Examining the Effect of Stress on Decision Making Under Risk and Ambiguity

Jacquelyn Du
Senior Essay, Yale Department of Economics

Ifat Levy
Advisor, Yale School of Medicine

April 3, 2019

Abstract

Economic decisions are often made in stressful decisions, but the effect of stress on decision making under risk and ambiguity has not been systematically studied thus far. This study provides preliminary data examining the effect of acute stress on decision making using binary lotteries from the one-urn Ellsberg paradigm. I ran nine subjects using this experiment design and found that relative to the control condition, stress caused subjects to be more risk averse when expected winnings were low, and more risk seeking when expected winnings were high. Additionally, stressed subjects had slower reaction times when making decisions. I conclude that acute stress increased cognitive load, but ultimately, facilitated decision making under risk and ambiguity.

1. Introduction

Decisions inundate everyday life – from deciding something as mundane as what to eat for breakfast to something as important as which job offer to accept. Classical economics assumes that people behave perfectly rationally, meaning that they choose the option that maximizes their utility. But oftentimes, these decisions present themselves with varying levels of uncertainty, specifically risk and ambiguity, which can strongly affect decision making (Simon, 1959) (Allais, 1953) (Kahneman & Tversky, 1979).

A decision is considered risky if the likelihood of each outcome is known, but the actual outcome is not definitively known. Alternatively, a decision is ambiguous if the odds of the outcomes are unknown. On the whole, people tend to be both risk averse and ambiguity averse (Epstein, 1999) (Camerer & Weber, 1992). A risk averse person prefers a more predictable outcome with a lower average expected payoff over a risky bet with a potentially high payoff. A An ambiguity averse person is best explained by the Ellsberg Paradox, which states that people prefer taking on risk in situations in which they know the specific probabilities rather than taking on risk in which the odds are unknown, even if the average outcome with the known probability is lower (Ellsberg, 1961).

One important note is that the degree to which people are risk averse and ambiguity averse varies on an individual level. Subjective expected utility models this phenomenon for risk (Savage, 1954); a person will calculate their own expected utility for each possible outcome, $\Sigma\mu(x_i)P(x_i)\ for\ x_1, x_2, \dots, x_i$, where μ is a subjective utility for a given probability. Ultimately, the person will prefer the outcome in which their own expected value of the utility is highest (Fischhoff, Goitein, Shapira, 1983). The model for ambiguity is the same with the addition of

another variable (ϕ) that represents the decision maker's attitude towards ambiguity over a probability distribution (Klibanoff, Marinacci, & Mukerji, 2005).

Beyond the characteristics of the decision itself that modulates rationality, exogenous variables—like stress—can also greatly impact decision making. Physical or psychological stress elicits an autonomic nervous system response, specifically an activation of the sympathetic nervous system but an inhibition of the parasympathetic nervous system. These responses are part of the process of preparing the body for a fight-or-flight response. A few of the sympathetic nerve responses include increased heart rate, pupil dilation, increased skin conductance, and increased blood pressure (Ziegler, 2004). The cold pressor test is a common method that has been replicated in many studies involving stress (Ishizuka, Hillier, & Beversdorf, 2007) (FeldmanHall, Raio, Kubota, Seiler & Phelps, 2015). Immersing one's hand in cold water, specifically 0-2 °C (Mitchell, MacDonald & Brodie, 2004), induces the same physiological responses as acute stress (Lovallo, 1975).

With respect to risky decision making, the effect of stress yields mixed results. While many studies report that subjects are more risk-seeking when under stress (Starcke, Wolf, Markowitsch & Brand, 2008) (Pabst, Schoofs, Parlikowski, Brand & Wolf, 2013) (Buckert, Schwieren, Kudielka & Fiebach, 2014); other studies suggest no effects (Delaney, Fink & Harmon, 2014) (Cano-Lopez, Cano-Lopez, Hidalgo & Gonzalez-Bono, 2016), or even that subjects are less risky when stressed (Pabst, Brand & Wolf, 2013).

Furthermore, stress effects are highly variable depending on experimental design. For example, the effect of stress on decisions under risk depends on stress-to-task latencies –subjects were less risk averse immediately after the presentation of a stressor, but that behavior returned to pre-stressor levels when completing the same task 45 minutes later (Bendahan et al., 2016).

Additionally, studies suggest that stress causes people to choose more conservatively for trials with potential gains, and more risk seeking when faced with potential losses (Pabst et al., 2013).

Much of the research on ambiguity in decision making utilizes tasks that incorporate some form of uncertainty into risky decisions, such as using the Iowa Gambling Task which requires choice based on ambiguous reinforcement patterns. While it is generally accepted that acute stress causes individuals to be more risk taking under these tasks (Morgado, Sousa & Cerqueiera, 2014) (Porcelli & Delgado, 2017), the results from various studies appear to be mixed. A study by Cano-Lopez et al. (2016) suggests that acute stress increases the number of risky decisions under ambiguous conditions, while others found that subjects under stress were more risk-seeking for both advantageous and disadvantageous decisions (Lighthall et al., 2009) (Bos et al., 2009).

Because these studies contain uncertainty embedded within the design, they are unable to separate the effects of risk and ambiguity. Therefore, these studies cannot examine the differential effect of stress on decision making under risk and ambiguity. Even studies that do compare these two categories of decision making use different tasks to measure each category; the differences in methodological design make it hard to directly compare choices and increase the variability in the comparisons (Cano-Lopez et al., 2016). Furthermore, many of these studies for both risk and ambiguity provided feedback immediately after each trial. This type of reward feedback could cause subjects to adapt their decisions, which disrupts the effect of stress on decision making over the course of the experiment. The one study that accounted for these variabilities in methodological factors used a similar paradigm as the one this study used[1]; these

[1] One difference is that this study examined both advantageous and disadvantageous decisions, whereas I only included advantageous decisions.

results suggested increased risk seeking for risky gains and no effect on decision making under ambiguous decisions (Buckert et al., 2014).

This present study provides preliminary data for comparing the effect of stress on risk and ambiguity in decision making. This experiment utilizes a one-urn Ellsberg paradigm, which has been used in several studies that measure risk and ambiguity attitudes (Levy, Snell, Nelson, Rustichini & Glimcher, 2010) (Grubb, Tymula, Gilaie-Dotan, Glimcher & Levy, 2016). The paradigm uses binary lotteries with known and unknown probabilities of winning to model risk and ambiguity—this allows ambiguity and risk effects to be separated with no other difference between these two trial types. The simplicity of the methodological design reduces variability that can otherwise cloud the true relationship between stress and decision making, as exemplified by the variety of results from the literature. Additionally, this experiment provides no feedback between trials and attempts to control for variability in responses to the cold pressor test.

2. Methods

Nine subjects (3 male and 6 female) participated in the experiment, which was comprised of two sessions given on consecutive days. Half of the subjects were randomly chosen to have the stress stimulus (i.e. the cold pressor test) presented on the first session, while the other half of the subjects had the stress stimulus presented on the second day. Then for each session, subjects played an economic game with a one-urn Ellsberg Paradigm for 6 blocks of 20 trials each.

The cold pressor test would be administered at the beginning of each session in which subjects are instructed to place their hand up to their wrist within a bucket of ice water (held constantly between 0-2 °C) for a total of three minutes while fixing their gaze on a cue on the computer screen. The session with the control condition instructed subjects to place their hand in

room temperature water (20-25 °C) – all other factors besides the water temperature would stay the same between the two conditions.

Each block of 20 trials was randomized for whether the subject would re-enter their hand into the water regardless of stress or control condition. This by-block randomization was an attempt to control for any variations in physiological responses to the cold pressor (Fasano et al., 1996) (Mishra, Manjareeka, & Mishra, 2012), such as subjects who do not respond as strongly to the initial three minutes of the cold pressor test or those whose stress responses would fade before the end of the session. Thus, this added re-application of the stimulus randomly throughout each session would ensure to some degree that each subject's stress response would be maintained for the entire duration of the session.

In each trial, subjects were presented with a lottery of a varying winning probability or ambiguity level and a varying winning amount. Subjects had to indicate whether they wanted to play that lottery or whether they preferred to play a reference lottery, which was the same for all trials (winning a fixed amount of $5). The reference lottery was presented to the subjects before the beginning of the experiment. The changing lottery appeared on the screen in the form of an "urn" painted partly red and partly blue (Fig. 1*A*). Subjects were told beforehand that all of the urns that they would see during the experiment contained a total number of 100 poker chips, but that the relative numbers of red and blue chips would be different in different urns. The percentages of red and blue chips were indicated by the red and blue regions of the urn. Numbers next to the red and blue areas represented the amounts of money that could be made if a chip of that color were drawn from the physical urn to which the display corresponded. For example, in Fig. 1*A*, if the subject draws a red chip, the subject would win $180, whereas nothing would be won if a blue chip is drawn.

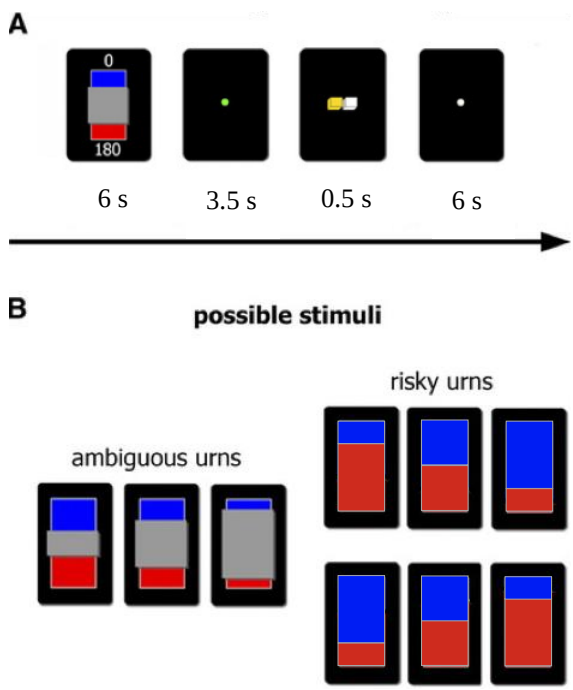


Fig. 1

Each stimulus was presented for 6-s, and then a green dot was presented, cuing subjects to press one of two buttons on a response box to indicate their choice between the lottery on the screen and the reference. The response had to be made within 3.5-s and was followed by a 0.5-s visual presentation of the pressed button (Fig. 1*A*). The buttons assigned for the reference and for the option on the screen were counterbalanced across subjects. Each trial was followed by a 6-s inter-trial interval during which a white fixation dot was presented at the center of the screen.

In half of the trials, part of the urn was hidden by a gray occluder, which was always placed over the center of the image (Fig. 1*B*, *left*). The probability of drawing a chip of a certain color was therefore incompletely known or ambiguous (ambiguous trials). For example, in the leftmost urns in Fig. 1*B*, 25% of the chips are occluded, and thus the probability of drawing a red chip can be anywhere between 37.5% (if all the chips behind the occluder are blue) and 62.5% (if all the chips behind the occluder are red). Similarly, the probability of drawing a blue chip can also be anywhere between these two values. Increasing the occluder size increases the ambiguity

level or the range of possible probabilities for drawing a red or blue chip. Three different occluder sizes (covering 25%, 50%, or 75% of the urn) were used in the experiment. In the other half of the trials, the entire urn was visible such that subjects had complete information about the ratio of red and blue chips in the urn (risky urns; Fig. 1*B*, *right*). Three winning probabilities were used (0.25, 0.50, and 0.75).

Subjects were told that each image on the screen represented a physical bag containing physical poker chips in it. Each unique image corresponded to one unique physical bag. *Thus each and every time they encountered a 25% ambiguous display, they were making choices about draws from the same bag*. In half the trials presented to the subjects, red was associated with winning a positive amount of money and blue yielded a zero amount. In the other half of trials, the contingencies were reversed. It is important to note that this design ensured that the objective winning probability in all the ambiguous trials, averaging across the 50% of red-winning and 50% of blue-winning trials, was effectively fixed at 0.5.

Twenty dollar amounts[2] were used at each risk and ambiguity level, yielding 120 unique trial types [(3 probabilities + 3 ambiguity levels) × (20 amounts)]. The 120 trials were presented in a random order for each session, thus resulting in 32 minute-long sessions. Subjects completed a few practice trials for each session before beginning the actual experiment.

As subjects had been informed at the beginning of the experiment, at the end of the experiment, one trial from each session was randomly selected and played for hypothetical money rewards. To select the trial, a random number generator was used to choose a number from 1 to 120. If in that corresponding trial the subject decided to play the lottery (as opposed to the reference amount of $5), subjects then drew a chip from the bag corresponding to the trial

[2] 5, 6, 7, 8, 10, 12, 14, 16, 19, 23, 27, 31, 37, 44, 52, 61, 73, 86, 101, and 120 dollars

and were told their potential reward amount according to the chip's color and the payment contingency on that trial. Subjects were informed that they would conduct all of these procedures before the experiment began.

Prior research suggests that there is no significant difference between real or hypothetical rewards (Locey, Jones, & Rachlin, 2011). This experiment used hypothetical payment presented in the same way as the standard payoff mechanism employed in behavioral and experimental economics. Furthermore, prior implementation of this paradigm using real money versus hypothetical money revealed no differences in choices for the trials.

3. Analysis

Using R-Studio statistical software packages, I repeatedly fit linear regression models to analyze the effect of stress on decision making. Statistical analysis was conducted for all trials in aggregate, as well as separately, for risky trials and ambiguous trials. This is the main linear regression that I ran:

$$Y = \beta_0 + \beta_1 isStress + \beta_2 isRisky + \beta_3 isStress * isRisky + \beta_4 vals + \beta_5 vals * isStress + \beta_6 probs + \beta_7 ambigs + \beta_8 gender + \beta_9 day + \varphi_s + \varepsilon$$

The dependent variable (Y) is `decision`, which is a dummy variable that encodes whether a subject chose to play the lottery or receive the reference amount of $5.[3] For graphical representations, I transform `decision` to the proportion of trials in which the subject chose to play the lottery for a given variable, such as dollar values or expected value. `isStress` is a dummy variable to encode whether the trial was within the stress or control group[4], and `isRisky`

[3] 0 = reference amount, 1 = lottery amount
[4] 0 = control, 1 = stress

is a dummy variable that indicates whether the trial was risky or ambiguous[5]. `vals` corresponds with the dollar value, `probs` with probability of winning the positive amounts, and `ambigs` with the ambiguity level[6]. φ_s represents individual fixed effects for the subjects, which controls for any exogenous unique characteristics of each subject that would affect decision making.

The interaction effects that I included in the regression were a result of initial data exploration in which I found the effect of stress to be modulated by these factors, i.e. whether the trials were risky or ambiguous, and the corresponding dollar amount of the trial. Including an interaction effect between gender and stress proved to be insignificant, so I excluded it from the main regressions. One note is that for the separate analysis on risk and ambiguity, the regressions excluded the `isRisky` and `isRisky*isStress` variables; otherwise, the regressions used were the same as the described regression.

I conducted initial analysis on the data from control sessions to ensure that the data abides by literature results in terms of risk aversion and ambiguity aversion, i.e. subjects were risk averse and ambiguity averse. Risk aversion was determined by looking at the proportion of risky trials chosen to play the varied lottery (versus the reference lottery) for each unique expected value – risk aversion occurs if subjects chose to play the lottery with proportion less than 1.00 for expected values greater than $5 (aka the reference lottery). To measure ambiguity aversion, only risky trials with 50% probability were used for comparison, as the objective winning probability for all ambiguous trials is 50%. For each unique expected value, the difference was taken between the proportion of trials chosen to play the lottery for ambiguous trials and risky trials ($\text{Prop.}_{\text{ambiguous}} - \text{Prop.}_{\text{risky}}$). A person is ambiguity averse on top of being

[5] 0 = ambiguous trial, 1 = risky trial

[6] For ambiguous trials, `probs` is equal to 0.5 (as that is the expected probability of winning). For risky trials, `ambigs` would be encoded as 0. While `ambigs` would have sufficiently indicated whether the trial was ambiguous or risky, it would not have provided the direct effect of ambiguous versus risky trials (as it also encodes the three ambiguity levels); hence, the rationale for creating the `isRisky` variable.

risk averse if this difference is negative, or that they chose to play the lottery more often for a risky trial than the corresponding ambiguous trials, even though the expected values are the same.

The main regressions analyzed the decisions between stress and control trials for risky and ambiguous trials. These regressions were conducted for two groups – all trials as a whole (2154 trials) and across day trials. Across day trials refers to all trials of a given subject, which is categorized based on if the subject had the stress treatment on the first or second session ("across day 1" indicates trials in which subjects had the stress stimulus on the first stimulus, and vice versa for "across day 2"). Looking at "across day 1" trials is effectively looking at between-group treatments, respectively. These trials can be compared to the whole data analysis to ensure that any noticeable patterns are consistent. The "across day 2" trials cannot be used in this sense as these trials are confounded with the fact that there might be some aspect of familiarization with the paradigm, i.e. we might not see as clear of a difference between stress and control treatment groups simply because subjects that fall in these categories have taken the experiment the day before. Nonetheless, looking at these "day 2" trials can help detect if there does exist convergence in choices between the stress and control group (within subjects and between subjects) – considering no difference between the two groups for across trial days, that convergence can be attributed to exposure to the experiment design. Thus, this added analysis can help understand variability in subjects' choices that cannot be explained by treatment group (stress vs. control) alone.

4. Results

4.1 General Data Exploration

A total of 2154 trials from the nine subjects were analyzed – 6 trials from the 2160 original trials were omitted as subjects failed to respond in those trials. Data from all nine subjects were used. The criterion for subject exclusion narrowed in on trials in which the choice was between the reference amount of $5 and a lottery offering $5 – in those trials, the subject should always choose the certain amount, so subjects would only be excluded if they chose to play the lottery over 50% of the time in those trials (Ruderman et al., 2016) (Grubb et al., 2016). While some variability existed between subjects (Fig. A-1), all subjects passed that criterion.

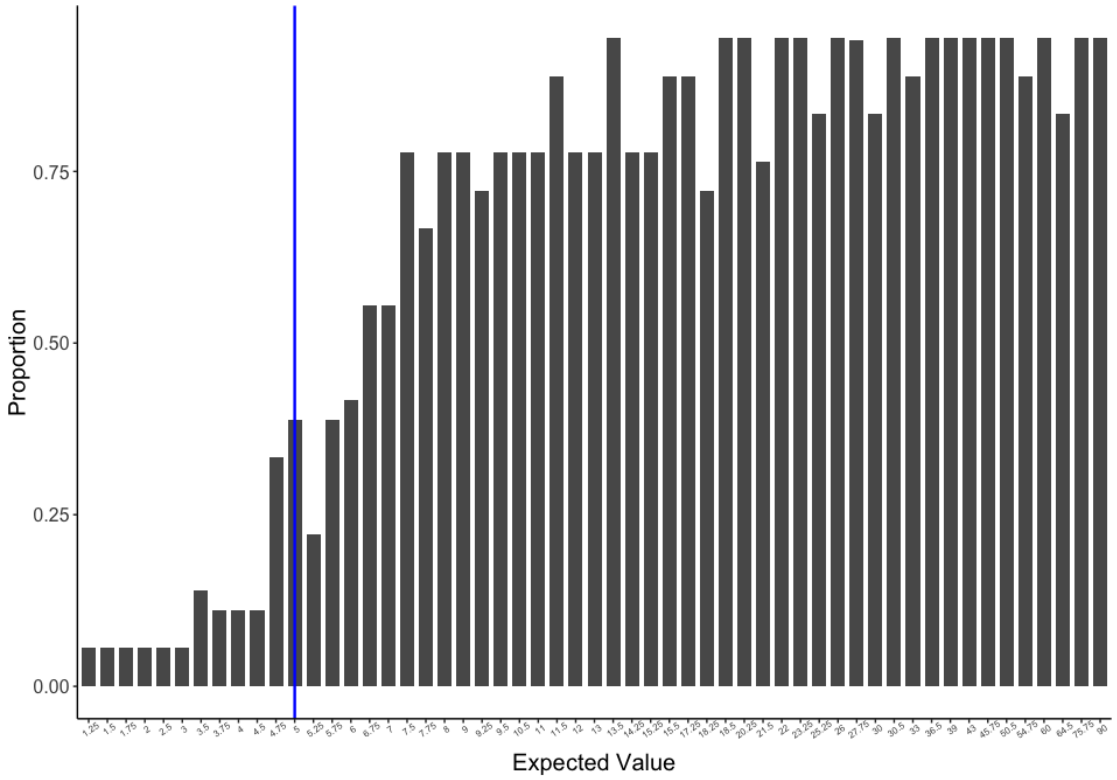


Fig. 2 – Proportion of risky trials chosen to play the lottery for each expected value. Blue vertical line demarcates an expected value of $5 – all values to the right of the line are higher than the reference amount for each trial.

Examining just the control trials, the data collected does indicate that subjects were generally risk averse and ambiguity averse. For risky trials, 76.24% of trials that had an expected win greater than or equal to $5 were chosen to play the lottery. A percentage less than 100% for these trials indicated risk aversion because subjects preferred the certain amount over a lottery even with a known higher average payoff. Fig. 2 (above) shows that this risk aversion stemmed not just from trials with expected value close to $5 – instead, subjects chose the reference amount almost 25% of the time for trials with expected winnings ranging from $7 to $64.

I then compared ambiguous trials with only risky trials that had 50% probability of winning. For trials with expected winnings greater than or equal to $5, subjects overwhelmingly chose to play the lottery more often for risky trials than ambiguous trials at the same expected value (Fig. A-2). This disparity is greatest for trials closer to the reference amount (subjects chose to play the lottery more for risky trials 25-30% of the time for expected winnings ranging $5 to $11.5). As expected winnings increase, this difference drops to around 10%.

Expanding this comparison for each ambiguity level separately reveals that these differences in choice between risk and ambiguous trials are most apparent for the highest ambiguity level (0.74), or trials in which 74% of the urn is occluded; the ambiguity level of 0.50 tracks the pattern of the higher ambiguity level at a smaller magnitude. For the lowest ambiguity level (0.24), there is essentially no difference in choice between those and risky trials for expected winnings greater than approximately $15. Therefore, these results, pictured below in Fig. 3, suggest that ambiguity aversion is dependent on both ambiguity level and expected winnings.

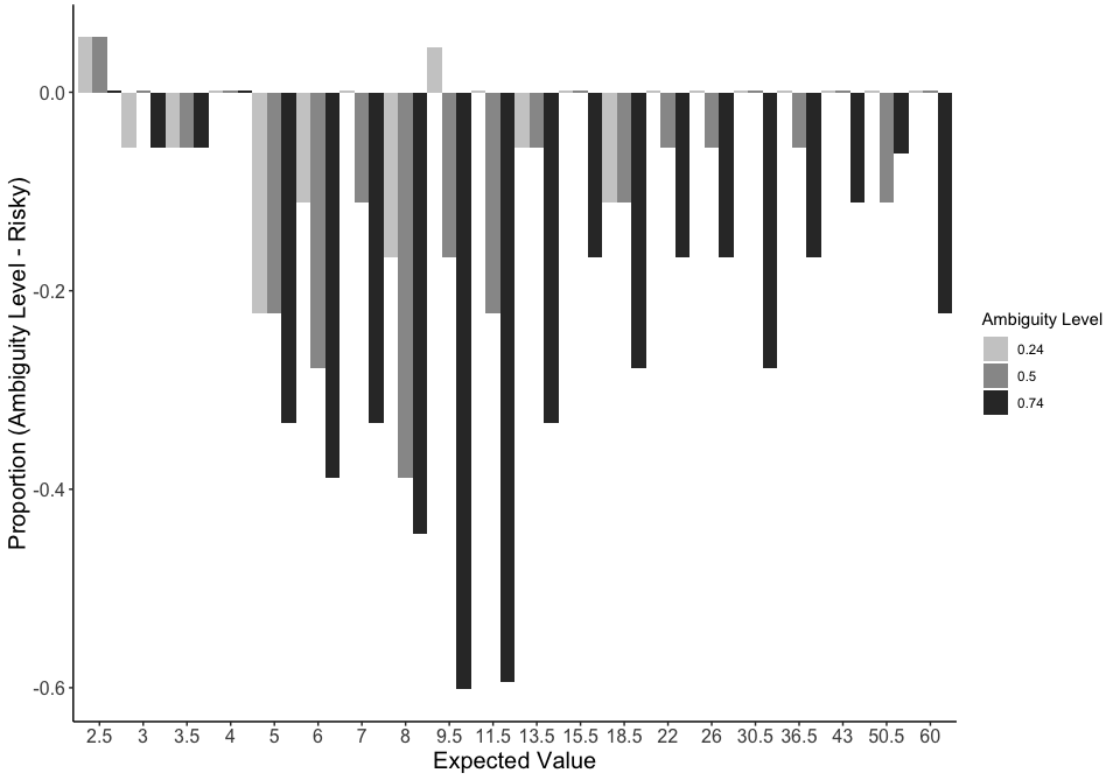


Fig. 3 – Difference between proportion of trials chosen to play the lottery for ambiguous trials and risky trials (with 0.5 winning probability) for each expected value. The lighter grey bar represents (Proportion $_{\text{Ambiguity Level = 0.24}}$ − Proportion $_{\text{Risky}}$). The darker grey bar represents that difference for an ambiguity level of 0.50, and the black bar represents that for 0.74 ambiguity level.

4.2 Effect of Stress

4.2.1 Whole-data Analysis

The first part of this main analysis examined all trials as a whole. The regression results, which are listed on the following page in Table 1, suggest that stress only significantly affected choice when interacted with the dollar amount possible in each trial. With each incremental increase in dollar amount, the effect of stress significantly increased decision making by 1.7% with a p-value of 0.00135. Although this coefficient estimate seems minute, at high dollar amounts like $61 or $120, the effect of stress would increase the percentage of trials chosen to play the lottery by 10.37% or 20.4%, respectively, compared to the lowest dollar amounts. The specifics of this interaction between values and stress becomes clearer when plotted (Fig. 4).

Table 1. Estimates of the effect of stress on decision in each trial. Each column corresponds to a separate regression which tests various interaction effects. Column (3) is a combination of (1) and (2) with an added interaction effect between stress and values; this regression was determined to be the optimal regression equation as the fourth column's interaction effect was insignificant.

	Dependent variable:			
	decision			
	(1)	(2)	(3)	(4)
isStress	0.033*	0.047*	-0.017	-0.002
	(0.018)	(0.025)	(0.032)	(0.034)
isRisky	-0.139***	-0.125***	-0.125***	-0.125***
	(0.035)	(0.039)	(0.039)	(0.039)
vals	0.007***	0.007***	0.006***	0.006***
	(0.0003)	(0.0003)	(0.0004)	(0.0004)
probs	0.600***	0.600***	0.599***	0.599***
	(0.061)	(0.061)	(0.061)	(0.061)
ambigs	-0.404***	-0.404***	-0.404***	-0.404***
	(0.061)	(0.061)	(0.061)	(0.061)
genderM	0.087**	0.087**	0.087**	0.110***
	(0.037)	(0.037)	(0.037)	(0.042)
day	-0.022	-0.022	-0.022	-0.025
	(0.018)	(0.018)	(0.018)	(0.018)
isStress:isRisky		-0.029	-0.029	-0.029
		(0.035)	(0.035)	(0.035)
isStress:vals			0.002***	0.002***
			(0.001)	(0.001)
isStress:genderM				-0.045
				(0.038)
Constant	0.244***	0.237***	0.269***	0.267***
	(0.060)	(0.060)	(0.061)	(0.061)
Observations	2,154	2,154	2,154	2,154
R^2	0.309	0.309	0.313	0.313
Adjusted R^2	0.305	0.305	0.308	0.308
Residual Std. Error	0.410 (df = 2139)	0.410 (df = 2138)	0.409 (df = 2137)	0.409 (df = 2136)
F Statistic	68.399*** (df = 14; 2139)	63.875*** (df = 15; 2138)	60.787*** (df = 16; 2137)	57.303*** (df = 17; 2136)
Note:				*p<0.1; **p<0.05; ***p<0.01

Additionally, the differential effect of stress on risky and ambiguous trials was not statistically significant. While a stressed subject tended to choose to play the lottery less by 2.91% under risky conditions compared to ambiguous conditions, this phenomenon was not statistically significant with a p-value of 0.41. This effect will be further analyzed when I run linear regressions for risky trials and ambiguous trials separately, as well as conduct a difference-in-difference regression between stress and control for trial types (risky and ambiguous).

All other regressors significantly affect decision making with the exception of `day`, which encodes what day in which the trial was played. Although insignificant, I kept it in the regression because it demarcated an important structural difference—subjects might have chosen differently on a day-to-day basis for exogenous factors, or because there was some familiarization involved. This particular option is further explored when within day/across day trials are analyzed.

The graph below (Fig. 4) plots the proportion of trials chosen to play the lottery (over the reference amount) for each dollar value and treatment group. The interaction effect revealed in the regression above is apparent in the plot—at low values, stressed individuals were less likely to play the lottery; conversely, stressed subjects were more likely to play the lottery at high dollar amounts (higher than approximately $27). A middle range of values acted as the inflection point in which there was no clear distinction in decisions between stress and control groups – this may be because these values ($12-$19) corresponded with expected values closer to the reference amount of $5 (Fig. A-3).

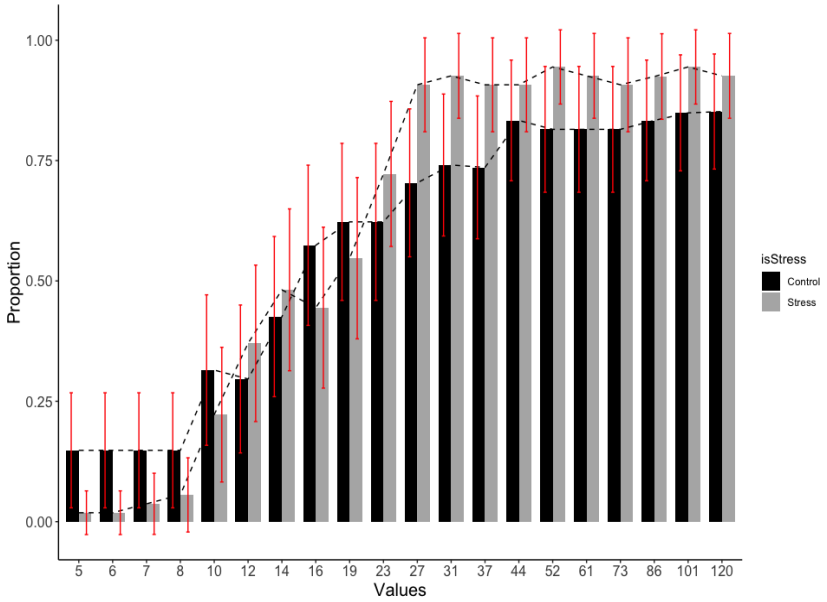


Fig. 4 – Proportion of trials chosen to play the varied lottery (versus reference amount) across all potential winning values. Black bars represent trials under the control condition; grey bars represent trials under the stress condition. Error bars represent standard errors.

To further explore this pattern, I ran regressions on subsets of trials. The three distinct groups that I picked track the interaction of stress and values—trials with dollar amounts less than $12, those with dollar amounts between $12 and $19 inclusive, and any trials with dollar amounts greater than $19. The regression output suggested that only the two groups on either end of the dollar amount scale (<$12 and >$19) had a significant effect on decision making (Table A-1). For values less than $12, a stress trial tended to significantly decrease the probability of playing the lottery by 11.0% with a p-value of 0.00102. Regressions on trials with high dollar amounts similarly reported a very significant effect of stress with a p-value of approximately zero (6.43e-08); at high values, subjects behaved the opposite – they were 13.6% more likely to play the lottery compared to the control group.

4.2.2 Risky Trials vs Ambiguous Trials Analysis

The next part of the analysis examined the effect of stress on risk and ambiguity separately. These regressions (Table 2 on next page) and accompanying graphs (Fig. A-5, Fig. A-6) suggest that the same pattern revealed in the whole data analysis exists for both risky and ambiguous trials data. The regressions indicate that like the main regression, the coefficients on `isStress` are both insignificant, but the interaction of stress and values is significant with p-values of 0.03 and 0.01 for risky trials and ambiguous trials, respectively. Additionally, the graphs of the proportion of trials chosen to play the varied lottery (versus reference amount) across all potential winning values for both kinds of trials depicted the same pattern as the main graph—the stress group tended to play the lottery less for lower potential winning values and more for higher values. The same values ($12 & $19) acted as the inflection points for each type of analysis; refitting the linear models for each distinct group of values confirmed that for both

risk and ambiguity, stress significantly affects decision making for the groups of low values and high values (Table A-2) (Table A-3).

Table 2. Estimates of the effect of stress on risky trials and ambiguous trials. Each column corresponds to a separate regression—Column (1) corresponds with risky trials; Column (2) with ambiguous trials .

	Dependent variable:	
	decision	
	(1)	(2)
isStress	-0.044	-0.018
	(0.037)	(0.038)
vals	0.006***	0.007***
	(0.001)	(0.001)
probs	0.600***	
	(0.061)	
ambigs		-0.404***
		(0.061)
genderM	0.058	0.117**
	(0.053)	(0.053)
day	-0.032	-0.012
	(0.025)	(0.025)
isStress:vals	0.002**	0.002**
	(0.001)	(0.001)
Constant	0.157**	0.556***
	(0.066)	(0.066)
Observations	1,078	1,076
R^2	0.307	0.329
Adjusted R^2	0.298	0.320
Residual Std. Error	0.407 (df = 1064)	0.409 (df = 1062)
F Statistic	36.190*** (df = 13; 1064)	40.000*** (df = 13; 1062)
Note:		*p<0.1; **p<0.05; ***p<0.01

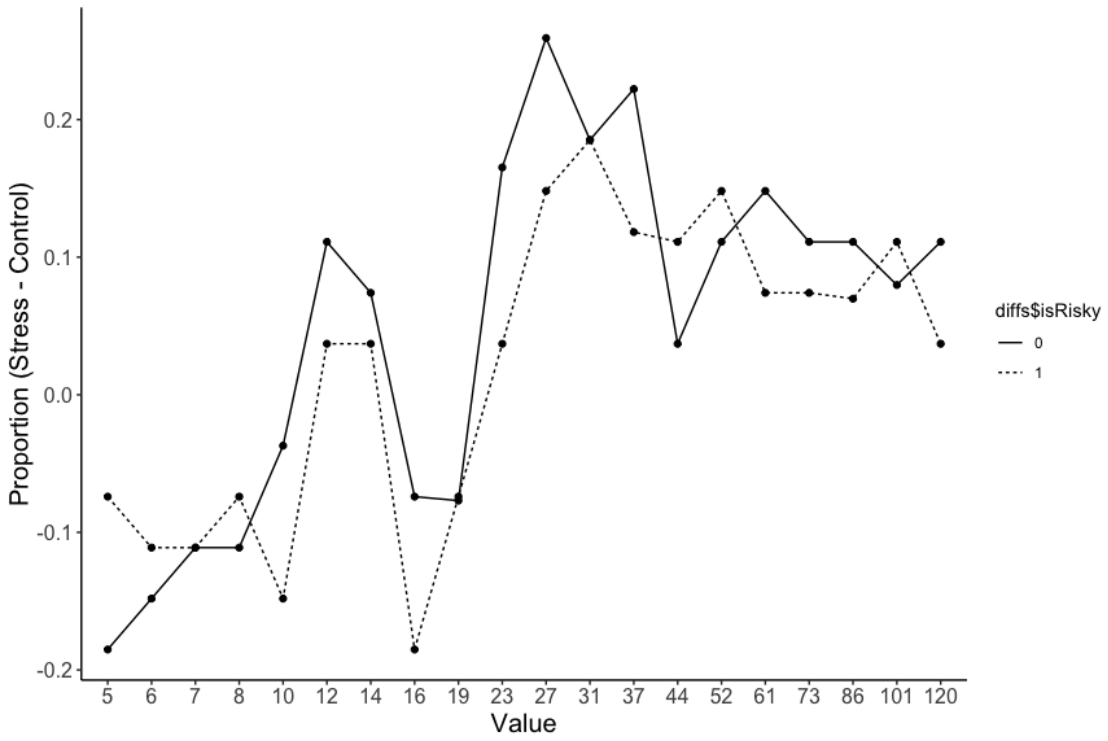
One interesting note from the regressions is the effect of gender on choice. For risky trials, choices are not significantly differentiated by gender—the coefficient estimate on `genderM` suggests that males chose to play the lottery 5.8% more often than females, though this finding is insignificant with a p-value of 0.27. Conversely, decision making in ambiguous settings does seem to depend on gender. Compared to females, males chose to play the lottery

11.67% more—this estimate was highly significant with a p-value of 0.028. But, as mentioned in the Analysis section (pg. 10), the interaction between gender and stress proved insignificant. Therefore, the data suggest that males tend to make more risky decisions under uncertain conditions, but under risky conditions, there is no difference in choice between genders. Furthermore, the introduction of stress does not cause genders to behave differently relative to control conditions.

The general patterns across values appear the same between risky and ambiguous trials (Fig. A-5, Fig. A-6), which can be explained by the estimates for the interaction between stress and values as they are the same for both risk and ambiguity (0.002). Therefore, each increase in value will have the same marginal increment on the effect of stress on choice regardless of risk or ambiguity conditions. Since the effect of stress at the lowest values is different between risk and ambiguity, an equal marginal increment might create a constant difference between trial type (risk/ambiguity) and treatment group (stress/control) for each value. The interaction effect between stress and trial type (ambiguous/risky) was not significant in the whole data analysis, but that might be because stress affects the choice for risky versus ambiguous trials inconsistently across values (i.e. for some trials, the effect of stress causes subjects to choose the reference amount more under risk versus ambiguity; for others, the opposite might apply). Even though a pattern between how subjects chose under risk compared to under ambiguity remains unclear, a significant difference between trial types might still exist. I conducted a difference-in-difference analysis to uncover if this was the case.

The graph below (Fig. 5) depicts trendlines for risky trials and ambiguous trials across all values. Each point on a trendline represents the difference in proportion of trials chosen to play the lottery between stress and control groups. While the trendlines track a general pattern

Fig. 5 – Difference in proportion of trials chosen to play the lottery between stress and control groups. Black line represents ambiguous trials; dotted line represents risky trials. The distance between points for each value is the difference-in-difference.



(similar to the one found in the main analysis - Fig. 4), the difference between the two trendlines is apparent. A paired t-test confirms that the true difference in means between the difference in risky trials between treatment groups and that of ambiguous trials is not equal to zero (Table A-4). In other words, stress affects choice differently for risk and ambiguous conditions, despite the same general trend across potential winning values.

4.3 Reaction Time

I first looked at a simple histogram of reaction time (Fig. A-4), which suggested that the stress group had slower reaction times on average. For further analysis, I then look at how reaction time varies by dollar value, which is depicted by Fig. 6 (pg. 22). $23 acts as an

inflection point—for values below $23, the reaction times for the stress group clearly trends above the control group's reaction time; for values above $23, the differentiation between the treatment groups is less clear. I regressed reaction time on similar variables as the main regression for values below $27; these results confirmed that the effect of stress was highly significant (Table A-5). Subjects took 0.61 seconds longer to react for stress trials compared to control trials—this coefficient estimate has a p-value of 0.001. The analogous regression for values greater than $27 revealed that the effect of stress on reaction time was weakly significant. This coefficient estimate had a p-value of 0.09 and suggested that subjects reacted 0.027 seconds slower for stress trials.

Given this pattern, I further examined how reaction time changed based on trial number—if reaction times would overall decrease as familiarization occurs, and if there existed any pattern that mirrored that of reaction times across values. Based on Fig. 7 below, reaction times do trend linearly downward over trial number across treatment groups. The difference between the trendlines for reaction time between the stress group and control group is generally consistent across trial numbers—the reaction times for the stress group trends distinctly higher than that for the control group. Besides the general downward trend, there does not seem to be any other discernible interaction between reaction time and trial number; therefore, the reason why stressed subjects took much longer to respond for trials with potential winning values less than $23 versus values greater than $23 is not correlated with trial number.

Fig. 6 – Average reaction time by potential winning value between treatment groups. Black line represents control group; dotted line represents stress group.

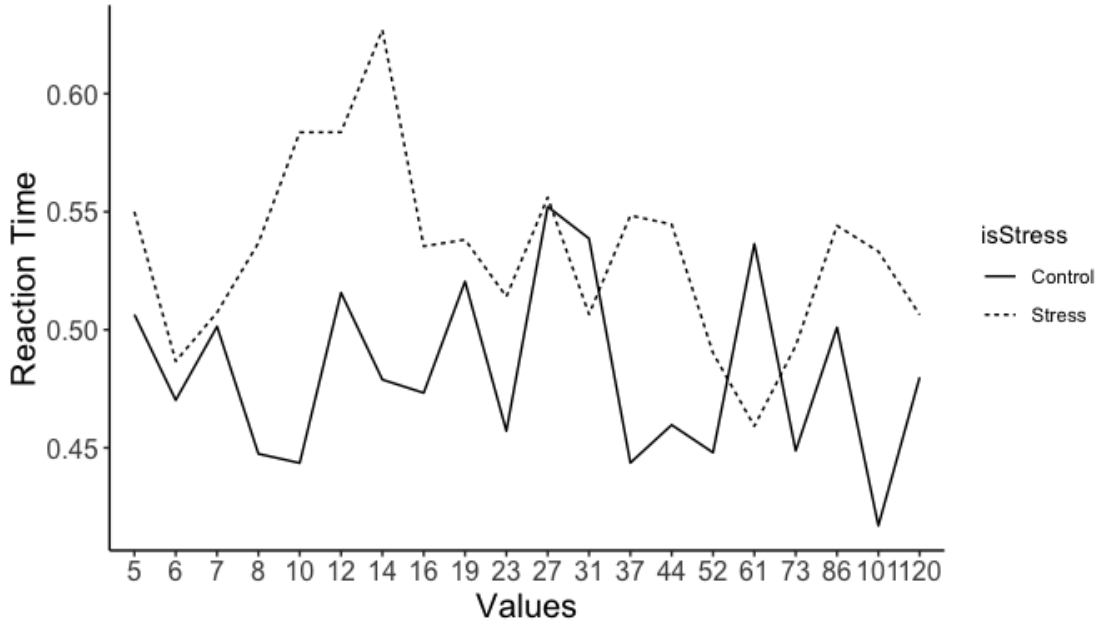
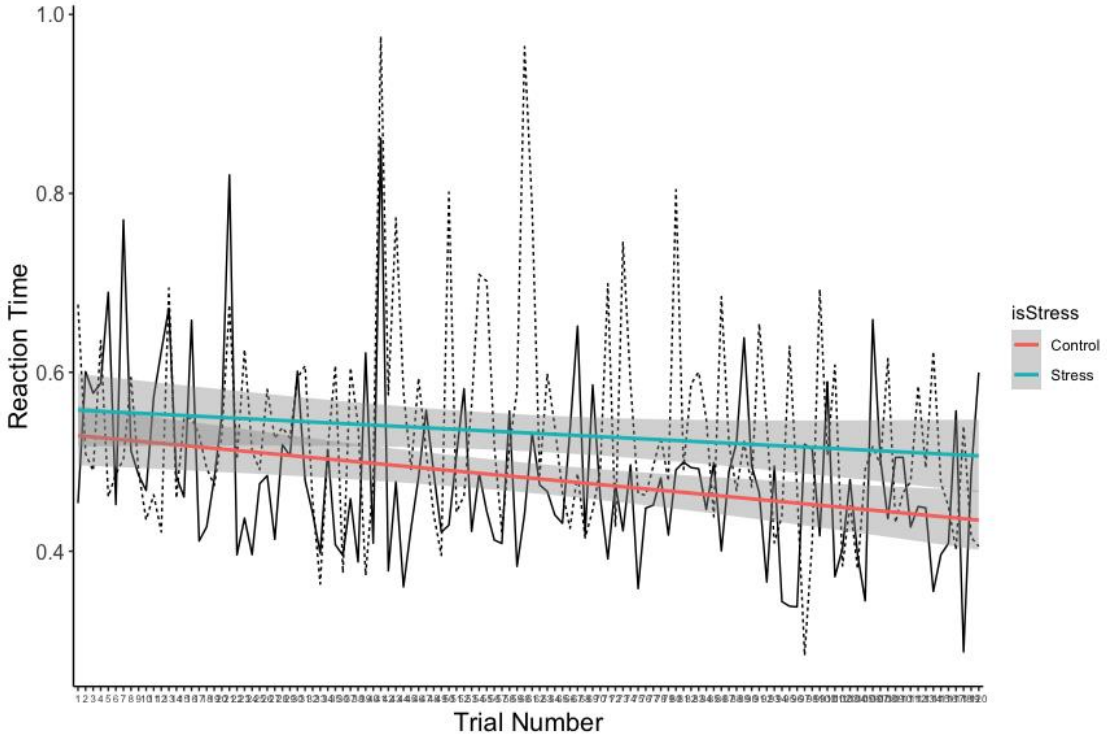


Fig. 7 – Average reaction time for each trial number by treatment group. Red line represents the trendline for control group; black line tracks the average reaction time for the control group. Blue line represents the trendline for stress group; dotted line tracks average reaction for the stress group.



4.4 Across Day Trials Analysis

As stated in the Analysis section, “across day 1” trials analysis are effectively within-subjects and between-subjects analysis. For “day 2” trials, one confounding factor is that the subjects have already had exposure to the experiment. As a result, the effect of stress may be confounded simply with familiarization with the experiment. But, since there is no other difference between the “day 1” and “day 2” trials besides the day the trials were played, any difference between “day 1” and “day 2” trials can be attributed to experiment familiarization.

Looking first at “across day 1” trials, or trials for subjects who were assigned to the stress group on the first day, subjects were both risk averse and ambiguity averse. One aside is that subjects in the “across day 1” group were less averse to ambiguity compared to everyone as a whole (Fig. A-7). This discrepancy does not seem to greatly skew results, as the effect of stress presents a very similar pattern of decision making to that in the main analysis, i.e., stressed subjects chose to play the lottery less for lower values and greater for higher values (Fig. A-8). The analogous regression showed similar results in term of the effect of stress (Table A-6). While the coefficient of stress at the lowest value is insignificant (p-value = 0.27), the interaction between stress and values was extremely significant with a p-value of approximately zero. One inconsistency between the analysis for the main data and for the “across day 1” data is that for the latter, stress does not significantly affect risky and ambiguous trials differently. Additionally, average reaction times for the “across day 1” trials were significantly slower for stress trials compared to control trials across all values (Figs. A-9, Table A-7(left)). Both the analysis on choice and on reaction time provide results that mirror the main analysis results.

Subjects in the “across day 2” group, or those individuals who had the stress stimulus on the second day, displayed levels of risk aversion and ambiguity aversion comparable to the levels

found in the whole-data analysis (Figs. A-10-A11). Analysis on the effect of stress on choice for all trials, risky trials, and ambiguous trials showed convergence of choice, or that there was no significant difference between proportion of trials chosen to play the lottery between stress and control groups (Figs. A-12, Table A-8). Furthermore, average reaction times between these two groups were not significantly different (Figs. A-13, Table A-7 (right)). Experiment familiarization explains the convergence in choice between stress and control groups, which can then explain variability in choice among stress trials.

5. Discussion

5.1 Results

In this study, I investigated whether acute stress affects decision making under uncertainty, specifically if stress affected decision making under risk and under ambiguity, by using a paradigm with a set of binary lotteries associated with hypothetical monetary incentives. A wide range of expected values were varied systematically in order to provide an understanding of decisions across a distribution of expected winnings. Additionally, the paradigm did not provide any feedback between trials; therefore, analysis of decisions is independent of any learning processes.

Results showed that acute stress caused subjects to choose more often the option with the higher expected value for each trial —stressed subjects were more risk-averse at lower potential winning values and more risk-seeking at higher values for both risky and ambiguous trials. The specificity of these findings is important because it suggests that the relationship between stress and decision making is not linear—stress did not cause individuals to choose the risky decision

regardless of value. In addition, stressed individuals tended to have slower reaction times compared to control individuals.

Stress has been found to affect cognitive load; those under stress tended to have lower measures of cognitive load, or cognitive resources available to complete tasks (Conway, Dick, Li, Wang & Chen 2013). Simultaneously, small amounts of acute stress have been proven to facilitate executive function (Lewis, Niolova, Chang & Weekes, 2008) (Duncko, Johnson, Merikangas & Grillon, 2009) [7]. Thus, slower reaction times in this context might suggest that the effect of stress was competing with necessary cognitive resources needed to decide, but ultimately, the effect of the immediate, acute stress caused subjects to perform better. Coupled with the behavioral results aforementioned, these results suggest that under stress, subjects revert to a simpler strategy; specifically, subjects consistently chose to receive the certain amount when the expected value of the lottery was low, and similarly chose to play the lottery when its expected value of winning was higher than the reference lottery.

This hypothesis is corroborated by the related graphs (Fig. 4) and the grouped regressions from the Results section. Above $19, stressed subjects chose to play the lottery at almost the exact proportion of trials; below $12, stressed subjects preferred to receive the certain amount with similarly low proportions across these values. Fig. 6 supports the notion that reduced cognitive load causes stressed subjects to react slower on average, but the magnitude in which they react slower depends on value. For very high values (greater than $27), or those whose expected values are certainly higher than $5, reaction times were closest between the two treatment groups. For very low values (below $8), the difference between reaction times for control vs stress was greater—the expected value was closer, but on average lower than $5. The

[7] Other studies have found that acute stress inhibit function. (Elzinga & Roelofs, 2005) (Schoofs, Preuss & Wolf, 2008)

greatest disparity between reaction times for the two groups was for the middle values in which expected values fluctuated right around $5, and in these cases, there was not a significant difference in choice between stress and control groups. The data supports that while imperfect, stressed subjects chose benchmark values with which they played this simpler strategy.

Other results from the data suggest that the effect of acute stress affected subjects' choices under risk and ambiguity significantly differently, albeit it unclear if this effect manifests itself in a pattern. Furthermore, the preliminary data from this study suggests that stress causes males to be more risk seeking under ambiguity conditions compared to females, but no such gender difference exists for risky trials.

5.2 Limitations

The limitations of the study arise mainly from the small sample size (N = 9). We cannot definitively draw a conclusion based on the results of this study because the variability between subjects in this relatively small sample size causes standard errors to be substantially large. One particular subject behaved significantly differently from the rest of the subjects such that this subject's trials were extremely influential when examining the effect of stress. Despite this inconsistency, this subject passed the "exclusion criterion" (as mentioned in the Analysis section) and was therefore included in the analysis. A larger sample size would help determine if this subject's trials were part of a broader pattern that explains the true effect of stress (which was not fully captured in this study), or if these trials were merely outliers.

The subject sample was skewed as subjects were all college students (age 19-22). Additionally, the sample was imbalanced in terms of gender with six females and three males. Therefore, the results of this analysis might not be representative of the broader population, as

people of this age range act differently when confronted with uncertain decisions as compared to older people (Tymula, Belmaker, Ruderman, Glimcher & Levy, 2013). In terms of the gender skew, more analysis is required to determine if the gender effect shown in the analysis remains with an increased sample size. Looking at choice by subject, it appears that all male subjects responded very similarly, which at the very least ascertains that this gender effect is not a result of one male subject. However, the small sample size makes it possible that the subjects who participated might not be representative of each gender, or the population as a whole.

Despite the limitations from the ample size, the results show that acute stress significantly affected decisions under uncertainty. While other studies suggest a linear relationship between stress and uncertainty (e.g. stress causes people to be more or less risk-seeking under risk), these results suggest a more fluid relationship between stress and decision making that is dependent on the magnitude of potential winnings, which could explain mixed results from the literature. These results present an interesting hypothesis for further research to better understand the impact of high cognitive load from stress on decision making under uncertain conditions.

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Appendix

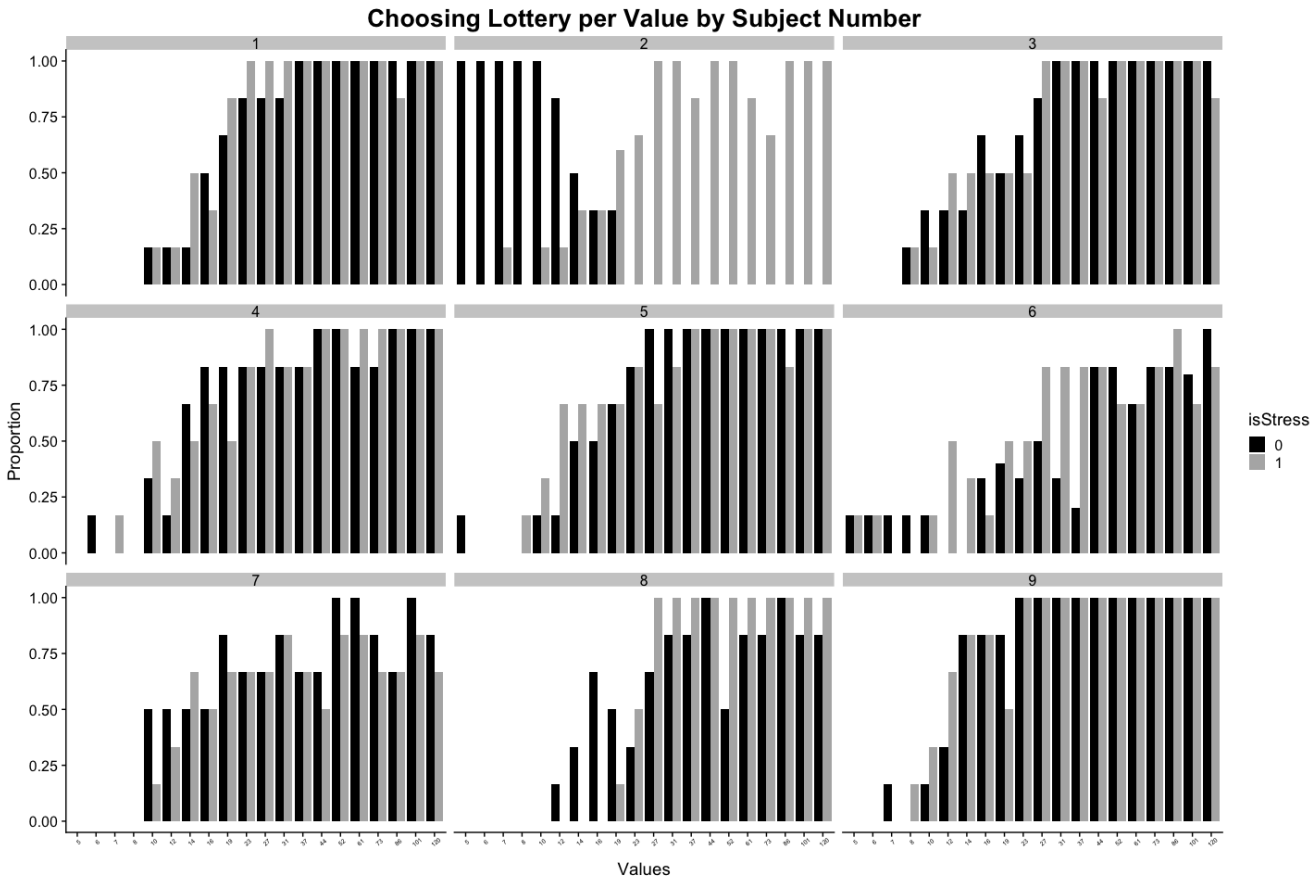


Fig. A-1 – Proportion of trials chosen to play the varied lottery (versus reference amount) across all potential winning values by subject number. Black bars represent control trials; grey bars represent stress trials.

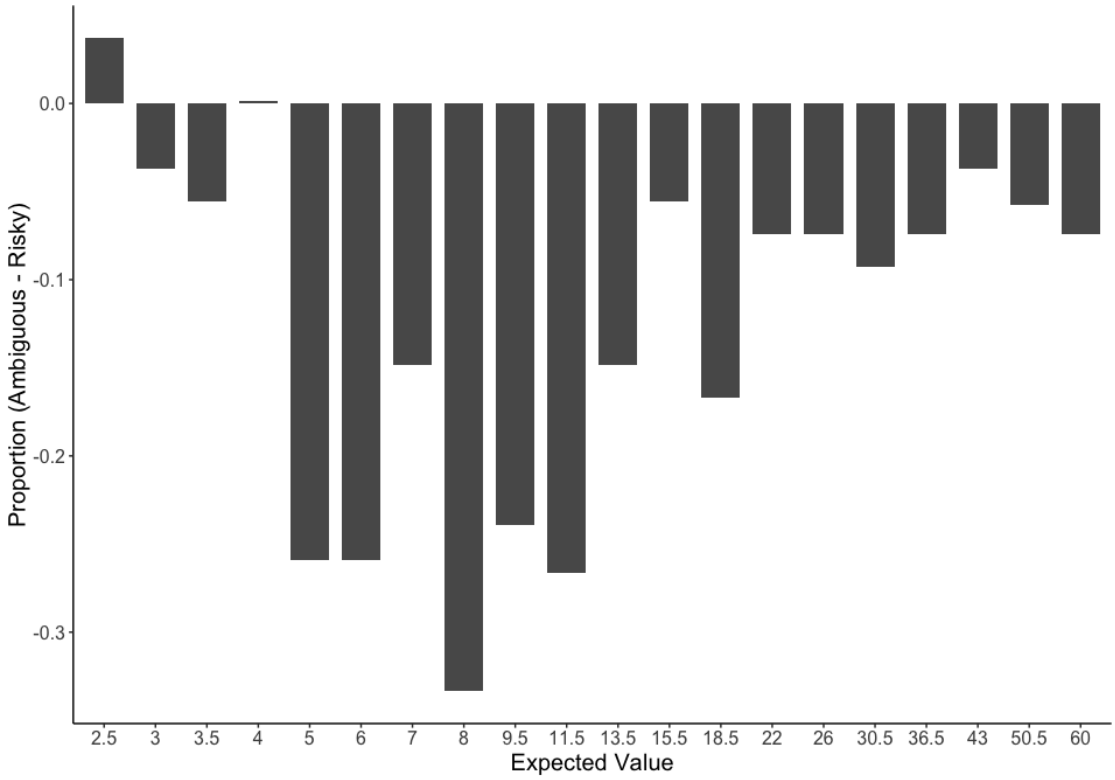


Fig. A-2 – Magnitude of ambiguity aversion across all values. Each bar represents the difference in proportion of trials chosen to play the lottery between ambiguous trials and risky trials (with 0.5 winning probability). A negative amount means that subjects chose to play the lottery more for risky trials than ambiguous trials for the same winning value.

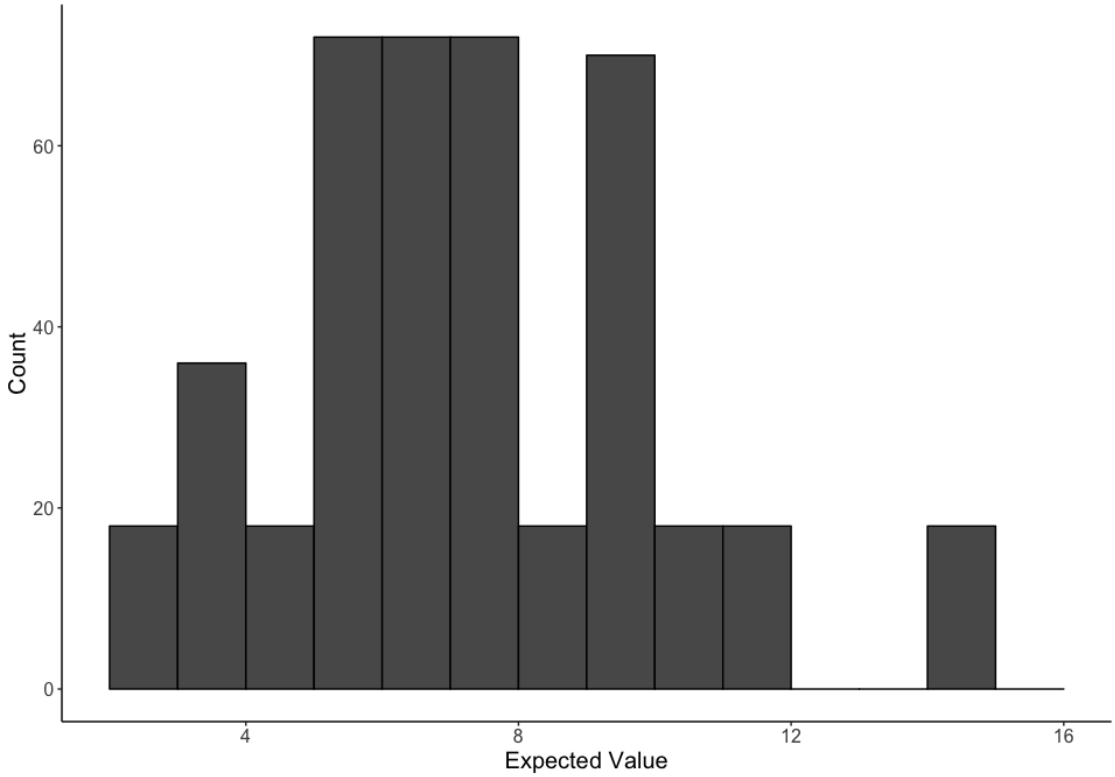


Fig. A-3 – Histogram of expected value for trials with winning values between $12 and $19.

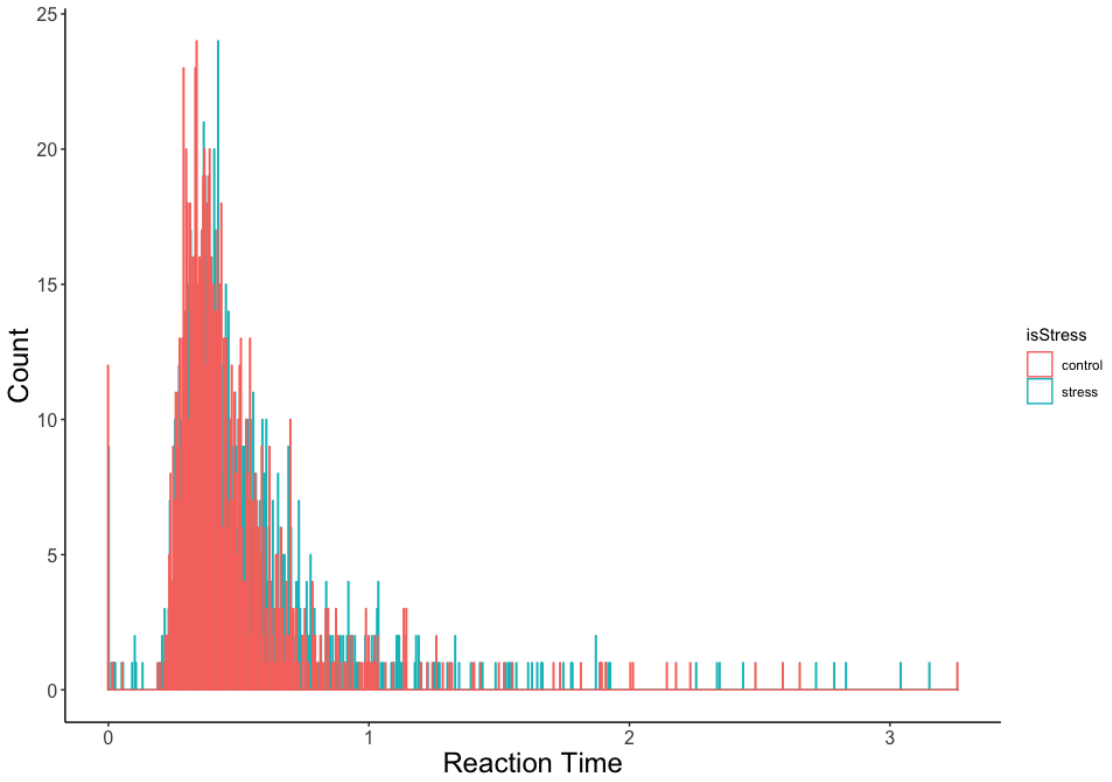
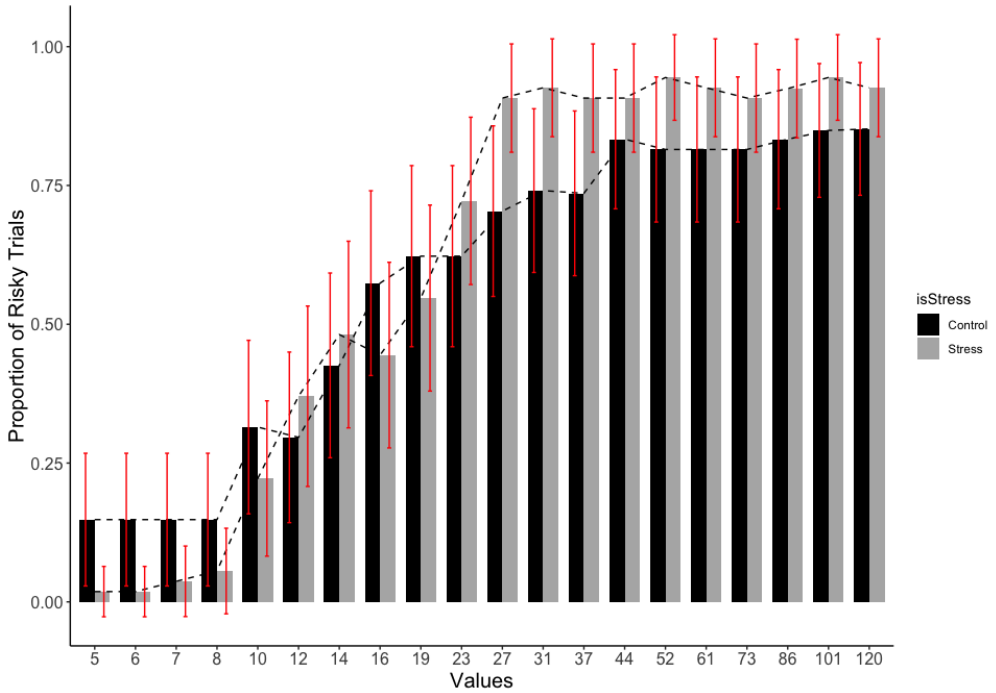
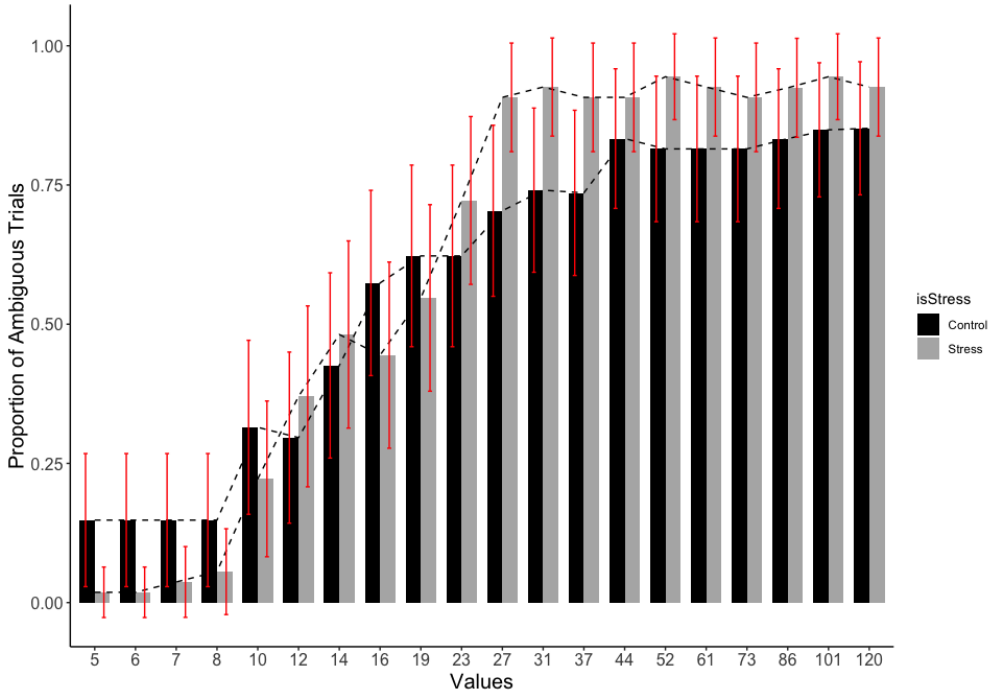


Fig. A-4 – Histogram of Reaction by Stress and Control Group. Red bars represent reaction times of control trials; blue bars represent reaction times of stress trials.

Fig. A-5 - Proportion of trials chosen to play the varied lottery (versus reference amount) across all potential winning values. Black bars represent trials under the control condition; grey bars represent trials under the stress condition. Error bars represent standard errors.

Top: Risky Trials; Bottom: Ambiguous Trials





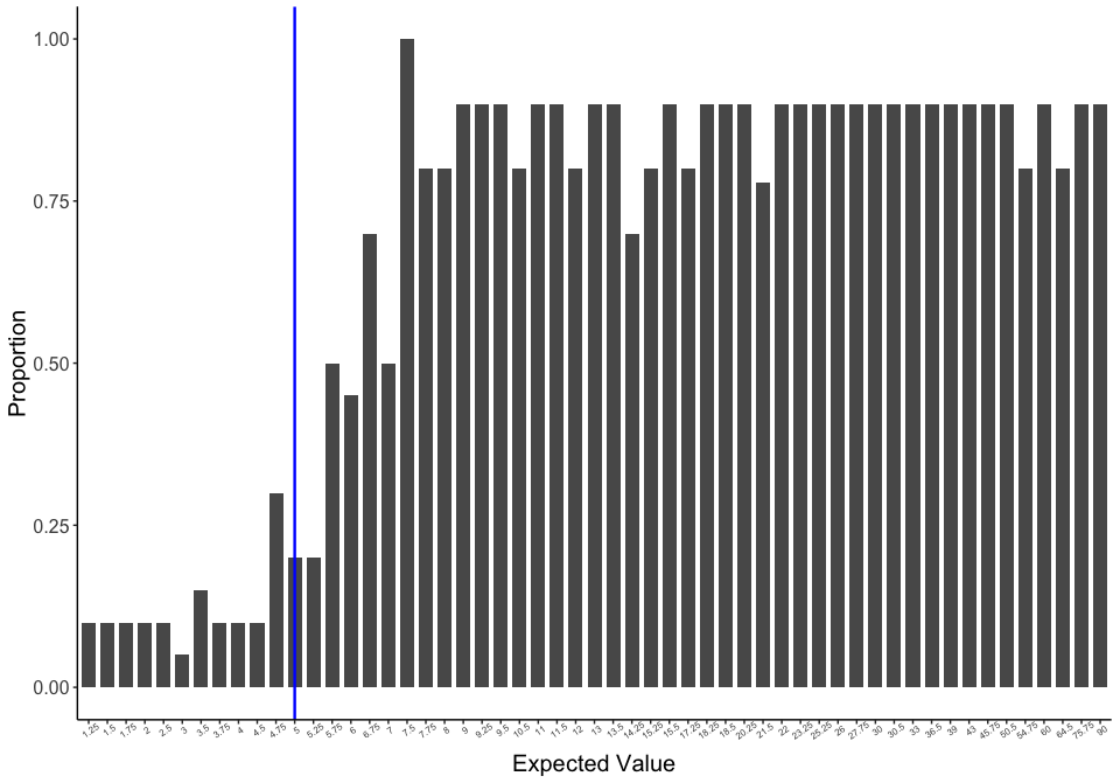
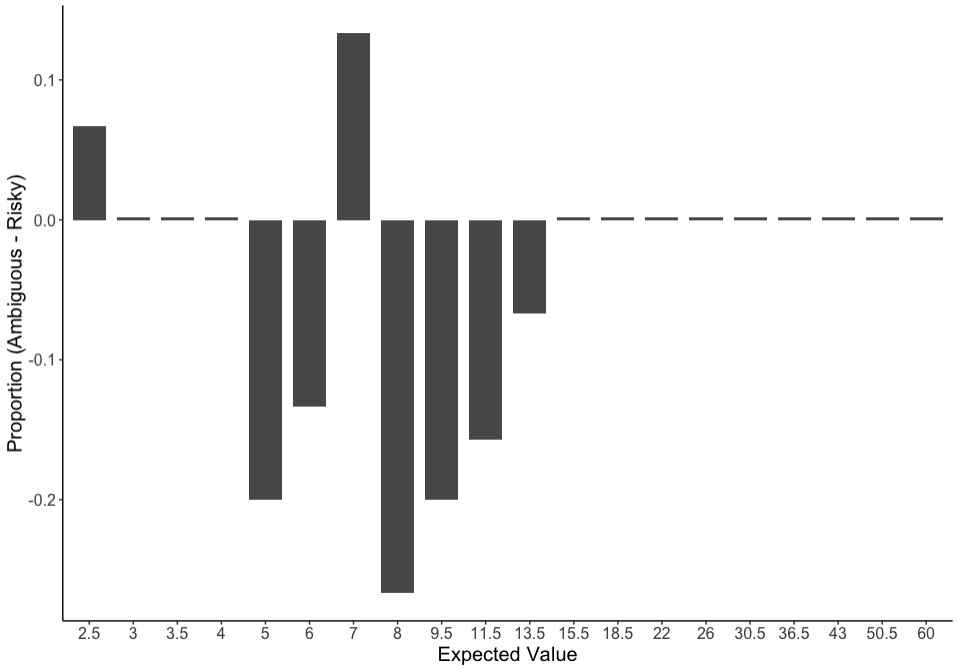


Fig. A-6 - Proportion of risky trials for "across day 1" Group chosen to play the lottery for each expected value. Blue vertical line demarcates an expected value of $5 – all values to the right of the line are higher than the reference amount for each trial.

Fig. A-7 - Difference between proportion of trials for "across day 1" group chosen to play the lottery for ambiguous trials and risky trials (with 0.5 winning probability) for each expected value.

Top: for all ambiguity levels; Bottom: by ambiguity level



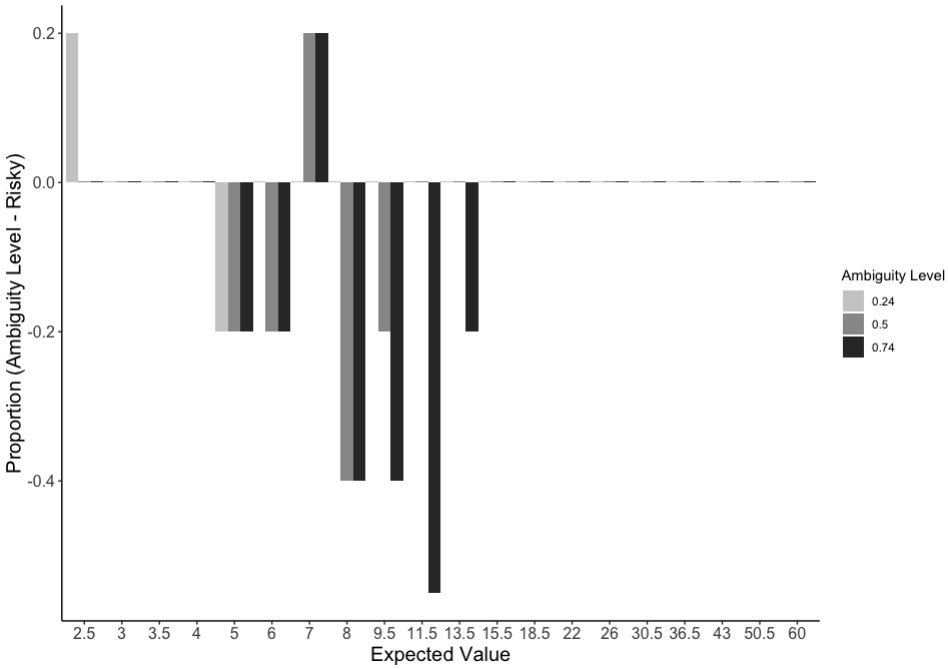
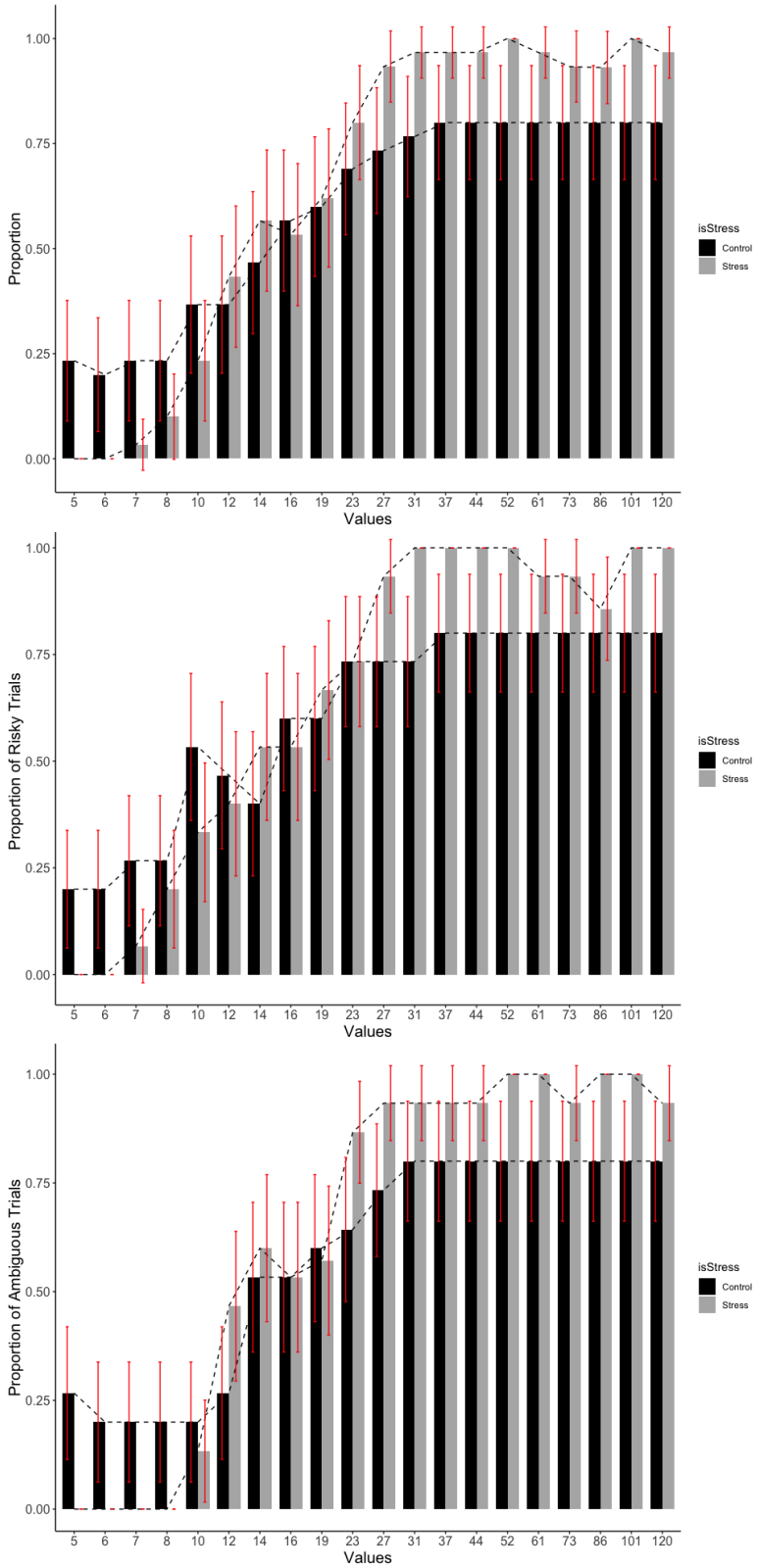


Fig. A-8 - Proportion of trials for "across day 1" group chosen to play the varied lottery (versus reference amount) across all potential winning values. Black bars represent trials under the control condition; grey bars represent trials under the stress condition. Error bars represent standard errors. (Top: All Trials; Middle: Risky Trials; Bottom: Ambiguous Trials)



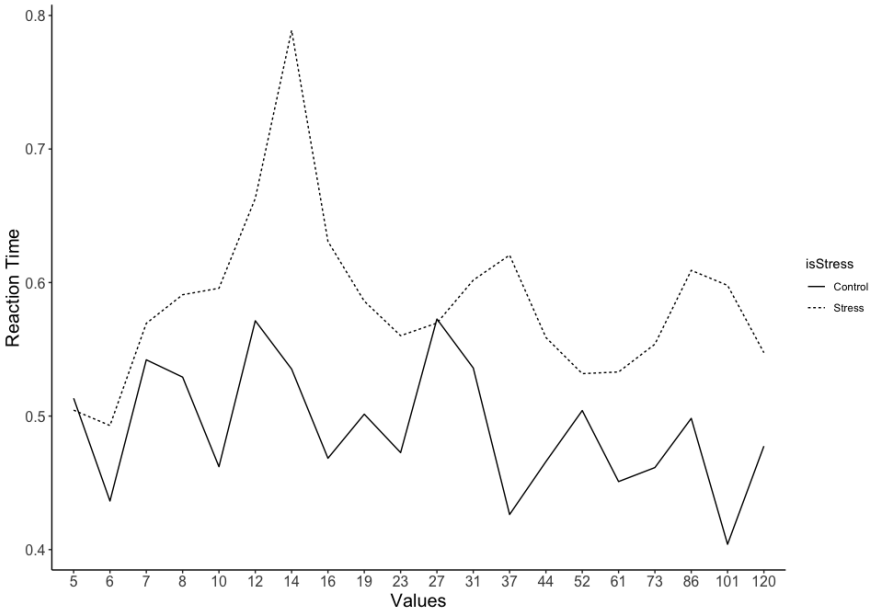


Fig. A-9- Average reaction time by potential winning value between treatment groups for "across day 1" group. Black line represents control group; dotted line represents stress group.

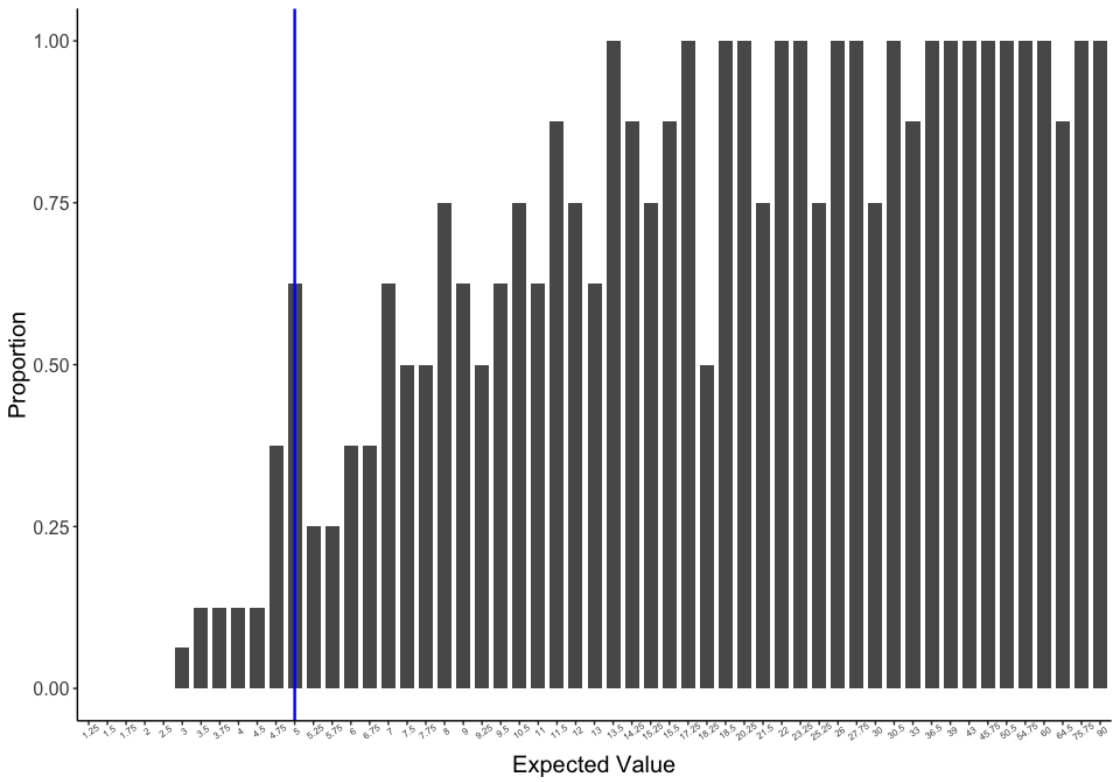
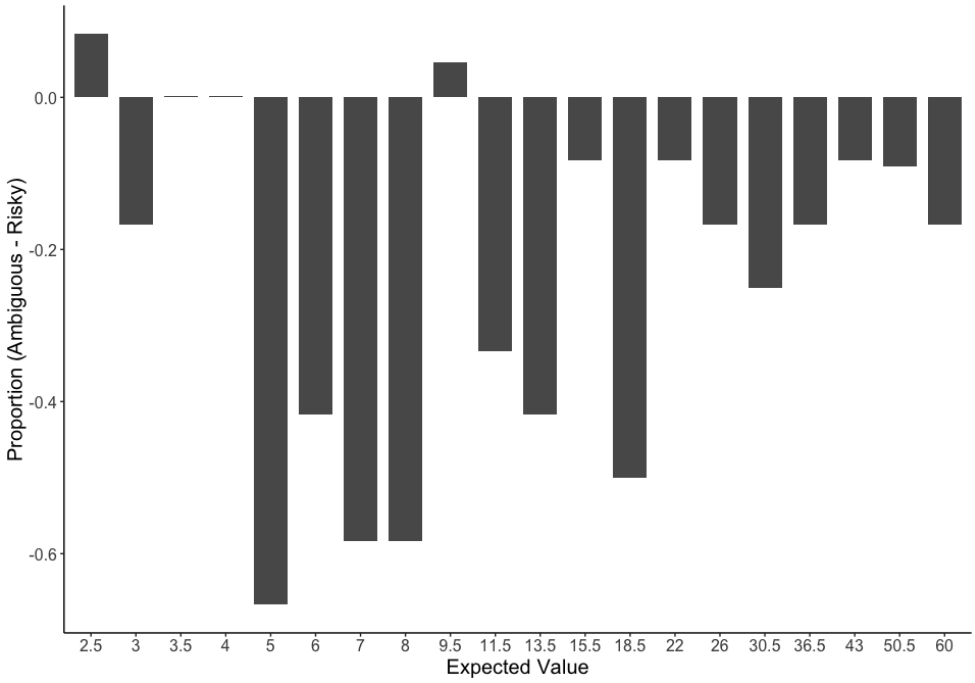


Fig. A-10 - Proportion of risky trials for "across day 2" Group chosen to play the lottery for each expected value. Blue vertical line demarcates an expected value of $5 – all values to the right of the line are higher than the reference amount for each trial.

Fig. A-11- Difference between proportion of trials for "across day 2" group chosen to play the lottery for ambiguous trials and risky trials (with 0.5 winning probability) for each expected value.

Top: for all ambiguity levels; Bottom: by ambiguity level



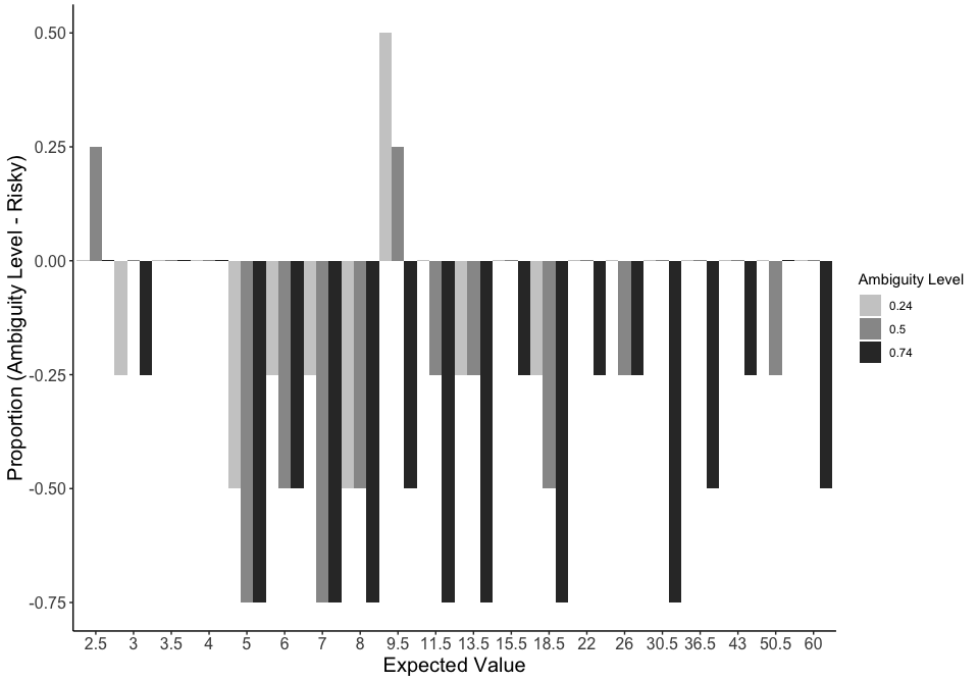


Fig. A-12 - Proportion of trials for "across day 1" group chosen to play the varied lottery (versus reference amount) across all potential winning values. Black bars represent trials under the control condition; grey bars represent trials under the stress condition. Error bars represent standard errors. (Top: All Trials; Middle: Risky Trials; Bottom: Ambiguous Trials)

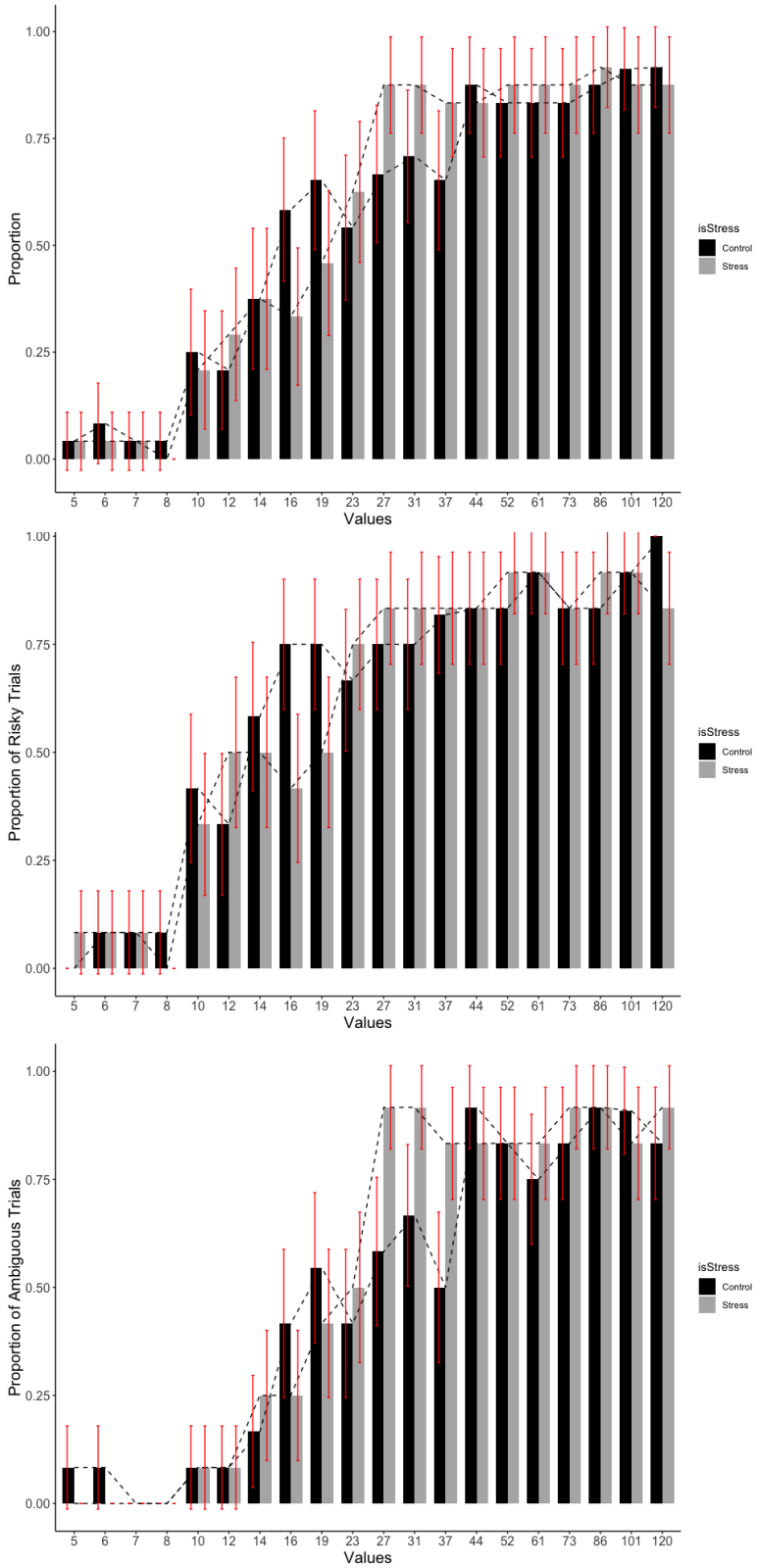


Fig. A-13 - Average reaction time by potential winning value between treatment groups for "across day 2" group. Black line represents control group; dotted line represents stress group.

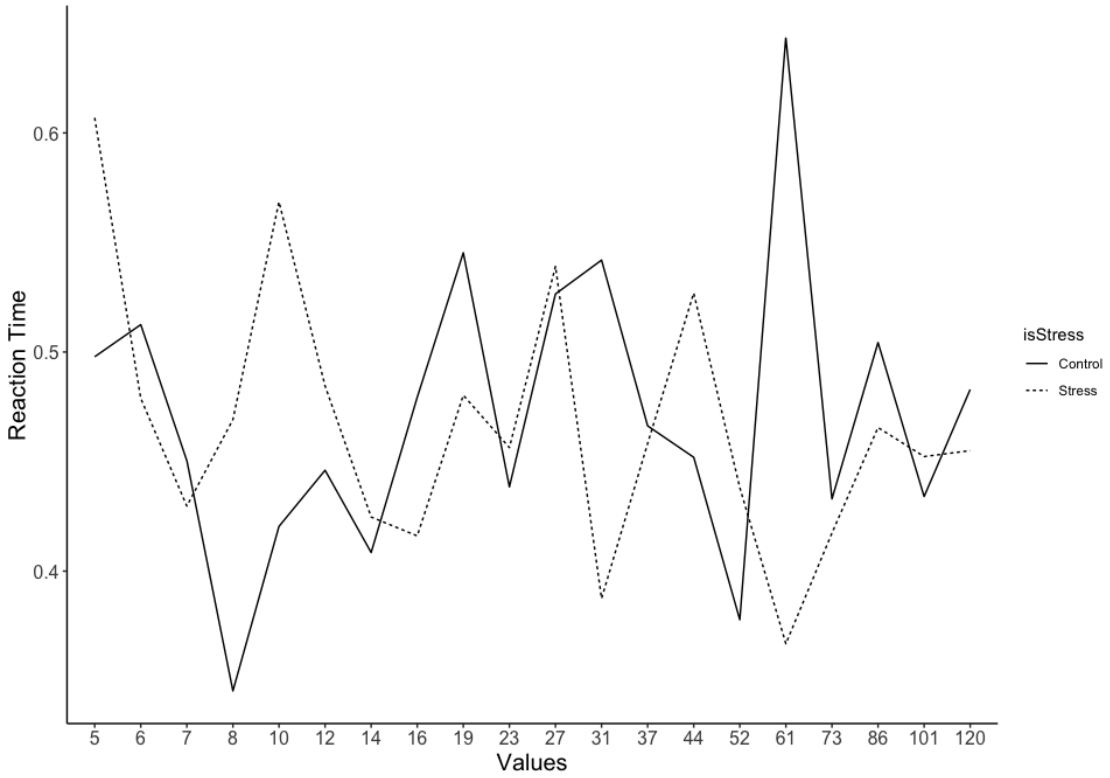


Table A-1. Estimates of the effect of stress on decisions for subsets of trials. Each column represents a separate regression. Column (1) corresponds with trials with values less than $12; Column (2) corresponds with trials with values between $12 and $19; Column (3) corresponds with trials with values greater than $19.

	Dependent variable:		
	decision		
	(1)	(2)	(3)
isStress	-0.110***	0.403	0.136***
	(0.033)	(0.247)	(0.025)
isRisky	0.049	-0.222**	-0.170***
	(0.052)	(0.091)	(0.039)
vals	0.036***	0.047***	0.001***
	(0.007)	(0.011)	(0.0003)
probs	0.511***	1.222***	0.417***
	(0.081)	(0.141)	(0.061)
ambigs	-0.065	-0.758***	-0.433***
	(0.081)	(0.142)	(0.061)
genderM	0.050	0.292***	0.030
	(0.050)	(0.086)	(0.037)
day	0.078***	-0.063	-0.052***
	(0.024)	(0.041)	(0.018)
isStress:isRisky	0.015	-0.052	-0.042
	(0.047)	(0.082)	(0.035)
isStress:vals		-0.026*	
		(0.016)	
Constant	-0.554***	-0.513**	0.894***
	(0.093)	(0.218)	(0.062)
Observations	540	430	1,184
R^2	0.346	0.311	0.310
Adjusted R^2	0.327	0.285	0.301
Residual Std. Error	0.272 (df = 524)	0.423 (df = 413)	0.304 (df = 1168)
F Statistic	18.474*** (df = 15; 524)	11.671*** (df = 16; 413)	34.965*** (df = 15; 1168)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table A-2. Estimates of the effect of stress on decisions for subsets of risky trials. Each column represents a separate regression. Column (1) corresponds with risky trials with values less than $12; Column (2) corresponds with risky trials with values between $12 and $19; Column (3) corresponds with risky trials with values greater than $19.

	Dependent variable:		
	decision		
	(1)	(2)	(3)
isStress	-0.095**	0.403	0.092***
	(0.038)	(0.247)	(0.024)
isRisky		-0.222**	
		(0.091)	
vals	0.065***	0.047***	0.001***
	(0.011)	(0.011)	(0.0004)
probs	0.511***	1.222***	0.417***
	(0.092)	(0.141)	(0.058)
ambigs		-0.758***	
		(0.142)	
genderM	0.067	0.292***	0.045
	(0.080)	(0.086)	(0.050)
day	0.078**	-0.063	-0.068***
	(0.038)	(0.041)	(0.024)
isStress:isRisky		-0.052	
		(0.082)	
isStress:vals		-0.026*	
		(0.016)	
Constant	-0.726***	-0.513**	0.737***
	(0.124)	(0.218)	(0.064)
Observations	270	430	592
R^2	0.360	0.311	0.350
Adjusted R^2	0.330	0.285	0.337
Residual Std. Error	0.308 (df = 257)	0.423 (df = 413)	0.287 (df = 579)
F Statistic	12.032*** (df = 12; 257)	11.671*** (df = 16; 413)	25.982*** (df = 12; 579)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table A-3. Estimates of the effect of stress on decisions for subsets of ambiguous trials. Each column represents a separate regression. Column (1) corresponds with ambiguous trials with values less than $12; Column (2) corresponds with ambiguous trials with values between $12 and $19; Column (3) corresponds with ambiguous trials with values greater than $19.

	Dependent variable:		
	decision		
	(1)	(2)	(3)
isStress	-0.110***	0.469	0.138***
	(0.027)	(0.342)	(0.026)
isRisky			
vals	0.007	0.055***	0.002***
	(0.008)	(0.016)	(0.0004)
probs			
ambigs	-0.065	-0.756***	-0.432***
	(0.066)	(0.140)	(0.064)
genderM	0.033	0.500***	0.015
	(0.057)	(0.120)	(0.055)
day	0.077***	-0.055	-0.037
	(0.027)	(0.057)	(0.026)
isStress:isRisky			
isStress:vals		-0.031	
		(0.022)	
Constant	-0.078	-0.005	1.089***
	(0.089)	(0.278)	(0.071)
Observations	270	214	592
R^2	0.371	0.326	0.289
Adjusted R^2	0.342	0.282	0.275
Residual Std. Error	0.222 (df = 257)	0.417 (df = 200)	0.318 (df = 579)
F Statistic	12.643*** (df = 12; 257)	7.443*** (df = 13; 200)	19.654*** (df = 12; 579)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table A-4. Paired t-test on risky and ambiguous trials. Each term represents the difference in proportion of trials chosen to play the lottery between stress and control conditions.

	t
Test statistic	1.842772
DF	19
p value	0.08102215
Alternative hypothesis	two.sided

Paired t-test: diffsy[diffsisRisky == 0] and diffsy[diffsisRisky == 1]

Table A-5. Estimates of the effect of stress on reaction time.

	Dependent variable:
	rT
isRisky	0.003
	(0.024)
isStress	0.044***
	(0.012)
vals	-0.0003*
	(0.0002)
genderM	0.160***
	(0.026)
ambigs	0.028
	(0.043)
probs	-0.078*
	(0.043)
day	-0.050***
	(0.012)
trialNumber	-0.001***
	(0.0002)
Constant	0.534***
	(0.043)
Observations	2,154
R^2	0.197
Adjusted R^2	0.192
Residual Std. Error	0.286 (df = 2138)
F Statistic	35.000*** (df = 15; 2138)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table A-6. Estimates of the effect of stress on decision making for the "across day 1" group. Each column represents a separate regression. Column (1) corresponds with all trials; column (2) corresponds with risky trials; column (3) corresponds with ambiguous trials.

	Dependent variable:		
	decision		
	(1)	(2)	(3)
isStress	-0.048	-0.060	-0.046
	(0.044)	(0.051)	(0.052)
isRisky	-0.096*		
	(0.053)		
vals	0.005***	0.005***	0.005***
	(0.001)	(0.001)	(0.001)
probs	0.472***	0.473***	
	(0.083)	(0.083)	
ambigs	-0.254***		-0.252***
	(0.084)		(0.084)
genderM	0.087**	0.058	0.147***
	(0.038)	(0.054)	(0.035)
day			
isStress:isRisky	-0.011		
	(0.048)		
isStress:vals	0.003***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)
Constant	0.280***	0.193***	0.438***
	(0.070)	(0.065)	(0.057)
Observations	1,197	599	598
R^2	0.270	0.271	0.267
Adjusted R^2	0.263	0.261	0.261
Residual Std. Error	0.417 (df = 1185)	0.415 (df = 590)	0.420 (df = 592)
F Statistic	39.884*** (df = 11; 1185)	27.433*** (df = 8; 590)	43.226*** (df = 5; 592)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table A-7. Estimates of the effect of stress on reaction time. Each column represents a separate regression. Column (1) corresponds with the "across day 1" group; Column (2) corresponds with the "across day 2" group.

	Dependent variable:	
	rT	
	(1)	(2)
isRisky	0.042	-0.054
	(0.032)	(0.038)
isStress	0.094***	-0.006
	(0.016)	(0.019)
vals	-0.0004*	-0.0001
	(0.0002)	(0.0003)
genderM	0.160***	0.086***
	(0.025)	(0.027)
ambigs	0.072	-0.038
	(0.056)	(0.067)
probs	-0.132**	-0.021
	(0.056)	(0.067)
day		
Constant	0.398***	0.392***
	(0.045)	(0.054)
Observations	1,197	957
R^2	0.148	0.222
Adjusted R^2	0.142	0.216
Residual Std. Error	0.278 (df = 1187)	0.298 (df = 948)
F Statistic	22.952*** (df = 9; 1187)	33.903*** (df = 8; 948)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table A-8. Estimates of the effect of stress on decision making for the "across day 2" group. Each column represents a separate regression. Column (1) corresponds with all trials; column (2) corresponds with risky trials; column (3) corresponds with ambiguous trials.

	Dependent variable:		
	decision		
	(1)	(2)	(3)
isStress	0.028	-0.016	0.020
	(0.046)	(0.054)	(0.054)
isRisky	-0.160***		
	(0.057)		
vals	0.008***	0.007***	0.008***
	(0.001)	(0.001)	(0.001)
probs	0.759***	0.759***	
	(0.088)	(0.088)	
ambigs	-0.590***		-0.590***
	(0.089)		(0.088)
genderM	0.133***	0.200***	0.080*
	(0.036)	(0.051)	(0.041)
day			
isStress:isRisky	-0.052		
	(0.051)		
isStress:vals	0.0002	0.00002	0.0004
	(0.001)	(0.001)	(0.001)
Constant	0.074	-0.083	0.438***
	(0.074)	(0.066)	(0.059)
Observations	957	479	478
R^2	0.377	0.363	0.391
Adjusted R^2	0.371	0.354	0.384
Residual Std. Error	0.395 (df = 946)	0.394 (df = 471)	0.393 (df = 472)
F Statistic	57.275*** (df = 10; 946)	38.377*** (df = 7; 471)	60.496*** (df = 5; 472)
Note:			*p<0.1; **p<0.05; ***p<0.01