. Begg and Mazumdar's rank correlation test was not significant (*r* = .39, *p* = .08). However, the funnel plot revealed a moderate one-tailed selection because it was skewed. Thus, selection based on one-tailed *p*-values might have led to a censorship of nonsignificant results or results in the unanticipated direction. The corrected effect size *d* would be -.01. The results are shown in Figure 2 and Figures 3b to 3e.

For completeness, we also report the main results for the fourfold subdivision of decision situations, as shown in Table 1. However, only a few studies are included in each of the categories, and the results should be interpreted with caution. For those seven datasets that examined decisions made under ambiguity and in which reward seeking and risk taking were disadvantageous, an effect size *d* of .44 was observed (lower *d* = .17, upper *d* = .72, standard error = .14, *z* = 3.12, *p* < .005). The test for homogeneity was not significant (X^2 = 5.62, *df* = 6, *p* = .47). Rosenthal's fail-safe *N* was 46. Begg and Mazumdar's rank correlation test was significant (*r* = -.71, *p* < .05). For those seven datasets that examined decisions made under ambiguity and in which reward seeking and risk taking were not disadvantageous, an effect size *d* of -.06 was observed (lower *d* = -.25, upper *d* = .14, standard error = .10, *z* =.56, *p* = .58). The test for homogeneity was not significant (X^2 = 5.93, *df* = 6, *p* = .43). Rosenthal's fail-safe *N* was -6. Begg and Mazumdar's rank correlation test was not significant (*r* = .05, *p* = .88). For those 13 datasets that examined decisions made under risk and in which reward seeking and risk taking were disadvantageous, an effect size *d* of .17 was observed (lower *d* = -.13, upper *d* = .46, standard error = .15, *z* = 1.10, *p* = .27). The test for homogeneity was not significant (X^2 = 14.63, *df* = 12, *p* = .26). Rosenthal's fail-safe *N* was 10. Begg and Mazumdar's rank correlation test was not significant (*r* = .15, *p* = .46). For those five datasets that examined decisions made under risk and in which reward seeking and risk taking were not disadvantageous, an effect size *d* of .13 was observed (lower *d* = -.19, upper *d* = .44, standard error = .16, *z* =.80, *p* = .42). The test for homogeneity was not significant (X^2 = 3.67, *df* = 4, *p* = .45). Rosenthal's fail-safe *N* was -3. Begg and Mazumdar's rank correlation test was significant (*r* = .80, *p* = .05). The results are shown in Figure 2 and Figures 4 to 7.

Figure 2. Effect sizes sorted according to the decision situation.

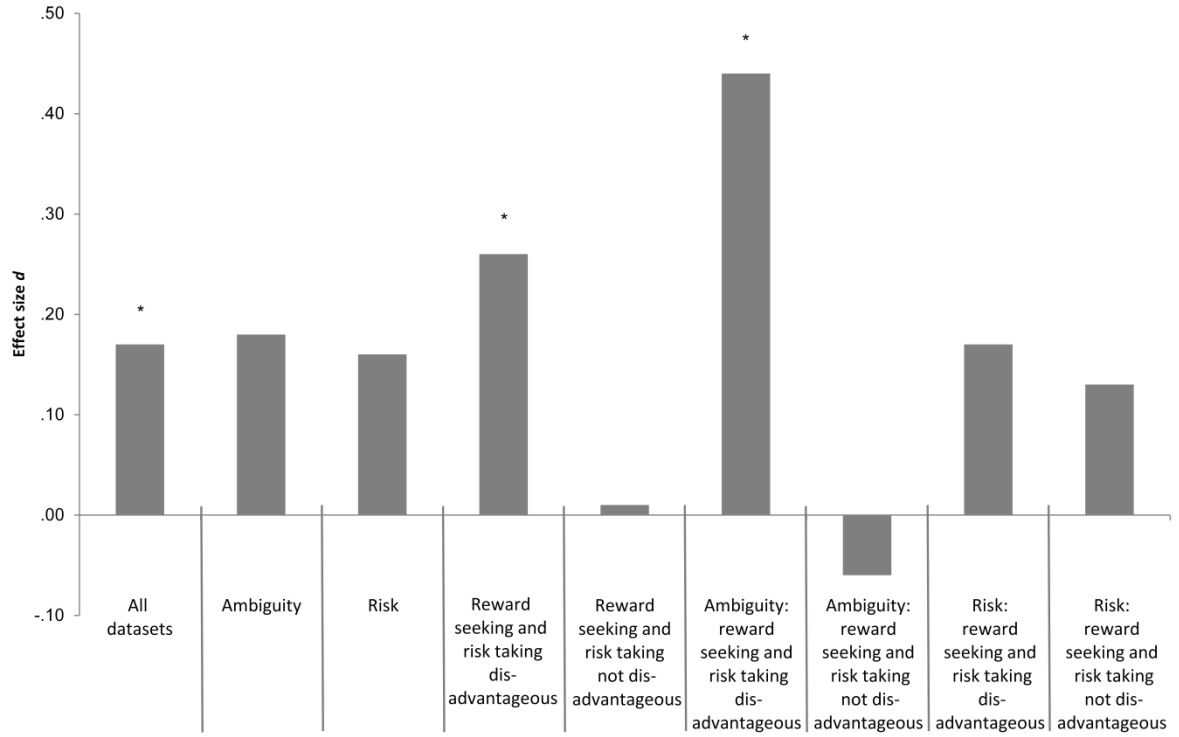


Figure 3. Funnel plot of effect sizes for all datasets.

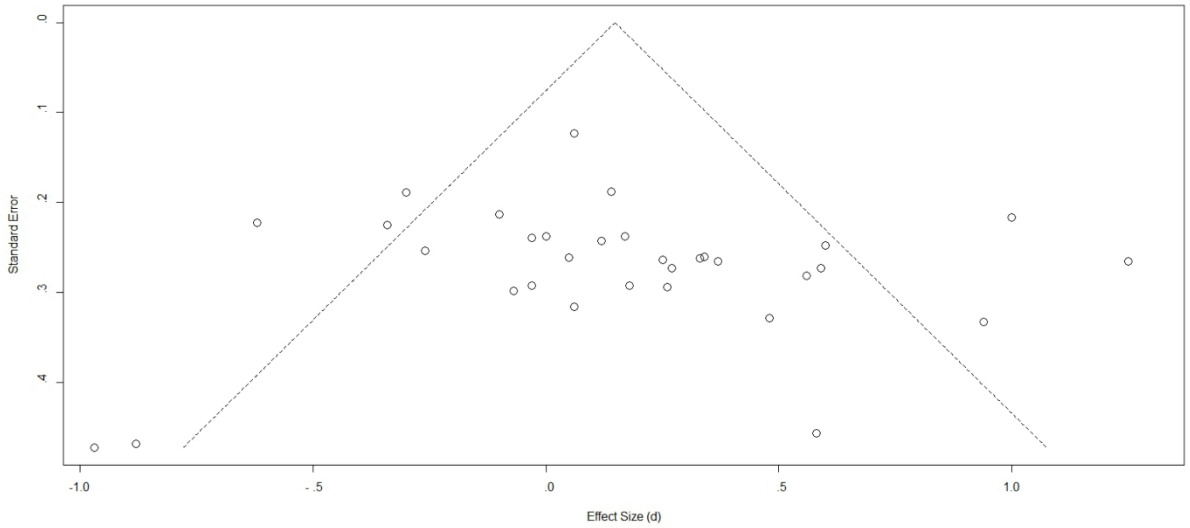


Figure 4. Funnel plot of effect sizes for decisions made under ambiguity.

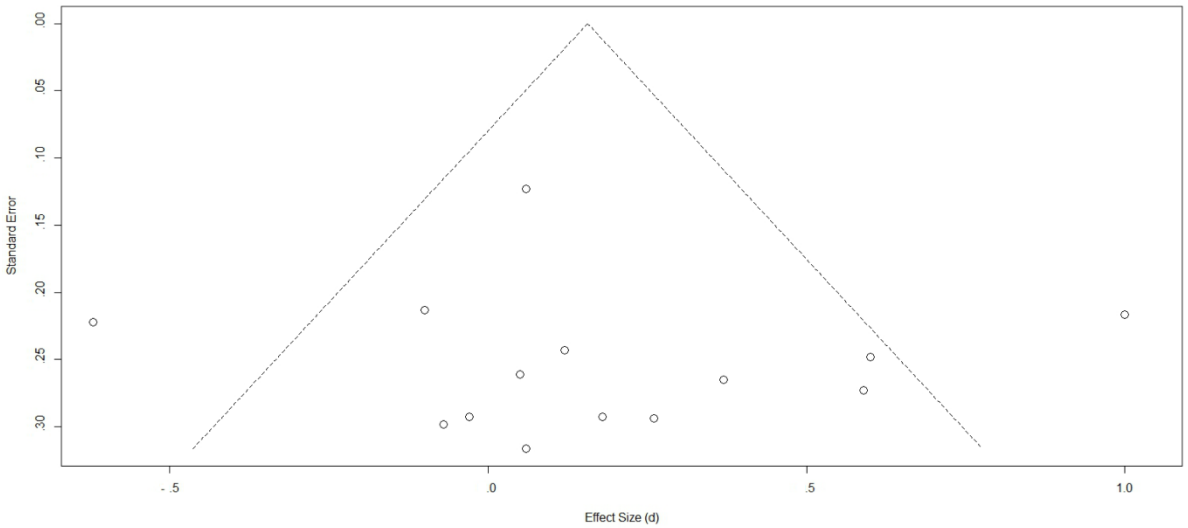


Figure 5. Funnel plot of effect sizes for decisions made under risk.

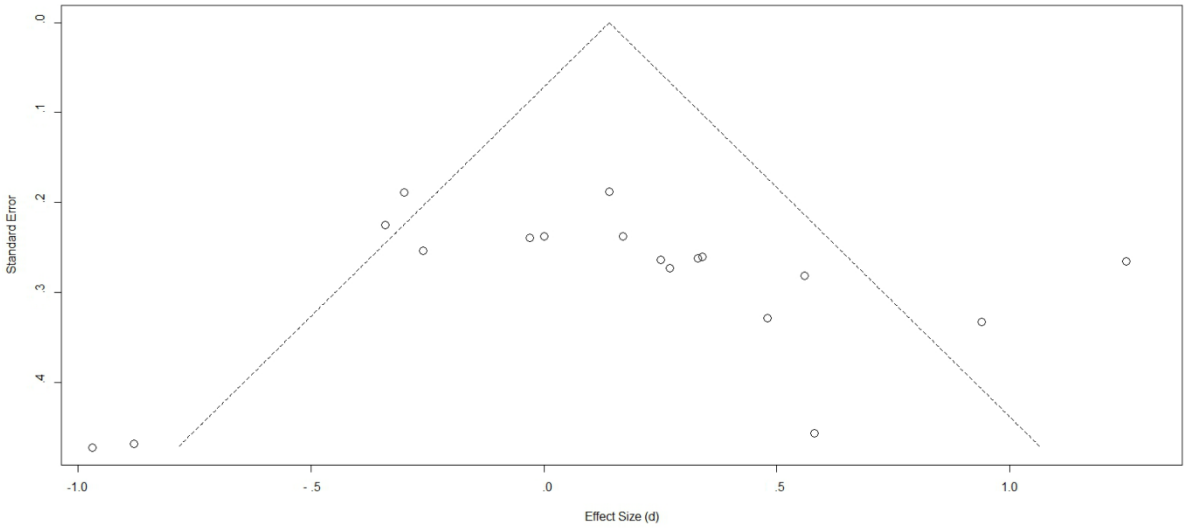


Figure 6. Funnel plot of effect sizes for decisions in which reward seeking and risk taking were disadvantageous.

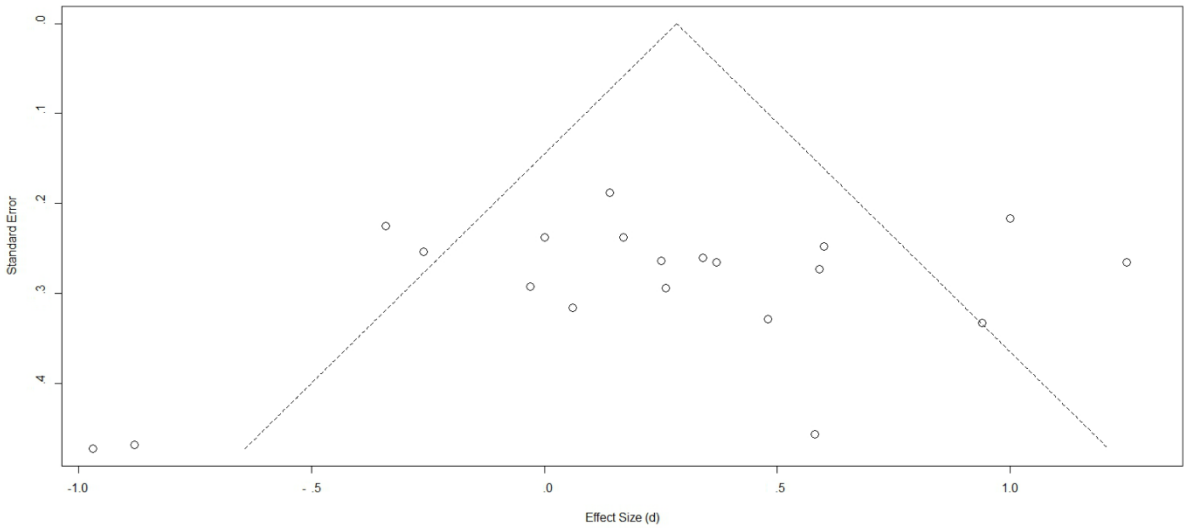
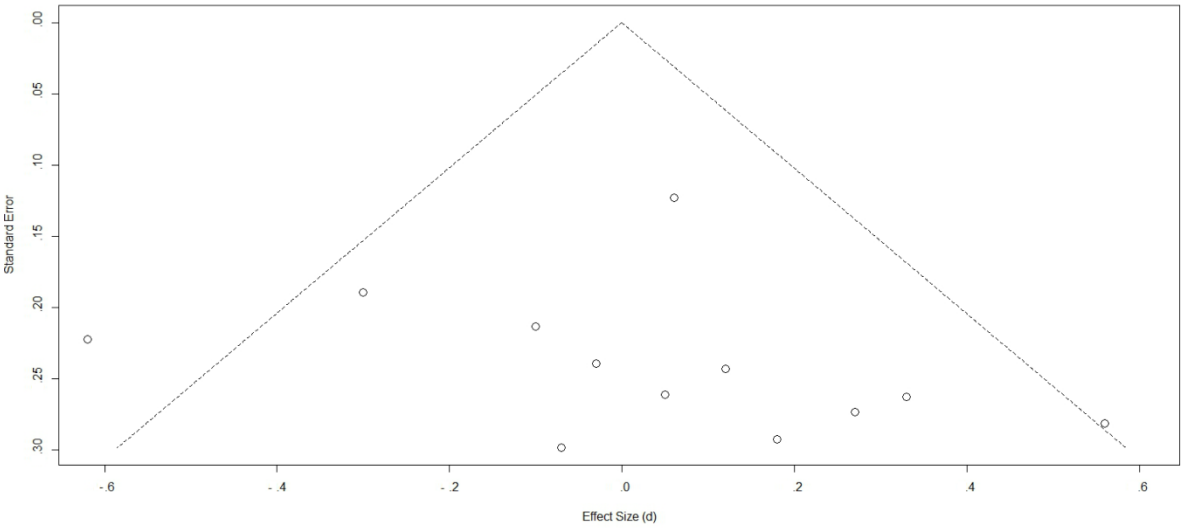


Figure 7. Funnel plot of effect sizes for decisions in which reward seeking and risk taking were not disadvantageous.



Effects of stressors. For those eight datasets that used a systemic stressor, an effect size *d* of .09 was observed (lower *d* = -.29, upper *d* = .48, standard error = .20, *z* = .47, *p* = .64). The test for homogeneity was not significant (X^2 = 5.40, *df* = 7, *p* = .61). Rosenthal's fail-safe *N* was -4. Begg and Mazumdar's rank correlation test was not significant (*r* = -.07, *p* = .81).

For those 24 datasets that used a processive stressor, an effect size *d* of .19 was observed (lower *d* = .03, upper *d* = .35, standard error = .08, *z* = 2.31, *p* < .05). The test for homogeneity was not significant (X^2 = 27.13, *df* = 23, *p* = .25). Rosenthal's fail-safe *N* was 90. Begg and Mazumdar's rank correlation test was not significant (*r* = .28, *p* = .06). However, the funnel plot showed a moderate two-tailed selection. Thus, selection based on two-tailed *p*-values might have led to a censorship of studies with small sample sizes and effects around zero. The corrected effect size *d* would be .17. The results are shown in Figures 8 and 9.

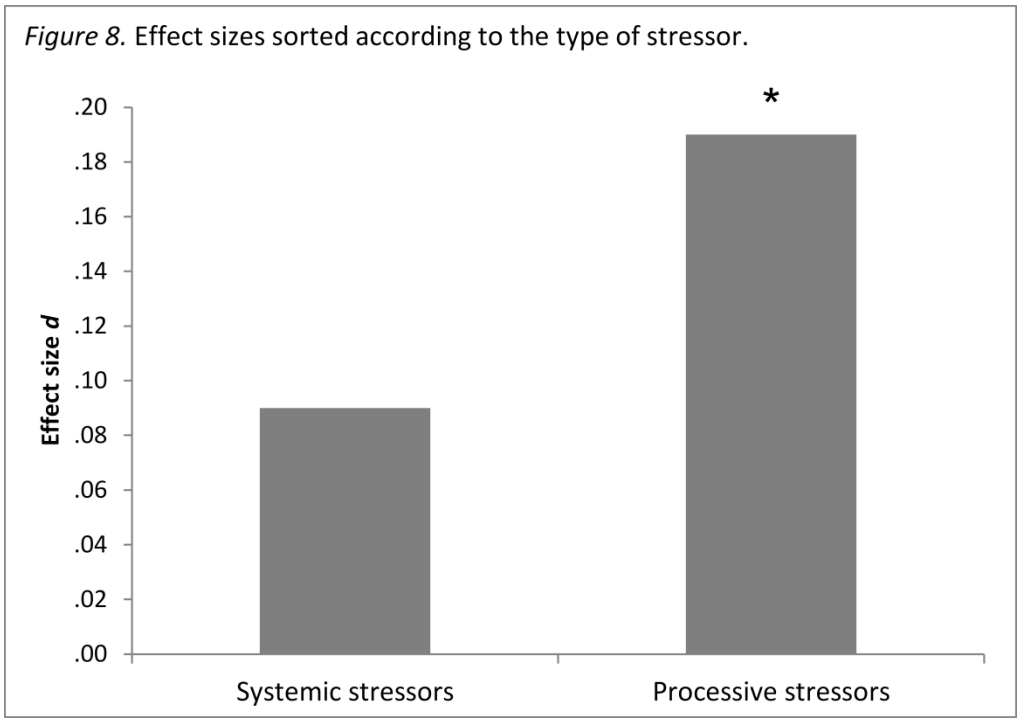
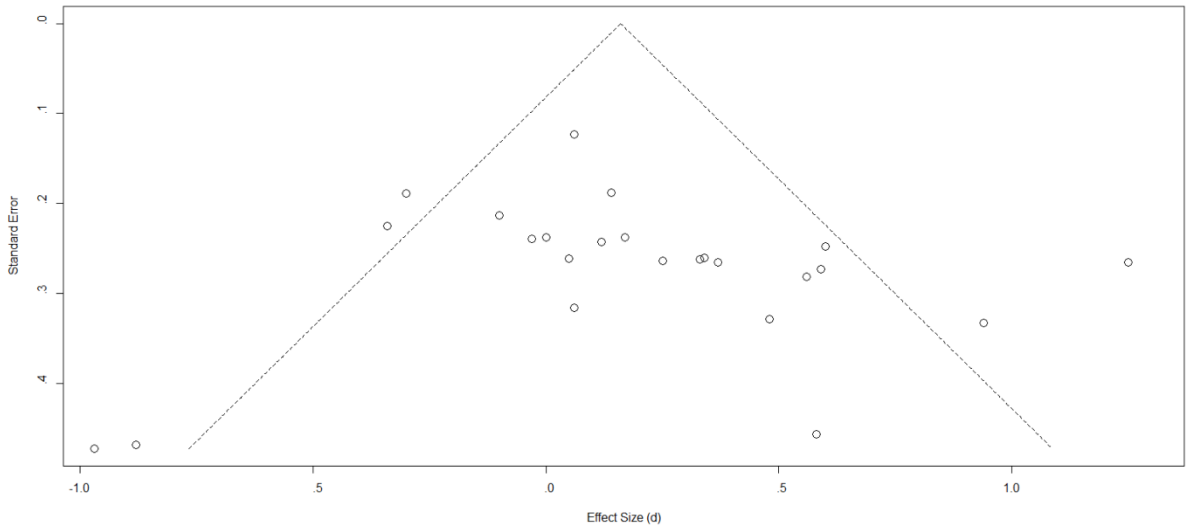


Figure 8. Effect sizes sorted according to the type of stressor.

Figure 9. Funnel plot of effect sizes for processive stressors.



Interactions between decision situations and stressors. We also calculated whether the decision situation and the type of stressor interacted in predicting the effect size *d* with the help of a moderated regression analysis. In our first calculation 'decision situation (ambiguity, risk)' and 'stressor (systemic, processive)' and the interaction of 'decision situation x stressor' were included as predictors, and 'effect size *d*' was the dependent variable. In our second calculation, 'decision situation (reward seeking disadvantageous, reward seeking not disadvantageous)' and 'stressor (systemic, processive)' and the interaction of 'decision situation x stressor' were included as predictors, and 'effect size *d*' was the dependent variable. However, no significant interactions were observed (all *p*-values > .05).

Moderator Analyses

Effects of the stress response. The cortisol stress response in the stress condition (peak minus baseline in nmol/l) was included as a marker of the HPA-axis stress response as a continuous moderator. The alpha-amylase stress response in the stress condition (peak minus baseline in u/ml) was also included as a continuous moderator as a marker of the SAM-stress response. We analyzed whether the stress responses predicted the *d* values when considering the effects' directions. Positive *d*-values represent better performance of the unstressed participants, whereas negative *d*-values represent better performance of the stressed participants. In 23 datasets, cortisol levels were assessed as a measure of stress response. For nine datasets, alpha-amylase reactions were available. All of the nine datasets assessed decisions made under risk in which reward seeking and risk taking were disadvantageous. No significant effects of stress responses were observed. The results are shown in Table 2.

We also calculated whether there were any quadratic relationships between the stress responses in the stress condition and the effect size *d*. However, no quadratic relationship could be detected between the cortisol and alpha-amylase stress responses and the effect sizes in any of the decision situations (all *p*-values > .05). We also performed a moderated regression analysis to determine whether there was an interaction between the cortisol response and the alpha-amylase response to predict *d*. However, the interaction between both types of stress responses did not predict *d* ($p > .05$).

Effects of the time between stress and decisions. The time between the onset of stress and the decision-making paradigm was included as a continuous moderator with which we aimed to predict *d*. We analyzed whether the time predicted the *d* values when considering the effects' directions. Positive *d*-values represent better performance of the unstressed participants, whereas negative *d*-values represent better performance of the stressed participants. As shown in Table 2, no significant results were observed.

Effects of gender distribution. The participants' gender was included as a continuous moderator with which we aimed to predict *d*, which was performed for the complete samples (stress conditions and control conditions) because gender distributions were matched between the groups in the studies included. Thus, for each study, the percentage of female participants was calculated and included in the moderator analysis. We analyzed whether the percentage of female participants predicted the *d* values when considering the effects' directions. Positive *d*-values represent better performance of the unstressed participants, whereas negative *d*-values represent better performance of the stressed participants. In those 24 datasets that used a processive stressor, the effect of gender on *d* only slightly failed to reach significance ($B = .006$, $df = 21$, $t = 2.07$, $p = .051$). All other effects also failed to reach significance, as indicated in Table 2.

Effects of age. The participants' age was included as a continuous moderator with which we aimed to predict *d*, which was performed for the complete sample (stress conditions and control conditions) because age was matched between the groups in the studies included. We analyzed whether the participants' age predicted the *d* values when considering the effects' directions. Positive *d*-values represent better performance of the unstressed participants, whereas negative *d*-values represent better performance of the stressed participants. In the 12 datasets in which reward seeking and risk taking was not disadvantageous, the effect of age on *d* only slightly failed to reach significance ($B = -.019$, $df = 9$, $t = -2.10$, $p = .07$). All other effects also failed to reach significance, as indicated in Table 2.

Table 2

Moderator analyses

	All datasets	Ambiguity	Risk	Reward seeking and risk taking disadvantageous	Reward seeking and risk taking not disadvantageous
Cortisol response	*B* = .002	*B* = -.03	*B* = .01	*B* = -.02	*B* = .06
	df = 20	*df* = 7	*df* = 10	*df* = 11	*df* = 6
	t = .09	*t* = -.56	*t* =.34	*t* = -.92	*t* = 1.54
	p = .93	*p* = .60	*p* = .74	*p* = .38	*p* = .17
Alpha-amylase response	*B* = -.02		*B* = -.02	*B* = -.02	
	df = 6		*df* = 6	*df* = 6	
	t = -.83		*t* = -.83	*t* = -.83	
	p = .44		*p* = .44	*p* = .44	
Time	*B* = .001	*B* = -.006	*B* = .005	*B* =.001	*B* = .005
	df = 29	*df* = 11	*df* = 15	*df* = 17	*df* = 9
	t = .23	*t* = -.55	*t* = .60	*t* = .08	*t* = .69
	p = .82	*p* = .60	*p* = .56	*p* = .94	*p* = .51
Gender distribution	*B* = .004	*B* = .015	*B* = .004	*B* = .005	*B* = .005
	df = 29	*df* = 11	*df* = 15	*df* = 17	*df* = 9
	t = 1.23	*t* = 1.07	*t* = 1.06	*t* = 1.21	*t* = 1.18
	p = .23	*p* = .31	*p* = .31	*p* = .25	*p* = .27
Age	*B* = .006	*B* = .003	*B* = .060	*B* = .027	*B* = -.019
	df = 29	*df* = 11	*df* = 15	*df* = 17	*df* = 9
	t = .54	*t* = .24	*t* = 1.25	*t* = 1.59	*t* = -2.10
	p = .59	*p* = .81	*p* = .23	*p* = .13	*p* = .07

Discussion

Summary of Evidence

Summary of evidence and strength of findings. The results indicate that stress has an effect on subsequent decisions. The effects are small but significant. Thus, unstressed participants perform slightly better and make more advantageous, safer, less risky, or more patient decisions than do stressed participants. Therefore, our first hypothesis can be maintained. The exact decision-making situation determines the observed effects. While decisions made under ambiguity and risk are affected similarly by stress, the exact reward contingencies play an important role: in situations in which reward seeking and risk taking are disadvantageous, small but significant effects emerged, whereas in situations in which reward seeking and risk taking is not generally disadvantageous, there are no effects of stress at all. The fourfold subdivision of the decision situation indicated that stress is most deteriorating in situations of ambiguity in which reward seeking and risk taking are disadvantageous (a close to medium and highly significant effect). Thus, we detected an influence of the exact decision situation, which means that we can maintain our second hypothesis. There are also differential effects depending on the type of stressor. While no effects were observed for datasets that used a systemic stressor, a small but significant effect was detected in datasets that worked with a processive stressor. This means that we can maintain our third hypothesis. However, an interaction between the decision situation and the type of stressor was not observed. Therefore, we answer our first exploratory question with ‘no.’

Our moderator analyses did not fulfill expectations. The height of the stress responses in the stress condition did not predict the effect sizes. Thus, stress responses are not regarded as a moderating effect, and hypotheses 4a and 4b must be rejected. An inverted u-shaped relationship between stress responses and effect sizes that would indicate an optimal stress level for decision making could not be observed either. Finally, no interaction between cortisol stress responses and alpha-amylase stress responses in predicting the effects was observed. Thus, our second and third exploratory questions must be answered with ‘no.’ The time between stress onset and decision making also did not predict the effect sizes, and we reject our fifth hypothesis. The gender distribution of a sample and the participants’ ages did not predict the effect size, so hypotheses six and seven must be rejected as well. Overall, a clear pattern can be observed: the decision situation and the stressor play an important role while characteristics of the individual do not determine the effects of stress on performance in the current analyses.

Relevance. Some jobs expose workers to stressful situations in which important decisions must be made (Kälvemark, et al., 2004; Larsson & Sanner, 2010). If reward seeking and risk taking are dysfunctional, the quality of decisions can deteriorate as a result of being exposed to a stressor. In these situations, stress should be avoided or decision-making abilities and stress management should be trained (Crichton & Flin, 2001). Special programs have been developed to increase decision-making performance in the presence of stress (Cannon-Bowers & Salas, 1998). The results of the meta-analysis emphasize the importance of the decision situation (whether reward seeking and risk taking are dysfunctional or not). Thus, a classification of the situation as the one or the other could increase decision-making performance under stress. Furthermore, poor decision making due to stress is also discussed as a potential link between stress and an unhealthy lifestyle, e.g., by promoting smoking, drinking, or unhealthy diet (McEwen, 2008). Current meta-analytical evidence indicates that decision-making performance deteriorates under stress if reward seeking and risk taking are dysfunctional. This is the case when facing the choice to take drugs or eat unhealthy but tasty food.

Limitations

Outcome level. Although the subdivision into different decision situations revealed some very interesting insights, it has to be stated that within each category, the decision-making tasks differed

from one another. Thus, different tasks have been summarized according to two main features (ambiguity vs. risk, and reward seeking and risk taking disadvantageous vs. not), but apart from these features, there might still be some variance between tasks. More fine-grained subdivision results in fewer studies within a category, and a further subdivision would not be useful for meta-analytical calculations. We therefore cannot rule out the possibility that decision situations differ from one another in features that have not been considered here. The same problems arise for the stressors that were used. Stressors differ concerning being systemic or processive in nature, with slightly different neural correlates (Herman, et al., 1996). While only the CPT was used as a systemic stressor in the current analysis (in one case with a processive element superimposed), the processive stressors that were included might differ from one another, and we cannot rule out the possibility that different types of processive stressors affect decision-making performance differently. We used the hormonal stress responses as moderators to address the actual stress reactions that each stressor elicits, but the number of studies that assessed either hormonal measure was small. Additionally, only two of the studies included used functional brain imaging, and therefore we could not include neural reactions as a moderating variable. The overall small number of studies might explain why our moderator analyses failed to detect effects of the participants' characteristics, such as stress responses, age, and gender. Thus, the effects of individual characteristics on decisions made under stress cannot be ruled out, but current empirical evidence is limited. Furthermore, other than the assessed moderators, and potential mediators could influence the effects of stress on decisions, such as personality, peripherphysiological reactions or executive functions (see Implications for future research section).

There is some evidence of publication bias in the current results. The rank correlation test for publication bias (Begg & Mazumdar, 1994) basically does not indicate publication bias, but this test can lack power for small meta-analyses such as these, and a non-significant correlation does not rule out any publication bias. The funnel plots with confidence intervals superimposed (Vevea & Woods, 2005) are suited for small meta-analyses. The results indicated asymmetries, and we therefore reported the estimated corrected effect sizes. Although the corrected effect sizes are somewhat lower compared with the original effect sizes, the main results did not change.

Finally, five of the studies reported more than one effect size, either because different groups of participants performed a decision-making task after various time intervals after stress onset or because all participants performed two independent decision-making tasks. Ishak et al. (2008) assume that dependencies similar to that one do not change the results. This is not without potential problems, but as this issue arises only for few of the studies, we did not change the common meta-analytical calculation methods.

Review level. Each of the 63.901 records that resulted from our literature search was screened by one person only due to limited resources. Although we think that the selection process is reliable, given the clear definition of inclusion and exclusion criteria, the carefully performed selection process, and the high hit rate of the two additional judges in the post-hoc evaluation design an overlooking of a potentially relevant study cannot be ruled out completely. We searched two databases that are suited for psychological studies, screened the references of selected articles, and explicitly searched for unpublished data. Nevertheless, the possibility exists that there are studies that are not covered by any of our database searches or that are published nowhere, not even in the gray literature. Unfortunately, one study could not be included because the paper did not include the relevant data and the authors could not provide them. In one study, no meaningful single score of decision-making performance could be created, and those data could not be included (in accordance with the corresponding author).

Conclusions

Interpretation. Two mechanisms were proposed to explain how acute stress may influence subsequent decision making under uncertainty: First, acute stress should increase the reliance on immediate and potentially high rewards via alterations in dopamine release at the cost of considering

potential losses (Mather & Lighthall, 2012). Second, stress may lead to hurried and unsystematic decision making without considering all of the options (review in Janis & Mann, 1977) and may generally impair executive control via reductions of prefrontal functioning (review in Hermans, et al., 2014). The results support the hypothesis that stress influences subsequent decision making and particularly the first mechanism is supported by our data: in situations in which reward seeking and subsequent risk taking are disadvantageous, participants under stress perform more poorly compared with unstressed participants. Thus, increased reward seeking and risk taking might be the underlying mechanism for poor performance. Processing of previous rewards and anticipating future rewards is important in both decisions made under ambiguity and decisions made under risk. Accordingly, the effect sizes in decisions made under ambiguity and risk only differ marginally from each other. Whether stress also disrupted executive control in the studies included is more difficult to conclude from the current data because reward processing also plays a role in situations in which executive control is important. Thus, both mechanisms coexist and cannot be disentangled via the current analysis. However, recent research suggest that executive control can be impaired by stress (Hermans, et al., 2014), and some authors even suggest that reduced executive functions can be an early warning system that something is not right, e.g., that high stress levels exist (Diamond, 2013). We therefore propose that both increased reward salience and risk taking, as well as reduced executive control, might have caused our main effects. Increased risk taking may be interpreted as the fight part of the fight-or-flight stress response, and the current results indicate that this is adaptive in some situations, but disadvantageous in others.

The finding that processive stressors led to effects while systemic stressors did not should be interpreted with caution because only eight studies included used systemic stressors. On a hormonal level, no differences between systemic and processive stressors were observed, and the assumption that stressors elicit different neural responses could not be tested here. Nevertheless, processive stressors are assumed to involve limbic structures prior to the projection to the paraventricular nucleus of the hypothalamus (Herman, et al., 1996) and limbic structures are involved in decision making (Vorhold, 2008). This might lead to a particularly high interference with resources that are needed for optimal decision making.

One causal role for increased reward sensitivity and risk taking, but reduced executive control that we proposed was the release of stress hormones. However, in our analyses, no moderating effect of stress responses could be detected, nor did we detect an inverted u-shaped relationship between cortisol responses and decision-making performance. We also found no effects of timing. Those findings are surprising as they contradict previous studies (*Leder, et al., 2013; *Pabst, Brand, et al., 2013a; *van den Bos, et al., 2009). Recent results suggest that the cortisol stress response in particular was related to decision-making performance, and that stress effects might be particularly detrimental at the time when the release of noradrenaline, dopamine and non-genomic cortisol responses overlap. Therefore, the results of this meta-analysis are consistent because no effects of stress responses and no effects of timing were observed. One reason for this might be the small amount of studies that included hormonal stress responses and the limited variance in time intervals between stress onset and decision making. It would have been better to have the same decision-making task after the same type of stressor with varying time intervals. Additionally, no studies included used intervals longer than one hour after stress onset, which means that the potential effects of genomic stress responses could not be addressed here.

We also did not find any moderating effects of gender. This contradicts some recent studies that report strong interactions between stress and gender (*Daughters, et al., 2013; *Lighthall, et al., 2009; *Lighthall, et al., 2012; *Preston, et al., 2007; *van den Bos, et al., 2009)**,** but is in line with others that do not find gender effects (*Gathmann, et al., 2014; *Starcke, et al., 2008). Thus, gender effects in decisions made under stress may be found only under some paradigms, and they appear to have been cancelled out by other results in the meta-analytical calculations. Concerning the participants' age we also found no effects. This reflects the existing contradictory literature: One recent study found that stressed older adults became most risk-averse, which led to a disadvantageous outcome in the task used (*Mather, et al., 2009), but another study from the same workgroup could not demonstrate a stress-age interaction in decision making (*Lighthall, et al., 2013).

Implications for future research. In order to more directly test the assumption that an increased firing rate of dopaminergic neurons causes alterations in decision making, they should be assessed directly. However, only two studies included in the current meta-analysis assessed neural activity at all (*Gathmann, et al., 2014; *Lighthall, et al., 2012). In the study conducted by Lighthall and colleagues, decisions made under stress are accompanied by alterations in the activation of the dorsal striatum and the insula, dependent on the participants' gender. These findings could be interpreted as a first indicator of dopaminergic activity in the dorsal striatum, affecting decisions made under stress.

In order to more directly test the assumption that stress disrupts executive control and consequently affects decision making, executive functions should be assessed in addition to decision making under stress. Most preferable would be a baseline assessment and a second assessment after stress induction. Both types of data could be analyzed then: baseline executive functioning and potential reductions of executive functioning due to stress induction, as proposed by Hermans et al. (2014). Thus far, a few studies have assessed working memory capacities in addition to decision making under stress (*Buckert, et al., 2014; *Gathmann, et al., 2014; *Lempert, et al., 2012; *Otto, et al., 2013; *Pabst, Schoofs, et al., 2013; *Porcelli & Delgado, 2009). For example, Otto et al. found that high baseline working memory capacities protect from stress-induced deteriorations in decision making. Only two studies have assessed executive functioning other than working memory thus far (*Pabst, Schoofs, et al., 2013; *Starcke, et al., 2008). Neural correlates could also help to specify whether executive control mechanisms are reduced under stress. Gathmann and colleagues found that the anterior dorsolateral prefrontal cortex shows heightened activation when deciding under stress. This could be interpreted as a heightened executive effort during decision making under stress. Assessing neural reactions in future studies would also allow us to detect why systemic and processive stressors show differential effects on decisions.

As summarized above, the features of a decision situation and the type of stressor appear to play a more important role than the characteristics of the participants. However, not finding any moderating effects of stress responses, age, and gender does not mean that these moderators do not exist in reality, but that current empirical evidence is limited. Therefore, these moderators should also be addressed in future studies. Particularly, individual stress responses should be addressed with HPA-axis responses and responses of the SAM-system, in order to gain a more complete picture of stress responses related to decision making. The impact of both systems on decision-making performance could also potentially be detected in future studies. In addition to neural and hormonal responses during decisions made under stress, peripheral-physiological responses could also be assessed. Under no-stress conditions, low anticipatory skin conductance responses prior to a disadvantageous decision and low skin conductance responses after a punishment are associated with dysfunctional decision making (Bechara, et al., 1999). Stress induction leads to an increase in the skin conductance levels (Lejuez, et al., 2003) which could lead to a dedifferentiation of skin conductance responses when decisions are made under stress (Stankovic, Fairchild, Aitken, & Clark, 2014). Additionally, personality variables influence decisions (Miu, Heilman, & Houser, 2008) and stress responses (Pruessner et al., 1997). However, only a few studies have assessed the effect of the personality traits of the participants in decisions made under stress (*Lempert, et al., 2012; *Reynolds, et al., 2013). The two studies indicate that trait anxiety interacts with acute stress induction to predict decision making under stress. Thus, different personality variables could also be a moderator for future research.

On a statistical level, it would be fruitful to test the results of multiple studies that assessed decisions made under stress with the help of a multi-level analysis or a mediation-moderation model. However, more data are necessary, and/or data must be available on the participants' level for doing so. For example, one could test whether stress responses mediate the potential moderating effects of timing on decisions made under stress. Additionally, one could test whether executive functioning at baseline moderates decisions made under stress, and whether a reduction of executive functioning after stress induction mediates the effects.

Finally, several studies indicate that difficult decisions elicit stress responses (Coates & Herbert, 2008). Given that stress alters decision making (as the current results indicate), we think it would be worthwhile to investigate the reciprocal connection between decision making and stress.

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