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The Effects of Social Context and Acute Stress on Decision-Making Under Uncertainty

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Abstract

Uncertainty preferences are typically studied in neutral, non-social contexts. This approach, however, fails to capture the dynamic factors that influence choices of uncertainty in the real world. Our goals were twofold, to test whether uncertainty valuation is similarly processed across social and non-social contexts, and investigate the effects of acute stress on uncertainty preferences. Participants completed matched gambling and trust games under either control or stress manipulations. Participants not under stress exhibited no differences between money gambled and money entrusted to partners. In contrast, stressed participants exhibited increased gambling but decreased trusting behavior. We further found that irrespective of stress, participants were highly attuned to irrelevant feedback in non-social gambling contexts, believing that every incremental loss led to a greater chance of winning (gamblers' fallacy). However, when deciding to trust a stranger, participants behaved rationally, treating each new interaction as independent. Stress compromised this adaptive behavior, increasing sensitivity to irrelevant social feedback.

Keywords

trust; risk; stress; social decision-making; learning

INTRODUCTION

Experimental economics has illustrated that uncertainty is ubiquitous in decision-making, influences learning, and contributes crucially to the valuation of options in diverse situations. One situation where uncertainty is endemic is deciding to trust another. In fact, a

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Author Contributions

OFH, CMR, JTK, & EAP developed and designed the experiment. OFH & MGS conducted data collection. OFH, CMR, JTK, & EAP performed the data analysis, OFH & EAP wrote the manuscript and CMR & JTK provided critical revisions.

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significant feature of any economic transaction (Arrow, 1974) is our ability to trust and cooperate with non-related others. Learning who to trust and deciding to trust requires the evaluation of numerous factors, including various risk and ambiguity considerations (Gambetta, 1988). For instance, an individual typically must evaluate how trustworthy another person appears to be, while also weighing whether past experiences to trust others has led to reciprocal exchanges. In these unknown environments, choosing to trust is tantamount to making a decision of uncertainty. While stress is known to affect choices involving uncertainty in non-social contexts (Starcke & Brand, 2012), little is known about how stress affects choices of uncertainty within social contexts.

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Current models of uncertainty preferences assume that people assess the desirability and likelihood of possible outcomes through some type of expectation-based calculus. In social contexts, uncertainty considerations become especially important when one must decide whether to trust another—a dynamic captured in the Trust game (Berg, Dickhaut, & McCabe, 1995). Since an individual can make more money by trusting another, but runs the risk of losing all the money if another player decides not to reciprocate, deciding to trust is highly uncertain (Ben-Ner & Putterman, 2001) and akin to playing a gamble where the probabilities of winning are unknown (Knight, 1921).

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One critical question that has received little attention is how uncertainty considerations are differentially valued in social and non-social contexts. Extensive research within non-social contexts illustrates that individuals can be averse to decisions of uncertainty, choosing the safe option that yields small but reliable payouts over the uncertain option that yields large but unreliable payouts (Holt & Laury, 2002). Notably, individuals react more aversively to decisions of uncertainty that have unknown probabilities (i.e. ambiguity) compared to known probabilities, such as a 50% chance of winning (i.e. risk). In the social domain where an individual must engage with others, relatively few decisions of uncertainty have known outcomes, and thus are best characterized by ambiguous uncertainty than risky uncertainty. Since little is known about how ambiguity considerations are valued in social situations, our first goal was to juxtapose how uncertainty considerations in non-social contexts are valued compared to uncertainty considerations in social contexts. To explore these putative differences in ambiguity preferences, we use two tasks—the Trust game and a matched Lottery task—where all components of the two tasks are held constant except the source of uncertainty (i.e. trusting others versus unknown probabilistic gambles). By directly measuring ambiguity under social and non-social contexts, we can observe whether individuals differentially compute ambiguous uncertainty for choices made during social interactions compared with choices devoid of any social component.

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A second question examines how acute stress might differentially affect the valuation of these uncertainty preferences within social and non-social contexts. Stress has a profound—albeit inconsistent (Pabst, Schoofs, Pawlikowski, Brand, & Wolf, 2013)—effect on risky decision-making in non-social contexts. In some cases individuals become less risk averse under stress (Lighthall, Mather, & Gorlick, 2009; Preston, Tansfield, Buchanan, & Bechara, 2007; Starcke, Wolf, Markowitsch, & Brand, 2008; van den Bos, Harteveld, & Stoop, 2009), while in other cases, stress makes individuals more risk averse (Lighthall et al., 2009; Porcelli & Delgado, 2009). Far less is known about how stress affects ambiguity

considerations within either non-social or social contexts. One recent study suggests that socially stressed individuals engage in greater trusting behavior than individuals who are not socially stressed (von Dawans, Fischbacher, Kirschbaum, Fehr, & Heinrichs, 2012). Evidence from this study of such trusting behavior is thought to demonstrate a need to ‘tend and befriend’ in order to strengthen potentially fragile social ties under stress (Taylor et al., 2000). However, it is unclear whether the social nature of the stressor used in this study (i.e. being evaluated while publically speaking), rather than the neurobiological stress response itself, is responsible for the increase in trusting behavior. By directly manipulating the effects of acute stress—indexed by increased levels of cortisol (Axelrod & Reisine, 1984)—using a non-social stressor in both social and non-social contexts, we can probe whether there are domain specific effects of acute stress on ambiguity considerations.

In addition, we can explore whether social context and acute stress biases the integration of past experiences and interactions when processing ambiguity considerations. For instance, given the nature of repeated one-shot games where each gamble and interaction is independent, there should be no influence of past experiences when deciding to take a new gamble or engage in trusting behavior with a new person. In other words, each new decision to gamble or trust should be treated independently. However, countering this rationalist perspective, it is well documented within the non-social domain that one's willingness to engage in decisions of uncertainty is highly influenced by recent outcomes, even when those past choices are completely independent. This is illustrated by the fact that individuals routinely exhibit the gamblers' fallacy (Oskarsson, Van Boven, McClelland, & Hastie, 2009; Rabin, 2002; Tversky & Kahneman, 1974), believing that a streak of losses indicates a greater likelihood of wins for future gambles. Given the robustness of this finding in the non-social domain, it is possible that similar behavior also occurs in social contexts, such that a decision to trust a new individual (i.e. in one-shot games) is influenced by whether previous, unrelated partners were trustworthy. By comparing wins and losses in a non-social lottery task to receiving either a ‘defect’ or ‘reciprocate’ after an initial decision to trust a stranger in the Trust game, we can assess whether social context and acute stress differentially influences how feedback is incorporated into decisions of uncertainty.

MATERIALS AND METHODS

Participants

58 participants were recruited and randomly assigned to be in either the stress condition or in the control condition (sample size based on extant research (Otto, Raio, Chiang, Phelps, & Daw, 2013)). One participant was subsequently excluded from the analysis for exhibiting decreased cortisol levels from baseline in the stress condition, and another subject was excluded from the analysis for exhibiting significantly increased cortisol levels from baseline in the control condition. The final sample included 56 participants, 28 of whom underwent the cold pressor manipulation (N=28; 13 males, mean age 22.33±3.15) and 28 who underwent the control manipulation (N=28, 15 males, mean age 21.0±2.49). Groups were matched on age ($t(54)=1.76, p=.09$) and gender ($t(54)=-.814, p=.42$), and all participants provided written consent in accordance with the standards of the New York University Committee on Activities Involving Human Subjects. Participants were paid \$15

and received additional compensation based on the result of one randomly selected trial from the Trust Game and one randomly selected trial from the Lottery Game.

Task Procedures

Before starting the experiment, participants were asked to read instructions about each game. They were given additional verbal and visual instructions to ensure full comprehension (see supplement). Participants were endowed with \$20, which was placed on the desk before them, \$10 to be used for the Trust Game and \$10 to be used for the Lottery Game. Participants also completed three practice trials before beginning each task. Both the Trust and Lottery games each had 36 trials and were matched on visual, temporal, and monetary dimensions. In order to counterbalance the order of the games, half of the participants played the Trust game first, while the other half played the Lottery game first.

The Trust Game (social task)

A typical Trust game involves a one-shot social interaction between two players, an Investor and a Trustee (Figure 1A). The first player (Investor) is initially faced with a decision to keep a sum of money (e.g., \$10) or share part of it with a Trustee. If shared, the investment is quadrupled (\$40) and the Trustee now faces the decision to repay the trust by sending back half of the increased sum (e.g., \$20 for each player), or to defect and violate trust by keeping the money (e.g. \$40 for the Trustee), leaving the Investor with nothing. The social dilemma for the Investor is clear as it is more profitable to trust, if trust is reciprocated, but doing so leaves the Investor susceptible to the risk of a breach in trust, and ultimately, the loss of money. Notably, these socially uncertain decisions combine risk (known probabilities, such as a 50% chance of winning) and ambiguity (unknown probabilities) (Knight, 1921)—parameters that behavioral economists have successfully deconstructed within the non-social domain.

In our task, participants were assigned to be the Investor and were informed that they would play 36 trials, each with a different Trustee. On each trial participants could choose to invest anywhere between \$0 and \$10, in increments of \$2 (i.e. \$0, \$2, \$4, etc). If the participant decided to invest, they could double their investment if the Trustee shared back with them, or lose the money if the Trustee decided to keep the money. For example, if the participant shares \$4 with the Trustee, the money quadruples to \$16. The Trustee can then either keep the \$16, or split the increased sum with the Investor such that both players each get \$8. In other words, if Trustees chose to share the money, participants could double their earnings. If Trustees chose to keep the money, participants could lose whatever money they invested. Although in the eyes of the participant the outcomes of whether a Trustee would keep or share back the money was not known and thus characteristic of ambiguous uncertainty, in reality, the payoff structure was calculated at 50% reciprocation. Participants were further informed that only one trial would be randomly realized to be paid out at the end of the experiment.

Stimuli—Participants were told that on each trial they would play with a different partner (the Trustee), and that they would be able to view a photo of the Trustee before making their decision to invest. All the photos were faces of white males, pre-rated by an independent

group (N=50; <http://www.pnas.org/content/108/19/7710.long>) and selected according to their levels of trustworthiness (within one standard deviation from mean trustworthiness ratings). Participants were further told that these Trustees had been previously brought into the lab and interviewed about their willingness to share or keep money with future partners, and that they would also be paid with a mailed check according to the decisions of the Investor. In reality, the Trustees' decisions to reciprocate or defect were created by a computer algorithm. To ensure that participants believed they were interacting with real offers from real players, we probed participants' beliefs about their partners during a tunnel debriefing session at the end of the experiment. Participants (N=2) who expressed doubts were not included in the behavioral or neuroendocrine analyses.

Timing structure—On each trial participants were presented with a photo of the Trustee and were given unlimited time to make their decision to invest (Figure 1B). Following their decision, participants were presented with a 2-6 second jitter of a fixation cross before either observing positive feedback “Your partner decided to share the money” or negative feedback “Your partner decided to keep the money” for three seconds. After receiving feedback, there was an inter-trial-interval jittered 2-6 seconds. In reality, the Trustee was a computer algorithm in which half the time the Trustee shared back and half the time the Trustee kept the money. Participants were not given any information about the probability distributions of Trustees reciprocating or defecting. The trials were pseudo-randomized such that a participant would never observe more than two ‘shares’ or two ‘keeps’ in a row.

The Lottery Game (non-social task)

The Lottery game was structured in the same manner as the Trust game, with the exception that there was no cover story about playing with partners and investing money in a Trustee. In essence, all components of the Trust and Lottery tasks were held constant except the social interaction of the Trust game. Accordingly, instead of being presented with photos of partners, participants viewed a stock image of a computer on each trial. Participants were told that on each trial, they could choose to gamble between \$0 and \$10 of their \$10 endowment, in increments of \$2. If they won the lottery they would double their gamble (a win). If they lost the gamble, they would lose the money (a loss). Wins and losses followed the same algorithm used in the Trust game, and trials were pseudo-randomized, such that no more than two wins or two losses were presented in a row. Furthermore, like the Trust game, participants were given no information about the probability of winning or losing a gamble. Thus, these lotteries are considered ambiguous probabilities. In reality, however, the lotteries were reinforced at a 50% win rate.

Stress Induction: Cold Pressor Task

Acute stress was induced by asking participants randomly assigned to be in the stress group to submerge their right forearm, hand through elbow, in ice-water (0-4 degree Celsius) for three consecutive minutes. The cold pressor task (CPT) has been shown to reliably increase sympathetic nervous system and HPA axis activity by activation of thermal and nociceptor afferents (Bullinger et al., 1984; Edelson & Robertson, 1986; Kelly & Cooper, 1998; Velasco, Gomez, Blanco, & Rodriguez, 1997) and has been previously used to elicit a stress response (Errico, Parsons, King, & Lovallo, 1993; Pascualy et al., 2000). Critically, the CPT

does not have any lasting psychological effects typically associated with other types of laboratory stressors {McRae, 2006 #3138}, and thus provides an ideal technique for isolating an increased neurohormonal stress response exclusive of ancillary effects that could bias behavior. Participants selected to be in the control group were asked to submerge their right forearm in room temperature water (32-35 degree Celsius) for three consecutive minutes.

Physiological Stress Measurement

In order to acquire a physiological measure of stress, salivary samples were collected and analyzed for concentrations of both cortisol—a measure of HPA axis engagement, and α -amylase—which indirectly assays noradrenergic activity. The salivary samples were obtained by having participants place an oral swab beneath their tongue for two minutes. In order to control for circadian rhythms and stress induced by travel, participants were only recruited to come into the laboratory between 12:00 PM - 5:00 PM. To ensure that cortisol levels were stable, the first salivary sample was taken ten minutes after the participant arrived at the laboratory. Salivary samples were taken four times during the course of the experiment: 1) Cortisol 1 - at baseline: 10 min after the participant's arrival; 2) Cortisol 2 - 10 min after the stress or control manipulation when cortisol is expected to rise; 3) Cortisol 3 - after completing the first task (approximately 25 minutes after the stress/control manipulation); and 4) Cortisol 4 - after completing the second task (approximately 35 minutes after the stress/control manipulation); see Figure 1C.

Data & Regression Analysis

For the linear regression models we fit participants' choices to gamble or trust (Choice_t) as a function of feedback on the previous trial ($t-1$), where 1 denotes a 'reciprocate' in the Trust game or 'win' in the Lottery game, -1 denotes a 'defect' in the Trust game or a 'loss' in the Lottery game, and 0 denotes a trial in which the participant chose not to gamble or trust. Participants chose to play at the same rate regardless of whether they were in the stress or control groups ($p > .05$; in both conditions approximately 70% of the time, see supplement). The parameters were entered into a mixed effects linear regression for each Condition \times Game, where the within-subject factors were the intercept and feedback received on the previous trial (Tables 1-2) which enabled us to explore the effects of stress on an individual's ability to incorporate feedback. See supplemental information for further details on the full regression model (Table S1), and for alternative models, including a reinforcement-learning model and weighted average model. We used the lme4 package in the R programming language to run all regressions.

RESULTS

Social versus Non-social Ambiguous Decisions

Our first question was whether socially ambiguous decisions are valued in a similar way as non-socially ambiguous decisions. Participants in the control condition spent approximately the same amount of money irrespective of whether they were gambling (Lottery game: mean $\$3.74 \pm 2.40$ SD) or entrusting money to a partner (Trust game: Mean $\$3.81 \pm 2.1$ SD) (paired samples t-test: $t(27) = -.25$, $p = .80$), indicating consistent overall behavior irrespective

of context (Fig 2B). Next, we wanted to investigate whether past, irrelevant feedback is incorporated and used in a similar manner during uncertain decisions to gamble and trust. To test this, we modeled decisions to trust and gamble as a function of the type of feedback participants received. We ran a trial-by-trial linear regression where outcome (win/loss in the Lottery game and reciprocate/defect in the Trust game) was used as lagged predictor of choice (how much money gambled/trusted on each trial). In other words, receiving a win/loss on trial 1 was yoked to choice on trial 2. This enabled us to examine how individuals use feedback to inform subsequent choices in both the social domain (trust) and the non-social domain (gamble); see supplemental methods for more details.

Results reveal that individuals in the control condition gambled more after experiencing a loss, partaking in the gamblers' fallacy by believing in the irrational notion that a streak of losses means a greater likelihood of wins for future gambles (Kahneman & Tversky, 1972) (Table 1; Lottery). This pattern was not observed in the social domain, as individuals did not rely on past, unrelated feedback when deciding to trust another (Table 1; Trust). That is, despite observing that their partners either defected or reciprocated their initial move to trust, subjects did not use this social feedback to inform their next choice to trust a new unrelated partner, effectively treating each new decision as an independent choice.

Neuroendocrine Results

To assess the efficacy of the cold pressor (CPT) manipulation, we measured salivary cortisol levels—an index of the hypothalamus-pituitary-adrenal (HPA) system and α -amylase—and index of sympathetic nervous system. Consistent with our prediction that the CPT induces increased cortisol, we found a main effect of Time ($F(3,162)=8.5, p<0.001$) and Condition ($F(1,54)=7.4, p=0.009$), as well as a Condition X Time interaction ($F(3,162)=12.6, p<0.001, \eta_p^2=.14$; Figure 2A). Independent t-tests revealed no differences between conditions at baseline cortisol ($t(54)=-.35, p=.73$); however, significantly higher cortisol was evident in the stress condition at each time point after the stress/control manipulation (+10 minutes: $t(54)=2.5, p=0.01$; +20 minutes: $t(54)=3.57, p=0.001$; +35 minutes: $t(54)=2.98, p=0.004$), indicating that the CPT manipulation was successful in increasing participants' cortisol and engaging greater HPA activation. We ran a similar analysis using α -amylase but did not find any main effects or a Condition x Time interaction ($F(3,162)=.56, p=.64$), perhaps because the timing of our assessment was not optimal for the relatively rapid response of α -amylase (Maruyama et al., 2012).

Effects of Acute Stress on Social and Non-social Ambiguous Decisions

To examine the effect of acute stress on social choices compared to non-social choices, a 2 (Condition: no stress vs. stress) X 2 (Task: social vs. non-social) repeated measures ANOVA was conducted on the amount of money trusted or gambled. Results reveal an interaction between Task and Condition, ($F(1,54)=6.2, p=0.016, \eta_p^2=.10$; Figure 2B), such that acute stress enhanced gambles and attenuated trusting behavior, as well as a main effect of Task ($F(1,54)=4.63, p=0.036, \eta_p^2=.08$). Participants spent the same amount of money in both the Lottery and Trust tasks. However, participants who underwent the stress manipulation exhibited a dissociation between decisions of uncertainty depending on the context of the task. Specifically, stressed participants spent significantly more money

gambling in the Lottery game (mean \$4.31 \pm 2.30 SD) than they did trusting their partners in the Trust game (mean \$3.27 \pm 1.96 SD) (paired samples t-test: $t(27)=3.1$, $p=.004$). This finding was due to acute stress both enhancing non-social gambling and diminishing social trusting behavior.

Effects of Acute Stress on Sensitivity to Feedback: Trial-by-Trial Analysis

Given the evidence that acute stress has differential effects on social vs. non-social choices under uncertainty, our next aim was to further decompose whether these effects of stress also bias how past, irrelevant feedback is incorporated into future decisions. To do this, we modeled the effect of stress on decisions to trust and gamble as a function of the feedback the participant received. As before, we ran a trial-by-trial linear regression where outcome was used as lagged predictor of choice, see supplemental methods for more details and full model specifications (Table S1).

Acute stress selectively effected how individuals incorporated social feedback. As in the control condition, when under stress, individuals used irrelevant, prior experiences to guide their future choices to gamble (Table 2; Lottery). In other words, stress had no effect on how irrelevant feedback biases choices to gamble. However, decisions to trust were effected by stress. Unlike subjects in the control condition, those in the stress condition used past, irrelevant feedback to guide choices to trust. After receiving negative feedback that a partner defected and did not share back the money, subjects subsequently entrusted *more* money to a new partner on the next trial (Table 2; Trust), effectively displaying a similar pattern of behavior observed in the gambling task. Simply put, stress compromised participants' ability to disregard irrelevant, past information when deciding to trust a new partner.

DISCUSSION

There is a wealth of research illustrating that humans are averse to making decisions under uncertainty in non-social contexts (Camerer & Weber, 1992) and that stress has mixed effects on an individual's engagement in non-socially risky and ambiguous decisions (Mather & Lighthall, 2012). Yet, despite the fact that many of our everyday choices of uncertainty are made within a social context, little is known about how individuals value decisions of uncertainty in the social domain compared to the non-social domain. Here, we find that although individuals who are not stressed gambled and trusted at overall similar rates, a trial-by-trial examination revealed that past irrelevant feedback had differential effects depending on context. In the non-social domain individuals exhibited the gamblers' fallacy, believing incorrectly that a spate of losses will result in a subsequent win, while in the social domain, approximating rational agents, individuals did not use irrelevant past information to guide their subsequent choices to trust another.

Acute stress had a divergent effect on decisions under uncertainty, increasing decisions of ambiguity in non-social contexts, but decreasing decisions of ambiguity in social contexts, indicating that there is a qualitative difference between how social and non-social uncertainty is processed. We also find that stress differentially influences whether an individual attends to and uses irrelevant feedback in social contexts relative to non-social contexts. While in non-social contexts individuals exhibited the gamblers' fallacy regardless

of stress levels, in social contexts stress compromised the adaptive behavioral pattern of treating each new choice independently. Rather, stressed individuals were more likely to trust a new partner after receiving negative feedback that a past partner did not reciprocate their trust.

The one study that we are aware of that examines the impact of stress on decisions of uncertainty within the social domain, demonstrates that acute stress increases trusting behavior (von Dawans et al., 2012). Our findings indicate the opposite: acute stress dampens an individual's likelihood of making ambiguously uncertain decisions in social contexts, but heightens how often they engage in ambiguously uncertain decisions in non-social contexts. One critical difference between the findings reported here and this past work is the type of stressor used—the CPT versus Trier Social Stress Test (TSST)—which may have an influence on social decision-making. Unlike the CPT, the TSST induces psychosocial stress by requiring individuals to undergo social evaluation—that is, speaking in front of a panel of evaluative peers. In fact, individuals who experience the TSST report greater emotional and psychological vulnerability, rumination, and an overall decline in mood relative to the CPT (McRae et al., 2006), which could dictate a need to resuscitate (the perception of) fragile social ties. Thus, the effect of increased trust following the TSST is consistent with the theory that individuals are attempting to repair putatively compromised social ties by displaying a greater degree of trusting behavior (von Dawans et al., 2012). However, these behavioral effects cannot be explained by the increase in the neurohormonal response alone, as other non-specific effects of social evaluation likely play a role. This confound presents a problem for interpreting whether increases in trusting behavior are due to the physiological response to stress, or the psychological effects of the social stressor (i.e. rumination and psychological vulnerability), or both. We have eliminated the putatively confounding psychosocial effects on social behavior and report that inducing non-social stress does not increase trusting behavior, but rather attenuates trusting behavior.

By more closely examining how an individual incorporates irrelevant social and non-social feedback to bias future choice, we can further decompose how ambiguity considerations are processed under different contexts. According to classic economic theory, rational agents should not be influenced by past experiences when deciding to take a new, independent gamble or engage in trusting behavior with a new person (Rabin, 2002). That is, every new choice should be treated independently of past, irrelevant experiences. However, there is robust evidence within the literature (Sundali & Croson, 2006; Tversky & Kahneman, 1974), and from the findings here, which indicate that individuals routinely violate this principle in non-social contexts, and systematically engage in what is known as the gamblers' fallacy. This finding is so robust that stress appears to have no bearing on an individual's belief that a streak of losses in non-social gambles will result in a subsequent win.

In contrast, we found that individuals in the control manipulation did not exhibit this behavior when deciding to trust another. Effectively, these non-stressed individuals correctly treated each decision to trust a new partner as an independent choice, indicating that, unlike in the non-social domain, individuals making ambiguous choices in a social context can successfully do so without relying on earlier irrelevant information. Given that all

components of the Trust and Lottery tasks were held constant except for the social interaction component, these divergent behavioral patterns constitute a powerful model for how socially ambiguous choices likely rely on distinct cognitive processes. Furthermore, these divergent behavioral patterns were observed within individuals, such that the same individuals who exhibited the gamblers' fallacy in the non-social domain, were able to rationally and adaptively make decisions without relying on irrelevant past information in the social domain.

That individuals are better at making independent ambiguous decisions that involve people than they are at making ambiguous decisions devoid of any social component, suggests that a ambiguous uncertainty is differentially valued depending on whether it is embedded in a social context or not. One explanation may be that people do not typically generalize a trait like trustworthiness across all individuals. Indeed, assuming that every individual can be trusted to the same degree would be highly maladaptive. Our data suggests that current relevant information—such as which person you are deciding to invest money in—is more highly weighted, or at least differentially valued than unconnected prior non-social experiences. Although, one important caveat is that any systematic violation of trust should cause an individual to be wary of trusting another. In our task, we attempted to approximate the level of trustworthy behavior observed outside the laboratory, where trustworthiness is highly variable across individuals.

Decision-making under uncertainty is ubiquitous to human life, and thus unsurprisingly, decades of research have explored how humans process uncertainty. Within the laboratory, uncertainty is typically studied within a neutral, non-social context. This approach, however, likely fails to capture the dynamic factors that influence decisions of uncertainty in the real world. Making decisions in uncertain environments during everyday life requires individuals to constantly assess risk and ambiguity under various shifting social contexts and varied emotional states. Here we find that both social context and mild acute stress independently, and jointly, contribute to the processing of uncertainty preferences.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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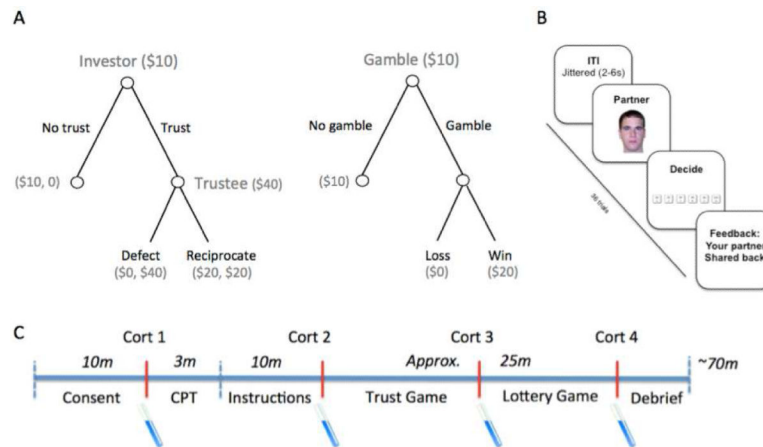


FIG 1. TASKS AND EXPERIMENTAL PROTOCOL

A. Trust and Lottery games and their payoff structures. An Investor (participants) is endowed with money and can decide whether to send money to their partner (trust, no trust), in which case the money is multiplied four times. The Trustee can then decide to reciprocate by splitting the money between the two players, or can defect by keeping all the money for him or herself. The Lottery task (gambles) is identical in all respects except for the social component. **B. Task structure.** Participants were shown a picture of their partners, before being asked how much money they would like to trust to their partner (between \$0 and \$10, in increments of \$2). After making a decision, participants were informed of whether their partners decided to defect or reciprocate (feedback). **C. Experimental parameters.** Cortisol measurements (Cort 1-4) were taken before the stress or control manipulation (baseline), ten minutes after the manipulation, between the two games (which were counterbalanced), and following the final game.

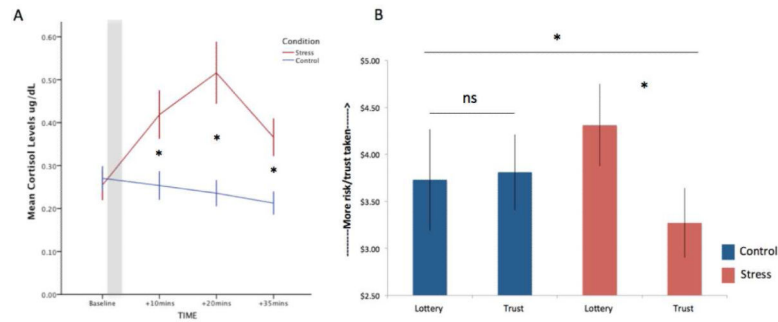


Fig 2. NEUROENDOCRINE AND BEHAVIORAL DATA

A. Mean cortisol levels across the experiment. Subjects in the stress condition exhibited increased cortisol levels at every time point (other than baseline) as compared to subjects in the control condition. Gray bar represents the timing for the stress and control manipulations. Bars represent 1 SEM. **B.** Participants gambled and trusted at the same rate when not under stress. However, acute stress differentially affected decision-making under uncertainty, such that stress increased gambles but decreased trust. *Significance at 0.05

TABLE 1**CONTROL**

Regression coefficients indicating the influence of the outcome of previous trial on amount of money trusted and gambled.

	Coefficient (β)	Estimate (SE)	t-value	P value
Lottery	Intercept	3.72 (.46)	8.07	<0.001
	Feedback	-.63 (0.28)*	-2.22	0.02
Trust	Intercept	3.81 (0.40)	9.49	<0.001
	Feedback	-.23(0.18)	-1.24	.22

* Significance at 0.05

TABLE 2**STRESS**

Regression coefficients indicating the influence of the outcome of previous trial on amount of money trusted and gambled.

	Coefficient (β)	Estimate (SE)	t-value	P value
Lottery	Intercept	4.33 (.43)	9.93	<0.001
	Feedback	-.43 (0.19)*	-2.19	0.02
Trust	Intercept	3.28 (0.37)	8.83	<0.001
	Feedback	-.40(0.13)**	-3.10	.002

* Significance at 0.05

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