The Effect of Stress on Risky Decision-Making in Adolescents Using a Decomposable Task

Koen I. Neijenhuijs

Research Master Behavioural Science

Behavioural Science Institute

Radboud University Nijmegen

Abstract

Stress is an important moderator of risky decision-making in adults (Starcke & Brand, 2012). The current study investigated the effect of stress on adolescents' risky decision-making. Due to the strong adolescent reactions of stress on arousal and affect (Larsen and Asmussen, 1991), and the known increase in adolescent risky decision-making after heightened arousal (Steinberg, 2008) and heightened affect (Figner et al., 2009; Figner & Weber, 2011); an increase in risky decision-making as well as moderating effects of the information use of choice characteristics (such as loss amount) were hypothesised. By using the Columbia Card Task (CCT; Figner & Weber, 2011), a number of issues (learning confounds and non-systematic variance of choice characteristics) regarding previous studies were circumvented. Ninety-six adolescents (aged 16 to 17) performed the CCT before and after a stress induction. While I hypothesized more risk-taking as well as less sensitivity to loss amount after stress, the opposite results were found. Additionally, after stress, adolescents' decision-making strategy came closer to the strategy that achieves the optimal expected value. These results may be explained by the Regulatory Focus Theory (Higgins, 1997; Higgins, 1998). By carefully disseminating the tasks used in previous research, comparability with the CCT is brought into question. Other possible explanations including strategy optimization and age differences are discussed. Further research is proposed to investigate these options, as well as improve on the limitations (i.e. no control group, no comparison of age groups, and the operationalization of cortisol) of the current study.

Keywords: risky decision-making, stress, adolescent, Columbia card task

The Effect of Stress on Risky Decision-Making in Adolescents Using a Decomposable Task

Adolescents often take more risks than individuals in other age groups (Reyna & Farley, 2006), resulting in an increased probability of fatality (Dahl, 2004). I define risk-taking as choosing options with more outcome variability, or put differently, options of which more uncertainty exists as to which outcome will be the one that the chooser ends up with (Figner & Weber, 2011). Context appears to be an important moderator of risk-taking (Defoe et al., 2015). Stress is one such contextual moderator: both stress induction and naturally occurring stress have been shown to lead to increased risk-taking in adults (Starcke & Brand, 2012). The effect of stress on adolescent risky decision-making has not yet been investigated. However, it is known that adolescents show more risk-taking under conditions of heightened arousal (Steinberg, 2008), as well as conditions of heightened affect (Figner et al., 2009; Figner & Weber, 2011). In the case of heightened affect, this increase in risk-taking is accompanied by diminished information use of choice characteristics, characterized by neglecting information on gain-, but particularly, loss amount (Figner et al., 2009; Figner & Weber, 2011). Furthermore, Larsen and Asmussen (1991) posited that particularly for adolescents, stress leads to heightened arousal and affect. Due to this increased adolescent reaction of arousal and affect in response to stress, and the effect of stress on risk-taking found in earlier studies, it is particularly relevant to investigate precisely how stress affects risky decision-making in adolescence.

Some of the previous research on stress and risky decision-making have shown a consistent increase in risk-taking after stress (Preston et al., 2007; Starcke et al., 2008; Pabst et al., 2013). Meanwhile others have shown moderating effects of gender (increase in risk-taking for men but a decrease in risk-taking for women; Lighthall, Mather, & Gorlick, 2009; increase in risk-taking for men but a U-curve for women; van den Bos, Harteveld, & Stoop, 2009), and age (elderly decreased in risk-taking while young adults showed no effect; Mather, Gorlick, & Lighthall, 2009). One last study found no behavioural effect (Porcelli & Delgado, 2009). The entire line of research seems to suggest a trend of increased risk-taking after to stress, which may be dependent on individual characteristics, such as gender or age.

However, the interpretation of these studies is complicated as a number of studies used tasks that confound decision-making and learning effects (Preston et al., 2007; van den Bos, Harteveld, & Stoop, 2009; Lighthall, Mather, & Gorlick, 2009; Mather, Gorlick, & Lighthall, 2009). Due to such confounds it is impossible to delineate whether the decision made by participants reflects a decision-strategy influenced by options that vary in riskiness, or whether the decision reflects the learning process of the knowledge regarding which options are riskier than others. Other studies did not systematically vary variables related to choice characteristics (e.g. win/lose probability, gain amount, and loss amount; Starcke et al., 2008; Pabst et al., 2013; Gathmann et al, 2014; Porcelli & Delgado, 2009). By not systematically varying such parameters, it is impossible to investigate which characteristics of the task actually influence the decision-making strategy of the participants. These two issues (learning confounds and no systematic variance of characteristics) compromise decomposability (e.g. which choice characteristics lead to which decisions), which is critical to determine how and why risk-taking levels change in different situations (Schönberg, Fox, & Poldrack, 2011).

The Columbia Card Task (CCT) does not suffer from the aforementioned issues. In this task, participants are instructed to turn over a number of cards. Each card can be either a winning or losing card, and the participant is informed of the total number of losing cards, the gain amount when they turn over a winning card, and the loss amount when they turn over a losing cards, per trial. By systematically and independently varying these trial characteristics, this task allows the assessment of risk-taking levels and decomposability of overt risk-taking levels into (i) sensitivity to probability, (ii) sensitivity to gain amounts, and (iii) sensitivity to loss amounts; each in a more affect-charged (hot CCT) and a more deliberative (cold CCT) context (Figner et al., 2009; Figner & Weber, 2011). The CCT has been used in aforementioned studies focused on risk-taking in adolescents (Figner et al., 2009; Figner & Weber, 2011). In general, it is found that adolescents take more risks, compared to adults, in the more affect-charged hot CCT compared to the more deliberative cold CCT. Adolescents have also shown to be less sensitive to gain, but particularly, loss amount in the more affect-charged hot CCT, compared to the more deliberative cold CCT.

The effect of stress on risk-taking during the cold CCT seems straight-forward: as affect and arousal are expected to be increased due to stress (Larsen & Amussen, 1991; Smeets et al., 2012), performance on the cold CCT is expected to become more affect-charged and therefore mimic the performance on the hot CCT (i.e. more risk-taking and less sensitivity to gain and/or loss amount). In contrast, the effect of stress on risk-taking during the hot CCT may be less straight-forward. Affect and arousal are already heightened during the hot CCT (Figner et al., 2009; Figner & Weber, 2011), therefore it is not clear whether stress will additively increase, multiplicatively increase, or meet a ceiling of affect and arousal. In turn, it is unclear how such an increase, or ceiling effect, may influence CCT performance.

The main objective of the current study was to investigate adolescent risky decision-making under stress, using a decomposable task (the CCT). My hypotheses were:

(i) As in previous research effects (Preston et al., 2007; van den Bos, Harteveld, & Stoop, 2009; Lighthall, Mather, & Gorlick, 2009; Starcke et al., 2008; Pabst et al., 2013; Gathmann et al, 2014); and as indicated by the effect of stress on the increase of arousal and affect in adolescents (Larsen & Asmussen, 1991) and the subsequent increase in adolescent risk-taking after heightened arousal and affect (Figner et al., 2009; Figner & Weber, 2011): stress and higher cortisol levels, induced by a stressor, are associated with an increase in risk-taking; compared to baseline risk-taking;

(ii) The increase in risk-taking due to stress, is larger for the cold CCT vs. the hot CCT (Figner et al., 2009; Figner & Weber, 2011);

(iii) The increase in risk-taking due to stress as well as the moderating effect of the task (cold CCT vs. the hot CCT) on this increase, is manifested in less information use, in particular loss amount (Figner et al., 2009; Figner & Weber, 2011).

While I did not have particular hypotheses regarding gender differences - as previous research has been inconsistent in reproducing such an effect - I did test for them as they were found in previous research (Lighthall, Mather, & Gorlick, 2009; van den Bos, Harteveld, & Stoop, 2009) and could possibly moderate the effects of stress.

Methods

Participants

Data were collected as part of the ninth measurement wave of the Nijmegen Longitudinal Study on Infant and Child Development (NLS; for a number of publications which investigated this longitudinal sample, see for example: van Bakel, & Ricksen-Walraven, 2002; Smeekens, Riksen-Walraven, & van Bakel, 2007; Smeekens, Riksen-Walrvan, & van Bakel, 2009; Peter, Rikse-Walraven, Cillesen, & de Weerth, 2011; van den Berg, Cillesen, 2013). Participants (N = 96, 47 females, age range 16.5-17.5 years) were compensated with 52 Euro, and could additionally win between 0 and 14 Euros based on their performance on the CCT. Three participants were excluded from analyses due to complications during the stressor task. One more participant was excluded from analyses for being unable to perform the stressor task due to medical history.

Materials

Columbia Card Task. The current study used a short CCT version, consisting of 24 trials (Figner & Weber, 2011), which varied three factors: (i) number of loss cards (1/3 loss cards, i.e. probability), (ii) gain amount (10/30 points), and (iii) loss amount (250/750 points). Each combination was repeated three times, with random trial order within each of the 3 blocks of (2x2x2=) 8 trials. During each trial, 32 cards were presented face down. The participant had to indicate the number of cards he/she wants to turn over. The information regarding number of loss cards, gain amount, and loss amount was presented on the screen throughout the task.

The hot CCT is designed to trigger substantial involvement of affect-charged decision-making. To accomplish this, the participant consecutively chooses to either turn over a next card or not and a running point total for the trial is shown. The cold CCT is designed to trigger substantial involvement of cognitive-deliberative decision-making. To accomplish this, the participant indicates how many cards in total he/she wants to turn over. Additionally, no running point total is shown to the participant, and no feedback on their performance is given until the end of the task. Both versions are incentive-compatible, i.e. participants have a chance to win an amount of money that depends on their decisions.

The Maastricht Acute Stress Test. The Maastricht Acute Stress Test (MAST) is a standardized protocol to induce moderate levels of stress using an unpredictable social-evaluative situation (Smeets et al., 2012). The procedure consists of a 5 minute instructional phase and a 10 minute stressor phase. During the stressor phase the participants were instructed to immerse their left hand in cold (0-2 °C) water during five intervals of varying duration (either 60 or 90 seconds), which the participants were told have been determined at random. Between water immersions, participants were instructed to perform an arithmetic task (for 45, 60 or 90 seconds), in which they had to count backwards in steps of 17 starting from 2043 or an equally high number determined by the experimenter. If the participant made an error while counting, he/she had to restart at the value provided by the experimenter.

Stress measurements. To validate the effect of the stress induction and to investigate the effect of cortisol on CCT performance, salivary cortisol, blood pressure, and subjective stress were assessed. Salivary cortisol was collected five times by passive drool of approximately 1 ml. Blood pressure was assessed using an electrical sphygmomanometer. Subjective stress was assessed with seven self-report items: "How [stressed/angry/tense/nervous/anxious/happy/irritated] do you feel right now?" Participants answered these questions on a scale from 0 to 100. The item regarding happiness was removed before analyses as it reduced Cronbach's Alpha across all measurement points (α range including happy = .51 – .77; α range excluding happy = .70 – .86).

Procedure

Participants entered the behavioural part of the NLS after having performed two fMRI tasks (120 minutes), except for participants who did not meet fMRI inclusion criteria (they entered the behavioural part right away, N = 22). The behavioural part of the study started at either 12:00 or 17:00 in the afternoon. After the hot and cold CCT (order of which was counterbalanced) were completed, the MAST was administered. Twenty-five minutes after MAST onset, coinciding with the cortisol peak (Dickerson &

Kemeny, 2004), the hot and cold CCT (order of which was counterbalanced) were completed once more. Physiological and subjective stress measures were assessed before, and immediately after (except for cortisol) the MAST as well as at approximately 18, 30, 40, and 55 minutes after MAST onset. Lastly, participants filled in several questionnaires. One of these questionnaires was relevant for collecting information used as a control variable (use of contraceptives), while the others were irrelevant for the current study. In between the tasks described, some tasks that were irrelevant to the current paper were performed[1]. The total time of the procedure was approximately 3 hours. For the complete procedure, see Figure 6 in the supplemental materials.

Data analysis

All analyses were performed in R (version 3.1.3; R Core Team, 2015); using linear mixed-effect models which were estimated with the lmer function of the lme4 package (version 1.1.7; Bates et al., 2014). To determine the structure of all mixed-effect models, I followed the advice of Barr et al. (2013). As such, we used a maximal random effects structure, so that random effects per subject were added for all repeated measures effects and their interactions; as well as a random intercept and all possible random correlation terms among the random effects. *p*-values for the manipulation check and the first linear mixed-effect model (without cortisol) were determined using parametric bootstrapping as implemented in lme4's bootMer function, with 1000 simulations and deriving confidence intervals using the function boot.ci of the package boot (version 1.3.15; Canty & Ripley, 2015). *p*-values for the second linear mixed-effect model (with cortisol) were determined using the same parametric bootstrapping, but with 500 simulations due to time constraints. *p*-values for post-hoc, and supplemental analyses were determined using conditional Type III F-tests with Kenward-Roger correction of degrees-of-freedom, as implemented in the Anova function from the package car (version 2.0.25; Fox & Wiesberg, 2011). The Anova function

[1] Irrelevant tasks performed included: fMRI Social Approach-Avoidance task (Volman, Toni, Verhagen, & Roelofs, 2011), a fMRI Freeze-Fight Task, Social Communication Task (Stolk 2013), Balance Board Social Freeze Task (Roelofs, Hagenaars & Stins, 2010), and Inter-temporal Choice Task (Figner et al., 2010).

calls the KRmodcomp function from the package pbkrtest (version 0.4.2; Halekoh & Højsgaard, 2014) for its computations.

Manipulation check. To investigate whether the MAST induced stress, separate mixed effect models were run for the polynomial (linear and quadratic) effect of time (approximately 5 minutes before, immediately after (except for cortisol), as well as 18, 30, 40, and 55 minutes after MAST) on subjective stress, systolic blood pressure, diastolic blood pressure, and cortisol. *p*-values for the effects of interest were Bonferroni-corrected[2], and effects were only considered significant if a coefficient's 99% confidence interval did not include 0. Of main interest was the quadratic trend, as I expected systolic and diastolic blood pressure, and subjective stress to rise immediately after the stressor and decrease on the first follow-follow-up measurement.

In contrast to the other stress measurements, cortisol was expected to show a peak on the follow-up measurement 30 minutes after stressor onset, given the delay in cortisol peaks of approximately 21-30 minutes (Dickerson & Kemeny, 2004). Control variables that are known to influence cortisol were used as covariates, e.g.: Time of day (van Eekelen, Kerkhog, & van Amsterdam, 2003), gender (van Cauter, Leproult, & Kupfer, 1996; Kirschbaum et al., 1999), and use of contraceptives in women (Kirschbaum et al., 1999).

Main analyses. To analyze the effect of stress on risky decision-making, a three-step analysis model was used. Firstly, a model was fitted to test the effect of stress (before vs. after MAST) on risky decision-making. Secondly, the first model was expanded by including cortisol measures. Both the first and second model included interaction terms of stress and/or cortisol with loss probability, loss amount, and gain amount; to test for moderating effects of information use of the choice characteristics. Both the first and second model were also expanded by adding gender to the model, to investigate possible moderating effects. Lastly, a mediation analysis was performed to investigate whether information use mediated the effect of stress and/or cortisol on number of cards turned over.

[2] Due to four different analysis, the Bonferonni correction was .05 / 4 = .0125, from which the decision to use the 99% confidence interval was derived.

The dependent variable of the first model (without cortisol) was the ‘number of cards turned over per game round’. The model tested the effects of stress (before vs. after MAST), task (hot vs. cold), loss probability (1 vs. 3 loss cards), gain amount (10 vs. 30 points), loss amount (250 vs. 750 points) and their interactions. Statistically, the first hypothesis (increase in risk-taking after stress) was tested via the main effect of stress (before vs. after) on number of cards turned over. The second hypothesis (larger increase of risk-taking for the cold CCT vs. the hot CCT) was tested via the two-way interaction of stress (before vs. after) and task (hot vs. cold). The third hypothesis (the moderating effect of information use) was tested via (a) the three two-way interactions between stress (before vs. after MAST) and number of loss cards, gain amount and loss amount respectively; and (b) the three three-way interactions between stress (before vs. after MAST), task (hot vs. cold) and number of loss cards, gain amount and loss amount respectively.

The second model was identical to the first model, with cortisol added as additional predictor. Cortisol was operationalized as “Area Under the Curve with respect to the increase” (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003), calculated from the cortisol measures starting with the measurement before the MAST until the last measurement of the experiment. This formula gives a summary of both the elevation in cortisol level as well as its decrease after the peak in response to the stressor. A higher AUC denotes a higher stress response (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003). By incorporating the AUC into the model, we modeled individual differences in stress reactions. Hypotheses (i), (ii), and (iii) were tested the same way as in the previous model, but substituting the stress (before vs. after) variable with the cortisol AUC variable (see Table 3 in the supplemental materials for the model formulation).

To investigate unexpected results, a third explorative linear mixed-effect model was run that was identical to the first model, substituting the dependent variable with the difference between the number of cards turned over by the participant and the number of cards turned over to achieve the optimal expected value. If this difference score reached zero the decision made by the participant was optimal and thus risk-neutral. If the difference score were to be above zero the participant would have chosen to turn over more cards than optimal and was thus risk-seeking, whereas if the difference score were to be negative the participant would have chosen to turn over less cards than optimal and was thus risk-avoidant.

Lastly, to further investigate the third hypothesis (the intervening effect of information use on the effect of stress on risk-taking), mediation analyses were performed. Firstly, the effects of probability, gain, and loss per participant were estimated from the second model (with cortisol). By adding together the slopes of the fixed effects (which are equal for the entire group of participants) with the slopes of the random effects (which are the individual differences from the fixed slopes) we were able to create individual estimates for the participants' sensitivity to loss probability, gain amount, and loss amount. Such an individual estimate is called the best linear unbiased predictions (BLUPs). Secondly, a path model was estimated using the SEM function of the lavaan package (version 0.5.18; Yves, 2012). The path model included the direct path of stress to number of cards turned over, as well as all indirect paths of stress to number of cards turned over through the BLUPs of loss probability, gain amount, and loss amount, respectively.

Results

Manipulation check. The effect of time on subjective stress comprised a significant linear trend (*Coef*= -47.40, 99% CI [-64.29, -28.93]) as well as a significant quadratic trend (*Coef* = -29.97, 99% CI [-48.69, -11.94]). The effect of time on the systolic blood pressure also showed a significant linear trend (*Coef* = -4.93, 99% CI [-6.56, -3.21]) as well as a significant quadratic trend (*Coef* = -4.62, 99% CI [-6.91, -2.44]). The effect of time on the diastolic blood pressure showed a similar significant linear trend (*Coef* = -4.26, 99% CI [-5.76, -2.88]) and significant quadratic trend (*Coef* = -3.83, 99% CI [-5.62, -1.77]). Lastly, the effect of time on cortisol did not show a significant linear trend (*Coef* = 8.75, 99% CI [-0.57, 17.32] but did show a significant quadratic trend (*Coef* = -10.40, 99% CI [-15.88, -5.46]. The quadratic effects are represented in Figure 1. The significant quadratic trends are of main interest as they show that participants' dependent variables went up and then down over time. Taking a look at Figure 1 shows that for subjective stress, systolic blood pressure, and diastolic blood pressure, this peak occurs right after the

MAST; while for cortisol, the peak occurs at approximately 30 minutes after the MAST. These patterns match my predictions and show a successful stress induction.

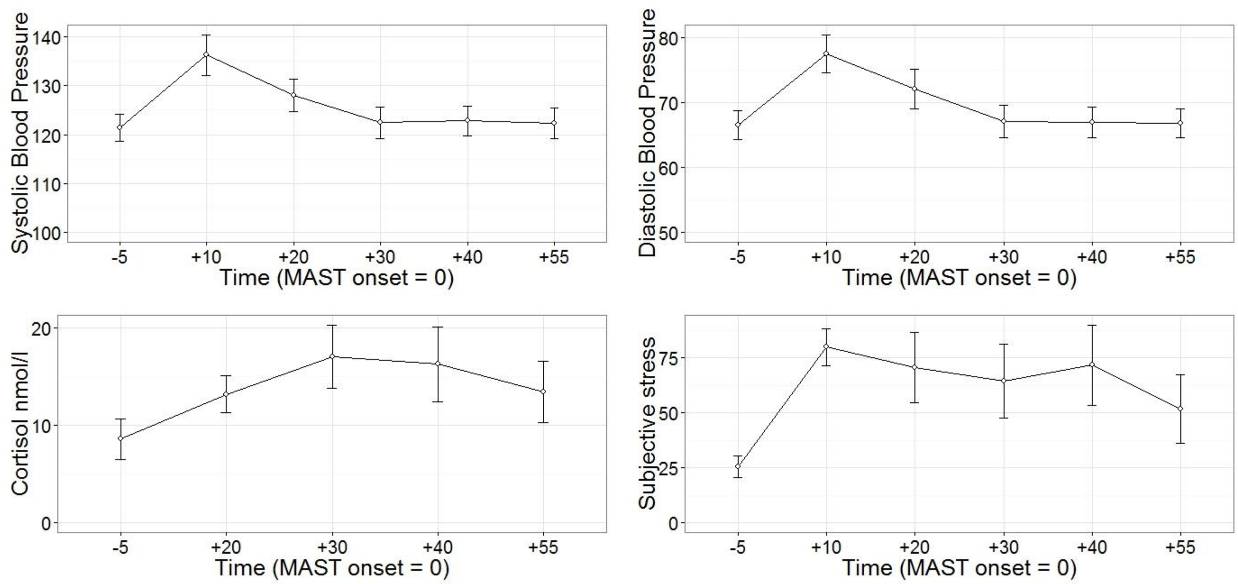

Figure 1. The effect of the MAST on subjective and physiological stress with 99% confidence intervals.

Main analyses. The results of the first model - which included fixed effects for the main effects of stress (before vs. after MAST), task (hot vs. cold), loss probability (1 vs. 3 loss cards), gain amount (10 vs. 30), loss amount (250 vs. 750), counterbalance order (either doing the hot CCT or the cold CCT first), and censored trials (a censored trial is a trial during the hot task where the trial was stopped by turning over a stop card); as well as fixed effects for the two- and three-way interactions between stress, task; and loss probability, gain amount, and loss amount (see Table 3 in the supplemental materials for the model formulation) - are presented in Table 1. The first hypothesis (an increase of risk-taking after stress) was not confirmed, as stress significantly *de*creased the number of cards turned over (*Coef* = 0.60, 99% CI [0.49, 0.72], $p < .01$). After stress ($M = 6.63$, $SD = 5.89$), participants chose an average of 1.06 cards less than before stress ($M = 7.69$, $SD = 6.2$). The second hypothesis (the increase of risk-taking being larger for the cold than hot CCT) was also not confirmed, as the effect of stress did not differ for the hot vs. the cold task (*Coef* = -0.06, 90% CI [-0.14, 0.02], $p > .10$).

The third hypothesis (the increase of risk-taking being manifested in less information use) was not confirmed. As predicted, the interaction between stress and loss was significant (*Coef* = -0.26, 99% CI [-0.35, -0.17], $p < .01$); however, in deviation from my hypothesis, two post-hoc models revealed that the effect of loss was steeper after stress (*Coef* = 1.54, $F(1,91) = 69.20$, $p < .001$) than before stress (*Coef* = 1.02, $F(1,92) = 161.03$, $p < .001$; see Figure 2).

Table 1

Results of model 1. The effect of stress, task, and information sources on amount of cards turned over.

Effect	Coef	95% CI		99% CI	
Stress (Hypothesis 1)	0.60**	0.52,	0.69	0.49,	0.72
Task	-0.11*	-0.21,	-0.004	-0.25,	0.04
Probability	2.48**	2.25,	2.71	2.16,	2.80
Gain	-0.95**	-1.14,	-0.76	-1.22,	-0.67
Loss	1.28*	1.05,	1.51	0.99,	1.60
Stress*Task (Hypothesis 2)	-0.06	-0.15,	0.03	-0.18,	0.06
Stress*Probability (Hypothesis 3)	0.07	-0.02,	0.16	-0.05,	0.19
Stress*Gain (Hypothesis 3)	0.08	-0.01,	0.17	-0.03,	0.21
Stress*Loss (Hypothesis 3)	-0.26**	-0.35,	-0.17	-0.38,	-0.14
Task*Probability	-0.03	-0.12,	0.06	-0.15,	0.09
Task*Gain	-0.12**	-0.21,	-0.03	-0.24,	-0.01
Task*Loss	0.29*	0.20,	0.37	0.16,	0.40
Stress*Task*Probability	-0.03	-0.12,	0.06	-0.15,	0.08
Stress*Task*Gain	-0.03	-0.12,	0.07	-0.14,	0.10
Stress*Task*Loss	0.06	-0.04,	0.15	-0.07,	0.17

* $p < .05$. ** $p < .01$.

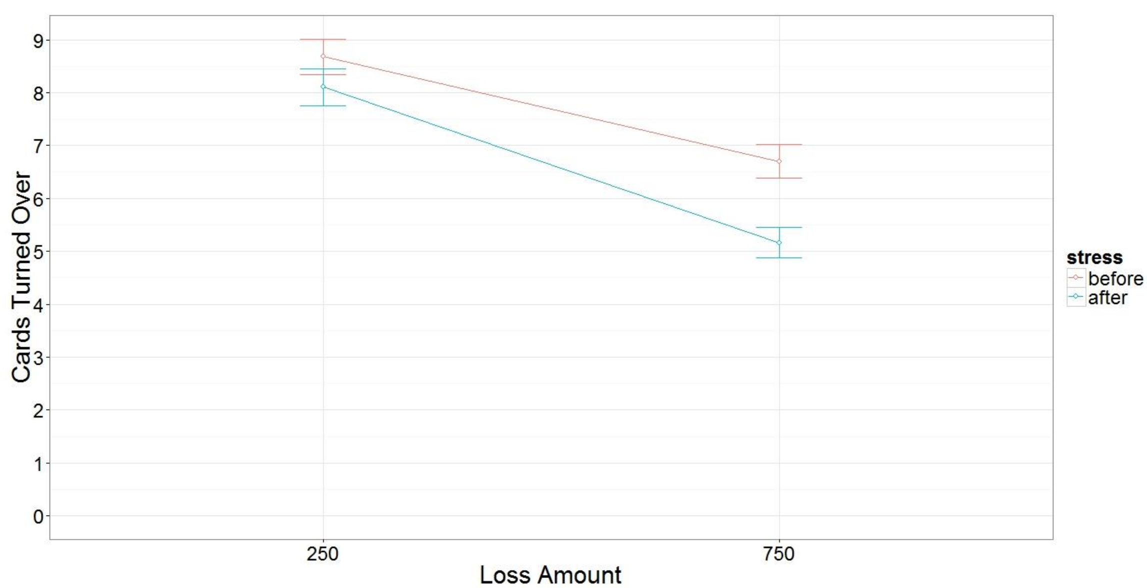

Figure 2. Interaction Effect of loss amount and stress on number of cards turned over. Error bars represent 99% confidence intervals.

Before stress, participants chose an average of 1.98 cards less when the loss amount was 750 (*M* = 6.7, *SD* = 5.94) than when the loss amount was 250 (*M* = 8.68, *SD* = 6.29). After stress, participants chose an average of 2.98 cards less when the loss amount was 750 (*M* = 5.17, *SD* = 5.12) than when the loss amount was 250 (*M* = 8.1, *SD* = 6.24). Meanwhile, the interaction between stress and gain was not significant (*Coef* = 0.08, 95% CI [-0.01, 0.17], $p > .05$), as was the interaction between stress and probability (*Coef* = 0.07, 90% CI [-0.008, 0.13], $p > .10$). Adding gender to the model did not change nor moderate any of the effects representing the hypotheses (see Table 4 in the supplementary materials).

The results of the second model - which tested the effect of cortisol, stress, task, loss probability, gain amount, and loss amount on number of cards turned over - are presented in Table 2.

Table 2

Results of model 2. The effects of stress, task, cortisol (AUC) and information sources on amount of cards turned over.

Effect	Coef	95%CI		99% CI	
AUC (Cortisol) (Hypothesis 1)	-0.0004	-0.002,	0.0008	-0.002,	0.001
Stress (Hypothesis 1)	0.60**	0.39,	0.82	0.30,	0.89
Task	-0.14	-0.44,	0.17	-0.52,	0.28
Probability	2.47**	2.24,	2.69	2.16,	2.78
Gain	-0.95**	-1.15,	-0.77	-1.23,	-0.70
Loss	1.28**	1.09	1.51	0.99,	1.57
AUC*Stress	0.0005*	0.0001,	0.001	0.0000,	0.0012
AUC*Task (Hypothesis 2)	-0.0001	-0.0007,	0.0006	-0.0008,	0.0007
AUC*Probability (Hypothesis 3)	-0.0002	-0.0006,	0.0003	-0.0009,	0.0006
AUC*Gain (Hypothesis 3)	-0.0005	-0.0006,	0.0003	-0.0007,	0.0005
AUC*Loss (Hypothesis 3)	-0.0001	-0.0006,	0.0006	-0.0008,	0.0005
Stress*Task (Hypothesis 2)	-0.06	-0.23,	0.12	-0.29,	0.17
Stress*Probability (Hypothesis 3)	0.07	-0.03,	0.18	-0.07,	0.21
Stress*Gain (Hypothesis 3)	0.09	-0.01,	0.18	-0.05,	0.21
Stress*Loss (Hypothesis 3)	-0.27**	-0.39,	-0.16	-0.44,	-0.11
Task*Probability	-0.03	-0.17,	0.13	-0.21,	0.16
Task*Gain	-0.20**	-0.23,	-0.02	-0.26,	-0.004
Task*Loss	0.29**	0.18,	0.39	0.15,	0.41
Stress*Task*Probability	-0.03	-0.14,	0.07	-0.19,	0.12
Stress*Task*Gain	-0.03	-0.12,	0.07	-0.16,	0.11
Stress*Task*Loss	0.06	-0.06,	0.17	-0.09,	0.21
AUC*Stress*Task	0.0002	-0.0001,	0.0005	-0.0003,	0.0007
AUC *Stress*Probability	0.0002	-0.0001,	0.0004	-0.0001,	0.0005
AUC*Stress*Gain	-0.0002	-0.0004,	0.0000	-0.0005,	0.0001
AUC*Stress*Loss	0.0003	0.0000,	0.0005	-0.0001,	0.0006
AUC*Task*Probability	-0.0000	-0.0003,	0.0004	-0.0004,	0.0004
AUC*Task*Gain	-0.0000	-0.0002,	0.0002	-0.0003,	0.0003
AUC*Task*Loss	-0.0001	-0.0003,	0.0001	-0.0004,	0.0002
AUC*Stress*Task*Probability	-0.0001	-0.0003,	0.0002	-0.0004	0.0003
AUC*Stress*Task*Gain	0.00001	-0.0001	0.0003	-0.0002	0.0003
AUC*Stress*Task*Loss	-0.00001	-0.0003	0.0001	-0.0005	0.0003

* $p < .05$. ** $p < .01$.

The results concerning the main effect of stress (before vs. after) on cards turned over remained the same in comparison to the first model. Concerning the results based on cortisol (AUC) the first hypothesis was not confirmed, as the main effect of cortisol was not significant (*Coef* = -0.0004, 90% CI [-0.0014, 0.0006], $p > .10$). The second hypothesis was also not confirmed, as the effect of cortisol did not differ for the hot vs. the cold CCT (*Coef* = -0.0001, 90% CI [-0.00, 0.00], $p > .10$). Lastly, the third hypothesis was also not confirmed, as the interaction between cortisol and loss probability (*Coef* = -0.0002, 90% CI [-0.00, 0.00], $p > .10$), cortisol and gain amount (*Coef* = -0.0005, 90% CI [-0.00, 0.00], $p > .10$), and cortisol and loss amount (*Coef* = -0.0001, 90% CI [-0.00, 0.00], $p > .10$) were all not significant. Adding gender to the model did not change nor moderate any of the effects representing the hypotheses (see Table 5 in the supplementary materials).

To investigate the unexpected direction of the observed results, an explorative analysis was conducted to explore whether participants became more risk-neutral or risk-aversive after stress (Figure 3). The effect of stress on the ‘difference score between the number of cards turned over by the participant and the number of cards turned over for the optimal expected value’ was significant (*Coef* = 0.60, $F(1,8454) = 106.62$, $p < .001$). Before stress participants were more risk-seeking ($M = 2.85$, $SD = 7.46$) than after stress ($M = 1.8$, $SD = 6.83$). For the full results of this model, see Table 6 in the supplementary materials.

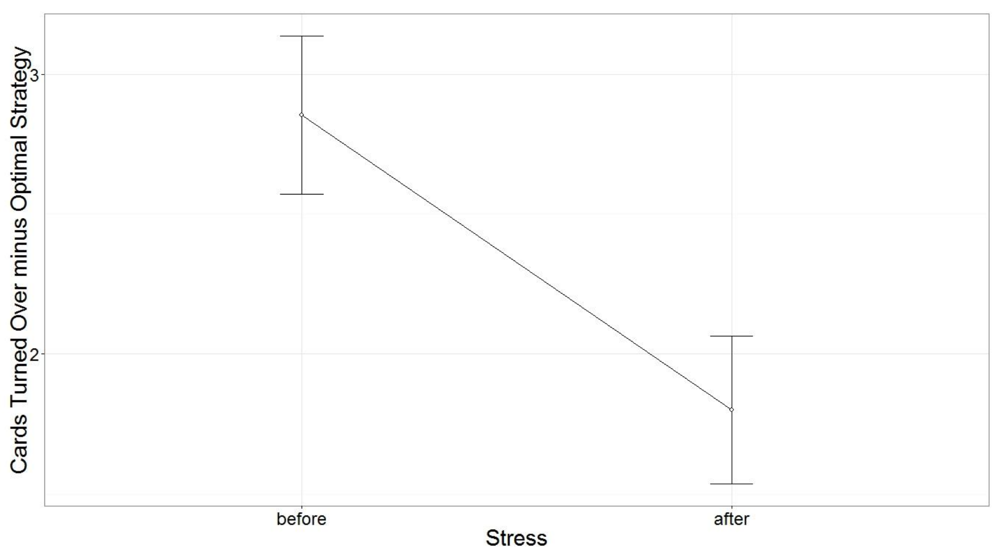

Figure 3. Main effect of stress on the difference between number of cards turned over and optimal strategy. Error bars represent 99% confidence intervals.

The mediation model (Figure 4) resulted in a bad fit ($Chi^2(10) = 341.07$, $p < .001$, $RMSEA$ = 0.637, CFI = 0.32, TLI = -1.24). Expanding the model by introducing cortisol as a predictor (Figure 5) did not increase the fit of the model ($Chi^2(14) = 343.28$, $RMSEA$ = 0.637, CFI = 0.32, TLI = -2.17). Due to the bad fit, the estimates cannot be interpreted.

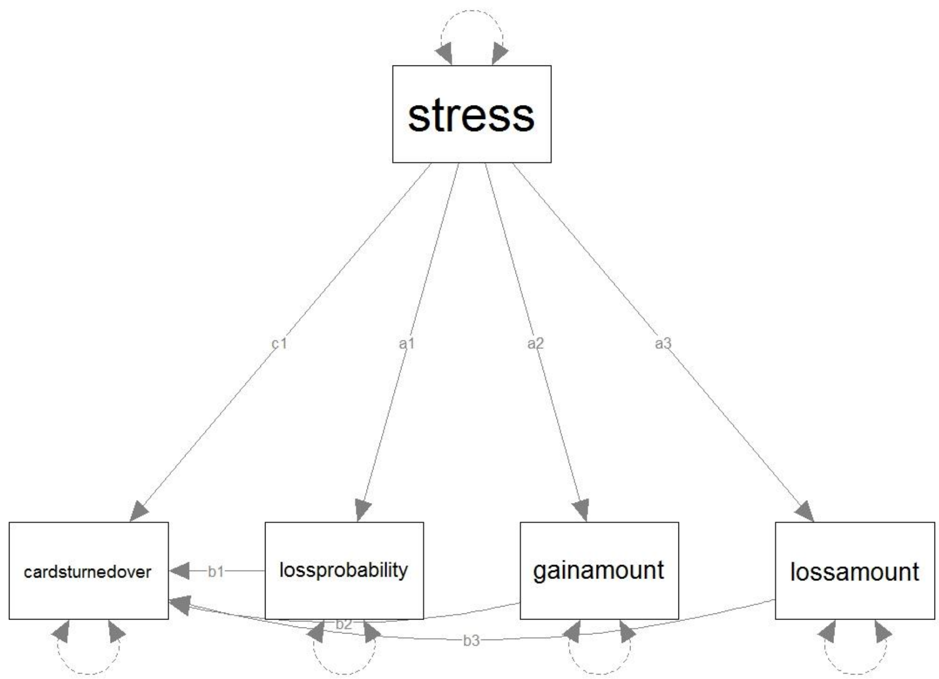

Figure 4. First mediation model.

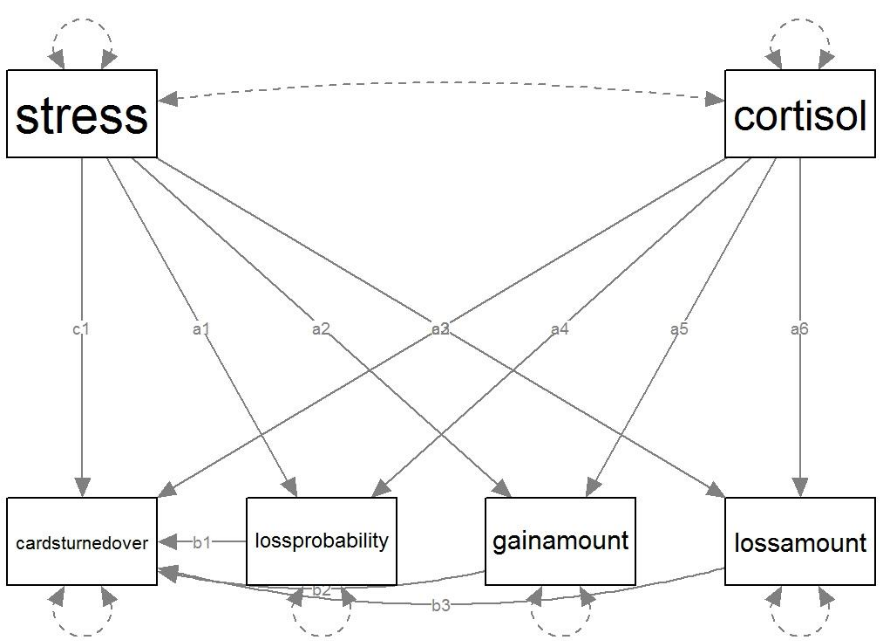

Figure 5. Second mediation model.

Discussion

The current study investigated the effect of stress on risky decision-making in adolescents. I hypothesized that: (i) greater stress and higher stress-induced cortisol levels were associated with an increase in risk-taking, (ii) this increase in risk-taking would be larger for the cold CCT vs. the hot CCT, and (iii) this increase in risk-taking due to stress as well as the moderating effect of the task (cold CCT vs. the hot CCT) on this increase, would be manifested in less information use of choice characteristics, in particular loss amount. Contradictory to my hypotheses, I found that (i) higher levels of stress, but not higher stress-induced cortisol levels, were associated with a decrease in risk-taking, (ii) this decrease was equal for the cold CCT and the hot CCT, and (iii) this decrease was manifested in more sensitivity to loss amount. As I had no hypotheses regarding gender effects and none were found in either the first or the second model, gender will not be discussed further.

While these results were unexpected, they may be explained by the Regulatory Focus Theory (Higgins, 1997; Higgins, 1998). This theory proposes two regulatory motivations: approaching of pleasure (promotion-focused) and avoidance of pain (prevention-focused). This theory predicts that agitating experiences (such as stress) are associated with a prevention focus of more agitation. From this perspective, stressed individuals would wish to avoid more negative affect which could be experienced by losing. This would explain both less risk-taking in the CCT (as turning over more cards makes it more likely for the next to be a losing card) as well as the higher weighting of loss amount. It is worth noting that a main competitor to this theory predicts completely opposing results and is able to explain the results found in previous studies. Mood repair theory (Tice, Bratslavsky, & Baumeister, 2001; Andrade, 2005) predicts that once an individual experiences negative affect, he/she will try to repair this mood. In the case of risky decision-making, mood repair theory would predict heightened risky decision-making after stress as higher gains are weighted more strongly than possible losses. As such, the results of the current study do not fit the mood repair theory.

The observed decrease in risk-taking after stress is contradictory to previous studies. However, this contradiction may be explained by differences in study design. In the CCT the characteristics of the trial (loss probability, gain amount, and loss amount) are completely independent of one another. Meanwhile, in a number of previous studies, these characteristics always varied together (e.g. when loss probability went up, so did gain amount and loss amount; Starcke et al., 2008; Porcelli & Delgado, 2009; Pabst et al., 2013; Gathmann et al., 2014). By confounding these characteristics, decision-making strategies may vary from the current study. As these different tasks are very similar in how their characteristics are varied together they can be compared to one another, but as the CCT varies these characteristics independently it may not be comparable with these tasks.

Meanwhile, the remaining studies who tested the effect of stress on decision-making who did not confound characteristics; did not explicitly show win- and loss probabilities to the participants. Thus the increase in risk-taking may, instead of representing a change in decision-making strategy, actually represent participants having more difficulty learning the probabilities of the task *after* stress (Preston et al., 2007; van den Bos et al., 2009; Lighthall et al., 2009; Mather et al., 2009). In fact, Preston et al. (2007) found that stress led to slower learning of the optimal strategy (i.e. in their task this meant choosing to draw a card from the deck with the highest win probability). It is conceivable that using the tasks confounded with learning effects, stress does not necessarily increase risk-taking, but rather decreases the capacity to learn the characteristics of the task. This decreased learning capacity could increase how often participants choose higher loss probability options, merely because they do not realize they *are* losing options. As these tasks define risk-taking as choosing higher loss probability options more often, the interpretation of the task may be confounded. While such learning confounds make these tasks comparable among themselves – as they all share the characteristic of not displaying win- and loss probabilities as well as defining risk as the choosing of higher loss probability options – because the CCT does not share these learning confounds it may not be comparable to these tasks.

One other important difference between the previous studies and the current one, was the participant population. Where most of the previous studies' samples consisted of students and young adults (mean ages ranging from 21 to 32), the current study investigated adolescents (aged 16 to 17). It has been shown that adolescents make riskier choices on the hot CCT as well as being less sensitive to loss amount, than adults (Figner et al., 2009; Figner & Weber, 2011). Furthermore, another age difference was found in a recent meta-analysis where adolescents were shown to take more risks than adults on hot tasks with immediate outcome feedback (Defoe et al., 2015). Lastly, an age difference has also been found on the effect of stress on risky decision-making, where elderly were found to take less risks after stress while young adults showed no effect of stress (Mather et al., 2009). Taking the aforementioned age differences on risky decision-making into account, it is certainly possible that the effect of stress is different for adolescents compared to adults. This possibility is theoretically substantiated by the stronger effect of stress that adolescents experience on affect and arousal, in comparison to adults (Larsen & Asmussen, 1991). However, without a direct comparison between adolescents and adults on the effect of stress on risky decision-making, this remains speculation.

Beyond identifying differences between the current study and previous studies, it may be worthwhile to identify possible similarities. It is possible that the effect of stress is mostly composed of individuals becoming more risk-neutral. In that sense, as the participants in the current study were more risk-seeking before stress, and decreased their risk-taking after stress; this may be interpreted as becoming more risk-neutral. This is shown by the results of the exploratory analysis, where the participants got closer to the optimal strategy (which is risk-neutral) after stress. For this to be consistent with the previous studies, the participants in those studies would have had to start out as risk-aversive, after which the increase in risk-taking may be interpreted as moving towards risk-neutrality. While not all previous studies mention whether participants get closer to the optimal decision-making strategy, they can be delineated from the task designs.

In the Game of Dice Task (used by Starcke et al., 2008; Pabst et al., 2013; Gathmann et al., 2014), participants choose to bet on a number of rolling dice. The participant can choose a number between one and six, and between one and four dice. If their chosen number is represented by one of the dice they chose, they win, otherwise they lose. The optimal strategy in the Game of Dice Task is to choose four dice as this has the highest winning probability. Risk-taking in this task is defined as choosing either one or two dice as it has a very low winning probability. As stress increased risk-taking, participants moved further away from the optimal strategy, which contradicts the current findings. It is important to note that the definition of risk-taking of the authors is in contrast to my definition of risk-taking, in which choosing more numbers would constitute risk-taking. While counter-intuitive – my definition which categorizes a choice as risky when the outcomes become more variable – dictates that when win and loss probability become closer to equal it becomes more uncertain what the outcome will be. In my definition risk-taking does not have a valence, given the context it can have either more likely positive or more likely negative consequences, depending on what can be gained or lost. Meanwhile, researchers using the Game of Dice Task invariably define risk-taking as negatively valenced, as it constitutes risk-taking as choosing options where one will lose more often. Given this difference in definition, it is uncertain whether the outcomes of the CCT can be compared with the outcomes of the Game of Dice Task.

In the Iowa Gambling Task (used by Preston et al., 2007; van den Bos et al., 2009) a participant is instructed to choose cards from four different decks. The optimal strategy in the Iowa Gambling Task is to choose the one of the two “good” decks (which have less losing cards). Risk-taking in this task is defined as choosing the two “wrong” decks, which have lower expected value. Thus, as risk-taking increases, participants become more risk-seeking and move further away from the optimal solution, which contradicts the current findings. However, the Iowa Gambling Task is confounded by learning effects due to which any difference in strategy may reflect a learning process rather than a decision-making process. As such, the observed change towards more risk-seeking behavior may be explained by an increased difficulty of learning which decks are “wrong”. In this sense it may be that they do not *intend* to be risk-seeking, but that they are making more mistakes before they figure out the characteristics of the task. Again, this is corroborated by the aforementioned findings by Preston et al. (2007) that stress led to slower learning of the optimal strategy.

In the Balloon Analogue Risk Task (used by Lighthall et al., 2009) participants are instructed to pump up a balloon. Each pump awards points, but if the balloon bursts all points are lost. The optimal strategy (with the highest expected value) in the Balloon Analogue Risk Task is to pump up the balloon quite a lot, and thus more risk-taking is related to a more optimal strategy. An increase of pumps of the balloon after stress is in line with the current findings, as participants get closer to risk-neutrality. Again, due to learning confounds, any difference in strategy may reflect a learning process. However, for this to be the case, learning would have to be improved after stress. While this is not directly investigated by the authors, an improvement in learning would contradict the findings by Preston et al. (2007); but no definite answer as to how learning is influenced after stress with the Balloon Analogue Risk Task can be given.

In the Driving Task (used by Mather et al., 2009) participants are instructed to drive while a stoplight is on the screen. Points are awarded for each second the participant drives while the stoplight is yellow, but all points are lost when the participant is still driving when it turns to red. The optimal strategy in the Driving Task is not entirely clear due to the complex design. However, the task is somewhat similar the Balloon Analogue Risk Task as driving for longer during the yellow light resulted in more awarded points. In this study, young adults did not show a different strategy after stress, while elderly drove for shorter periods of time during the yellow light after stress. As such, the elderly became more risk-aversive and moved away from the optimal solution; contradicting the current findings.

Lastly, no optimal strategy can be identified in the Financial Decision-making Task (used by Porcelli & Delgado, 2009) as the choices presented are always of equal expected value. While this creates a very stable task as expected value cannot be a confounder, it does make it entirely impossible to decompose any effects found using this task. As such, no other interpretation can be formulated beyond whether participants choose options which are more or less likely to win and lose.

To summarize, when comparing the results of the current study on how stress affected the participants' decision-making strategy; we find that the current study is in line with the results presented by Lighthall et al. (2009), while the comparison to the Mather et al. (2009) study is inconclusive, and contradictory to the results presented by the remaining studies (Preston et al., 2007; van den Bos et al., 2009; Starcke et al., 2008; Pabst et al., 2013; Gathmann et al., 2014). However, confounds with learning strategy (Preston et al., 2007; van den Bos et al., 2009) and large differences between the conceptualization of risk-taking with the CCT (Starcke et al., 2008; Pabst et al., 2013; Gathmann et al., 2014) makes these comparisons difficult to interpret.

It is important to note three limitations of the current study. Firstly, the current study did not include a control group (i.e. a group that did not experience a stressor). While my analyses controlled for learning effects *within* the tasks by including the effect of the blocks during the tasks; due to the lack of a control group, I was unable to control for possible learning effects *between* tasks. Secondly, while the AUC is a reliable summary of stress reactivity, it is imprecise and actually comprises three components: the baseline cortisol level, the steepness of baseline to peak, and the steepness from peak to recovery. By aggregating, nuances of the cortisol data are lost, e.g. individuals with very fast and high rising as well as fast recovering cortisol reactions may have an equal AUC as individuals with slow and low rising as well as slow recovering cortisol reactions. Thirdly, as discussed, there may be moderating age effects. It seems prudent to investigate such possible moderation to be able to explain the results of the current study. The current study is unable to make such a comparison, and as such future research is necessary.

Given the limitations as well as the theoretical implications of the current results, I propose some avenues of future research. Firstly, replication with a control group is desirable. Secondly, a direct comparison between adolescents and adults is necessary to model possibly important age effects. Thirdly, other cortisol properties (e.g. steepness of baseline to peak or steepness of peak to recovery) may be included as predictors, moderators and/or mediators. Lastly, due to the issues with comparing the CCT to previously used tasks, replication with a new task is of interest. Such a replication can serve to investigate the effects found in the current study in a different context, which will improve external validity as well as forming a coherent theory on the effect of stress on risky decision-making. This new task should include the same definition of risk-taking (choosing of options with more variable outcomes), systematically vary choice characteristics as well as not being confounded with learning effects; but the new task should conceptualize how choices are made in a different way than the CCT used in the current study. For example, instead of turning over cards, a lottery gambling task with a number of choices (akin to the Iowa Gambling Task) could be constructed which keeps the structure of systematically varying choice characteristics and explicitly stating these characteristics. It is important for all proposed future research to include measures to investigate whether participants deviate more or less from the optimal decision-making strategy.

The current results have implications for both theory concerning adolescent risky decision-making and the way adolescent decision-making is viewed by society. Both theory and society are often concerned with adolescent vulnerabilities to making risky decisions. For example, the high impact review on adolescent risky decision-making by Reyna and Farley (2006) states:

> "In practice, much depends on the particular situation in which a decision is made. In the heat of passion, in the presence of peers, on the spur of the moment, in unfamiliar situations, when trading off risks and benefits favors bad long-term outcomes, and when behavioral inhibition is required for good outcomes, adolescents are likely to reason more poorly than adults do" (p. 1).

The current results directly contradict this statement. Stress is often an unfamiliar as well as heated experience. Again, while I made no direct comparison to adults and am thus not in the position to conclude whether adolescent reasoned more poorly than adults; the results clearly show that after the heated experience of stress adolescents actually "reason" better than before. While we take note of vulnerabilities to risky decision-making in adolescents, it is just as important to investigate and celebrate any and all positive reactions of adolescents during risky decision-making.

References

Andrade, E. B. (2005). Behavioral consequences of affect: Combining evaluative and regulatory mechanisms. *Journal of Consumer Research, 32,* 355–362. doi: 10.1086/497546

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68,* 255-278. doi: 10.1016/j.jml.2012.11.001

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014*). lme4: Linear mixed-effects models using Eigen and S4*. R package version 1.1-7. http://CRAN.R-project.org/package=lme4

Canty, A., & Ripley, B. (2015). *boot: Bootstrap R (S-Plus) Functions*. R package version 1.3-15. http://CRAN.R-project.org/package=boot

Dahl, R. E. (2004). Adolescent brain development: A period of vulnerabilities and opportunities. *Annals of the New York Academy of Sciences, 1021,* 1–22. doi: 10.1196/annals.1308.001

Defoe, I. N., Dubas, J. S., Figner, B., & van Aken, M. A. G. (2015). A meta-analysis on age differences in risky decision making: Adolescents versus children and adults. *Psychological Bulletin, 141,* 48-84. doi: 10.1037/a0038088

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin, 130,* 355-391. doi: 10.1037/0033-2909.130.3.355

Figner, B., & Weber, E. U. (2011). Who takes risks when and why? : Determinants of risk taking. *Current Directions in Psychological Science, 20,* 211-216. doi: 10.1177/0963721411415790

Figner, B., Knoch, D., Johnson, E. J., Krosch, A. R., Lisanby, S. H., Fehr, E., & Weber, E. U. (2010). Lateral prefrontal cortex and self-control in intertemporal choice. *Nature Neuroscience, 13,* 538-539. doi: 10.1038/nn.2516

Figner, B., Mackinlay, R. J., Wilkening, F., & Weber, E. U. (2009). Affective and deliberative processes in risky choice: Age differences in risk taking in the Columbia Card Task. *Journal of*

Experimental Psychology: Learning, Memory, and Cognition, 35, 709-730. doi: 10.1037/a0014983

Fox, J., & Wiesberg, S. (2011). *An {R} companion to applied regression, second edition*. Thousand Oaks CA: Sage. ISBN: 978-1-4129-7514-8

Gathmann, B., Schulte, F. P., Maderwald, S., Pawlikowski, M., Starcke, K., Schäfer, L. C., ... Brand, M. (2014). Stress and decision making: neural correlates of the interaction between stress, executive functions, and decision making under risk. *Experimental Brain Research, 232,* 957-973. doi: 10.1007/s00221-013-3808-6

Halekoh, U., & Højsgaard, S. (2014). A Kenward-Roger approximation and parametric bootstrap methods for tests in linear mixed models – The R package pbkrtest. *Journal of Statistical Software, 59,* 1-30.

Higgins, E. T. (1997). Beyond pleasure and pain. *American Psychologist, 52,* 1280–1300. doi: 10.1006/obhd.1996.2675

Higgins, E. T. (1998). Promotion and prevention: Regulatory focus as a motivational principle. *Advances in experimental social psychology, 30,* 1-46.Kirschbaum, C., Kudielka, B. M., Gaab, J., Schommer, N. C., & Hellhammer, D. H. (1999). Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamus-pituitary-adrenal axis. *Psychosomatic medicine, 61,* 154-162.

Larsen, R., & Asmussen, L. (1991). *Chapter 2: Anger, worry and hurt in early adolescence: An enlarging world of negative emotions.* In Adolescent Stress: Causes and Consequences. New York: Transaction Publishers. ISBN: 978-0-202-30421-2

Lighthall, N. R., Mather, M., & Gorlick, M. A. (2009). Acute stress increases sex differences in risk seeking in the Balloon Analogue Risk Task. *PLoS One, 4.* doi: 10.1371/journal.pone.0006002

Mather, M., Gorlick, M. A., & Lighthall, N. R. (2009). To brake or accelerate when the light turns yellow? Stress reduces older adults' risk taking in a driving game. *Psychological Science, 20,* 174–176. doi: 10.1111/j.1467-9280.2009.02275.x

Pabst, S., Schoofs, D., Pawlikowski, M., Brand, M., & Wolf, O. T. (2013). Paradoxical effects of stress and an executive task on decisions under risk. *Behavioral Neuroscience.* Advance online publication. doi: 10.1037/a0032334.

Peters, E., Riksen-Walraven, J. M., Cillessen, A. H., & de Weerth, C. (2011). Peer rejection and HPA activity in middle childhood: Friendship makes a difference. *Child development, 82,* 1906-1920. doi: 10.1111/j.1467-8624.2011.01647.x

Porcelli, A. J., & Delgado, M. R. (2009). Acute stress modulates risk taking in financial decision making. *Psychological Science, 20,* 278–283. doi: 10.1111/j.1467-9280.2009.02288.x

Preston, S. D., Buchanan, T. W., Stansfield, R. B., & Bechara, A. (2007). Effects of anticipatory stress on decision-making in a gambling task. *Behavioural Neuroscience*, *121,* 257–263. doi: 10.1037/0735-7044.121.2.257

Pruessner, J. C., Kirschbaum, C., Meinlschmid, G., & Hellhammer, D. H. (2003). Two formulas for computation of the area under the curve represent measures of total hormone concentration versus time-dependent change. *Psychoneuroendocrinology, 28,* 916-931. doi: 10.1016/S0306-4530(02)00108-7

R Core Team (2015). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Reyna, V. F., & Farley, F. (2006). Risk and rationality in adolescent decision making: implications for theory, practice, and public policy. *Psychological Science in the Public Interest*, *7,* 1-41. doi: 10.1111/j.1529-1006.2006.00026.x

Roelofs, K.., Hagenaars, M. A., & Stins, J. (2010). Facing freeze: Social threat induces bodily freeze in humans. *Psychological Science, 21, 1575-1581*. doi: 10.1177/0956797610384746

Schonberg, T., Fox, C. R., & Poldrack, R. A. (2011). Mind the gap: bridging economic and naturalistic risk-taking with cognitive neuroscience. *Trends in Cognitive Sciences, 15,* 11-19. doi: 10.1016/j.tics.2010.10.002

Smeekens, S., Marianne Riksen-Walraven, J., & Van Bakel, H. J. (2007). Cortisol reactions in five-year-olds to parent–child interaction: the moderating role of ego-resiliency. *Journal of Child Psychology and Psychiatry, 48,* 649-656. doi: 10.1111/j.1469-7610.2007.01753.x

Smeekens, S., Riksen-Walraven, J. M., & Van Bakel, H. J. (2009). The predictive value of different infant attachment measures for socioemotional development at age 5 years. *Infant Mental Health Journal, 30,* 366-383. doi: 10.1002/imhj.20219

Smeets, T., Cornelisse, S., Quaedflieg, C. W., Meyer, T., Jelicic, M., & Merckelbach, H. (2012). Introducing the Maastricht Acute Stress Test (MAST): a quick and non-invasive approach to elicit robust autonomic and glucocorticoid stress responses. *Psychoneuroendocrinology, 37,* 1998-2008. doi: 10.1016/j.psyneuen.2012.04.012

Starcke, K., & Brand, M. (2012). Decision making under stress: A selective review. *Neuroscience and Biobehavioural Reviews, 36,*1228-1248. doi: 10.1016/j.neubiorev.2012.02.003

Starcke, K., Wolf, O. T., Markowitsch, H. J., & Brand, M. (2008). Anticipatory stress influences decision making under explicit risk conditions. *Behavioural Neuroscience, 122,* 1352–1360. doi: 10.1037/a0013281

Steinberg, L. S. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review, 28,* 78-106. doi: 10.1016/j.dr.2007.08.002

Stolk A., Hunnius S., Bekkering H., Toni I. (2013). Early social experience predicts referential communicative adjustments in five-year-old children. *PLOS one 8 (8),* e72667. doi: 10.1371/journal.pone.0072667

Tice, D. M., Bratslavsky, E., & Baumeister, R. F. (2001). Emotional distress regulation takes precedence over impulse control: If you feel bad, do it. *Journal of Personality and Social Psychology, 80,* 53–67. doi: 10.1037/0022-3514.80.1.53

Van Bakel, H. J., & Riksen-Walraven, J. M. (2002). Quality of infant–parent attachment as reflected in infant interactive behaviour during instructional tasks. *Journal of Child Psychology and Psychiatry, 43,* 387-394. doi: 10.1111/1469-7610.00029 van Cauter, E., Leproult, R., & Kupfer, D. J. (1996). Effects of gender and age on the levels and circadian rhythmicity of plasma cortisol. *The Journal of Clinical Endocrinology & Metabolism, 81,* 2468-2473. doi: 10.1210/jcem.81.7.8675562

van den Berg, Y. H., & Cillessen, A. H. (2013). Computerized sociometric and peer assessment An empirical and practical evaluation. *International Journal of Behavioral Development, 37,* 68-76. doi: 10.1177/0165025412463508

van den Bos, R., Harteveld, M., & Stoop, H. (2009). Stress and decision-making in humans: performance is related to cortisol reactivity, albeit differently in men and women. *Psychoneuroendocrinology, 34,* 1449–1458. doi:10.1016/j.psyneuen.2009.04.016

van Eekelen, A. P. J., Kerkhof, G. A., & van Amsterdam, G. C. (2003). Circadian variation in cortisol reactivity to an acute stressor. *Chronobiology International, 20,* 863-878. doi: 10.1081/CBI-120024212

Volman, I., Toni, I., Verhagen, L., & Roelofs, K. (2011). Endogenous testosterone modulates prefrontal–amygdala connectivity during social emotional behavior. *Cerebral Cortex, bhr001*. doi: 10.1093/cercor/bhr001

Yves, R. (2012). lavaan: an R package for structural equation modeling. *Journal of Statistical Software, 48,* 1-36.

Supplemental Materials

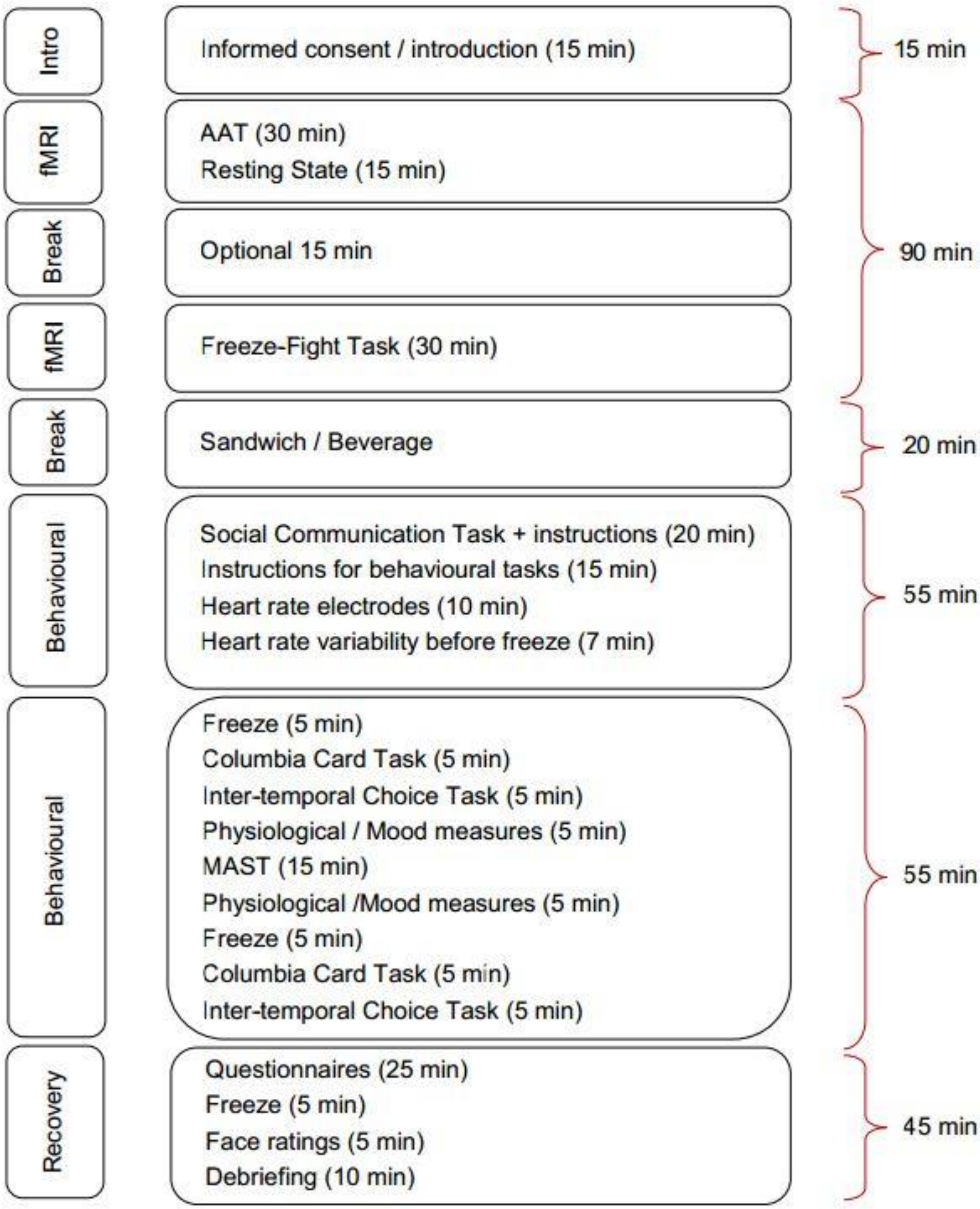

Figure 6. Complete protocol, including irrelevant tasks tot the current study.

Table 3
Model formulation

Model 1 (no cortisol)	Model 1' (added gender)	Model 2 (with cortisol)	Model 2' (added gender)
Cards_turned_over ~ stress * task * (loss_probability + gain_amount + loss_amount) + counterbalancing + censored + (1 + stress * task * (loss_probability + gain_amount + loss_amount | pp_code)	Cards_turned_over ~ gender * stress * task * (loss_probability + gain_amount + loss_amount) + counterbalancing + censored + (1 + stress * task * (loss_probability + gain_amount + loss_amount | pp_code)	Cards_turned_over ~ AUC * stress * task * (loss_probability + gain_amount + loss_amount) + counterbalancing + censored + (1 + stress * task * (loss_probability + gain_amount + loss_amount | pp_code)	Cards_turned_over ~ gender * AUC * stress * task * (loss_probability + gain_amount + loss_amount) + counterbalancing + censored + (1 + stress * task * (loss_probability + gain_amount + loss_amount | pp_code)

Table 4

Results of model 1' . The effects of gender, stress, task, and information sources on amount of cards turned over.

Effect	***Coef***	Df_{model}	Df_{error}	F	p
Gender	0.08	1	88	0.09	.76
Stress (Hypothesis 1)	0.59*	1	90	30.54	< .001
Task	-0.14*	1	90	0.96	.33
Probability	2.47*	1	90	441.25	< .001
Gain	-0.94*	1	90	102.36	< .001
Loss	1.28*	1	90	138.41	< .001
Gender*Stress	-0.13	1	90	1.48	.22
Gender*Task	-0.09	1	90	0.39	.53
Gender*Probability	-0.09	1	90	0.61	.43
Gender*Gain	0.27	1	90	2.54	.11
Gender*Loss	-0.06	1	90	0.37	.56
Stress*Task (Hypothesis 2)	-0.06	1	90	0.54	.46
Stress*Probability (Hypothesis 3)	0.07	1	90	1.90	.17
Stress*Gain (Hypothesis 3)	008	1	90	2.54	.11
Stress*Loss (Hypothesis 3)	-0.26*	1	90	20.86	< .001
Task*Probability	-0.02	1	90	0.09	.76
Task*Gain	-0.12*	1	90	5.52	.02
Task*Loss	0.29*	1	90	29.38	< .001
Stress*Task*Probability	-0.03	1	90	0.31	.58
Stress*Task*Gain	-0.03	1	90	0.43	.51
Stress*Task*Loss	0.06	1	90	0.91	.34
Gender*Stress*Task	0.09	1	90	1.24	.26
Gender *Stress*Probability	-0.04	1	90	0.82	.36
Gender*Stress*Gain	0.002	1	90	0.003	.95
Gender*Stress*Loss	0.03	1	90	0.20	.65
Gender*Task*Probability	0.04	1	90	0.23	.63
Gender*Task*Gain	-0.03	1	90	0.41	.52
Gender*Task*Loss	0.07	1	90	1.76	.19
Gender*Stress*Task*Probability	0.01	1	90	0.04	.85
Gender*Stress*Task*Gain	-0.04	1	90	0.70	.41
Gender*Stress*Task*Loss	0.02	1	90	0.08	.77

* $p < .05$. ** $p < .01$.

Table 5

Results of model 2' . The effects of gender, stress, task, cortisol (AUC), and information sources on amount of cards turned over.

Effect	***Coef***	***Df****model*	***Df****error*	***F***	***p***
Gender	0.06	1	86	0.05	.83
AUC (Cortisol) (Hypothesis 1)	-0.0004	1	87	0.56	.45
Stress (Hypothesis 1)	0.54**	1	88	26.73	< .001
Task	0.32*	1	88	4.88	.03
Probability	2.51**	1	88	473.14	< .001
Gain	-0.88**	1	88	96.08	< .001
Loss	1.21**	1	88	137.09	< .001
Gender*AUC	-0.0002	1	87	0.15	.70
Gender*Stress	-0.12	1	88	1.26	.27
Gender*Task	-0.08	1	88	0.30	.59
Gender*Probability	-0.08	1	88	0.42	.52
Gender*Gain	-0.25**	1	88	8.04	.006
Gender*Loss	-0.05	1	88	0.27	.61
AUC*Stress	0.0005*	1	88	4.85	.03
AUC*Task (Hypothesis 2)	-0.0002	1	88	0.22	.64
AUC*Probability (Hypothesis 3)	-0.0001	1	88	0.29	.60
AUC*Gain (Hypothesis 3)	-0.0001	1	88	0.41	.52
AUC*Loss (Hypothesis 3)	-0.0001	1	88	0.16	.69
Stress*Task (Hypothesis 2)	-0.008	1	88	0.01	.92
Stress*Probability (Hypothesis 3)	0.09	1	88	2.69	.10
Stress*Gain (Hypothesis 3)	0.08	1	88	2.71	.10
Stress*Loss (Hypothesis 3)	-0.25**	1	88	19.43	< .001
Task*Probability	-0.06	1	88	0.69	.41
Task*Gain	-0.18**	1	88	11.77	< .001
Task*Loss	0.36**	1	88	44.60	< .001
Gender*AUC*Stress	-0.0002	1	88	0.54	.46
Gender*AUC*Task	-0.0006	1	88	3.24	.08
Gender*AUC*Probability	0.0004	1	88	1.86	.18
Gender*AUC*Gain	-0.0002	1	88	0.57	.45
Gender*AUC*Loss	0.0003	1	88	1.23	.27
Gender*Stress*Task	0.09	1	88	1.28	.26
Gender*Stress*Probability	-0.04	1	88	0.48	.49
Gender*Stress*Gain	0.008	1	88	0.02	.88
Gender*Stress*Loss	0.04	1	88	0.48	.49
Gender*Task*Probability	0.02	1	88	0.05	.83
Gender*Task*Gain	-0.02	1	88	0.09	.77
Gender*Task*Loss	0.06	1	88	1.15	.29
Stress*Task*Probability	-0.05	1	88	0.77	.38
Stress*Task*Gain	-0.03	1	88	0.42	.52
Stress*Task*Loss	0.05	1	88	0.67	.42
AUC*Stress*Task	0.0002	1	88	1.28	.26
AUC *Stress*Probability	0.0002	1	88	1.99	.16
AUC*Stress*Gain	-0.0003*	1	88	5.04	.03
AUC*Stress*Loss	0.0003	1	88	3.86	.053
AUC*Task*Probability	-0.0000	1	88	0.02	.90
AUC*Task*Gain	-0.0000	1	88	0.04	.85
AUC*Task*Loss	-0.0001	1	88	0.72	.40
Gender*AUC*Stress*Task	0.0000	1	88	0.09	.77
Gender*AUC*Stress*Probability	-0.0001	1	88	0.74	.39
Gender*AUC*Stress*Gain	0.0000	1	88	0.26	.61

Gender*AUC*Stress*Loss	0.0000	1	88	0.29	.59
Gender*AUC*Task*Probability	-0.0003	1	88	3.91	.051
Gender*AUC*Task*Gain	0.0000	1	88	0.70	.40
Gender*AUC*Task*Loss	-0.0001	1	88	0.80	.37
Gender*Stress*Task*Probability	0.009	1	88	0.03	.88
Gender*Stress*Task*Gain	-0.05	1	88	0.97	.33
Gender*Stress*Task*Loss	0.007	1	88	0.01	.91
AUC*Stress*Task*Probability	-0.0000	1	88	0.09	.76
AUC*Stress*Task*Gain	0.0000	1	88	0.74	.39
AUC*Stress*Task*Loss	-0.0000	1	88	0.32	.57
Gender*AUC*Stress*Task*Probability	0.0001	1	88	0.90	.35
Gender*AUC*Stress*Task*Gain	0.0000	1	88	0.06	.80
Gender*AUC*Stress*Task*Loss	0.0000	1	88	0.21	.65

* $p < .05$. ** $p < .01$.

Table 6

Results of model 3. The effects, stress, task, and information sources on the difference score between the number of cards turned over by the participant, and the number of cards turned over resulting in the optimal expected value.

Effect	***Coef***	Df_{model}	Df_{error}	***F***	***p***
Stress (Hypothesis 1)	0.60**	1	8454	106.62	< .001
Task	-0.14*	1	8562	4.08	.04
Probability	-1.36**	1	91	135.11	< .001
Gain	2.38**	1	92	615.99	< .001
Loss	-2.05**	1	92	360.99	< .001
Stress*Task (Hypothesis 2)	-0.06	1	8454	1.18	.28
Stress*Probability (Hypothesis 3)	0.07	1	8451	1.37	.24
Stress*Gain (Hypothesis 3)	0.08	1	8451	1.92	.17
Stress*Loss (Hypothesis 3)	-0.27**	1	8451	20.60	< .001
Task*Probability	-0.03	1	8452	0.19	.67
Task*Gain	-0.12*	1	8452	4.18	.04
Task*Loss	0.28**	1	8452	23.22	< .001
Stress*Task*Probability	-0.03	1	8451	0.30	.58
Stress*Task*Gain	-0.03	1	8451	0.25	.62
Stress*Task*Loss	0.06	1	8451	0.90	.34

* $p < .05$. ** $p < .01$.