No effect of glucocorticoid and noradrenergic activity on consistency in prosocial choice

Luca M. Lüpken, Alfons Schnitzler, Tobias Kalenscher

Suggested Citation:
Lüpken, L. M., Schnitzler, A., & Kalenscher, T. (2025). No effect of glucocorticoid and noradrenergic activity on consistency in prosocial choice. Hormones and Behavior, 177, Article 105863. https://doi.org/10.1016/j.yhbeh.2025.105863

Hormones and Behavior 177 (2026) 105863

Contents lists available at ScienceDirect

Hormones and Behavior

journal homepage: www.elsevier.com/locate/yhbeh

No effect of glucocorticoid and noradrenergic activity on consistency in prosocial choice

Luca M. Lüpken [a,*], Alfons Schnitzler [b], Tobias Kalenscher [a]

[a] Comparative Psychology, Institute of Experimental Psychology, Heinrich Heine University, 40225, Düsseldorf, Germany
[b] Institute of Clinical Neuroscience and Medical Psychology, Medical Faculty and University Hospital Düsseldorf, Heinrich Heine University, 40225, Düsseldorf, Germany

ARTICLE INFO

Keywords:
Choice consistency
Rationality
Social preferences
Cortisol
Noradrenaline
Stress

ABSTRACT

Stress can alter the way people make decisions, affecting domains such as risk-taking and social interaction. Growing evidence suggests that this may be driven by distinct effects of the stress neuromodulators cortisol and noradrenaline. For example, stress-induced neuromodulatory changes can influence social decision-making, promoting either prosocial or antagonistic tendencies and consequently shifting underlying values and preferences. While choices are directly observable, preferences are not and must instead be inferred from observed choice patterns. This inference relies on the assumption that preferences remain stable throughout the observation period, as reflected in the internal consistency of choices. However, the effects of stress on social decision-making challenge this notion. This raises the question of whether choice consistency – the basis for inferring preferences from choices – remains robust across dynamic changes in neuromodulator activity. Therefore, we examined whether cortisol and noradrenaline affect prosocial decision-making and choice consistency. In a double-blind psychopharmacological study, we exogenously manipulated cortisol and/or noradrenaline activity by administering hydrocortisone, yohimbine, both hydrocortisone and yohimbine, or placebo to 129 participants. Prosocial decision-making was measured using a modified dictator game before and after drug administration, and choice consistency was quantified within the framework of the Generalized Axiom of Revealed Preferences. Our results indicate that neither cortisol nor noradrenergic activity affected prosocial decision-making or choice consistency, suggesting that social preferences remain stable despite changes in neurohormonal states. These findings underscore the robustness of choice consistency across neurohormonal fluctuations and illustrate the complexity of how stress neuromodulators shape (social) decision-making.

1. Introduction

Stress changes how people make decisions. Stress effects on decision-making have been reported for a range of domains, including risk-taking, loss aversion, and social interaction (Margittai et al., 2018a, 2018b; Sarmiento et al., 2024; Starcke and Brand, 2012; Von Dawans et al., 2021). While the effects are often complex and somewhat unreliable (Forbes et al., 2024; Nitschke et al., 2022), some of these complexities may reflect distinct roles of the main stress neuromodulators cortisol and noradrenaline (Dashti et al., 2025; Margittai et al., 2018b; Schweda et al., 2019).

In the social domain, cortisol has been associated with affiliative and prosocial behavior (Berger et al., 2016; Dashti et al., 2025; Duque et al., 2022; Margittai et al., 2018b; Schweda et al., 2019), and noradrenergic activity has been linked to more antagonistic tendencies (Dashti et al., 2025; Haden and Scarpa, 2007; Nelson and Trainor, 2007; Schweda et al., 2019). For example, Margittai et al. (2018b) studied social discounting, that is, the decrease in financial generosity across social-emotional distance between participant and another person. They found that hydrocortisone administration (a synthetic form of cortisol) increased generosity toward socially close others, e.g., very good friends. This hydrocortisone-driven increase in generosity was mitigated by the additional administration of yohimbine (an alpha-2 adrenergic receptor antagonist that increases noradrenaline release). This suggests that increased noradrenergic activity may counteract cortisol's prosocial effects, possibly by shifting motivation from affiliative toward more defensive tendencies. In line with this, Dashti et al. (2025) showed that cortisol promoted generosity toward in-group members, whereas noradrenaline promoted hostility toward out-groups. These findings suggest that stress-induced neuromodulatory changes bias social

* Corresponding author.
E-mail address: luca.luepken@hhu.de (L.M. Lüpken).

https://doi.org/10.1016/j.yhbeh.2025.105863
Received 23 September 2024; Received in revised form 17 November 2025; Accepted 17 November 2025
Available online 22 November 2025

decision-making toward either prosocial or antagonistic tendencies, depending on the prevailing neuromodulatory profile, thus shifting the underlying social preferences.

Social preferences are latent constructs that capture how individuals value outcomes for themselves and others. They are central to models of collective behaviors and are assumed to underlie social decisions (Fisman et al., 2017; Kerschbamer and Müller, 2020). Because preferences are not directly observable, they must be inferred from choice patterns. For example, observing an individual's donation behavior toward a charity reveals something about their valuation of this charity. A basic requirement for the inference of preferences from choices is internal consistency in choices – a hallmark of economic rationality. The Generalized Axiom of Revealed Preference and related axioms (GARP; Houthakker, 1950; Samuelson, 1938) formalize this principle (not just in the social domain, but in general) by imposing logical constraints on observed choices. Put simply, if choice alternative A is chosen over alternative B, B cannot be preferred to A, since, otherwise, B would have been chosen. Additionally, if A is more expensive than B, yet it is still chosen, A must be strictly preferred to B. Violations of GARP indicate that choices cannot be rationalized by a stable preference function, undermining the ability to infer underlying preferences from choices (Afriat, 1967).

This is not merely a formal concern: economic models typically assume stable preferences, at least over short periods of time. However, if internal states, such as stress, alter social preferences, as prior studies suggest, this assumption may no longer hold, and preferences estimated in one internal state (e.g., at baseline) may not generalize to another (e.g., under stress).

Prior research has demonstrated that human choices often adhere to GARP under conditions of cognitive load or physiological strain, such as sleep deprivation, alcohol consumption, drug influence, acute stress, or menstrual cycle phases (Bedi and Burghart, 2018; Burghart et al., 2013; Castillo et al., 2017; Cettolin et al., 2020; Drichoutis and Nayga, 2020; Lazzaro et al., 2016; Nitsch et al., 2021). These findings have been interpreted as evidence that preference-based decision models are robust to such perturbations. However, these studies investigated choice consistency within a given internal state, e.g. within specific time windows of the stress response (Nitsch et al., 2021). They did not address whether choice consistency holds across dynamically shifting states, such as short-term changes in cortisol or noradrenaline in the neurohormonal stress response.

This is a crucial limitation. If preferences are stable within a state but shift between states, individuals may exhibit high block-wise consistency but violate GARP when choices are pooled. For example, someone may act selfishly at baseline and generously during cortisol peak; both patterns may be internally consistent within each neurohormonal state, but the combined choices across neurohormonal states would violate GARP. Such violations would reflect state-dependent shifts in preferences that go undetected unless these internal states are explicitly included in the model.

Thus, in sum, if preferences and choices systematically vary with neurohormonal states, as prior research suggests (Dashti et al., 2025; Margittai et al., 2018b), then behavior aggregated across states may no longer be rationalizable by a stable preference function, challenging a core assumption of economic modelling.

However, the question of whether choice consistency holds across dynamically shifting neurohormonal states has not yet been systematically investigated, even though neuromodulator levels such as cortisol and noradrenaline are known to fluctuate substantially over short time frames (Hermans et al., 2014; Joëls and Baram, 2009). Acute stress, for example, activates the sympathetic-adrenal-medullary (SAM) system and the hypothalamic-pituitary-adrenal (HPA) axis in a time-dependent manner, with noradrenaline peaking rapidly and cortisol rising more slowly but lasting longer.

We, therefore, set out to test whether choice consistency is preserved across neurohormonal stress states, or whether state-dependent shifts in preferences and choices reduce overall consistency. For this, we pharmacologically manipulated cortisol and noradrenaline action by administering the drugs hydrocortisone and/or yohimbine in a placebo-controlled double-blind psychopharmacological study. We hypothesized that, while the drug effects unfold over time, cortisol would increase generosity, whereas noradrenaline would counteract this effect (Dashti et al., 2025; Margittai et al., 2018b), thus reducing choice consistency. Crucially, we analyzed choice consistency by aggregating decisions across multiple time points within the same individuals across the entire experimental session, from baseline to post-drug administration. In sum, this allowed us to assess whether pharmacologically induced changes in neurohormonal states lead to systematic changes in preferences that manifest as reduced choice consistency when decisions are aggregated.

Hence, the contribution of our paper is twofold: first, we complement and extend the literature on the effects of stress on economic decision making by testing the robustness of choice consistency across different stress neuromodulator states. Second, we extend the literature on the effects of stress neuromodulators on social decision making.

2. Method

2.1. Participants

After excluding the data of one participant who reported concerns about the quality of their data, a total of 129 participants (male: $n = 63$, female: $n = 64$, non-binary: $n = 2$) aged between 18 and 35 years were included in the experiment. As described in Section 2.6, we took a Bayesian approach to our data analysis. Consequently, our sample size was determined using an a priori Bayesian stopping rule in line with our prior work and current recommendations (Nitsch et al., 2021; Rouder, 2014; Schönbrodt et al., 2017): data collection continued until we achieved at least moderate evidence for or against our hypotheses, defined as a Bayes factor (BF) of $BF \geq 3$ in either direction (Jeffreys, 1939; Van Doorn et al., 2021). This threshold has been suggested as roughly analogous to a classical p-value of 0.05 (Jeffreys, 1961; Keysers et al., 2020).

Participants were included if they were healthy, did not smoke or drink alcohol excessively, did not take drugs and had a BMI between 19 and 26. Pregnant participants and psychology students from the second semester onwards were excluded from participation. Biologically female participants took a pregnancy test to ensure that they were not pregnant. Additionally, participants were instructed to abstain from exercise, sexual activity, alcohol consumption, and medication 24 h before participation and to stop eating, smoking, and caffeine consumption two hours before participation.

Participants received a fixed compensation of €10 and could earn up to €90 additionally during the experiment. This additional compensation depended both on chance and on the choices participants made during the experiment.

The study was approved by the ethics committee of the University Hospital Düsseldorf and complied with the Declaration of Helsinki.

2.2. Pharmacological manipulation

Participants were pseudo-randomly assigned to one of four experimental groups: hydrocortisone (H; 20 mg, Jenapharm, mibe GmbH; $N = 31$), yohimbine (Y; 20 mg, Yocon-Glenwood, Cheplapharm Arzneimittel GmbH; $N = 34$), hydrocortisone and yohimbine (H + Y; $N = 33$), or placebo (P; $N = 31$). The dosage corresponded to previous studies (Margittai et al., 2018b, 2018a) and results in cortisol levels comparable to those observed after intense stress (Cook et al., 1987; Strojny et al., 2024). To ensure that participants could not infer which drug they had received, all groups received six pills. Because the individual pills differed in dosage (hydrocortisone: 10 mg; yohimbine: 5 mg), the final scheme was as follows: H group – 2 hydrocortisone (10 mg) + 4 placebo pills; Y group – 4 yohimbine (5 mg) + 2 placebo pills; H + Y group – 2

hydrocortisone (10 mg) + 4 yohimbine (5 mg) pills; P group – 6 placebo pills. This ensured equal pill counts across groups while delivering 20 mg of the respective active substances.

2.3. Control measures

2.3.1. Physiological stress response

Cortisol and noradrenergic activation were measured using saliva samples (stress samples; Salivettes; Sarstedt AG & Co. KG, Nümbrecht, Germany) collected at four time points during the experiment (see Fig. 1; note that we collected saliva probes at seven time points, but only analyzed four time points). After collection, the samples were frozen at −20 °C until analysis by Dresden Lab Services GmbH. While cortisol was measured directly in saliva by immunoassay, salivary alpha-amylase, an indirect marker of noradrenergic activation (Nater and Rohleder, 2009), was determined by an enzyme kinetic method as described in Rohleder et al. (2006). Eight out of 516 total samples could not be analyzed due to insufficient saliva or contamination of the sample.

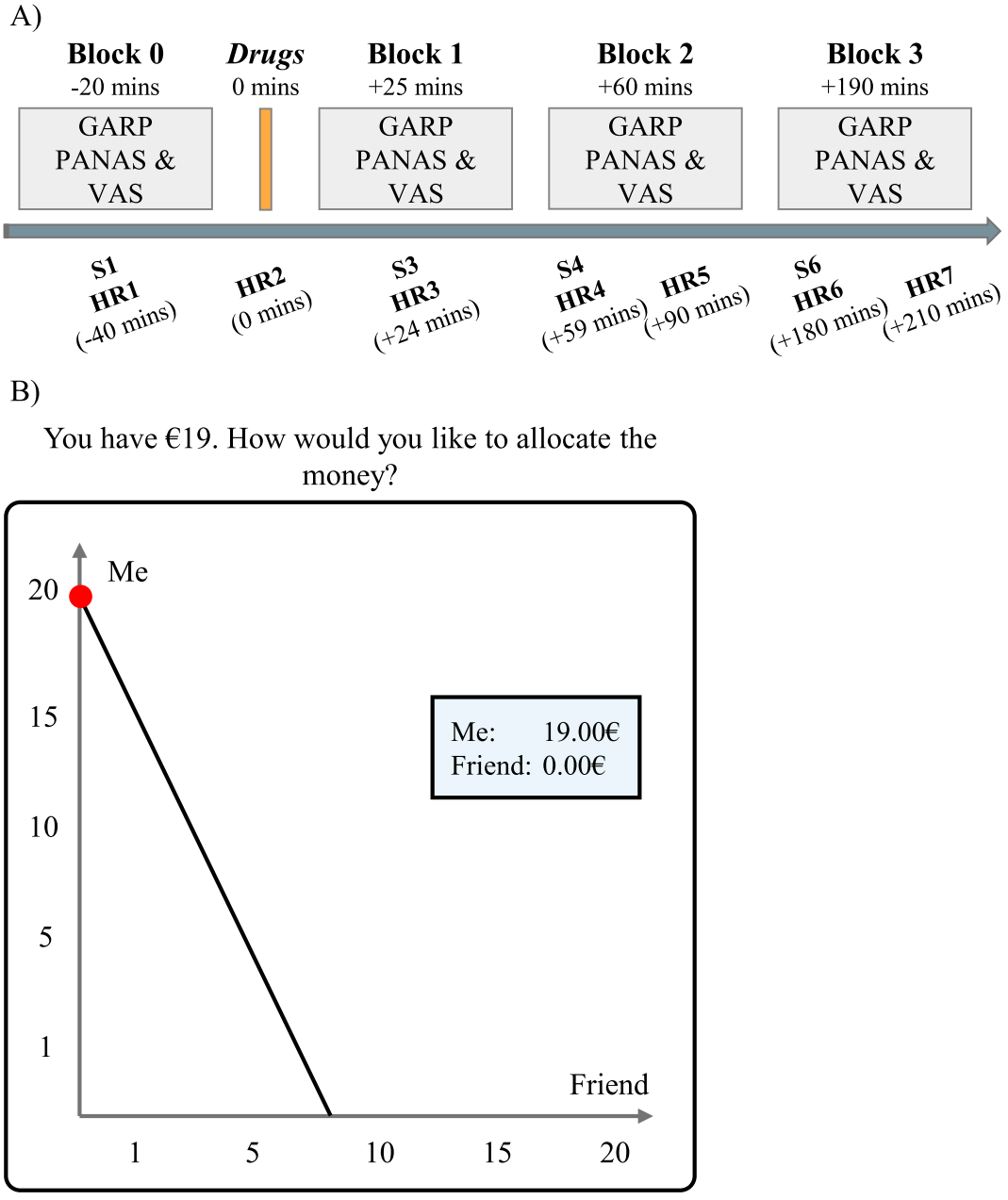

Fig. 1. A) Experimental timeline. Trait measures were collected online before data collection in the lab. Saliva samples to analyze sex hormones were taken prior to block 0. Drug intake depended on the group allocation: Participants took either hydrocortisone, yohimbine, hydrocortisone and yohimbine combined, or placebo. Heart rate was measured continuously throughout the session, and values were extracted at the time points indicated in the figure. Abbreviations: S = stress saliva sample, HR = heart rate measurement, GARP = economic decision-making task (GARP task), PANAS = Positive and Negative Affect Schedule, VAS = Visual Analogue Scale for momentary stress. B) Illustration of an example trial of the GARP task. Here, participants had a budget of 19 EUR to allocate between themselves and their best friend by moving a red dot along a diagonal budget line, representing all possible allocation choices. The payouts for each person were displayed dynamically in the upper right corner as the dot was moved. In our task, sharing with others was costly, akin to transfer and transaction costs (see text for details): for example, in this trial, sharing with the best friend was more expensive than keeping money for oneself. Thus, here, if the entire budget of 19 EUR was shared with the best friend, they would receive only 9.50 EUR. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

As an additional marker of sympathetic nervous system activation, heart rate (beats per minute, bpm) was measured at seven time points (Fig. 1) throughout the experiment (using Polar A370 watches; Polar Electro Oy).

2.3.2. Subjective stress response

To assess subjective stress levels and mood, participants rated their perceived stress levels on a visual analog scale (VAS) ranging from 0 to 100 and completed the German version of the Positive and Negative Affect Schedule (PANAS, Watson et al., 1988) at four time points (Fig. 1).

2.3.3. Sex hormone levels

Because HPA axis reactivity may be influenced by both menstrual cycle and hormonal contraceptives (Kirschbaum et al., 1999), we additionally assessed sex hormone levels (estradiol, progesterone and testosterone) using three saliva samples, collected in approximately 5-min intervals (sex samples; SaliCaps; TECAN Trading AG) prior to drug intake. The samples were frozen at −20 °C after collection and analyzed at Dresden Lab Service GmbH using LC-MS/MS procedure. The three samples were pooled for this analysis to obtain a more reliable result.

2.3.4. Trait measures

To verify successful group randomization and to control for potential confounding factors, we collected several trait measures via an online questionnaire prior to participation in the experiment. The online questionnaire took approximately 45 min to complete and included a list of the exclusion criteria as well as eleven questionnaires (see Supplementary Materials for a list).

2.4. Procedure

Prior to participating in the experiment, participants completed the online questionnaire, which included the trait measures and exclusion criteria. The experimental sessions always started at 2 pm to control for circadian variations in cortisol levels and lasted on average 4 h and 15 min (SD = 0.18). Upon arrival at the lab, participants were given information about the experiment, gave informed consent, and filled in a screening questionnaire to check for exclusion criteria. Participants who met any of the exclusion criteria were excluded from participation. Subsequently, participants provided the three sex saliva samples as well as demographic information, including age, gender, education, and gross monthly income.

As mentioned, participants were pseudo-randomly assigned to one of the four pharmacological conditions (H, Y, H + Y and P; see above). All participants completed our experimental task (GARP task, see below) at four time points relative to drug intake: −20 min (block 0/baseline), +25 min (block 1), +60 min (block 2), +190 min (block 3, see Fig. 1). We opted for repeated measures of our GARP task to observe the evolution of choices and preferences as the drug effects unfolded.

Hydrocortisone and yohimbine are both rapidly absorbed after oral administration, typically reaching peak plasma concentrations within approximately 60 mins. The elimination half-life of hydrocortisone is about 1.7–2.15 h for total cortisol and 1.39 h for free cortisol (Derendorf et al., 1991; Patel et al., 1984), while that of yohimbine varies across individuals (range: 0.25–2.5 h; Derendorf et al., 1991; Hedner et al., 1992; Owen et al., 1987; Patel et al., 1984). Notably, even in extensive metabolizers, the half-life of yohimbine is usually over an hour, and in poor metabolizers, it can extend to over 6 h (Hedner et al., 1992; Owen et al., 1987). Based on this, our task blocks were timed to capture multiple phases of pharmacological action: early exposure (block 1), peak activity (block 2), and potential delayed or genomic effects of cortisol (block 3; Riis-Vestergaard et al., 2018).

In addition to our experimental GARP task, participants completed other behavioral tasks at these time points as well (Moral Decision-Making Task, EMCS, Singer et al., 2019; Affect Misattribution Task, AMT, Ling et al., 2023), the data of which will be reported elsewhere. After the last measurement block, the participants provided information about their beliefs about the effects of the drugs and guessed which drug they had received. Additionally, we emphasized the importance of data quality and acknowledged the potential challenges of maintaining attention during the lengthy experiment. Participants were then asked if they consented to the use of their data and were assured that there would be no repercussions for refusing.

During the shorter breaks immediately after drug intake and after block 1, participants were given simple 200-piece puzzles. During the longer break after block 2, participants watched emotionally neutral documentaries about nature and craftsmanship. Throughout the experiment, participants were asked not to use their phones or talk to each other.

2.5. GARP task

We employed a modified dictator game adapted from Andreoni and Miller (2002), in which participants allocate money between themselves and another person. In this game, we manipulated the social distance to the other person: participants decided on the allocation between either themselves and their best friend, or themselves and a stranger. To be able to quantify choice consistency within the GARP framework, we additionally manipulated the budget constraint as well as the prices of the money allocations to oneself and the other person, as explained in the following. In each trial, participants had varying amounts of money available to allocate between themselves and the other person, i.e., the budget constraint was variable. The prices for these allocations also varied from trial to trial, akin to transfer and transaction costs. This implies that participants or the other persons did not necessarily receive exactly what the participants allocated, but potentially less, depending on the transfer prices set for each trial. To illustrate, let's consider two scenarios with different price settings. If the price was set to 1/3, the participant kept precisely what they allocated to themselves, while the other person received only 1/3 of the participant's allocation to that person - equivalent to an exchange rate of 1/3. Conversely, if the price was 3, the participant kept only 1/3 of their allocation to themselves, while the other person received precisely what the participant allocated to that person. For further clarification, consider a trial with a budget of €20 and a price of 1/3. If the participant allocated, say, €5 to the other person and €15 to themselves, the participant would receive €15, while the other person would receive only €1.67, i.e., one third of the €5 allocated to the other person.

In contrast to Andreoni and Miller (2002), we used a graphical representation inspired by Choi et al. (2007) and analogous to the diagram task in Nitsch et al. (2022). In this representation, in each trial, participants saw a coordinate system in which the y-axis represented themselves, and the x-axis represented the other person (best friend or stranger). Within this graphical space, participants chose by selecting a point along a diagonal line that represented all possible money allocation options based on the budget and price constraints of the trial. At the same time, they could check the current money allocation to themselves and to the other person (best friend or stranger) in a box in the upper right corner of the coordinate system (see Fig. 1). The slope of the diagonal line reflected the price in each trial, i.e., a steeper line indicated a potentially higher maximum payout for the participant compared to the other person (best friend or stranger).

Participants made a total of 160 decisions throughout the experiment, with each decision involving either their best friend or a stranger as the recipient. Within each block, participants made 20 decisions with their best friend and 20 decisions with a stranger, for a total of 80 decisions per recipient type. The budget for each decision ranged from €5 to €20 in whole numbers, and the prices varied among 1/3, 1/2, 1, 2, or 3. This setup resulted in 15 budget levels and 5 price levels. All price x budget combinations were presented for both recipient types, resulting

in 80 unique trials per recipient type. The order of the trials was pseudo-randomized across the experiment for each recipient type. We ensured that this task setup was sufficiently sensitive to detect GARP violations by running multiple simulations (see Supplementary Materials).

At the end of each measurement block, one decision made within that block was randomly selected, and the amount the participant allocated to themselves, and the other person (best friend or stranger) was added to the total payout. Thus, the money the participant allocated to themselves was paid out directly to the participant, while the money allocated to the other person was paid out to that person. The participant's best friend received their share by mail, while the stranger was a randomly selected individual encountered by the research team on campus. For example, if the randomly selected decision involved an allocation of €15 to the participant and €1.67 to a stranger, the participant would receive an additional €15 at the end of the study, while a random person on campus would receive €1.67.

On each trial, participants were given 20 s to make their allocation decision. The time limit was set to ensure that the time constraints of the experimental protocol could be met. Reaction time data from a previous study indicated an average decision speed of 4 s. Thus, the 20-s time limit gave participants sufficient time to make their decision. In our experiment, participants took an average of 5.8 s to decide, confirming the adequacy of the time limit. On average, participants missed 2.89 (SD = 4.75) trials, indicating that while most decisions were made within the allotted time, there were occasional cases where the time limit was exceeded.

Prior to the baseline measurement, comprehension of the task and its payout structure was assessed using 5 comprehension questions. These questions addressed different aspects of the task, such as the possibility of earning additional money for oneself, understanding the allocation of money to friends and strangers, and understanding of the payout process. Participants could only proceed with the task if they answered correctly. If they answered incorrectly, the experimenter explained the task again to ensure correct understanding. In addition, participants were given 5 practice trials to familiarize themselves with the task and ensure that they understood how to interact with the task interface.

Each block included an attention check trial for decisions involving both the best friend and the stranger as the recipient, which occurred after half of the decisions within the block had been made for each recipient type. The intention behind these trials was to ensure participants' continued engagement and attention to the task instructions. Participants who failed all attention checks were excluded from the main analyses ($N = 10$), resulting in a final sample of 119 participants (H: $N = 30$, Y: $N = 29$, H + Y: $N = 31$, P: N = 29). Importantly, our results remained robust across a range of exclusion criteria based on attention checks. This included analyzing the full sample (i.e., including participants who failed all attention checks) as well as analyses applying increasingly stringent thresholds, such as excluding participants who failed at least one, two, or three checks (see Supplementary Materials).

2.5.1. Prosocial decision-making

To quantify prosocial decision-making, we calculated the proportion of the budget that participants shared with the other person for each trial. These proportions were then averaged per participant to obtain a mean "share" score for each recipient type within each measurement block.

2.5.2. Choice consistency

Several indices have been developed to quantify the extent to which participants make internally inconsistent choices in economic decision tasks, i.e., the extent to which they deviate from satisfying GARP. One of the most prominent of these indices is the Critical Cost Efficiency Index (CCEI; Afriat, 1973, 1972; Varian, 1993).

The CCEI measures how cost-efficient choices are: internally consistent choices are perfectly cost-efficient, while inconsistent choices are not. Cost-inefficiency means that an individual with inconsistent choices could have obtained alternative, but equally valued options for less money, thereby wasting some of their budget. For example, imagine someone's choice reveals that they value sharing 5 EUR with a friend at least as much as keeping 5 EUR to themselves. Later, they again choose to share 5 EUR with their friend, even though the price of sharing money has increased by 10 % more than the price of keeping it. Knowing that keeping 5 EUR is at least as good as sharing 5 EUR, the decision-maker has overspent by at least 10 %, making their choices 90 % cost-efficient (example adapted from Nitsch et al., 2021, p. 105289).

The CCEI identifies the most severe violation of GARP and then determines the minimum amount by which the budget must be reduced to eliminate all GARP violations. It ranges from 0 (representing minimal choice consistency) to 1 (representing perfect choice consistency). Thus, the CCEI for the example above would be 0.9, reflecting a 90 % cost-efficiency. For each participant, we calculated CCEI scores across all choices made in the experiment per recipient type following the methodology previously used by Nitsch et al. (2022).

2.6. Data analysis

We chose a Bayesian data analysis approach because it allows us to quantify evidence against effects (Van Den Bergh et al., 2020).

To test our hypotheses, we averaged across matched models to extract Bayes factors (BF) for each predictor (Van Den Bergh et al., 2020). Therefore, we used Bayes factors for inclusion ("BF_{incl}") to represent evidence in favor of a predictor and Bayes factors for exclusion ("BF_{excl}") to represent evidence against a predictor. This approach efficiently handled the extensive model comparisons required for our hypotheses and maintains consistency.

We used uninformative default priors (Rouder et al., 2012) due to limited or inconclusive prior evidence on the effects of stress neuromodulators on choice consistency and prosocial decision-making. Bayes factors are interpreted as follows: inconclusive or weak evidence for $BF < 3$, moderate evidence for $3 \leq BF \leq 10$, and strong evidence for $BF > 10$ (Jeffreys, 1939; Van Doorn et al., 2021). Post-hoc tests with repeated analyses were corrected by fixing prior probabilities that the null hypothesis holds to 0.5 (JASP Team, 2024; Westfall et al., 1997).

To test our first hypothesis that cortisol would increase generosity, whereas noradrenaline would counteract this generosity-boosting effect of cortisol, we conducted a mixed factorial Bayesian analysis of variance (ANOVA). Social distance (friend, stranger) and block (baseline, block 1, block 2, block 3) were within-subject factors, and drug condition (H, Y, H + Y, P) was a between-subject factor. The dependent variable was the share score.

To test the second hypothesis that the shift in prosocial choices over time would manifest as reduced choice consistency if all choices across the experiment were considered, we used a similar model but removed the within-subject factor block and instead used the CCEI as the dependent variable. To assess the effectiveness of the pharmacological manipulation, we used the respective subjective or physiological stress measure as the dependent variable, including only block as a within-subject factor and drug condition as a between-subject factor.

Note, that in these analyses, drug condition was treated as a four-level between-subject predictor, following Dashti et al. (2025). This approach treats the combined administration of hydrocortisone and yohimbine as a pharmacologically distinct treatment rather than the simple sum of two independent factors as was done in previous analytical frameworks (e.g., Margittai et al., 2018b). This structure allows all relevant effects, i.e., additive, synergistic, or non-additive, to be captured through direct comparison of the combined and single-drug conditions while maintaining interpretability with respect to the underlying pharmacological manipulations.

Additionally, we tested for group differences in each trait measure using Bayesian ANOVA for continuous measures and Bayesian contingency tables for categorical measures to rule out systematic group differences prior to our manipulation. We also evaluated the success of the

double-blinding by using a Bayesian binomial test to determine whether subjects could correctly guess which substance they had received.

Preprocessed data are available online: https://osf.io/bnxjt/?view_only=64e5a13c91ad4eb7a98d6f338a46ccb9.

3. Results

3.1. Trait and baseline measures

Overall, our analysis showed no conclusive evidence of group differences across a range of trait, demographic, and baseline measures, including sex hormone levels, heart rate, subjective stress and mood, salivary cortisol, and salivary alpha-amylase (see Table 1). This

Table 1
Demographic and trait measures per experimental group.

Variable	Placebo	Hydrocortisone	Yohimbine	Hydrocortisone + Yohimbine	BF_{10}
	N	*N*	*N*	*N*	
Sample	31	31	34	33	
Gender					<0.01
Female	14	15	18	17	
Male	16	15	16	16	
Non-binary	1	1	0	0	
University degree					0.59
Yes	9	16	7	10	
No	22	15	27	23	
Income friend < €20,000					<0.01
Yes	14	14	20	23	
No	10	8	6	7	
SVO					0.06
Competitive	0	1	0	3	
Individualistic	16	6	10	5	
Prosocial	14	20	21	18	
Unclassified	1	4	3	7	

Variable	Placebo	Hydrocortisone	Yohimbine	Hydrocortisone + Yohimbine	BF_{10}
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	
Age (years)	24.16 (3.09)	24.35 (4.1)	23.47 (3.41)	24.00 (3.67)	0.06
Income (€)	1338.71 (1600.14)	1725.81 (1862.07)	1370.59 (1781.31)	1093.94 (1130.80)	0.11
TICS	139.68 (33.87)	147.48 (28.43)	147.79 (27.28)	145.48 (32.08)	0.07
BIS/BAS					
Behavioral inhibition	15.45 (4.75)	13.65 (3.31)	14.38 (3.95)	13.97 (4.64)	0.14
Fun seeking	7.58 (2.13)	7.68 (1.99)	7.26 (1.78)	7.73 (2.04)	0.06
Reward responsiveness	7.94 (1.75)	8.00 (1.73)	7.24 (1.94)	7.97 (2.32)	0.16
Drive	7.19 (2.15)	7.23 (1.69)	7.41 (2.05)	7.06 (2.34)	0.05
BFI-10					
Extraversion	3.02 (1.06)	3.34 (0.79)	2.99 (1.03)	3.06 (0.97)	0.11
Openness	3.94 (0.89)	3.53 (1.13)	3.66 (1.13)	3.44 (1.10)	0.18
Agreeableness	3.40 (0.89)	3.19 (0.90)	3.22 (0.75)	3.14 (0.85)	0.08
Conscientiousness	3.39 (0.86)	3.53 (0.90)	3.41 (0.82)	3.44 (0.82)	0.05
Neuroticism	2.84 (1.01)	3.00 (0.72)	2.87 (1.01)	2.88 (0.96)	0.05
BIS-15	36.65 (2.60)	36.45 (2.55)	36.62 (2.37)	37.00 (2.32)	0.06
CRT	2.07 (1.00)	1.65 (1.08)	1.74 (1.14)	2.06 (1.00)	0.20
E-Scale	77.58 (16.05)	79.35 (13.68)	81.62 (13.18)	80.58 (16.65)	0.07
MEQ	13.42 (3.91)	12.45 (3.44)	13.32 (3.35)	13.03 (3.36)	0.07
STAI					
General	39.68 (7.89)	41.45 (6.59)	43.85 (7.93)	42.24 (8.91)	0.25
Moment	35.45 (8.45)	36.94 (8.37)	37.18 (7.88)	37.03 (9.11)	0.06
SDS-17	10.90 (2.29)	10.23 (2.50)	10.21 (2.66)	10.03 (3.07)	0.09
Perspective taking	−0.01 (0.14)	0.02 (0.15)	−0.11 (0.24)	−0.10 (0.32)	0.74
Testosterone (pg/ml)	54.67 (54.07)	47.33 (47.88)	51.59 (49.63)	53.74 (50.93)	0.05
Progesterone (pg/ml)	12.84 (29.73)	11.13 (22.50)	18.98 (45.13)	11.45 (33.49)	0.07
Estradiol (pg/ml)	5.80 (7.84)	3.68 (1.30)	3.38 (1.87)	3.67 (2.57)	0.53
Baseline					
Cortisol (nmol/L)	6.27 (5.86)	5.10 (4.73)	6.48 (6.80)	4.60 (3.85)	0.12
Alpha-amylase (U/ml)	79.80 (70.21)	63.06 (59.45)	92.93 (110.66)	58.36 (57.73)	0.19
Heart rate (bpm)	73.74 (13.65)	71.06 (9.55)	75.47 (11.06)	70.61 (11.7)	0.18
Positive affect	2.92 (0.63)	2.68 (0.72)	2.75 (0.60)	2.79 (0.72)	0.09
Negative affect	1.27 (0.40)	1.35 (0.38)	1.26 (0.39)	1.29 (0.36)	0.06
Subjective stress	20.29 (19.57)	20.55 (21.78)	23.62 (18.84)	14.06 (17.02)	0.22

As described in Section 2.6, we used a Bayesian approach to our data analysis. Bayes factors (BF) were calculated using uninformative priors. BF_{10} represents evidence in favor of the alternative hypothesis: values of $BF_{10} \geq 3$ can be interpreted as moderate evidence for systematic group differences prior to pharmacological manipulation, while values of $BF_{10} < 1$ can be interpreted as evidence against systematic group differences. Abbreviations: BFI-10 = Big Five Inventory (10 item version), BIS-15 = Barratt Impulsiveness Scale, BIS/BAS = Behavioral Inhibition/Activation Scale, bpm = beats per minute, CRT = Cognitive Reflection Test, M = mean, MEQ = Morningness-Eveningness-Scale, nmol/L = nanomoles per liter, pg/ml = picograms per milliliter, SD = standard deviation, SDS-17 = Social Desirability Scale (17 item version), STAI = State-Trait-Anxiety Inventory, SVO = Social Value Orientation, TICS = Trier Inventory of Chronic Stress, U/ml = units per milliliter. For a complete list of the trait questionnaires and references, see Supplementary Materials.

indicates that our randomization protocol was effective in ensuring that there were no systematic differences between experimental conditions prior to the pharmacological manipulation.

3.2. Subjective stress measures

3.2.1. Positive affect

We found strong evidence for an effect of measurement block ($BF_{incl} > 100$) on positive affect in the PANAS, and moderate to strong evidence against an effect of drug condition ($BF_{excl} = 4.20$) or a condition by block interaction ($BF_{excl} > 100$). Post-hoc tests showed evidence of a decrease in positive affect between baseline and block 2 (adjusted posterior odds >100), baseline and block 3 (adjusted posterior odds >100), block 1 and block 2 (adjusted posterior odds >100), and block 1 and block 3 (adjusted posterior odds >100). Thus, positive affect decreased across the experiment regardless of drug condition (see Fig. 2).

3.2.2. Negative affect

We found strong evidence for an effect of measurement block ($BF_{incl} > 100$) on negative affect in the PANAS, and moderate evidence against an effect of drug condition ($BF_{excl} = 6.12$). Additionally, we found no conclusive evidence supporting a condition by block interaction ($BF_{incl} = 0.70$). Post-hoc tests showed evidence of a decrease in negative affect from baseline to block 3 (adjusted posterior odds >100), block 1 to block 3 (adjusted posterior odds >100), and block 2 to block 3 (adjusted posterior odds = 21.74, see Fig. 2). This means, negative affect remained relatively stable throughout the experiment until block 3, when it decreased across all drug conditions.

3.2.3. Subjective stress level

We found strong evidence for a main effect of measurement block ($BF_{incl} > 100$) on subjective stress levels, and moderate evidence for a block x drug condition interaction ($BF_{incl} = 3.16$), but no conclusive evidence for a main effect of drug condition alone ($BF_{incl} = 0.80$). To follow up on the interaction effect, we conducted block-wise analyses of drug effects. These revealed no evidence for drug effects in block 1 ($BF_{incl} = 0.46$) or in block 3 ($BF_{incl} = 0.07$). In block 2, there was strong evidence for a drug effect ($BF_{incl} = 13.33$), with participants in the yohimbine group reporting higher subjective stress than those in the hydrocortisone (adjusted posterior odds = 7.58) or placebo groups (adjusted posterior odds = 7.13; all other adjusted posterior odds <0.5).

3.3. Physiological stress measures

3.3.1. Heart rate

We found moderate evidence for an effect of time point ($BF_{incl} = 5.56$) on heart rate, and strong evidence against a time point by drug condition interaction ($BF_{excl} > 100$). There was no conclusive evidence in favor of an effect of condition ($BF_{incl} = 0.57$). Post-hoc tests revealed strong evidence for differences between time point 1 and all other time points (all adjusted posterior odds >100), as well as between baseline and time point 3 (adjusted posterior odds = 13.48), and time point 4 (adjusted posterior odds = 35.33, see Fig. 3). Descriptively, we observed an increase in heart rate during drug intake, followed by a decrease below baseline, after which it remained relatively stable.

3.3.2. Cortisol

We found strong evidence for a main effect of measurement block ($BF_{incl} > 100$), drug condition ($BF_{incl} > 100$), and a block x condition

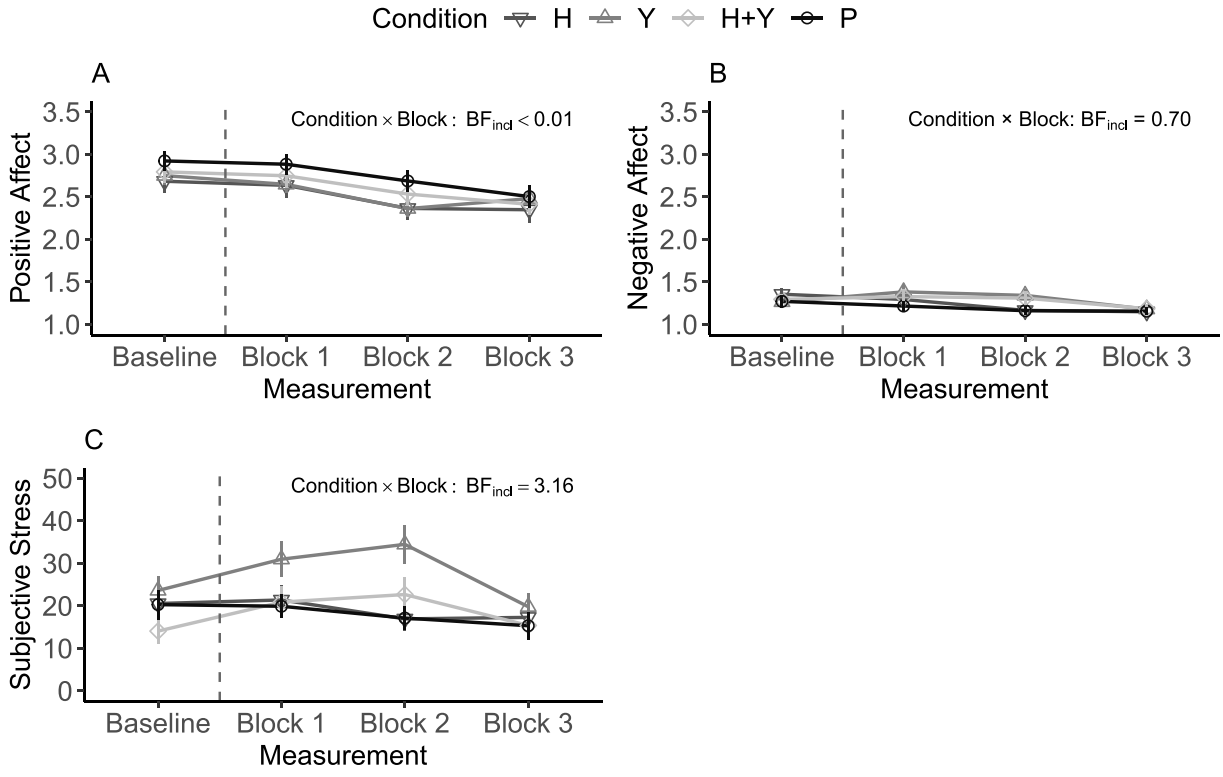

Fig. 2. Subjective stress and affect measures. (A) Mean positive affect (± standard error of the mean, SEM), (B) negative affect (± SEM), and (C) subjective stress levels (± SEM) across measurement blocks by drug condition. Affect was measured using the Positive and Negative Affect Schedule and subjective stress was measured using a visual analogue scale ranging from 0 to 100. The vertical dashed line marks the moment of drug administration (after baseline and before block 1). Blocks correspond to the approximate time point post-intake (in minutes) of stress and affect measures: Block 1 ~ +25 min, Block 2 ~ +60 min, Block 3 ~ +190 min. Subjective stress levels were increased in the yohimbine group compared to the hydrocortisone and placebo groups in block 2 (adjusted posterior odds = 7.58 and 7.13, respectively). No group differences were observed at baseline, block 1, or block 3. Abbreviations: H = hydrocortisone, Y = yohimbine, H + Y = hydrocortisone and yohimbine combined, P = placebo.

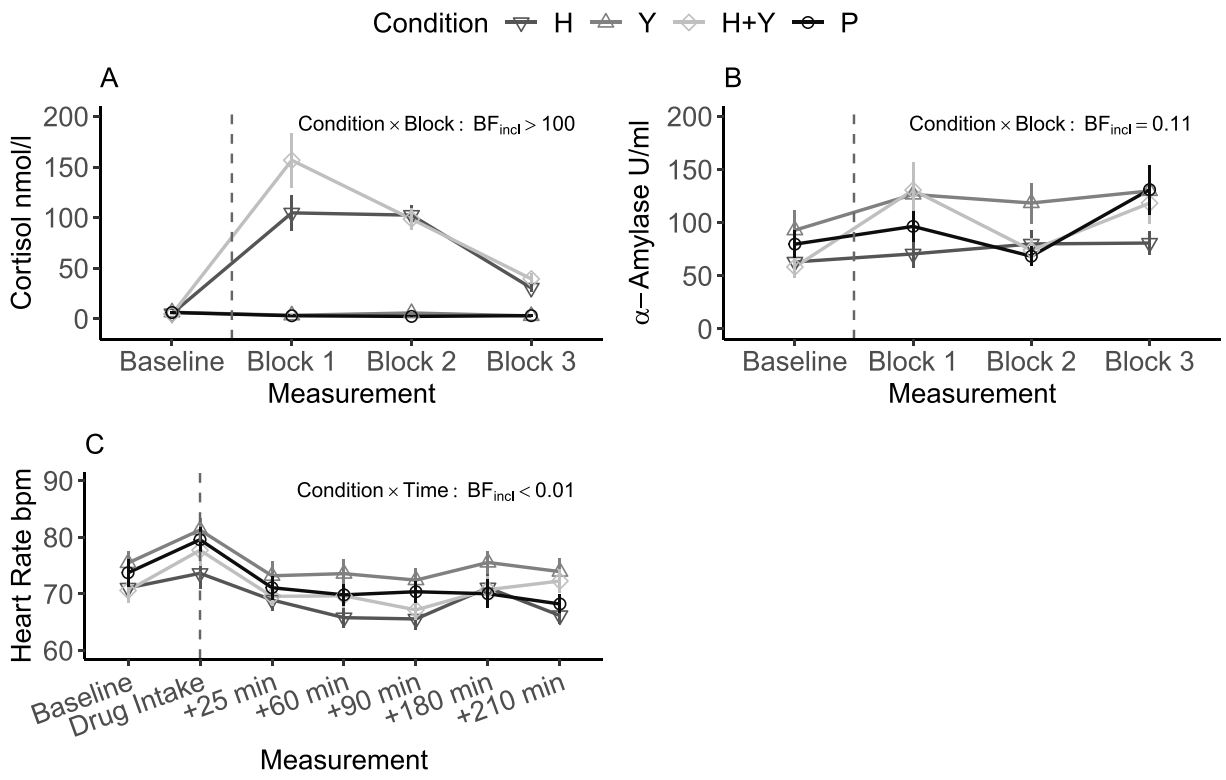

Fig. 3. Physiological stress measures. (A) Mean salivary cortisol levels (±SEM), (B) salivary alpha-amylase activity (±SEM), and (C) heart rate (±SEM) across measurement blocks by drug condition. The vertical dashed line marks the moment of drug administration (after baseline and before block 1). Blocks correspond to the approximate time point post-intake (in minutes) of physiological stress measures: Block 1 ~ +24 min, Block 2 ~ +59 min, Block 3 ~ +180 min. Salivary cortisol levels were increased in the hydrocortisone and combined groups compared to the placebo and yohimbine groups at each post-baseline time point (blocks 1–3; all adjusted posterior odds >100). They remained stable across blocks in the placebo and yohimbine groups (all adjusted posterior odds <0.89). Salivary alpha-amylase activity increased in all participants, exploratory analyses suggest that this was more pronounced in participants receiving yohimbine alone, or combined with hydrocortisone. Abbreviations: H = hydrocortisone, Y = yohimbine, H + Y = hydrocortisone and yohimbine combined, P = placebo, nmol/L = nanomoles per liter, U/ml = units per milliliter, bpm = beats per minute.

interaction ($BF_{incl} > 100$) on salivary cortisol levels. To follow up on the interaction effect, we conducted block-wise comparisons between drug groups. These revealed a drug effect in all blocks (BFincl >100). Cortisol levels rose sharply from baseline in the hydrocortisone and combined groups and remained elevated throughout the experiment (blocks 1, 2, and 3; all adjusted posterior odds >100). In contrast, cortisol levels in the yohimbine and placebo groups remained relatively stable across all blocks (all adjusted posterior odds <0.89; see Fig. 3). This confirms that hydrocortisone administration, either alone or in combination with yohimbine, effectively manipulated cortisol levels.

3.3.3. *Alpha-amylase*

We found strong evidence for an effect of measurement block ($BF_{incl} > 100$), and moderate evidence against an effect of drug condition ($BF_{excl} = 3.52$) or a block by condition interaction ($BF_{excl} = 8.86$) on salivary alpha-amylase. Post-hoc tests showed evidence of increased salivary alpha-amylase in blocks 1 and 3 compared to baseline (all adjusted posterior odds >100), as well as in block 3 compared to block 2 (adjusted posterior odds = 19.60, see Fig. 3). The block effect indicates that the autonomic activity of our participants changed over the course of the experiment.

Exploratory analyses of the area under the curve with respect to increase of salivary alpha-amylase activity (AUC_I; Pruessner et al., 2003) provide a somewhat more nuanced picture. Both the yohimbine and yohimbine + hydrocortisone groups showed AUC_I values clearly above zero (all $BF_{+0} > 10$), while the hydrocortisone and placebo groups did not ($BF_{+0} = 0.84$ and 1.08, respectively). This suggests that alpha-amylase activity increased more strongly in the groups that received yohimbine relative to a generally elevated alpha-amylase response across all conditions.

This somewhat unclear interaction effect between measurement block and drug condition on salivary alpha-amylase is not particularly surprising given that it is only an indirect and very noisy measure of central noradrenergic activity (Rohleder and Nater, 2009). For instance, it was demonstrated that alpha-amylase correlates with serum noradrenaline only to a limited extent, which is why alpha-amylase is only partially suitable as a marker for changes in noradrenergic activity (Nater et al., 2006). In addition, it is possible that the general autonomic activity of the participants in all conditions masked effects of increased noradrenergic activity due to bathroom breaks and general arousal and subjective nervousness, e.g., during drug intake (white coat effects).

3.3.4. *Treatment belief*

Consistent with previous studies (Margittai et al., 2018b), participants were unable to accurately identify which drug they had received. In fact, their guesses were systematically incorrect, with false guesses exceeding the 25 % chance level ($BF_{+0} > 100$).

3.4. *GARP task*

3.4.1. *Prosocial decision-making*

To test if the drugs changed social preferences as their pharmacological effects unfolded, we calculated how much money the participants shared with their friend, or with a stranger, in each measurement block and drug condition. We found moderate to strong evidence against an effect of condition ($BF_{excl} = 3.89$) or interactions between condition and any other factor on the share score (x distance: $BF_{excl} = 2.38$, x block: $BF_{excl} = 11.12$, x distance x block: $BF_{excl} = 14.49$), as well as

strong evidence against a social distance by block interaction (BF_{excl} = 79.70). Additionally, we found strong evidence for an effect of distance (BF_{incl} > 100) and moderate evidence for an effect of block (BF_{incl} = 9.43). Post-hoc tests showed that there was a decrease in sharing from baseline to block 3 (adjusted posterior odds = 5.24) as well as from block 1 to block 3 (adjusted posterior odds = 6.68). Overall, participants shared less with socially distant than with socially close others, and they also shared less at the end of the experiment than in the beginning (see Fig. 4). However, we found conclusive evidence against an effect of the drugs on sharing behavior, suggesting that the drugs did not change our participants' social preferences.

3.4.2. Choice consistency

As explained above, for each participant, we computed the CCEI across all trials and measurement blocks in the experiment. If the drugs indeed changed the participants' social preferences as their pharmacological effects unfolded, we would expect a systematic change in prosocial allocation choices, which should manifest in a lowered CCEI when computed across all trials. However, we found moderate evidence against an effect of drug condition (BF_{excl} = 7.52), social distance (BF_{excl} = 4.20), or condition by social distance interaction (BF_{excl} = 6.85) on the CCEI. This means, participants' CCEI across all choices made in the experiment were unaffected by the pharmacological manipulation (see Fig. 5).

4. Discussion

In our study, we used a psychopharmacological approach to test the stability of choice consistency and social preferences across varying levels of glucocorticoid and noradrenergic activity. To this end, we administered hydrocortisone, yohimbine, a combination of both hydrocortisone and yohimbine, or placebo to participants playing a modified dictator game. In this game, participants made repeated choices on money allocations between themselves and either a friend or a stranger. To be able to quantify choice consistency within the GARP framework, we manipulated the budget constraint as well as the prices of the money allocations (akin to transfer and transactions costs). We measured sharing behavior at baseline and at several time points after drug administration and assessed choice consistency across all choices. We found moderate to strong evidence against drug effects on both sharing behavior and choice consistency.

Specifically, across all drug conditions, participants shared more with close others (best friends) than with distant others (strangers), replicating the well-documented social discounting phenomenon (Jones and Rachlin, 2006; Margittai et al., 2018b, 2015), but they shared less over time. Hence, contrary to our hypotheses, fluctuating levels of stress neuromodulators did not systematically alter social preferences or choice consistency.

These findings extend prior work on the robustness of choice consistency during altered cognitive or neurohormonal states such as stress, menstrual cycle phases, or cognitive load (Cettolin et al., 2020; Drichoutis and Nayga, 2020; Lazzaro et al., 2016; Nitsch et al., 2021). Importantly, these past studies have focused on within-state choice consistency, i.e. whether individuals make internally consistent choices during a specific internal state, such as specific time windows of the stress response (Nitsch et al., 2021). Our design instead assessed whether choices remained internally consistent across transitions in neurohormonal states. For this, we computed our consistency measure across the entire time course as the drugs unfolded their effects. Despite these dynamic shifts in cortisol and noradrenaline action, we found no drug effects on choice consistency, likely due to the stability of social preferences. Our results suggest that even under dynamic internal states, social preferences remain sufficiently stable to satisfy the core assumption of preference-based choice models, thus implying that it is not necessary to consider transient but unobservable stress states of individuals in the analysis of choices and preferences.

At the same time, we did not replicate previous findings that showed that hydrocortisone administration increased generosity toward close others and that concurrent yohimbine administration abolished this effect (Margittai et al., 2018b). Although we used an identical pharmacological protocol, our study design differed in several ways. Specifically, we used a more complex choice environment, where we introduced transaction costs (prices of sharing) to assess choice consistency, had repeated within-subject measurements, and employed a budget line as a response scale. These design differences may have increased cognitive demands or masked subtle motivational shifts that can be observed in simpler choice paradigms, potentially contributing to our inability to replicate prior findings.

This discrepancy aligns with recent evidence showing that the effects of stress on social decision-making are not universal, but rather appear to be highly complex and context-dependent (Nitschke et al., 2022; Sarmiento et al., 2024). For example, minor methodological differences, such as different response scales, may influence the observed stress effects on prosocial choice (Nitschke et al., 2022). In this context, it has been suggested that stress does not uniformly increase or decrease prosocial behavior, but, instead, the effects may vary depending on the

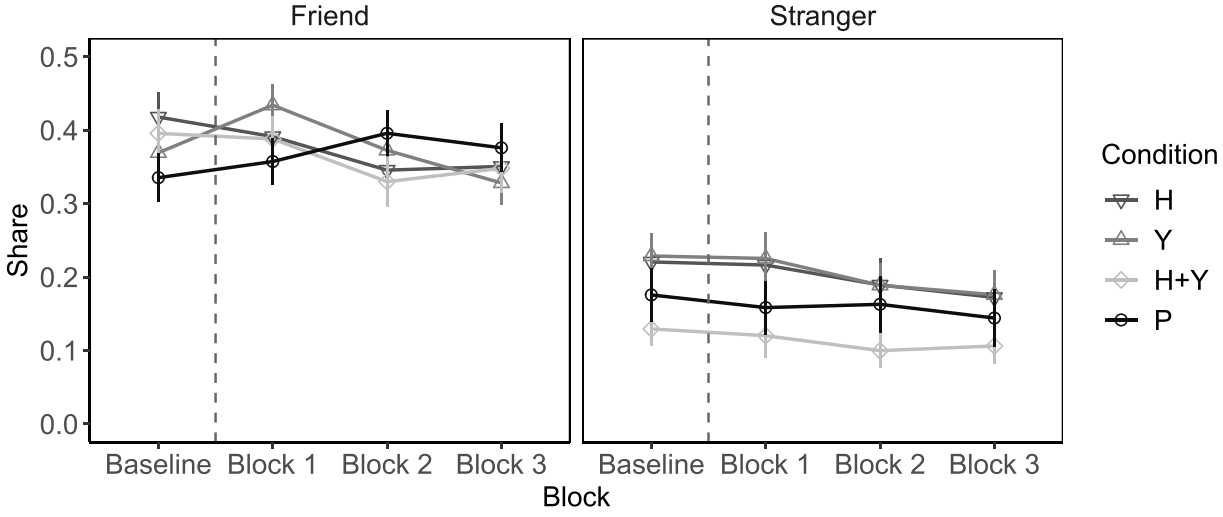

Fig. 4. Prosocial behavior. Mean share score (±SEM) across measurement blocks by drug condition, separately for recipient type (friend or stranger). The vertical dashed line indicates the time of drug administration (after baseline and before block 1). Blocks correspond to approximate minutes post-intake: Block 1 ~ +25 min, Block 2 ~ +60 min, Block 3 ~ +190 min. Abbreviations: H = hydrocortisone, Y = yohimbine, H + Y = hydrocortisone and yohimbine combined, P = placebo.

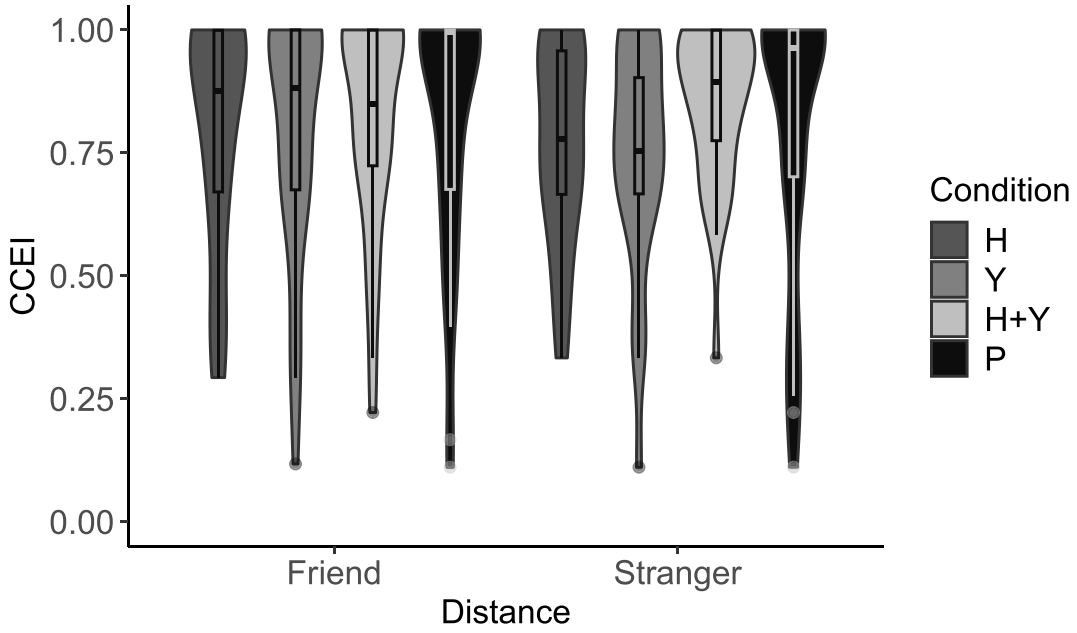

Fig. 5. Choice consistency. Mean CCEI scores (±SEM) by drug condition, separately for recipient type (friend or stranger). Abbreviations: H = hydrocortisone, Y = yohimbine, H + Y = hydrocortisone and yohimbine combined, P = placebo.

specific needs triggered and the contextual stimuli present (Dashti et al., 2025; Faber and Häusser, 2022). Taken together, these findings and recent theoretical advances suggest that stress and stress neuromodulators do influence social preferences, but in ways that are context-sensitive, goal-dependent, and shaped by the structure of the choice environment.

The manipulation checks provided strong evidence for the successful manipulation of cortisol levels by hydrocortisone administration. In contrast, yohimbine administration did not reliably produce elevated salivary alpha-amylase as an indirect proxy for central noradrenergic activity. However, this is not particularly surprising given that previous studies have shown that salivary alpha-amylase does not reliably correlate with serum noradrenaline, suggesting that it reflects general autonomic activity rather than specific noradrenergic effects in the brain (Nater et al., 2006). In addition, general autonomic activity in participants, such as arousal and physical activity, may have masked yohimbine-induced effects on salivary alpha-amylase. Since the mechanism of yohimbine's action on noradrenaline is well-established (Berlan et al., 1991; Charney et al., 1982; Goldberg et al., 1983), we are confident that our manipulation was successful, although, admittedly, our study lacks data to support this, highlighting the need for better readouts of central noradrenergic activity.

Choice consistency is often used to define economic rationality and treated as a trait or state characteristic of individuals. However, we have recently criticized the psychometric properties of contemporary measures of choice consistency, such as the CCEI (Nitsch et al., 2022). Specifically, we identified low inter-method and test-retest reliability in these measures, implying that they are not reliable enough to qualify as psychometric indices of economic rationality as a characteristic of individuals (Nitsch et al., 2022). While this is a major problem for correlational studies (Nitsch et al., 2022), it is less of a problem for designs involving experimental manipulations and group comparisons, as we have done here. In addition, here, we explicitly refrain from making claims about economic rationality as an individual state or trait, thus avoiding psychometric statements and conclusions. We opted for the CCEI as a measure of choice consistency in the absence of a better measure. Yet, we continue to stress the clear need within economic modelling to develop alternative measures with improved psychometric properties. These new measures would not only enhance the accuracy and reliability of the assessment of choice consistency but would also contribute to a more nuanced understanding of how various factors, including neurobiological influences and, perhaps, stress, shape economic behavior.

5. Conclusion

In conclusion, our study provides evidence for consistency in social choice behavior across varying levels of glucocorticoid and noradrenergic activation. It extends previous findings showing that choice consistency is maintained during altered cognitive and neurohormonal states. We show that standard economic modelling and preference analyses are not affected by dynamically changing neurohormonal states. Furthermore, our results advance the ongoing controversy as to whether stress or stress neuromodulators affect decision-making, especially social decision-making. They indicate that the behavioral effects of stress neuromodulators may be more context-dependent than previously assumed. Rather than producing uniform shifts in prosociality, cortisol and noradrenaline may modulate behavior in distinct ways that depend on the choice environment, social context, and motivational salience. We advocate the need to develop more reliable measures of choice consistency and to explore additional factors that may affect the stability of social preferences.

CRediT authorship contribution statement

Luca M. Lüpken: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alfons Schnitzler:** Writing – review & editing, Resources. **Tobias Kalenscher:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT 3.5 in order to improve readability and language. After using this tool/service, the authors reviewed and edited the content as needed and take full

responsibility for the content of the publication.

Funding

The work was supported by a grant from the German Research Foundation (Deutsche Forschungsgemeinschaft, Bonn, Germany) to Tobias Kalenscher (grant-ID: DFG-KA 2675/7-1).

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Tobias Kalenscher reports financial support was provided by German Research Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank José Michele Dören and Maurice Zech for valuable comments on the study design, the statistical analyses and the manuscript. We also thank Damon Dashti, Helena El Kholy, Franziska Faust, Julian Grefer, Sofia Guerreri, Ariane Quade, Luna Seume, Daniel Siman, Hannah Wahle, and Marie Wülfing for their invaluable assistance with data collection.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.yhbeh.2025.105863.

Data availability

Preprocessed data are available online: https://osf.io/bnxjt/?view_only=64e5a13c91ad4eb7a98d6f338a46ccb9.

References

Afriat, S.N., 1967. The construction of utility functions from expenditure data. Int. Econ. Rev. 8, 67–77. https://doi.org/10.2307/2525382.
Afriat, S.N., 1972. Efficiency estimation of production functions. Int. Econ. Rev. 13, 568–598. https://doi.org/10.2307/2525845.
Afriat, S.N., 1973. On a system of inequalities in demand analysis: an extension of the classical method. Int. Econ. Rev. 14, 460–472. https://doi.org/10.2307/2525934.
Andreoni, J., Miller, J., 2002. Giving according to GARP: an experimental test of the consistency of preferences for altruism. Econometrica 70, 737–753.
Bedi, G., Burghart, D.R., 2018. Is utility maximization compromised by acute intoxication with THC or MDMA? Econ. Lett. 171, 128–132. https://doi.org/10.1016/j.econlet.2018.06.021.
Berger, J., Heinrichs, M., Von Dawans, B., Way, B.M., Chen, F.S., 2016. Cortisol modulates men's affiliative responses to acute social stress. Psychoneuroendocrinology 63, 1–9. https://doi.org/10.1016/j.psyneuen.2015.09.004.
Berlan, M., Galitzky, J., Riviere, D., Foureau, M., Tran, M.A., Flores, R., Louvet, J.P., Houin, G., Lafontan, M., 1991. Plasma catecholamine levels and lipid mobilization induced by yohimbine in obese and non-obese women. Int. J. Obes. 15, 305–315.
Burghart, D.R., Glimcher, P.W., Lazzaro, S.C., 2013. An expected utility maximizer walks into a bar. J. Risk Uncertain. 46, 215–246. https://doi.org/10.1007/s11166-013-9167-7.
Castillo, M., Dickinson, D.L., Petrie, R., 2017. Sleepiness, choice consistency, and risk preferences. Theor. Decis. 82, 41–73. https://doi.org/10.1007/s11238-016-9559-7.
Cettolin, E., Dalton, P.S., Kop, W.J., Zhang, W., 2020. Cortisol meets GARP: the effect of stress on economic rationality. Exp. Econ. 23, 554–574. https://doi.org/10.1007/s10683-019-09624-z.
Charney, D.S., Heninger, G.R., Sternberg, D.E., 1982. Assessment of α2 adrenergic autoreceptor function in humans: effects of oral yohimbine. Life Sci. 30, 2033–2041. https://doi.org/10.1016/0024-3205(82)90444-1.
Choi, S., Fisman, R., Gale, D.M., Kariv, S., 2007. Revealing preferences graphically: an old method gets a new tool kit. Am. Econ. Rev. 97, 153–158. https://doi.org/10.1257/aer.97.2.153.
Cook, N.J., Ng, A., Read, G.F., Harris, B., Riad-Fahmy, D., 1987. Salivary cortisol for monitoring adrenal activity during marathon runs. Horm. Res. 25, 18–23. https://doi.org/10.1159/000180628.
Dashti, D., Lüpken, L.M., Seidisarouei, M., Forbes, P.A.G., Schnitzler, A., Kalenscher, T., 2025. Dissociable glucocorticoid and noradrenergic effects on parochial cooperation and competition in intergroup conflict. Proc. Natl. Acad. Sci. 122, e2502257122. https://doi.org/10.1073/pnas.2502257122.
Derendorf, H., Möllmann, H., Barth, J., Möllmann, C., Tunn, S., Krieg, M., 1991. Pharmacokinetics and oral bioavailability of hydrocortisone. J. Clin. Pharmacol. 31, 473–476. https://doi.org/10.1002/j.1552-4604.1991.tb01906.x.
Drichoutis, A.C., Nayga, R.M., 2020. Economic rationality under cognitive load. Econ. J. 130, 2382–2409. https://doi.org/10.1093/ej/ueaa052.
Duque, A., Cano-López, I., Puig-Pérez, S., 2022. Effects of psychological stress and cortisol on decision making and modulating factors: a systematic review. Eur. J. Neurosci. 56, 3889–3920. https://doi.org/10.1111/ejn.15721.
Faber, N.S., Häusser, J.A., 2022. Why stress and hunger both increase and decrease prosocial behaviour. Curr. Opin. Psychol. 44, 49–57. https://doi.org/10.1016/j.copsyc.2021.08.023.
Fisman, R., Jakiela, P., Kariv, S., 2017. Distributional preferences and political behavior. J. Public Econ. 155, 1–10. https://doi.org/10.1016/j.jpubeco.2017.08.010.
Forbes, P.A.G., Nitschke, J.P., Hochmeister, N., Kalenscher, T., Lamm, C., 2024. No effects of acute stress on monetary delay discounting: a systematic literature review and meta-analysis. Neurobiol. Stress 31, 100653. https://doi.org/10.1016/j.ynstr.2024.100653.
Goldberg, M.R., Hollister, A.S., Robertson, D., 1983. Influence of yohimbine on blood pressure, autonomic reflexes, and plasma catecholamines in humans. Hypertension 5, 772–778. https://doi.org/10.1161/01.HYP.5.5.772.
Haden, S.C., Scarpa, A., 2007. The noradrenergic system and its involvement in aggressive behaviors. Aggress. Violent Behav. 12, 1–15. https://doi.org/10.1016/j.avb.2006.01.012.
Hedner, T., Edgar, B., Edvinsson, L., Hedner, J., Persson, B., Pettersson, A., 1992. Yohimbine pharmacokinetics and interaction with the sympathetic nervous system in normal volunteers. Eur. J. Clin. Pharmacol. 43, 651–656. https://doi.org/10.1007/bf02284967.
Hermans, E.J., Henckens, M.J.A.G., Joëls, M., Fernández, G., 2014. Dynamic adaptation of large-scale brain networks in response to acute stressors. Trends Neurosci. 37, 304–314. https://doi.org/10.1016/j.tins.2014.03.006.
Houthakker, H.S., 1950. Revealed preference and the utility function. Economica 17, 159–174. https://doi.org/10.2307/2549382.
JASP Team, 2024. JASP (Version 0.18.3) (Computer software).
Jeffreys, H., 1939. Theory of Probability. Clarendon Press.
Jeffreys, H., 1961. Theory of Probability. Oxford University Press.
Joëls, M., Baram, T.Z., 2009. The neuro-symphony of stress. Nat. Rev. Neurosci. 10, 459–466. https://doi.org/10.1038/nrn2632.
Jones, B., Rachlin, H., 2006. Social discounting. Psychol. Sci. 17, 283–286. https://doi.org/10.1111/j.1467-9280.2006.01699.x.
Kerschbamer, R., Müller, D., 2020. Social preferences and political attitudes: an online experiment on a large heterogeneous sample. J. Public Econ. 182, 104076. https://doi.org/10.1016/j.jpubeco.2019.104076.
Keysers, C., Gazzola, V., Wagenmakers, E.-J., 2020. Using Bayes factor hypothesis testing in neuroscience to establish evidence of absence. Nat. Neurosci. 23, 788–799. https://doi.org/10.1038/s41593-020-0660-4.
Kirschbaum, C., Kudielka, B.M., Gaab, J., Schommer, N.C., Hellhammer, D.H., 1999. Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamus-pituitary-adrenal axis. Psychosom. Med. 61, 154–162. https://doi.org/10.1097/00006842-199903000-00006.
Lazzaro, S.C., Rutledge, R.B., Burghart, D.R., Glimcher, P.W., 2016. The impact of menstrual cycle phase on economic choice and rationality. PLoS One 11, e0144080. https://doi.org/10.1371/journal.pone.0144080.
Ling, A., George, N., Shiv, B., Plassmann, H., 2023. Altering experienced utility by incidental affect: the interplay of valence and arousal in incidental affect infusion processes. Emotion 23, 2179–2193. https://doi.org/10.1037/emo0001241.
Margittai, Z., Strombach, T., Van Wingerden, M., Joëls, M., Schwabe, L., Kalenscher, T., 2015. A friend in need: time-dependent effects of stress on social discounting in men. Horm. Behav. 73, 75–82. https://doi.org/10.1016/j.yhbeh.2015.05.019.
Margittai, Z., Nave, G., Van Wingerden, M., Schnitzler, A., Schwabe, L., Kalenscher, T., 2018a. Combined effects of glucocorticoid and noradrenergic activity on loss aversion. Neuropsychopharmacology 43, 334–341. https://doi.org/10.1038/npp.2017.75.
Margittai, Z., Van Wingerden, M., Schnitzler, A., Joëls, M., Kalenscher, T., 2018b. Dissociable roles of glucocorticoid and noradrenergic activation on social discounting. Psychoneuroendocrinology 90, 22–28. https://doi.org/10.1016/j.psyneuen.2018.01.015.
Nater, U.M., Rohleder, N., 2009. Salivary alpha-amylase as a non-invasive biomarker for the sympathetic nervous system: Current state of research. Psychoneuroendocrinology 34, 486–496. https://doi.org/10.1016/j.psyneuen.2009.01.014.
Nater, U.M., Lamarca, R., Florin, L., Moses, A., Langhans, W., Koller, M., Ehlert, U., 2006. Stress-induced changes in human salivary alpha-amylase activity—associations with adrenergic activity. Psychoneuroendocrinology 31, 49–58. https://doi.org/10.1016/j.psyneuen.2005.05.010.
Nelson, R.J., Trainor, B.C., 2007. Neural mechanisms of aggression. Nat. Rev. Neurosci. 8, 536–546. https://doi.org/10.1038/nrn2174.
Nitsch, F.J., Sellitto, M., Kalenscher, T., 2021. The effects of acute and chronic stress on choice consistency. Psychoneuroendocrinology 131, 105289. https://doi.org/10.1016/j.psyneuen.2021.105289.
Nitsch, F.J., Lüpken, L.M., Lüschow, N., Kalenscher, T., 2022. On the reliability of individual economic rationality measurements. Proc. Natl. Acad. Sci. 119, e2202070119. https://doi.org/10.1073/pnas.2202070119.

Nitschke, J.P., Forbes, P.A.G., Lamm, C., 2022. Does stress make us more—or less—prosocial? A systematic review and meta-analysis of the effects of acute stress on prosocial behaviours using economic games. Neurosci. Biobehav. Rev. 142, 104905. https://doi.org/10.1016/j.neubiorev.2022.104905.

Owen, J.A., Nakatsu, S.L., Fenemore, J., Condra, M., Surridge, D.H.C., Morales, A., 1987. The pharmacokinetics of yohimbine in man. Eur. J. Clin. Pharmacol. 32, 577–582. https://doi.org/10.1007/bf02455991.

Patel, R.B., Rogge, M.C., Selen, A., Goehl, T.J., Shah, V.P., Prasad, V.K., Welling, P.G., 1984. Bioavailability of hydrocortisone from commercial 20-mg tablets. J. Pharm. Sci. 73, 964–966. https://doi.org/10.1002/jps.2600730726.

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

Riis-Vestergaard, M.I., Van Ast, V., Cornelisse, S., Joëls, M., Haushofer, J., 2018. The effect of hydrocortisone administration on intertemporal choice. Psychoneuroendocrinology 88, 173–182. https://doi.org/10.1016/j.psyneuen.2017.10.002.

Rohleder, N., Nater, U.M., 2009. Determinants of salivary α-amylase in humans and methodological considerations. Psychoneuroendocrinology 34, 469–485. https://doi.org/10.1016/j.psyneuen.2008.12.004.

Rohleder, N., Wolf, J.M., Maldonado, E.F., Kirschbaum, C., 2006. The psychosocial stress-induced increase in salivary alpha-amylase is independent of saliva flow rate. Psychophysiology 43, 645–652. https://doi.org/10.1111/j.1469-8986.2006.00457.x.

Rouder, J.N., 2014. Optional stopping: no problem for Bayesians. Psychon. Bull. Rev. 21, 301–308. https://doi.org/10.3758/s13423-014-0595-4.

Rouder, J.N., Morey, R.D., Speckman, P.L., Province, J.M., 2012. Default Bayes factors for ANOVA designs. J. Math. Psychol. 56, 356–374. https://doi.org/10.1016/j.jmp.2012.08.001.

Samuelson, P.A., 1938. A note on the pure theory of consumer's behaviour. Economica 5, 61–71. https://doi.org/10.2307/2548836.

Sarmiento, L.F., Ríos-Flórez, J.A., Rincón Uribe, F.A., Rodrigues Lima, R., Kalenscher, T., Gouveia, A., Nitsch, F.J., 2024. Do stress hormones influence choice? A systematic review of pharmacological interventions on the HPA axis and/or SAM system. Soc. Cogn. Affect. Neurosci. 19, nsae069. https://doi.org/10.1093/scan/nsae069.

Schönbrodt, F.D., Wagenmakers, E.-J., Zehetleitner, M., Perugini, M., 2017. Sequential hypothesis testing with Bayes factors: efficiently testing mean differences. Psychol. Methods 22, 322–339. https://doi.org/10.1037/met0000061.

Schweda, A., Faber, N.S., Crockett, M.J., Kalenscher, T., 2019. The effects of psychosocial stress on intergroup resource allocation. Sci. Rep. 9, 18620. https://doi.org/10.1038/s41598-019-54954-w.

Singer, N., Kreuzpointner, L., Sommer, M., Wüst, S., Kudielka, B.M., 2019. Decision-making in everyday moral conflict situations: development and validation of a new measure. PLoS One 14, e0214747. https://doi.org/10.1371/journal.pone.0214747.

Starcke, K., Brand, M., 2012. Decision making under stress: a selective review. Neurosci. Biobehav. Rev. 36, 1228–1248. https://doi.org/10.1016/j.neubiorev.2012.02.003.

Strojny, J., Von Dawans, B., Schächinger, H., Domes, G., 2024. Hydrocortisone reduces altruistic punishment in healthy men. Psychoneuroendocrinology 165, 107027. https://doi.org/10.1016/j.psyneuen.2024.107027.

Van Den Bergh, D., Van Doorn, J., Marsman, M., Draws, T., Van Kesteren, E.-J., Derks, K., Dablander, F., Gronau, Q.F., Kucharský, Š., Gupta, A.R.K.N., Sarafoglou, A., Voelkel, J.G., Stefan, A., Ly, A., Hinne, M., Matzke, D., Wagenmakers, E.-J., 2020. A tutorial on conducting and interpreting a Bayesian ANOVA in JASP. Ann. Psychol. 120, 73–96. https://doi.org/10.3917/anpsy1.201.0073.

Van Doorn, J., Van Den Bergh, D., Böhm, U., Dablander, F., Derks, K., Draws, T., Etz, A., Evans, N.J., Gronau, Q.F., Haaf, J.M., Hinne, M., Kucharský, Š., Ly, A., Marsman, M., Matzke, D., Gupta, A.R.K.N., Sarafoglou, A., Stefan, A., Voelkel, J.G., Wagenmakers, E.-J., 2021. The JASP guidelines for conducting and reporting a Bayesian analysis. Psychon. Bull. Rev. 28, 813–826. https://doi.org/10.3758/s13423-020-01798-5.

Varian, H.R., 1993. Goodness-of-fit for Revealed Preference Tests.

Von Dawans, B., Strojny, J., Domes, G., 2021. The effects of acute stress and stress hormones on social cognition and behavior: current state of research and future directions. Neurosci. Biobehav. Rev. 121, 75–88. https://doi.org/10.1016/j.neubiorev.2020.11.026.

Watson, D., Clark, L.A., Tellegen, A., 1988. Development and validation of brief measures of positive and negative affect: the PANAS scales. J. Pers. Soc. Psychol. 54, 1063–1070. https://doi.org/10.1037/0022-3514.54.6.1063.

Westfall, P., Johnson, W.O., Utts, J.M., 1997. A bayesian perspective on the Bonferroni adjustment. Biometrika 84, 419–427. https://doi.org/10.1093/biomet/84.2.419.