The Effect of Hydrocortisone Administration on Intertemporal Choice*

Michala Iben Riis-Vestergaard†, Vanessa van Ast ‡, Sandra Cornelisse§, Maayke Seinstra ¶, Marian Joëls†, Johannes Haushofer‖

February 28, 2017

Abstract

We ask whether the hormone cortisol, released during stress, increases temporal discounting. We randomly assigned 78 males to one of three groups: the "rapid cort" group received 10mg of hydrocortisone, a synthetic form of cortisol, 15 minutes before performing an intertemporal choice task. The "slow cort" group received hydrocortisone 195 minutes before the same task. The "placebo" group received placebo pills. Participants in the "rapid cort" group, but not the "slow cort" group, were significantly more impatient compared to placebo. These results suggest that the hormones released during acute stress may increase temporal discounting over the short term.

Keywords: Intertemporal choice; stress; laboratory experiment
JEL codes: C91, D9, D03

*This work was supported by a TopTalent grant (VvA, #021.002.103), a Cogito Foundation Grant (JH, R-116/10) and a NIH grant (JH, 1R01AG039297). We thank Clemens Kirschbaum, Ph.D., Technical University of Dresden, Germany, for analyzing the salivary cortisol samples, and Conor Hughes and Nicholas Otis for excellent research assistance.

†Department of Psychology, Woodrow Wilson School of Public and International Affairs, Princeton University, USA; and Busara Center for Behavioral Economics, Nairobi, Kenya. michalar@princeton.edu

‡Department of Clinical Psychology, University of Amsterdam, Amsterdam, The Netherlands

§Department of Neuroscience and Pharmacology, Rudolf Magnus Institute of Neuroscience, University Medical Center Utrecht, 3508 AB, Utrecht, The Netherlands

¶Comparative Psychology, Institute of Experimental Psychology, Heinrich-Heine University, Düsseldorf, 40225, Düsseldorf, Germany

‖Corresponding author. Department of Psychology, Woodrow Wilson School of Public and International Affairs, and Department of Economics, Princeton University, USA; and Busara Center for Behavioral Economics, Nairobi, Kenya. haushofer@princeton.edu

1 Introduction

Stress is a prominent feature of everyday life, and people frequently make important economic decisions under its influence.[1] Recent research has begun to ask whether stress causally affects economic choice; existing evidence suggests that acute stress may affect productivity (Angelucci and Córdova 2014), risk preferences (Kandasamy et al. 2014; Porcelli and Delgado 2009; Delaney et al. 2014; Bendahan et al. 2016), and social preferences (von Dawans et al. 2012; Vinkers et al. 2013). Here, we focus on the effect of the stress hormone cortisol on temporal discounting. Existing studies have produced inconclusive results: Koppel et al. (2017) find increases in discounting after inducing physical stress in the form of thermal pain; Delaney et al. (2014) find increases in temporal discounting after exposure to the "cold pressor task", a physical stressor consisting of holding one's hand in cold water. In contrast, we have previously found no effects of the cold pressor task and a social stressor, the Trier Social Stress Test, on temporal discounting (Haushofer et al. 2013; Haushofer et al. 2015). One possibility for these discrepant findings is that the different induction methods lead to a host of physiological changes, not only in cortisol, but also in adrenaline and noradrenaline levels and heart rate. In this paper, we isolate one of these mechanisms by pharmacologically increasing levels of the stress hormone cortisol in a laboratory study. This manipulation allows us to ask whether increased levels of the stress hormone cortisol causally affect temporal discounting.

To answer this question, we combine measures of intertemporal choice with pharmacological manipulation of the stress hormone cortisol. Specifically, we administered either placebo or hydrocortisone, a drug that increases the biological levels of the stress hormone cortisol, to healthy human participants, and then asked them to complete a temporal discounting task. Participants were divided into three groups: the "rapid cort" group received 10mg of hydro-

[1] The definition of stress has been subject to intense debate in the psychology and neurobiology literature. The most common definition is in terms of "allostatic load", i.e. demands placed on an organism by a changing environment to which it needs to adapt (McEwen 1998).

cortisone 15 minutes before completing the discounting task; the "slow cort" group received 10 mg of hydrocortisone 195 minutes before the task. Both groups received a placebo pill at the respective other timepoint. The placebo group received placebo pills at both timepoints. Administering hydrocortisone at two different timepoints with respect to the discounting task allows us to trace out the timecourse of the effect. The motivation for this design feature is that recent literature in neurobiology has suggested that cortisol has different immediate vs. delayed effects on behavior: immediately after stress, cortisol promotes emotional and reflex-like behavior (Schwabe et al. 2010; Henckens et al. 2012; Vedhara et al. 2000), at the expense of goal-directed behavior and higher cognitive functioning (Elzinga and Roelofs 2005; Schwabe et al. 2010). By contrast, the delayed effects of cortisol, mediated by changes in gene transcription that require about one hour to develop and last for several hours (Datson et al. 2008), promote memory formation and consolidation (Barsegyan et al. 2010; Oitzl et al. 2001; Henckens et al. 2011) and sustained attentional processing (Henckens et al. 2012). Relatedly, it has recently been shown that stress has a time-dependent effect on both social (Vinkers et al. 2013) and risk preferences (Bendahan et al. 2016). Thus, the early behavioral responses to cortisol are thought to shift the focus to the present, while the slower actions of cortisol are thought to prepare the organism for the future. We therefore hypothesized that cortisol would increase discounting 15 minutes after administration, and decrease it 195 minutes after administration.

Indeed, we find strong increases in impatience 15 minutes after hydrocortisone administration; hydrocortisone doubles the implied annual discount rate from 31 to 64 percent. This effect is restricted to impatience and does not affect present bias, i.e. the extent to which participants place a disproportionally high weight on the present compared to all future time points. Finally, we find that the effects of hydrocortisone administration and discounting are no longer present after three hours; we find no treatment effect when presenting the participants with the intertemporal choice task 195 minutes after hydrocortisone administration.

This study contributes to the emerging literature on the effect of stress

on economic choice in general, and intertemporal choice in particular. As described above, physical stress, experimentally induced by thermal stimulation or by the "Cold Pressor Task"[2], has been shown to increase discounting in some studies (Koppel et al. 2017; Delaney et al. 2014), but not others (Haushofer et al. 2015), while social stress induced by the "Trier Social Stress Test"[3] appears not to affect discounting (Haushofer et al. 2013; Haushofer et al. 2015). Our finding that increased levels of the stress hormone cortisol lead to increased discounting suggests that these discrepant existing findings might be reconciled by differential effects of the stress induction methods on cortisol levels; this is a topic for future study. Relatedly, negative affect has been shown to increase discounting (Lerner et al. 2013; McLeish and Oxoby 2007), while positive affect decreases discounting (Pyone and Isen 2011; Ifcher and Zarghamee 2011); to the extent that negative affect correlates with stress, these findings mirror our results.

More broadly, this study extends the literature that estimates the effect of stress on economic behaviors. Existing evidence suggests that stress increases risk aversion in the gains domain (Delaney et al. 2014; Porcelli and Delgado 2009), and that this effect is mediated by cortisol levels (Kandasamy et al. 2014). Acute stress has also been shown to increase pro-social behavior in economic exchange games (von Dawans et al. 2012). Together, these findings begin to map the landscape of the effect of stress on economic behavior, and the present study contributes by demonstrating that pharmacologically elevated cortisol levels increase temporal discounting.

The remainder of the paper is organized as follows. Section 2 outlines the experimental design; Section 3 presents results; Section 4 concludes.

[2]This tasks induces stress by asking participants to hold their hand in cold water.

[3]This tasks induces stress by asking participants to give a speech and perform mental arithmetic in front of a panel of judges.

2 Experimental design

2.1 Participants

The sample was restricted to male participants to minimize confounds from hormonal fluctuations during the female cycle. A total of 79 male participants gave written informed consent. Sample size was determined by a power analysis (power $> 0.80; \alpha = 0.05$) for detecting medium (Cohen's d ranging from 0.50 to 0.80) effects in group comparisons. Ex-post minimum detectable effect sizes (MDEs) are presented in Appendix Table A.3. The local ethical committee of the University of Amsterdam approved the study. Inclusion criteria as assessed by self-report were: no past or present psychiatric or neurological condition, and age between 18 and 35 years. Men having any somatic or endocrine disease (e.g., acute asthma), or taking any medication known to influence central nervous system or endocrine systems were excluded from participation. Further, participants were asked to refrain from taking any drugs three days prior to participation, and to get a night of proper sleep, refrain from heavy exercise, alcohol and caffeine intake 12 hours prior to participation, and not to eat, drink, smoke, or brush teeth two hours before participation. We had to eliminate one participant due to violation of the study requirements, leaving us with 78 participants for the analysis.

Participants were rewarded for their participation with a show-up fee of €30 (this fee could alternatively be exchanged for course credit); in addition, a single trial of the intertemporal choice task was randomly chosen for payment (maximum €20, minimum €5, translating into an approximate hourly wage of €10-14.25).

2.2 Drug administration and assessment

Hydrocortisone and placebo (albochin) treatments were administered through identically appearing pills. A single dose of 10 mg of hydrocortisone was employed to elevate endogenous cortisol to a level equivalent to moderate acute stress (Abercrombie et al. 2003). To assess salivary free cortisol concentrations in each participant throughout the experiment, participants were asked

at different times to lightly chew on salivette collection devices (Sarstedt, Nümbrecht, Germany) for one minute, or until it was completely saturated with saliva. Cortisol levels were assessed at 8 time points spread throughout the experiment (Figure 1). After testing, the salivettes were stored at $-25°$C. Upon completion of the entire study, samples were analyzed for salivary free cortisol concentrations using a commercially available chemiluminescence immunoassay (CLIA) with high sensitivity of 0.16 ng/ml (IBL, Hamburg, Germany) by Technische Universität, Dresden, Germany.

2.3 Intertemporal choice task

Participants performed 6 blocks of an intertemporal choice task in which they made decisions between a sooner smaller reward and a later larger reward, with varying delays. In the first four blocks participants had the choice between a smaller reward tomorrow, and a larger reward in a) 3 months and 1 day, b) 6 months and 1 day, c) 9 months and 1 day, and d) 12 months and 1 day. In the last two blocks, participants chose between a smaller reward in 6 months and 1 day, and a larger reward in e) 9 months and 1 day, and f) 12 months and 1 day. Subsequently, we shall refer to each block by its combination of the sooner date, t, and the later date, T, such that $(t, T) \in \{(0, 3), (0, 6), (0, 9), (0, 12), (6, 9), (6, 12)\}$. The short delay was purposefully set to 'tomorrow' rather than today to keep implied transaction costs the same for sooner and later payments (see below for details on transaction costs). Each block consisted of 7 binary choice trials, resulting in a total of 42 trials. Across all trials the larger reward was kept constant at an amount of €20, while the sooner smaller reward started at €10 and was then adjusted with a titration method according to the choices the participant made.

Titration is one of the standard methods for studying time preferences in the discounting literature (Mazur 1988; Falk et al. 2016). We used a bisection algorithm, which worked as follows: for each choice of the later reward, the sooner reward was increased by half the difference between that and €20; for instance, if a participant chose €20 in 12 months and 1 day over €10 tomorrow, the next trial would offer the participant a choice between €20 in 12 months

and 1 day and €15 tomorrow; if the participant still chose €20 in 12 months and 1 day, the next offer would be €20 in 12 months and 1 day vs. €17.50 tomorrow, and so on. For each choice of the sooner reward, the sooner reward was decreased by half of the difference between it and the previously offered soon reward. For instance, if a participant chose €10 tomorrow over €20 in 12 months and 1 day, the next trial would offer the participant a choice between €5 tomorrow and €20 in 12 months and 1 day; if the participant chose €5 tomorrow, the next offer would be €2.50 tomorrow vs. €20 in 12 months and 1 day, and so on. The titration procedure lasted for 6 trials at each combination of delays; this means that each indifference point was identified to a precision of €0.0781 (i.e. the initial difference between €10 and €20/€0 was halved seven times). The amount of the sooner reward at the end of this titration procedure was taken as the *indifference point* for the particular delay combination, i.e. the amount where participants were indifferent between receiving the sooner and later reward offered.[4]

In our analysis, the main measure of time preference is the indifference points measured as the seventh iteration of the titration process described above. This is a parameter-free measure of time preference that does not require functional form assumptions about the discount function. We compare these indifference points between experimental groups separately for each combination of sooner and later date, (t, T).

Reimbursement consisted of the show-up fee of €30, plus the amount chosen by the participant in a randomly chosen trial of the intertemporal choice

[4]Note that the titration method is not incentive compatible, as with each "patient" choice the expected payment increases. We dealt with this problem by paying out only *one* randomly picked choice across all combinations of (t, T), such that a participant who strategically chose the patient option while preferring the impatient option risked receiving a dominated outcome. We cannot completely rule out that some participants chose strategically. However, the data reveal that only 44.8% of participants *never* chose the early reward in the first round of titration across all six (t, T) combinations. As this choice decreases the expected reward with €10 for a given set of choices in the second to sixth iteration, this finding indicates that either the participants did not understand that the task was not incentive compatible, or they were too risk averse to risk being paid out a dominated outcome. Furthermore, there are no between-group differences in whether participants chose the impatient option in the first iteration (see Appendix Table A.4).

task. Due to a restriction imposed by the human subjects committee, all participants were paid the entire amount on the day following the experiment. We took two approaches to preserve the integrity of the intertemporal choice task while avoiding deception. First, participants were informed before the experiment that they would receive a show-up fee of €30 and the amount they chose in one of the trials of the intertemporal choice task; no information was given about the timing of the payment. This approach is similar to that taken by other experiments in economics (Karlan and Zinman 2010), in which "surprising" participants with better outcomes than they originally chose (the terms of a microfinance loan in the case of Karlan & Zinman) is thought to elicit accurate responses from participants while remaining ethically acceptable. Second, at the end of the experiment, each participant reported whether or not they believed that they would receive the chosen amount at the corresponding delay. In total, there were 24 participants that indicated that they did not believe this. We include a robustness check in our analysis in which we exclude these "payment non-believers".

2.4 General Procedure

In a between-subjects, placebo-controlled, double blind study design, participants were randomly assigned to either the rapid cort (hydrocortisone 15 min prior to testing) or slow cort (hydrocortisone 195 min prior to testing) or placebo group (see experimental outline in Figure 1). Testing took place in between 12 pm and 8 pm, when endogenous cortisol levels are stable and relatively low (Pruessner et al. 1997).

Upon arrival at the lab, participants read an information brochure, were interviewed to assess eligibility for participation, and provided informed consent. Baseline self-reported mood state was assessed with the Positive Affect and Negative Affect Schedule (PANAS; Watson et al. 1988); state and trait anxiety were assessed with the State Trait Anxiety Inventory (STAIS/T; Spielberger 2010); and a first baseline saliva sample was collected.

Directly following a second baseline saliva sample, participants received their first pill (cortisol or placebo). To ascertain that cortisol levels would

return to baseline in the slow cort group, a three-hour waiting period followed, during which participants either read or studied in the same room. During this time, participants were provided lunch, and four more saliva samples were obtained at regular intervals (see Figure 1 for timeline of the study).

The second pill (cortisol or placebo) was given three hours after the first. A second resting period of 15 min followed to allow cortisol plasma levels to reach their peak following administration for the rapid cort group (Czock et al. 2005). Participants then gave another saliva sample and again filled out the mood questionnaires (PANAS and STAIS/T), followed by the intertemporal choice task. A final saliva sample was taken, and a post-experimental questionnaire assessed 1) whether participants believed that their monetary decisions would indeed be rewarded with the promised amount at the promised time, 2) whether participants knew which substance they had received at what time.

2.5 Econometric approach

We assessed the effect of hydrocortisone administration on intertemporal choice by estimating the following model:

$$Ipoint_i^{(t,T)} = \beta_0 + \beta_1 Rapid_i^{(t,T)} + \beta_2 Slow_i^{(\mathrm{t,T})} + \varepsilon_i^{(t,T)}, \tag{1}$$

for each combination of t and T. Here, the outcome variable $Ipoint_i^{(t,T)}$ is the individual indifference point for participant i for the block (t, T). $Rapid_i$ and $Slow_i$ are treatment dummies denoting the rapid vs. slow cort treatments; β_0 captures the mean indifference point for the placebo group; and $\varepsilon_i^{(t,T)}$ is the usual idiosyncratic error term. To account for intra-participant correlations of indifference points across blocks and to increase power, we run seemingly unrelated linear regressions (SUR) with robust standard errors where we simultaneously estimate the between-group differences in indifference points across the six blocks.[5] Possible serial correlation and order effects in participants' responses were controlled for by randomizing the order of trials across blocks, i.e. the order in which the various indifference points were determined. In addi-

[5]Results are robust to estimation with plain OLS instead of SUR, as shown in Appendix Table A.5.

tion, the side of the screen (left or right) on which the "late" and "soon" options were presented on each trial was randomized across trials. Each participant enters the analysis only once per equation.

Our coefficients of interest are β_1, i.e. the average difference in indifference points between the rapid cort group and the placebo group, and β_2, i.e. the average difference in indifference points between the slow cort group and the placebo group. Given that each participant is a member of only one of the three groups, we can also compare the indifference points between the rapid cort group and the slow cort group by comparing β_1 to β_2. However, our main conclusions will rely on comparison between treatment and placebo.

As robustness checks, we also estimate the following modified versions of the model:

$$Ipoint_i^{(t,T)} = \beta_0 + \beta_1 Rapid_i^{(t,T)} + \beta_2 Slow_i^{(t,T)} + \boldsymbol{\alpha}\mathbf{X_i} + \varepsilon_i, \tag{2}$$

$$Ipoint_i^{(t,T)} = \beta_0 + \beta_1 Rapid_i^{(t,T)} + \beta_2 Slow_i^{(t,T)} + \boldsymbol{\gamma}\mathbf{W}_i + \varepsilon_i, \tag{3}$$

where $\mathbf{X_i}$ and $\mathbf{W_i}$ are vectors of control variables, which we shall specify in the next section.

Furthermore, we are interested in how any potential treatment effects on indifference points translate into differences in discount rates and present bias. We start by estimating a non-structural model for present bias. We calculate present bias as difference in indifference point for a given delay when the sooner date is "tomorrow" relative to when it is "6 months from now. Thus, for each participant we have two measures of present bias: the differences in revealed indifference point between the two blocks $(t,T) = (0,3)$ and $(t,T) = (6,9)$ ($Bias^{3m} = Ipoint_i^{(6,9)} - Ipoint_i^{(0,3)}$), and the differences in revealed indifference point between the two blocks $(t,T) = (0,6)$ and $(t,T) = (6,12)$ ($Bias^{6m} = Ipoint_i^{(6,12)} - Ipoint_i^{(0,6)}$). This is an easily interpretable and non-structural estimate of present bias. To estimate treatment-specific differences in present bias, we estimate Equations 1 and 2 using seemingly unrelated regressions with

these measures of present bias as dependent variables:

$$Bias_i^m = \beta_0 + \beta_1 Rapid_i^{(t,T)} + \beta_2 Slow_i^{(\mathrm{t,T})} + \varepsilon_i \tag{4}$$

$$Bias_i^m = \beta_0 + \beta_1 Rapid_i^{(t,T)} + \beta_2 Slow_i^{(\mathrm{t,T})} + \boldsymbol{\beta_3 X_i} + \varepsilon_i, \tag{5}$$

where $m \in \{3m, 6m\}$.

Finally, we estimate a *structural model* of time preferences. Given evidence of present bias in the participants' preferences (see Section 3.2), we assume a quasi-hyperbolic model (Laibson 1997):

$$U_t(x^{(t,T)}) = \begin{cases} \delta^{T-t} u(x) & \text{if } t > 0 \\ \beta \delta^{T-t} u(x) & \text{if } t = 0 \end{cases},$$

where $U_t(x^{(t,T)})$ is the utility at time t of a reward x paid out at time T. δ is the discount factor and β is present bias.

Because of the small stakes used in this study, we assume a linear utility function when estimating the discounting parameters:[6]

$$U_t(x^{(t,T)}) = \begin{cases} \delta^{T-t} x & \text{if } t > 0 \\ \beta \delta^{T} x & \text{if } t = 0 \end{cases}.$$

Or equivalently:

$$V_t(x^{(t,T)}) = \frac{U_t(x^{(t,T)})}{x} = \begin{cases} \delta^{T-t} & \text{if } t > 0 \\ \beta \delta^{T} & \text{if } t = 0 \end{cases}.$$

The term $V_t(x^{(t,T)})$ captures the discounted value at time t of an outcome of €1 paid out at time T, which is equivalent to the indifference point for €1 at time t. Thus, if we scale all the indifference points measured in our experiment

[6] We show robustness of our results to relaxing this assumption in Section 3.3.

by $x = 20$, we have individual measures of:

$$\left[\begin{array}{lcll} V_{i0}(x^{(0,3)}) & = & \beta_i\delta_i^3 & \\ V_{i0}(x^{(0,6)}) & = & \beta_i\delta_i^6 & \\ V_{i0}(x^{(0,9)}) & = & \beta_i\delta_i^9 & \\ V_{i0}(x^{(0,12)}) & = & \beta_i\delta_i^{12} & \\ V_{i6}(x^{(6,9)}) & = & \delta_i^{6-9} & = \quad \delta_i^3 \\ V_{i6}(x^{(6,12)}) & = & \delta_i^{6-12} & = \quad \delta_i^6 \end{array}\right]$$

Note here that an important feature of the exponential discounting model is that it assumes constant discounting across time, such that e.g. $V_{i3}(x^{(6,9)}) = \beta_i V_{i0}(x^{(0,3)})$, and $V_{i3}(x^{(6,12)}) = V_{i0}(x^{(0,6)})$. This allows us to separately identify the discount factor, δ, and present bias, β. Specifically, we fit all individual level indifferent points to the following non-linear equation:

$$\frac{Ipoint_i^{(t,T)}}{20} = \delta_i^{T-t} \cdot \mathbf{1}(t = 6) + \beta_i\delta_i^T \cdot \mathbf{1}(t = 0) + \varepsilon_i,$$

where $\mathbf{1}(t > 0)$ denotes a dummy for whether the indifference point is measured for $t = 6$, $\mathbf{1}(t = 0)$ denotes a dummy for whether the indifference point is measured for $t = 0$, and ε_i is the standard error term, which is clustered by participant as we have six observations for each participant.[7] To measure whether there are treatment-specific differences in discounting and present bias, we include interaction terms for treatment groups:

$$\frac{Ipoint_i^{(t,T)}}{20} = \begin{array}{l} \left(\delta_i^{T-t} + \delta_i^{T-t} \times Rapid_i + \delta_i^{T-t} \times Slow_i\right) \cdot \mathbf{1}(t = 6) + \\ \left(\beta_i\delta_i^T + \beta_i\delta_i^T \times Rapid_i + \beta_i\delta_i^T \times Slow_i\right) \cdot \mathbf{1}(t = 0) + \varepsilon_i \end{array}. \quad (6)$$

Finally, as a robustness check, we also estimate the following modified version of the model as above:

$$\frac{Ipoint_i^{(t,T)}}{20} = \begin{array}{l} \left(\delta_i^{T-t} + \delta_i^{T-t} \times Rapid_i + \delta_i^{T-t} \times Slow_i\right) \cdot \mathbf{1}(t = 6) + \\ \left(\beta_i\delta_i^T + \beta_i\delta_i^T \times Rapid_i + \beta_i\delta_i^T \times Slow_i\right) \cdot \mathbf{1}(t = 0) + \mathbf{X}_i + \varepsilon_i \end{array}, \quad (7)$$

[7] In the non-linear regression we use the value 1 as the starting point for both β and δ.

where $\mathbf{X}_i$ is the same vector of control variables as included in Equation 2, which will be specified in the next section.

2.6 Baseline comparison

Table 1 reports baseline balance between the three treatment groups. Each column is the result of a regression of the baseline variable, y, on dummies for the two treatments as specified in Section 2.5. Columns (1) through (4) present variables that are expected to biologically affect cortisol: age, body mass index, baseline cortisol levels, and whether or not the participant broke the study requirements of not eating or drinking two hours before the beginning of the study. Columns (5) through (7) present economic variables that may affect intertemporal choices through budget constraints and preferences for consumption smoothing (see e.g. Carvalho, Meier, and Wang 2016): a dummy for whether the recipients expected their income to change in the immediate future, disposable income, and a dummy for whether the recipient had debt. Finally, columns (8) through (12) include psychological variables that might affect intertemporal choices (see e.g. Lerner, Li, and Weber 2013): positive and negative affect (measured by the PANAS), anxiety sensitivity (measured by the Anxiety Sensitivity Index), and state and trait anxiety (measured by the State-Trait Anxiety Inventory).

Given that our comparisons of interest are between treatments and placebo, we are mostly worried about baseline differences between each treatment group and the control group. In Table 1 we see that there are no significant differences between either treatment group and the placebo group for any of the variables expected to biologically affect cortisol (columns (1) to (4)) or any of the economic variables (columns (5) to (7)). Among the psychological variables, there are no significant differences between the slow cort group and the placebo group. However, we find significant differences between the rapid cort and placebo groups in negative affect and state anxiety – two variables that are highly correlated, $\rho = 0.49$ – posing a challenge to a direct comparison between the rapid cort group and the placebo group. Given that Lerner, Li, and Weber 2013 show that negative affect is *negatively* correlated with patience,

this baseline difference would lead us to expect baseline patience to be *higher* among the rapid cort group compared to the placebo group, which means that any post treatment difference between the rapid cort and the placebo group is likely to be underestimated. However, to ensure that any identified differences in indifference points between the rapid cort group and the placebo group are not driven by baseline differences in negative affect and state anxiety, we include these two variables in the vector of controls $\mathbf{X_i}$ presented in Equation 2.

Finally, we note that there are significant differences between the rapid cort group and the slow cort group for several of the psychological variables (see the lower panel of Table 1 for F statistics and p-values for comparisons of the rapid cort and the slow cort groups). Specifically, there are significant baseline differences in positive affect, negative affect (significant on a 10% significance level), anxiety sensitivity, and state anxiety. Furthermore, the rapid cort group is significantly less likely to have debt than the slow cort group. We include these five variables in the control variable vector $\mathbf{W_i}$, and report results in Appendix Table A.1.

3 Results

3.1 Manipulation check

Table 2 and Figure 2 display the salivary cortisol levels for the three experimental groups during the experiment. As expected, the average cortisol level for the participants in the rapid cort group is significantly elevated relative to that of participants in the slow cort and placebo group at the first measure after they have received the hydrocortisone pill (immediately after the sixth cortisol measure at minute 200). A similar pattern emerges for the average cortisol levels for the participants in the slow cort group, which is significantly elevated relative to that for participants in the rapid cort and placebo group at the first measure after the slow cort group received the hydrocortisone pill (immediately after the second cortisol measure at minute 20).[8] Furthermore,

[8]The relatively larger increase in cortisol levels for the rapid cort group between (6) and

at the time of the intertemporal choice task (immediately after the seventh cortisol measure at minute 215), the average cortisol level for the rapid cort group is still statistically higher than that of the placebo group. The same is true for the slow cort group, but the absolute value of the cortisol elevation of this group relative to the placebo group, 2.27 nmol/l, is low in both absolute and relative terms. Furthermore, this difference becomes statistically insignificant within the duration of the intertemporal choice task (between minutes 215 and 230), and we thus deem it unlikely that this elevation affects the behavior of the slow cort group.

3.2 Intertemporal choice performance

3.2.1 Non-parametric estimation of treatment effects on indifference points

Figure 3 displays the intertemporal choice performance (mean indifference points) for the three experimental groups. Table 3 reports the results from the non-parametric regressions presented in Equations 1 (top panel) and 2 (lower panel), where the vector of controls consists of the variables for which there was a baseline difference between at least one of the treatment groups and the control group at a 10% significance level, as discussed in Section 3.1 (negative affect and state anxiety). The constant is to be interpreted as the average indifference point for each combination of (t, T) for the placebo group; the coefficients for the rapid cort group and the slow cort group are to be interpreted as the difference in indifference points between the placebo group and each treatment group.

Because larger indifference points correspond to less discounting, we would expect them to decrease with the delay of the "later" payment $T - t$ if participants discount future outcomes. Furthermore, if participants are present biased, we would expect more discounting of future outcomes when the early

(7) compared to that of the slow cort group between (2) and (3) is due to the difference in timing of the first cortisol measure after the administration of the pill: for the rapid cort group the first measure happens 15 minutes after the administration of the pill, whereas for the slow cort group the first measure happens 40 minutes after the administration of the pill.

date of a given delay combination is shifted into the future, $t > 0$.

The left panel of Figure 3 shows that, on average, participants discount future outcomes: for all three experimental groups, the average indifference points decrease the further into the future the "later" payment is, $T \in \{3, 6, 9, 12\}$. At the same time, comparing the left and the right panels of Figure 3, we see that, on average, participants exhibit present bias. For example, the average indifference point for the placebo group for a three months delay between "tomorrow" and "three months + 1 day", $(t, T) = (0, 3)$, is €16. However, when the three month's delay is instead between "6 months + 1 day" and "9 months + 1 day," $(t, T) = (6, 9)$, this average indifference point for the placebo group increases to €18.62.

More importantly, Figure 3 and the upper panel in Table 3 show differences between the treatment groups. Specifically, for each (t, T) combination, the point estimate of the indifference point for the rapid cort group is lower than that of the placebo group, indicating higher discounting. The point estimates for this difference between the rapid cort group and the control group range between €1.91 for $(t, T) = (0, 3)$ (a difference of 11.94%) and €2.89 for $(t, T) = (0, 6)$ (a difference of 20.11%), and the differences are statistically significant at the 5% significance level for three blocks, $(t, T) = \{(0, 6), (6, 9), (6, 12)\}$, statistically significant at the 10% significance level for two blocks, $(t, T) = \{(0, 9), (0, 12)\}$, and statistically insignificant for one block, $(t, T) = (0, 3)$. Overall, when averaging indifference points across blocks within each participant, the coefficient for the rapid cort group, $\beta = -2.27$ $(s.e. = 1.05)$, is statistically significant at the 5% significance level. We thus have good evidence that hydrocortisone administration increases impatience immediately after administration. Figure 4 presents kernel density estimates of this effect, and shows that hydrocortisone shifts the entire distribution of intertemporal choices.

The upper panel in Table 3 shows that there are no statistically significant differences between the indifference points of the slow cort group and the placebo group, indicating that the effect of hydrocortisone on discounting has worn off three hours after hydrocortisone administration, or that a putative

delayed effect counteracts the acute effect.[9]

The lower panel of Table 3 shows that the point estimates change very little when controlling for negative affect and state anxiety, the two variables for which there were baseline differences between the rapid cort and placebo group.[10] Furthermore, none of the variables individually significantly explain variation in the indifference points, and the results of Wald tests of joint significance of both variables, presented in the lower part of the table, indicate that the two variables do not jointly explain variation in the indifference points either. Appendix Table A.5 shows that the results do not change when we use OLS instead of SUR to estimate all equations.

3.2.2 Distinguishing impatience and present bias (non-parametrically)

To test if the treatment affected present bias in addition to impatience, we report the results from regressions based on equations 4 and 5 in Table 4. The dependent variable can be interpreted as the amount of money the participant is willing to give up to receive the money tomorrow as opposed to six months from tomorrow; and higher values therefore indicate more present bias. First, we note that the constant, which reports the average present bias for the control group, is highly significantly different from zero for both delay lengths, indicating strong present bias for the control group. Second, the point estimates are positive for both the rapid cort and the slow cort groups, but neither is statistically significant. We thus conclude that participants in our sample on average display present bias, but that hydrocortisone administration does not seem to affect present bias.

[9] Interestingly, the point estimates for the slow cort group are between those for the rapid cort group and those for the placebo group for each (t, T) combination. Given that the average cortisol level of the slow cort group was slightly higher than that of the placebo group at the time of the intertemporal choice task, this difference could indicate that hydrocortisone administration affects intertemporal choices even for small increases in cortisol. However, the difference could also indicate that hydrocortisone administration affects intertemporal choices even after the effect on cortisol levels has subsided, which could indicate a lasting physiological effect of hydrocortisone administration.

[10] This is also true when controlling for all baseline variables for which there are baseline differences between any two groups; see Appendix Table A.1.

3.2.3 Parametric estimation of impatience and present bias

Finally, we jointly analyze treatment effects on impatience and present bias by estimating the quasi-hyperbolic model in Equation 6. The results are presented in Table 5. Column (1) shows that the annual discount factor for the placebo group is $\delta = 0.77$, which translates into a annual discount rate of $r_{Placebo} = \frac{1-0.77}{0.77} = 0.31$ (reported in the lower panel of the table). This discount rate is high compared to outside option interest rates; however, it is not unreasonable compared to discount rates usually elicited in laboratory settings (Frederick et al. 2002). Table 5 column (1) shows that the estimated average present bias is $\beta_{Placebo} = 0.84$, which is reasonable compared to previous estimates (e.g. Andersen et al. 2008). The lower panel of the table shows that both the annual discount factor and present bias for the placebo group differ significantly from one.

Importantly, the annual discount factor is 15 percentage points lower for the rapid cort group than the placebo group. This discount rate difference translates into a difference in annual discount rates of 33 percentage points (31% versus 64%); the rapid cort group on average requires an annual interest rate that is more than twice as high as the placebo group to be indifferent between receiving money tomorrow and one year from tomorrow. This difference stays almost constant when we control for all variables for which there are baseline differences, and a similar difference is not found between the slow cort group and the placebo group. Furthermore, treatment does not affect present bias, consistent with the results from the non-parametric analysis presented above. Thus, these results suggest that hydrocortisone administration increases discounting, but not present bias, immediately after administration, but not three hours later.

3.3 Robustness

3.3.1 Payment belief

As mentioned in Section 2, all participants were paid the entire amount chosen in the intertemporal choice the day after the experiment due to a

restriction imposed by the human subjects committee. Participants were not informed about this fact before the study, and it is therefore unlikely to have affected results. Nevertheless, we perform three robustness checks for disbelief in the timing of the payment.

First, notice that we would expect participants who believed that they would receive the entire amount "tomorrow" to exhibit no discounting. Thus, we would expect their indifference points to be independent of the delay in the task, and always equal to €20.[11] We define participants as being *fully patient* if their average indifference points are ≥ 19. Under this definition there are 16 fully patient participants in our sample (3 in the rapid cort group, 6 in the slow cort group, and 7 in the placebo group). This indicates that at most 20.5% of the participants can have fully integrated their belief that all payments would happen "tomorrow" into their behavior.

Second, we explicitly asked about respondents' beliefs. Specifically, respondents answered the question (translated from Dutch): "To what extent do you think you will get the amount on said date?" on a 1-9 scale from "Not at all" to "Completely." Importantly, this question was asked to the respondents the day after the intertemporal choice task (before payment), such that we were certain that the treatment had worn off for all participants when they answered this question. Interestingly, behavior in the time preference task is independent of this measure of belief in payment timing. First, the mean belief of the fully patient participants ($M = 5.85$) is no different than that of all other participants ($M = 5.97$, $t = 0.12$, $p(|T| > |t|) = 0.9033$). Second, there is no significant differences in payment beliefs between either of the treatment groups and the control group ($M^{Control} = 5.85$, $M^{Rapid} = 5.81$, $t = 0.53$, $p(|T| < |t|) = 0.95$, and $M^{Slow} = 6.24$, $t = 0.62$, $p(|T| < |t|) = 0.53$).

Finally, the continuous belief variable has no significant explanatory power for the indifference points at any delay combination. To show this we ran regressions based on Equations 1 and 2 in which we controlled for the re-

[11] In fact, the inferred indifference point for a participant who always chose the patient option is €19.84, which equals the distance between the first choice between €10 and €20 halved 7 times.

verse coded continuous measure of payment belief (such that higher values correspond to a lower degree of belief). The results of these regressions are reported in Appendix Table A.6. This table shows that the continuous measure of disbelief in payment timing does not predict discounting behavior in any time frame. In addition, the treatment-specific differences in indifference points are almost unaffected by controlling for the continuous measure of disbelief in payment timing. Our results are therefore unlikely to be driven by participants who did not believe in the timing of the payment.

3.3.2 Experimenter demand effects

One advantage of manipulating cortisol levels pharmacologically instead of e.g. physically (Cold Pressor Task) or socially (Trier Social Stress Test) is that these other stress induction methods are likely to generate experimenter demand effects, given that everyone observes their treatment. In this section we argue that our results are not driven by experimenter demand effects.

To elicit whether participants were able to asses which treatment they received, we asked them to guess which treatment group they were in. Specifically, the day after the intertemporal choice task (the same time as we asked about belief in payment timing), we asked each participant to indicate which pill they thought they received at time point 1 and time point 2, respectively. For both time points the options were "Hydrocortisone," "Placebo," and "Don't know." The participants were explicitly instructed that they would be given hydrocortisone in at most one pill, there were four meaningful combinations of guesses for the two pills: placebo, (pill 1,pill 2) = (Placebo,Placebo); rapid cort, (pill 1,pill 2) = (Placebo,Hydrocortisone); slow cort, (pill 1,pill 2) = (Hydrocortisone,Placebo); and don't know, (pill 1,pill 2) = (Don't know,Don't know).[12]

[12]One participant guessed "Don't know" for pill 1 and "Hydrocortisone" for pill 2, which indicates a lack of understanding. To be conservative we treat this participant as if he guessed to be in the rapid cort treatment. Additionally, one participant guessed "Placebo" for first pill and "Don't know" for the second pill, and five participants guessed "Don't know" for the first pill and "Placebo" for the second pill. For a conservative measure of how may participants correctly guessed their treatment, these six participants are interpreted as having correctly guessed their treatment to the extent that this is consistent with their responses (e.g. a participant in the slow cort group who guessed "Don't know" for the first pill and "Placebo" for the second pill is interpreted as having correctly guessed being in the

Overall, 33.33% of the participants ($n = 26$) correctly guessed their treatment.[13]

Given that there were three treatments, this proportion corresponds to chance performance. Thus, participants were unable to guess which pill they received at which time point. Furthermore, almost half of the participants, 44.9% ($n = 35$), guessed "Don't know" for both pills, further confirming that it was not evident for the participants in which treatment group they were. Finally, when restricting the regressions presented in Table 3 to participants who did *not* correctly guess their treatment, the results change very little (see Appendix Table A.7). In fact, while the average indifference point is slightly higher for the participants in the placebo group who did not correctly guess their treatment (16.29 compared to 15.52 for the entire placebo group), the treatment coefficient on the rapid cort group is almost the same when restricting to only participants who did not correctly guess their treatment compared to the full sample (-2.53 compared to -2.27 for the entire sample). Furthermore, the coefficient is still significant at the 5% level, despite the sample size falling to $n = 19$ in the rapid cort group and $n = 14$ in the control group.

3.3.3 Consistency

Another potential challenge to the interpretation of our results in terms of reflecting an effect of hydrocortisone administration on time preference is that participants in the rapid cort group may simply have made more errors in their choices (Franco-Watkins et al. 2006), which may have resulted in them appearing more impatient. To rule out this possibility, we asked whether treatment assignment affected the consistency of participants' choices. To measure consistency we asked each respondent to repeat some of their choices. Specifically, for each time frame (t, T) the participant was asked the first question

slow cort group).

[13] Specifically, 24.0% ($n = 19$) of all participants guessed that they received the rapid cort treatment with a hit rate ($= \frac{\text{True positive}}{\text{All positive}}$) of 68.4% ($n = 13$); 17.9% of all participants ($n = 14$) guessed that they received the placebo treatment, with a hit rate of 50% ($n = 7$); and 12.8% of all participants ($n = 10$) guessed that they received the slow cort treatment, with a hit rate of 60% ($n = 6$).

(involving a choice between €10 tomorrow or €20 in the future) twice – once in the beginning of that block, and once at the end. For each participant we define consistency as the proportion of blocks in which the participant made the same choice in the beginning and in the end of that block. 80.8% of participants ($n = 63$) are consistent in all of the blocks, and the remaining 19.2% of participants ($n = 15$) are consistent in all but one block. Thus, even the participants who are occasionally inconsistent are maximally inconsistent in one out of six blocks. Of the 15 participants who ever exhibit inconsistency in choices, 6 are in the rapid cort group, 7 are in the slow cort group, and 2 are in the placebo group. Even though participants were slightly more likely to exhibit inconsistency in their choices in the rapid cort group than in the placebo group, 4 participants who each made mistakes in one block cannot have driven our results, which hold across blocks, and we therefore feel confident that any differences in indifference points between the rapid cort group and the placebo group are not driven by differences in error rates between those two groups.

3.3.4 Concavity of the utility function

In Section 3 we estimated the group-level discount rate and present bias assuming a linear utility function. However, as mentioned in the introduction, Porcelli and Delgado 2009 found that the cold pressor task increased risk aversion in the gains domain. Such an increase in risk aversion will mechanistically appear as an increase in impatience under the assumption of a linear utility function Andreoni and Sprenger 2012 note, risk preferences are not time preferences. Thus, if participants in the rapid cort group exhibit a higher degree of risk aversion than participants in the placebo group, the differences in discount rates between the two groups might have been overestimated. We therefore estimate robustness of our results to different curvatures of the utility function.

Unfortunately, our elicitation method of intertemporal preferences does not allow us to simultaneously measure the curvature of the utility functions. Instead, in this section we present results from a simulation exercise in which we assume the above linear utility function for the placebo group and a power

utility function for the rapid cort and slow cort groups:

$$U_t(x^{(t,T)}) = \begin{cases} \delta^{T-t}x^{\alpha} & \text{if } t > 0 \\ \beta\delta^{T}x^{\alpha} & \text{if } t = 0 \end{cases}.$$

We repeat the estimation presented in Equation 6 for $\alpha \in \{1.0; 0.95; 0.90; 0.85; 0.80\}$. Results are presented in Appendix Table A.8. The difference in discount factors between the rapid cort and the placebo group is still significant on a 5% significance level for $\alpha = 0.95$. The significance level decreases to 10% for $\alpha \in \{0.90; 0.85\}$, and becomes insignificant for $\alpha = 0.80$. To get a sense of just how concave a utility function with $\alpha = 0.80$ is, note that a decision-maker with such preferences would be indifferent between a certain payment of \$10,000 and the toss of a fair coin for \$100,000 or nothing. Thus, our results are robust to significant changes in utility function curvature. In addition, Kandasamy et al. (2014) found no significant increase in the curvature of the utility function for participants who, as in our study, had been given an acute dose of hydrocortisone. It is therefore unlikely that our results can be explained by changes in utility function curvature.

3.4 Mechanisms

We obtained several measures of affect both at baseline and immediately after the participants had completed the intertemporal choice task, and can therefore ask whether the effect of hydrocortisone on intertemporal choice was mediated by any of these variables. Table A.9 reports regression results for the effect of treatment on positive affect, negative affect, state anxiety, and impulsiveness, all measured with questionnaires. Due to baseline differences in positive affect, negative affect, and state anxiety, we report difference-in-differences measures for these three variables. Impulsiveness is only measured at endline.

In the rapid cort group relative to placebo, we find a significant decrease in positive affect (significant at the 10 percent level), and significant increases in negative effect and state anxiety (significant at the 5 percent level). We find no effects of the rapid cort treatment on impulsiveness, and no effects of

the slow cort treatment on any outcome. Thus, positive affect, negative affect, and state anxiety are potential mechanisms for the effects of hydrocortisone administration on discounting.

We next ask whether these affective variables are predictive of discounting behavior. Table A.10 shows the results for OLS regressions of the average indifference points for each participant on the affective variables. Interestingly, the affective variables seem to be uncorrelated with discounting behavior. As expected given the findings in Lerner et al. (2013), the point estimate of the change in positive affect is positive, indicating slightly lower discounting for participants who experienced higher increases in positive affect, while the point estimates of the change in negative affect and state anxiety are negative, indicating slightly higher discounting for participants who experienced higher increases in negative affect. However, none of the affective variables significantly predict behavior in the discounting task. One possible explanation for these results is that the study was not adequately powered to study these effects.

4 Conclusion

In this study we demonstrate an effect of hydrocortisone administration on intertemporal choice. Specifically, we show that hydrocortisone increases participants' impatience, as measured by their willingness to give up a larger later reward in order to gain a smaller sooner reward immediately after hydrocortisone administration. In contrast, hydrocortisone does not affect present bias. In addition, hydrocortisone administration does not affect impatience or present bias when participants are tested several hours later, suggesting either that the effect of acute stress decreases over three hours, or that a delayed effect of hydrocortisone counteracts it.

Our results complement and extend several previous studies of the effect of stress hormones and negative affect on decision-making. Koppel et al. (2017) and Delaney et al. (2014) find increases in temporal discounting after exposure to physical pain, and Lerner et al. (2013) demonstrate that experimentally induced negative affect increases discount rates. In contrast, we have previ-

ously found no effects of physical and social stress on temporal discounting (Haushofer et al. 2013; Haushofer et al. 2015). One possible explanation for the divergent findings of the present study and our previous work is that social stressors may not produce a sufficient increase in cortisol levels to generate a behavioral effect on intertemporal choice.

This rapid effect of hydrocortisone on impatience is in line with current views that shortly after stress, individuals turn to simple behavioral strategies. For instance, humans exposed to a psychosocial stressor switch from complex, goal-directed learning strategies to simpler, reflex-like strategies (Schwabe et al. 2007; Schwabe et al. 2010). This shift is accompanied by the activation of a salience network (Hermans et al. 2011), and mediated by the joint actions of cortisol and another prominent neurotransmitter involved in the stress response, norepinephrine (Schwabe et al. 2010). This increase in habitual responding is broadly consistent with our finding of increased impatient responding under the influence of hydrocortisone in light of the fact that impatient responding in intertemporal choice tasks is commonly understood to be partly due to impulsive responses. However, we obtain this effect in the absence of concurrent noradrenergic stimulation, suggesting that some behaviors may be affected by cortisol alone, at least in the short run.

One limitation of our study is that the soonest delay available was tomorrow, which complicates studying present bias. Future studies will need to explore different time scales, varying both the delay between hydrocortisone administration and the task, as well as the rewards delays within the intertemporal choice task, to fully understand the complexity of the effects of stress and stress hormones on intertemporal choice. Moreover, the intertemporal choice task in the present study was not fully incentivized, in the sense that participants were paid the amount of a randomly chosen trial from the intertemporal choice task, but this payment was made on the day following the experiment, raising the possibility that the behavioral effect may have been underestimated. Furthermore, the elicitation method (titration) was not fully incentive compatible. Future studies should test the robustness of our results in a fully incentivized and incentive compatible way.

Together, our findings suggest that time preference is not a stable trait, as traditionally assumed in economic theory (Samuelson 1937; Lancaster 1963), but is strongly susceptible to environmental and somatic factors, such as individuals' responses to hormones like cortisol. Regardless of the internal mechanisms, the fragility of time preference and its complex dependence on stress need to be considered in the design of optimal policies aiming at decisions that are consistent with an individual's long-term economic interests.

References

Abercrombie, H. C., N. H. Kalin, M. E. Thurow, M. A. Rosenkranz, and R. J. Davidson (2003). Cortisol variation in humans affects memory for emotionally laden and neutral information. *Behavioral Neuroscience 117*(3), 505–516.

Andersen, S., G. W. Harrison, M. I. Lau, and E. E. Rutström (2008, May). Eliciting Risk and Time Preferences. *Econometrica 76*(3), 583–618.

Andreoni, J. and C. Sprenger (2012). Risk preferences are not time preferences. *The American Economic Review 102*(7), 3357–3376.

Angelucci, M. and K. Córdova (2014). Productivity and choice under stress: Are men and women different? *Working paper*.

Barsegyan, A., S. M. Mackenzie, B. D. Kurose, J. L. McGaugh, and B. Roozendaal (2010). Glucocorticoids in the prefrontal cortex enhance memory consolidation and impair working memory by a common neural mechanism. *Proceedings of the National Academy of Sciences 107*(38), 16655–16660.

Bendahan, S., L. Goette, J. Thoresen, L. Loued-Khenissi, F. Hollis, and C. Sandi (2016). Acute stress alters individual risk taking in a time-dependent manner and leads to anti-social risk. *European Journal of Neuroscience*, 13395.

Carvalho, L. S., S. Meier, and S. W. Wang (2016). Poverty and economic decision-making: Evidence from changes in financial resources at payday. *The American Economic Review 106*(2), 260–284.

Czock, D., F. Keller, F. M. Rasche, and U. Häussler (2005). Pharmacokinetics and pharmacodynamics of systemically administered glucocorticoids. *Clinical Pharmacokinetics 44*(1), 61–98.

Datson, N. A., M. C. Morsink, O. C. Meijer, and E. R. de Kloet (2008). Central corticosteroid actions: Search for gene targets. *European Journal of Pharmacology 583*(2-3), 272–289.

Delaney, L., G. Fink, and C. P. Harmon (2014). Effects of stress on economic decision-making: Evidence from laboratory experiments. *Working paper*.

Elzinga, B. M. and K. Roelofs (2005). Cortisol-induced impairments of working memory require acute sympathetic activation. *Behavioral Neuroscience 119*(1), 98.

Falk, A., A. Becker, T. Dohmen, D. Huffman, and U. Sunde (2016). The Preference Survey Module: A Validated Instrument for Measuring Risk, Time, and Social Preferences. Working Paper 2016-003, Human Capital and Economic Opportunity Working Group.

Franco-Watkins, A. M., H. Pashler, and T. C. Rickard (2006). Does working memory load lead to greater impulsivity? Commentary on Hinson, Jameson, and Whitney (2003). *Journal of Experimental Psychology: Learning, Memory, and Cognition*.

Frederick, S., G. Loewenstein, and T. O'donoghue (2002). Time Discounting and Time Preference: A Critical Review. *Journal of Economic Literature 40*(2), 351–401.

Haushofer, J., S. Cornelisse, M. Seinstra, E. Fehr, M. Joëls, and T. Kalenscher (2013). No Effects of Psychosocial Stress on Intertemporal Choice. *PLoS ONE 8*(11), e78597.

Haushofer, J., C. Jang, and J. Lynham (2015). Stress and Temporal Discounting: Do Domains Matter? *Working paper*.

Henckens, M. J. A. G., G. A. van Wingen, M. Joels, and G. Fernandez (2011). Time-dependent corticosteroid modulation of prefrontal working memory processing. *Proceedings of the National Academy of Sciences of the United States of America 108*(14), 5801–5806.

Henckens, M. J. A. G., G. A. v. Wingen, M. Joëls, and G. Fernández (2012). Corticosteroid Induced Decoupling of the Amygdala in Men. *Cerebral Cortex 22*(10), 2336–2345.

Hermans, E. J., H. J. F. v. Marle, L. Ossewaarde, M. J. A. G. Henckens, S. Qin, M. T. R. v. Kesteren, V. C. Schoots, H. Cousijn, M. Rijpkema, R. Oostenveld, and G. Fernández (2011). Stress-Related Noradrenergic Activity Prompts Large-Scale Neural Network Reconfiguration. *Science 334*(6059), 1151–1153.

Ifcher, J. and H. Zarghamee (2011). Happiness and Time Preference: The Effect of Positive Affect in a Random-Assignment Experiment. *American Economic Review 101*(7), 3109–3129.

Kandasamy, N., B. Hardy, L. Page, M. Schaffner, J. Graggaber, A. S. Powlson, P. C. Fletcher, M. Gurnell, and J. Coates (2014). Cortisol shifts financial risk preferences. *Proceedings of the National Academy of Sciences 111*(9), 3608–3613.

Karlan, D. and J. Zinman (2010). Expanding Credit Access: Using Randomized Supply Decisions to Estimate the Impacts. *Review of Financial Studies 23*(1), 433–464.

Koppel, L., D. Andersson, I. Morrison, K. Posadzy, D. Västfjäll, and G. Tinghög (2017). The effect of acute pain on risky and intertemporal choice. *Experimental Economics*, 1–16.

Laibson, D. (1997). Golden Eggs and Hyperbolic Discounting. *The Quarterly Journal of Economics 112*(2), 443–478.

Lancaster, K. (1963). An axiomatic theory of consumer time preference. *International Economic Review 4*(2), 221–231.

Lerner, J. S., Y. Li, and E. U. Weber (2013). The financial costs of sadness. *Psychological Science 24*(1), 72–29.

Mazur, J. E. (1988). Estimation of Indifference Points with an Adjusting-Delay Procedure. *Journal of the Experimental Analysis of Behavior 49*(1), 37–47.

McEwen, B. S. (1998). Stress, adaptation, and disease. Allostasis and allostatic load. *Annals of the New York Academy of Sciences 840*, 33–44.

McLeish, K. N. and R. J. Oxoby (2007). Gender, Affect and Intertemporal Consistency: An Experimental Approach. IZA Discussion Paper 2663, Institute for the Study of Labor (IZA).

Oitzl, M. S., H. M. Reichardt, M. Joëls, and E. R. d. Kloet (2001). Point mutation in the mouse glucocorticoid receptor preventing DNA binding impairs spatial memory. *Proceedings of the National Academy of Sciences 98*(22), 12790–12795.

Porcelli, A. J. and M. R. Delgado (2009). Acute stress modulates risk taking in financial decision making. *Psychological Science 20*(3), 278–283.

Pruessner, J. C., O. T. Wolf, D. H. Hellhammer, A. Buske-Kirschbaum, K. von Auer, S. Jobst, F. Kaspers, and C. Kirschbaum (1997). Free cortisol levels after awakening: a reliable biological marker for the assessment of adrenocortical activity. *Life Sciences 61*(26), 2539–2549.

Pyone, J. S. and A. M. Isen (2011). Positive Affect, Intertemporal Choice, and Levels of Thinking: Increasing Consumers' Willingness to Wait. *Journal of Marketing Research 48*(3), 532–543.

Samuelson, P. A. (1937). A note on measurement of utility. *The Review of Economic Studies 4*(2), 155–161.

Schwabe, L., M. S. Oitzl, C. Philippsen, S. Richter, A. Bohringer, W. Wippich, and H. Schachinger (2007). Stress modulates the use of spatial versus stimulus-response learning strategies in humans. *Learning & Memory 14*(1-2), 109–116.

Schwabe, L., M. Tegenthoff, O. Hoffken, and O. T. Wolf (2010). Concurrent Glucocorticoid and Noradrenergic Activity Shifts Instrumental Behavior from Goal-Directed to Habitual Control. *Journal of Neuroscience 30*(24), 8190–8196.

Spielberger, C. D. (2010). *State-Trait anxiety inventory*. Wiley Online Library.

Vedhara, K., J. Hyde, I. D. Gilchrist, M. Tytherleigh, and S. Plummer (2000). Acute stress, memory, attention and cortisol. *Psychoneuroendocrinology 25*(6), 535–549.

Vinkers, C. H., J. V. Zorn, S. Cornelisse, S. Koot, L. C. Houtepen, B. Olivier, J. C. Verster, R. S. Kahn, M. P. M. Boks, T. Kalenscher, and M. Joëls (2013). Time-dependent changes in altruistic punishment following stress. *Psychoneuroendocrinology 38*(9), 1467–1475.

von Dawans, B., U. Fischbacher, C. Kirschbaum, E. Fehr, and M. Heinrichs (2012). The social dimension of stress reactivity: acute stress increases prosocial behavior in humans. *Psychological science 23*(6), 651–660.

Watson, D., L. A. Clark, and A. Tellegen (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology 54*(6), 1063.

Table 1: Baseline balance

	(1) Age	(2) BMI	(3) Baseline cortisol	(4) Broke study req.	(5) Exp. income changes	(6) Disp. income	(7) Debt	(8) Positive affect	(9) Negative affect	(10) Anxiety sensitivity	(11) State anxiety	(12) Trait anxiety
Rapid cort group	-0.53	-0.62	-1.54	-0.03	-0.18	78.16	-0.18	-1.57	-1.74***	-1.43	-3.21*	0.67
	(0.88)	(0.78)	(1.92)	(0.09)	(0.15)	(84.52)	(0.13)	(1.99)	(0.57)	(1.42)	(1.79)	(1.93)
Slow cort group	-0.34	-0.66	-0.34	-0.03	0.12	119.76	0.16	1.26	-0.65	2.30	1.20	0.12
	(0.91)	(0.86)	(1.94)	(0.10)	(0.18)	(93.45)	(0.14)	(1.93)	(0.70)	(1.74)	(2.48)	(2.27)
Constant	22.26***	23.27***	13.39***	0.15**	0.26**	423.04***	0.44***	31.22***	12.85***	8.70***	31.52***	32.52***
	(0.70)	(0.62)	(1.55)	(0.07)	(0.10)	(61.26)	(0.10)	(1.69)	(0.46)	(1.16)	(1.45)	(1.54)
N	78	78	78	78	77	76	78	78	78	78	78	78
Rapid vs. Slow F	0.06	0.00	0.55	0.00	2.69	0.21	6.13	4.00	2.89	6.01	3.80	0.07
Rapid vs. Slow p	0.81	0.95	0.46	0.96	0.11	0.65	0.02	0.05	0.09	0.02	0.05	0.79
Joint sig. F	0.18	0.39	0.42	0.07	1.49	0.89	3.10	2.00	4.92	3.05	2.77	0.07
Joint sig. p	0.84	0.68	0.66	0.93	0.23	0.42	0.05	0.14	0.01	0.05	0.07	0.93

Notes: OLS estimates of baseline balance in (1) age (measured in years), (2) body mass index, (3) cortisol level just before administration of the first pill (measured in nmol/l), (4) dummy for whether participant partially violated study requirements for consumption, (5) expected changes in future income (-1 if "decrease", 0 "if stay the same", 1 if "increase"), (6) disposable income (mesaured in Euro per month), (7) dummy for whether the participants had debt, (8) positive affect (measured by PANAS), (9) negative affect (measured by PANAS), (10) anxiety sensitivity (measured by the Anxiety Sensitivity Index), (11) state anxiety (measured by the State-Trait Anxiety Index), (12) trait anxiety (measured by the State-Trait Anxiety Index). The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, and tests of joint significance for the rapid cort and slow cort groups. *$*p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table 2: Manipulation check (cortisol)

	(1) C at m0	(2) C at m20	(3) C at m50	(4) C at m80	(5) C at m110	(6) C at m200	(7) C at m215	(8) C at m230
Rapid cort group	-0.01	-1.54	-0.53	-0.24	-1.05	0.14	443.46***	263.22***
	(1.97)	(1.92)	(1.14)	(0.88)	(1.24)	(0.92)	(94.00)	(75.06)
Slow cort group	0.39	-0.34	93.83***	61.07***	29.27***	3.52***	2.27**	0.86
	(1.85)	(1.94)	(15.73)	(6.30)	(2.79)	(1.16)	(1.07)	(1.00)
Constant	13.28***	13.39***	8.91***	6.51***	6.23***	6.36***	7.29***	7.08***
	(1.47)	(1.55)	(0.92)	(0.75)	(1.18)	(0.78)	(0.80)	(0.79)
N	77	78	78	78	78	78	78	78
Rapid vs. Slow F	0.05	0.55	36.05	95.47	140.79	11.52	22.03	12.22
Rapid vs. Slow p	0.82	0.46	0.00	0.00	0.00	0.00	0.00	0.00
Joint sig. F	0.04	0.42	18.08	47.74	70.45	6.35	13.33	6.50
Joint sig. p	0.96	0.66	0.00	0.00	0.00	0.00	0.00	0.00

Notes: OLS estimates of cortisol at various time points, expressed in minutes after the beginning of the study, regressed on treatment conditions. The first pill was administered between minute 20 (m20) and minute 50 (m50). The second pill was administered between m200 and m215. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, and tests of joint significance for the rapid cort and slow cort groups. *$*p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table 3: Impatience (non-structural estimation)

	Indifference points for (t,T) Without controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-1.91	-2.89**	-2.80*	-2.45*	-1.45**	-2.11**	-2.27**
	(1.23)	(1.44)	(1.49)	(1.45)	(0.69)	(0.90)	(1.05)
Slow cort group	-1.81	-1.58	-1.52	-1.20	-0.30	-0.99	-1.23
	(1.36)	(1.57)	(1.69)	(1.64)	(0.55)	(0.87)	(1.13)
Constant	16.00***	14.37***	13.55***	12.78***	18.62***	17.78***	15.52***
	(0.93)	(1.07)	(1.13)	(1.02)	(0.34)	(0.51)	(0.74)
N	78	78	78	78	78	78	78
Rapid vs. Slow χ^2	0.01	0.77	0.65	0.58	2.46	1.18	0.83
Rapid vs. Slow p	0.93	0.38	0.42	0.45	0.12	0.28	0.28
Joint sig. treatments χ^2	2.79	4.06	3.53	2.86	4.45	5.60	4.68
Joint sig. treatmets p	0.25	0.13	0.17	0.24	0.11	0.06	0.10
	Indifference points for (t,T) With controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-2.27*	-3.06**	-3.27**	-3.10**	-1.47*	-2.10**	-2.54**
	(1.28)	(1.55)	(1.62)	(1.57)	(0.78)	(0.98)	(1.15)
Slow cort group	-2.03	-1.81	-1.84	-1.63	-0.35	-0.97	-1.44
	(1.31)	(1.56)	(1.68)	(1.60)	(0.58)	(0.90)	(1.12)
Negative affect	-0.65	-0.54	-0.90	-1.22	-0.10	0.04	-0.56
	(0.60)	(0.73)	(0.75)	(0.76)	(0.35)	(0.43)	(0.52)
State anxiety	0.30	0.58	0.47	0.61	0.16	-0.03	0.35
	(0.76)	(0.82)	(0.84)	(0.80)	(0.21)	(0.40)	(0.56)
Constant	16.19***	14.50***	13.80***	13.13***	18.64***	17.77***	15.67***
	(0.96)	(1.12)	(1.19)	(1.07)	(0.37)	(0.54)	(0.78)
N	78	78	78	78	78	78	78
Rapid vs. Slow χ^2	0.04	0.67	0.79	0.79	2.20	1.10	0.91
Rapid vs. Slow p	0.85	0.41	0.37	0.37	0.14	0.29	0.34
Joint sig. treatments χ^2	3.64	3.91	4.09	3.88	3.60	4.70	4.98
Joint sig. treatments p	0.16	0.14	0.13	0.14	0.17	0.10	0.08
Joint sig. controls χ^2	1.23	0.68	1.44	2.58	0.56	0.01	1.16
Joint sig. controls p	0.54	0.71	0.49	0.27	0.76	1.00	0.56

Notes: Seemingly unrelated regression estimates of differences in indifference points between the three treatment groups. t indicates the *early* date, with 0 being "tomorrow" and 6 being six months from "tomorrow;" T indicates the delay of the *later* date in months from "tomorrow". Indifference points indicate the point at which an individual is indifferent between the observed amount at the earlier date and €20 at the later date. Negative affect is standardized and measured by PANAS; State anxiety is standardized and measured by the State-Trait Anxiety Index. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, tests of joint significance for the rapid cort and slow cort groups, and tests of joint significance of the control variables. *$*p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table 4: Present bias (non-structural estimation)

	Present bias Without controls		Present Bias With controls	
	3 months	6 months	3 months	6 months
Rapid cort group	0.46	0.78	0.80	0.96
	(1.15)	(1.31)	(1.23)	(1.38)
Slow cort group	1.51	0.59	1.68	0.84
	(1.34)	(1.46)	(1.30)	(1.45)
Negative affect			0.55	0.58
			(0.64)	(0.67)
State anxiety			-0.15	-0.61
			(0.76)	(0.86)
Constant	2.62***	3.41***	2.45**	3.28***
	(0.92)	(1.03)	(0.94)	(1.07)
N	78	78	78	78
Rapid vs. Slow F	0.78	0.02	0.57	0.01
Rapid vs. Slow p	0.38	0.88	0.45	0.93
Joint sig. treatments F	0.67	0.18	0.85	0.27
Joint sig. treatments p	0.51	0.84	0.43	0.77
Joint sig. controls F			0.42	0.40
Joint sig. controls p			0.66	0.67

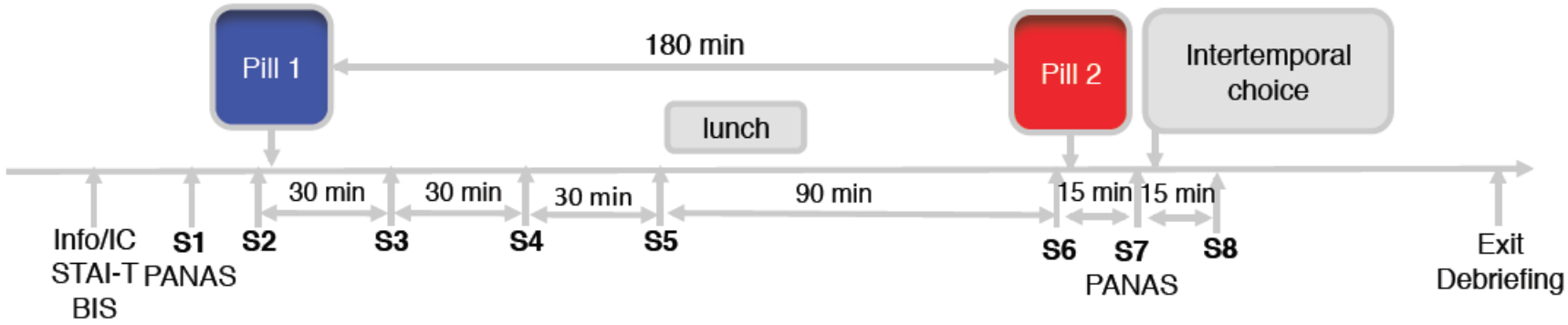
Notes: OLS regression estimates of differences in present bias between the three treatment groups. Present bias is calculated as the difference in indifference points between two blocks in which the delay, $T-t$, is identical but the sooner time point, t, is different. "3 months" is the difference in indifference points between block $(t,T) = (0,3)$ and block $(t,T) = (6,9)$; "6 months" is the difference in indifference points between block $(t,T) = (1,6)$ and block $(t,T) = (6,12)$. Negative affect is standardized and measured by PANAS; State anxiety is standardized and measured by the State-Trait Anxiety Index. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, tests of joint significance for the rapid cort and slow cort groups, and tests of joint significance of the control variables. *$p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table 5: Joint estimation of impatience and present bias (structual estimation)

	Relative indifference points		
	(1)	(2)	(3)
Annual discount factor: Placebo	0.77***	0.78***	0.76***
	(0.04)	(0.04)	(0.04)
Δ Annual discount factor: Rapid cort group	-0.15**	-0.17**	-0.15**
	(0.07)	(0.07)	(0.08)
Δ Annual discount factor: Slow cort group	-0.04	-0.06	-0.08
	(0.07)	(0.07)	(0.07)
Present bias: Placebo	0.84***	0.84***	0.83***
	(0.05)	(0.05)	(0.05)
Δ Present bias: Rapid cort group	-0.05	-0.06	-0.05
	(0.07)	(0.07)	(0.07)
Δ Present bias: Slow cort group	-0.06	-0.07	-0.07
	(0.07)	(0.07)	(0.07)
Negative affect		-0.03	-0.04
		(0.03)	(0.03)
State anxiety		0.02	0.03
		(0.03)	(0.03)
Positive affect			0.03
			(0.02)
Anxiety sensitivity			0.01
			(0.02)
Debt			0.03
			(0.04)
Discount factor: Rapid vs. Slow, F	1.98	1.95	0.63
Discount factor: Rapid vs. Slow, p	(0.16)	(0.17)	(0.43)
Present bias: Rapid vs. Slow, F	0.03	0.02	0.08
Present bias: Rapid vs. Slow, p	(0.87)	(0.88)	(0.78)
Joint sig. (treatments), F	1.50	1.49	1.27
Joint sig. (treatments), p	(0.21)	(0.21)	(0.29)
Annual discount factor (placebo) = 1, F	42.49	30.31	29.56
Annual discount factor (placebo) = 1, p	(0.00)	(0.00)	(0.00)
Present bias (placebo) = 1, F	10.03	9.81	9.91
Present bias (placebo) = 1, p	(0.00)	(0.00)	(0.00)
Annual discount rate: Placebo	0.31	0.29	0.31
Annual discount rate: Rapid cort	0.63	0.65	0.64
Annual discount rate: Slow cort	0.38	0.39	0.47

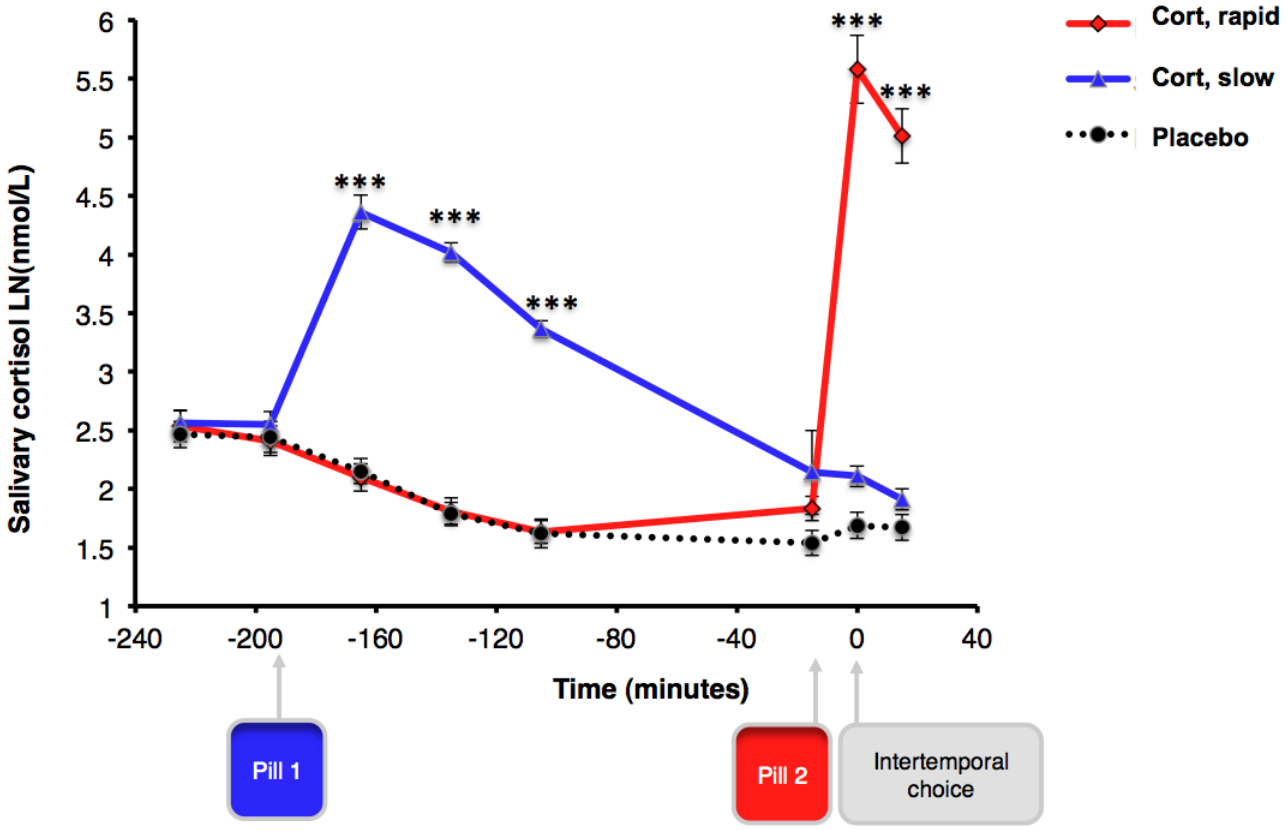
Notes: Non-linear regression estimates of differences in discounting parameters, annual discount factor (δ) and present bias (β), between the three treatment groups. Δ indicates the difference in a parameter between the placebo group and a treatment group. Positive and negative affect are measured by PANAS, state anxiety is measured by the State-Trait Anxiety Index, anxiety sensitivity is measured by the Anxiety Sensitivity Index, and debt is a dummy for whether the participants had debt. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups separately for impatience and present bias, tests of joint significance of the rapid cort and slow cort groups, and tests of the annual discount factor and the present bias coefficient for the placebo group against unity (corresponding to no discounting and no prosent bias). The lower panel of the table also reports the annual discount rate for each treatment group, calculated as $\frac{1-\delta}{\delta}$.
*$p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Figure 1: Timeline of the experiment



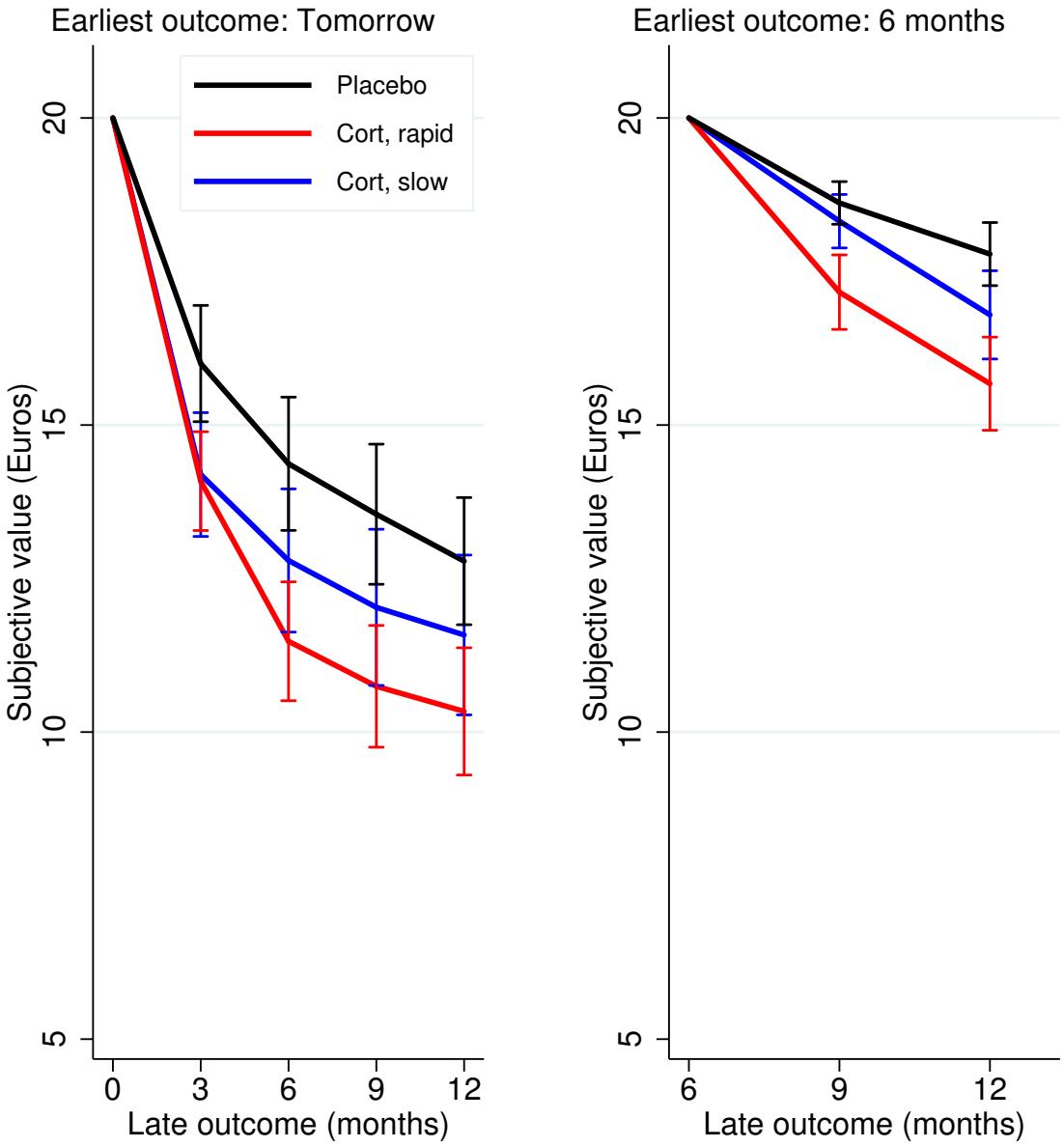
Notes: Timeline of the experiment. Upon arrival, participants read the information brochure (Info), filled out the informed consent (IC) and the Barratt Impulsivity Scale (BIS). As a manipulation check of the cortisol manipulation, saliva samples were taken throughout the experiment (S1-S8). Time between the samples was fixed and is indicated with gray arrows. The first and second pills (Pill 1 and Pill 2) were administered directly after S1 and S6, respectively. Positive and negative affect (PANAS) was measured at the same time as S1 and S7. The intertemporal choice task took place immediately after S7.

Figure 2: Salivary cortisol curves for the three experimental groups



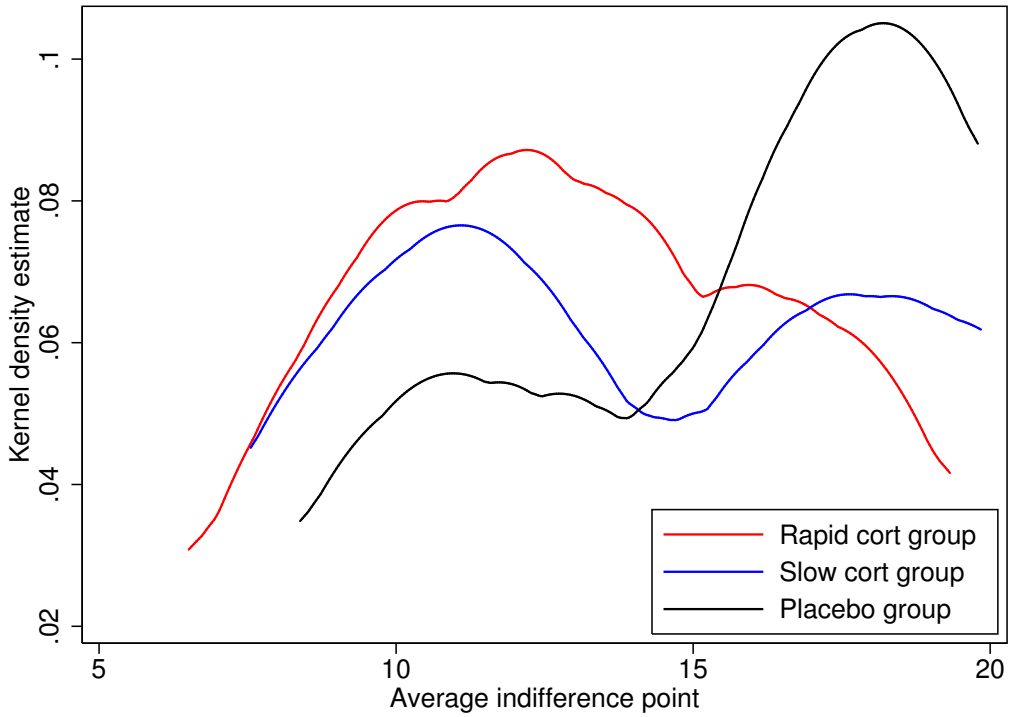
Notes: Salivary cortisol levels in the three treatment groups over time. Error bars represent one standard error of the mean (SEM). Participants received a pill 195 minutes (pill 1) and 15 minutes (pill 2) prior to the intertemporal choice task (t = 0). The pill either contained 10 mg hydrocortisone or placebo (albochin). In the "rapid cort" group, the first pill was placebo and the second hydrocortisone; the "slow cort" group, the first pill was hydrocortisone and the second placebo; in the "placebo" group, both pills were placebo. Saliva samples were taken at 225, 195, 165, 135, 105, 15 and 0 minutes before intertemporal choice, and 15 minutes after. Significant Bonferroni-corrected differences with placebo are depicted by *** = p *<0.005*. Hydrocortisone administration in both groups significantly elevated salivary cortisol as compared to placebo, but did not differ immediately before each pill intake.

Figure 3: Intertemporal choice performance



Notes: Intertemporal choice performance of placebo (black), rapid cort (red), and slow cort (blue) groups. Shown are mean indifference points +/- 1 SEM. The subjective value of an indifference point can be interpreted as the amount at which a participant is indifferent between receiving that amount tomorrow vs. receiving €20 after the specified delay. Lower indifference points therefore indicate greater discounting. The left panel shows discounting between tomorrow and 3, 6, 9, and 12 months from tomorrow; the right panel shows discounting between 6 months and 9 and 12 months.

Figure 4: Kernel density plot of treatment groups



Notes: Kernel density estimation of intertemporal choice of placebo (black), short delay (red), and long delay (blue) groups, using an Epanechnikov kernel with optimal half-width (i.e. the half-width that would minimize the mean squared error if the data were Gaussian).

Appendix for Online Publication

Table A.1: Impatience (non-structural estimation)

	Indifference points for (t,T) With full set of controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-1.89	-2.62*	-2.81*	-2.66*	-1.58**	-2.17**	-2.29**
	(1.25)	(1.53)	(1.62)	(1.58)	(0.80)	(1.01)	(1.15)
Slow cort group	-2.65**	-2.51	-2.49	-2.27	-0.19	-0.75	-1.81
	(1.31)	(1.54)	(1.70)	(1.63)	(0.54)	(0.92)	(1.14)
Positive affect	0.78	0.94	1.19*	1.08*	-0.33	0.01	0.61
	(0.53)	(0.64)	(0.63)	(0.61)	(0.28)	(0.37)	(0.43)
Negative affect	-0.97	-0.89	-1.22	-1.53**	-0.06	0.12	-0.76
	(0.64)	(0.75)	(0.77)	(0.77)	(0.35)	(0.45)	(0.54)
Anxiety sensitivity	0.37	0.45	0.36	0.36	-0.23	-0.37	0.16
	(0.46)	(0.57)	(0.63)	(0.63)	(0.25)	(0.36)	(0.43)
State anxiety	0.58	0.91	0.94	1.03	0.04	0.05	0.59
	(0.87)	(0.92)	(0.90)	(0.88)	(0.22)	(0.40)	(0.62)
Debt	1.24	1.24	0.77	0.86	0.16	-0.46	0.64
	(1.04)	(1.22)	(1.29)	(1.29)	(0.56)	(0.78)	(0.90)
Constant	15.72***	14.03***	13.52***	12.81***	18.56***	17.93***	15.43***
	(1.08)	(1.20)	(1.22)	(1.20)	(0.46)	(0.54)	(0.83)
N	78	78	78	78	78	78	78
Rapid vs. slow χ^2	0.32	0.00	0.03	0.05	3.26	1.60	0.15
Rapid vs. slow p	0.57	0.94	0.86	0.83	0.07	0.21	0.70
Joint sig. treatments χ^2	4.54	3.85	3.63	3.52	4.09	4.59	4.67
Joint sig. treatments p	0.10	0.15	0.16	0.17	0.13	0.10	0.10
Joint sig. controls χ^2	5.34	4.35	6.34	7.06	2.32	1.41	4.21
Joint sig. controls p	0.38	0.50	0.27	0.22	0.80	0.92	0.52

Notes: Seemingly unrelated regression estimates of differences in indifference points between the three threatment groups. t indicates the *early* date, with 0 being "tomorrow" and 6 being six months from now, and T indicates the delay of the *later* date in months from "tomorrow". Indifference points indicate the point at which an individual is indifferent between the observed amount at the earlier date and €20 at a later date. All control variables are standardized. Positive and negative affect are measured by PANAS; Anxiety sensitivity is measures by Anxiety Sensitivity Index; State anxiety is measured by the State-Trait Anxiety Index; Debt is a dummy for whether the participant had debt. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, tests of joint significance for the rapid cort and slow cort groups, and tests of joint significance of the control variables. *$*p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table A.2: Present bias (non-structural estimation)

	Present bias With full set of controls	
	3 months	6 months
Rapid cort group	0.31	0.45
	(1.23)	(1.38)
Slow cort group	2.46*	1.77
	(1.28)	(1.39)
Positive affect	-1.11*	-0.94
	(0.59)	(0.66)
Negative affect	0.91	1.02
	(0.69)	(0.73)
Anxiety sensitivity	-0.60	-0.82
	(0.46)	(0.54)
State anxiety	-0.53	-0.86
	(0.89)	(0.98)
Debt	-1.08	-1.70
	(1.05)	(1.14)
Constant	2.84**	3.90***
	(1.12)	(1.21)
N	78	78
Rapid vs. Slow F	2.86	0.85
Rapid vs. Slow p	0.10	0.36
Joint sig. treatments F	2.14	0.86
Joint sig. treatments p	0.13	0.43
Joint sig. controls F	1.31	1.29
Joint sig. controls p	0.27	0.28

Notes: OLS regression estimates of differences in present bias between the three treatment groups. Present bias is calculated as the difference in indifference points between two blocks in which the delay, $T - t$, is the same but the sooner time point, t, is different. "3 months" compares indifference points from block $(t, T) = (0, 3)$ to block $(t, T) = (6, 9)$; "6 months" compares indifference points from block $(t, T) = (0, 6)$ to block $(t, T) = (6, 12)$. All control variables are standardized. Negative affect is standardized and measured by PANAS; State anxiety is standardized and measured by the State-Trait Anxiety Index. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, tests of joint significance for the rapid cort and slow cort groups, and tests of joint significance of the control variables.

Minimum detectable effect sizes (MDEs)

We calculate *ex post* minimum detectable effect sizes (MDEs) with 80 percent power at a significance level of 0.05 as follows:

$$MDE = (t_{1-\kappa} + t_{\alpha/2}) \times \frac{\sigma}{\sqrt{NP(1-P)}},$$

where $t_{1-\kappa}$ is the value of the t-statistic required to obtain 80 percent power, $t_{\alpha/2}$ is the critical t-value required to achieve a significance level of 0.05, P is the fraction of the sample that were treated, and $\frac{\sigma}{\sqrt{NP(1-P)}}$ is the standard error of the treatment coefficient. With $P = 0:5$, $t_{1-\kappa} = 0.84$, and $t_{\alpha/2} = 1.96$, this expression simplifies to a simple multiple of the standard error of the treatment coefficient, $SE(\hat{\beta})$:

$$MDE = 2.8 \times SE(\hat{\beta}).$$

The MDE for the main results are reported in Table A.3, together with the actual estimated effects and the mean for the placebo group for comparison.

Table A.3: *Ex post* minimum detectable effect sizes (*MDEs*)

	Seemingly unrelated reg., (t,T)							Non-linear reg.	
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average	δ	β
Indifference point units									
Mean placebo group	16.00	14.37	13.55	12.78	18.62	17.78	15.52	0.77	0.84
Coeff. rapid cort group	−1.91	−2.89	−2.80	−2.45	−1.45	−2.11	−2.27	−0.15	−0.05
MDE rapid cort group	−3.43	−4.02	−4.18	−4.05	−1.93	−2.53	−2.94	−0.21	−0.18
Coeff. slow cort group	−1.91	−2.89	−2.80	−2.45	−1.45	−2.11	−2.27	−0.08	−0.07
MDE slow cort group	−3.82	−4.40	−4.72	−4.59	−1.54	−2.44	−3.17	−0.20	−0.21
Z-score units									
Effect size rapid cort group	−0.39	−0.51	−0.47	−0.45	−0.81	−0.79	−0.59	−0.48	−0.12
MDE rapid cort group	−0.70	−0.71	−0.70	−0.75	−1.07	−0.95	−0.76	−0.68	−0.40
Effect size slow cort group	−0.37	−0.28	−0.26	−0.22	−0.17	−0.37	−0.32	−0.27	−0.16
MDE slow cort group	−0.78	−0.78	−0.80	−0.85	−0.85	−0.91	−0.82	−0.64	−0.46

Notes: Ex post power calculations and minimum detectable effect sizes for main outcomes and treatment arms. In indifference point units the MDE represents the minimum absolute difference between the placebo group and the treatment groups that we would have been able to detect with 80 percent power at a significance level of 0.05. For each coefficient, $\hat{\beta}$, the MDE size is calculated as (-)$2.8 \times SE(\hat{\beta})$. In Z-score units the MDE represents the minimum detectable effect size. For each actual effect size, $\beta/SD^{placebo}$, the MDE is calculated as $MDE/SD^{placebo}$.

Table A.4: Strategic behavior

	Dummy for impatient option chosen in first iteration for (t, T)						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	0.09	0.17	0.21	0.21	0.04	0.12	0.08
	(0.12)	(0.14)	(0.14)	(0.14)	(0.04)	(0.08)	(0.11)
Slow cort group	0.18	0.07	0.11	0.11	0.00	0.08	0.09
	(0.13)	(0.14)	(0.14)	(0.14)	(0.00)	(0.08)	(0.11)
Constant	0.22***	0.37***	0.37***	0.41***	-0.00	0.04	0.15**
	(0.08)	(0.09)	(0.09)	(0.10)	(0.00)	(0.04)	(0.07)
N	78	78	78	78	78	78	78
Rapid vs. Slow F	0.46	0.48	0.47	0.46	1.00	0.12	0.01
Rapid vs. Slow p	0.50	0.49	0.50	0.50	0.32	0.73	0.94
Joint sig. F	0.96	0.75	1.14	1.16	1.00	1.35	0.45
Joint sig. p	0.39	0.48	0.32	0.32	0.32	0.27	0.64

Notes: Seemingly unrelated regression estimates of differences in the prevalence of strategic behavior between the three treatment groups. The dependent variable is a dummy for whether the participant chose the impatient option in the first iteration for combination (t, T). *$p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table A.5: Impatience (non-structural estimation): OLS

	Indifference points for (t,T) Without controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-1.91	-2.89*	-2.80*	-2.45*	-1.45**	-2.11**	-2.27**
	(1.24)	(1.45)	(1.51)	(1.47)	(0.70)	(0.92)	(1.07)
Slow cort group	-1.81	-1.58	-1.52	-1.20	-0.30	-0.99	-1.23
	(1.38)	(1.59)	(1.71)	(1.66)	(0.56)	(0.88)	(1.15)
Constant	16.00***	14.37***	13.55***	12.78***	18.62***	17.78***	15.52***
	(0.95)	(1.09)	(1.14)	(1.04)	(0.35)	(0.51)	(0.75)
N	78	78	78	78	78	78	78
Rapid vs. Slow F	0.01	0.75	0.64	0.56	2.40	1.15	0.81
Rapid vs. Slow p	0.93	0.39	0.43	0.46	0.13	0.29	0.37
Joint sig. F	1.36	1.98	1.72	1.39	2.17	2.73	2.28
Joint sig. p	0.26	0.15	0.19	0.25	0.12	0.07	0.11
	Indifference points for (t,T) With controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-2.27*	-3.06*	-3.27*	-3.10*	-1.47*	-2.10**	-2.54**
	(1.31)	(1.59)	(1.66)	(1.62)	(0.80)	(1.01)	(1.18)
Slow cort group	-2.03	-1.81	-1.84	-1.63	-0.35	-0.97	-1.44
	(1.35)	(1.60)	(1.72)	(1.64)	(0.59)	(0.92)	(1.15)
Negative affect	-0.65	-0.54	-0.90	-1.22	-0.10	0.04	-0.56
	(0.62)	(0.75)	(0.77)	(0.78)	(0.36)	(0.44)	(0.54)
State anxiety	0.30	0.58	0.47	0.61	0.16	-0.03	0.35
	(0.78)	(0.85)	(0.86)	(0.82)	(0.22)	(0.41)	(0.58)
Constant	16.19***	14.50***	13.80***	13.13***	18.64***	17.77***	15.67***
	(0.99)	(1.15)	(1.22)	(1.10)	(0.38)	(0.56)	(0.80)
N	78	78	78	78	78	78	78
Rapid vs. Slow F	0.03	0.63	0.75	0.75	2.09	1.05	0.86
Rapid vs. Slow p	0.85	0.43	0.39	0.39	0.15	0.31	0.36
Joint sig. F	1.72	1.85	1.94	1.84	1.71	2.23	2.36
Joint sig. p	0.19	0.16	0.15	0.17	0.19	0.12	0.10

Notes: OLS estimates of differences in indifference points between the three threatment groups. t indicates the *early* date, with 0 being "tomorrow" and 6 being six months from "tomorrow;" T indicates the delay of the *later* date in months from "tomorrow". Indifference points indicate the point at which an individual is indifferent between the observed amount at the earlier date and €20 at the later date. Negative affect is standardized and measured by PANAS; State anxiety is standardized and measured by the State-Trait Anxiety Index. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, tests of joint significance for the rapid cort and slow cort groups, and tests of joint significance of the control variables. **p < 0.10, ** p < 0.50, *** p < 0.01*

Table A.6: Impatience controlling for belief in payment timing

	Indifference points for (t,T) Without controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-1.91	-2.88**	-2.79*	-2.44*	-1.45**	-2.11**	-2.26**
	(1.23)	(1.45)	(1.50)	(1.46)	(0.69)	(0.90)	(1.06)
Slow cort group	-1.86	-1.66	-1.59	-1.26	-0.31	-1.04	-1.29
	(1.36)	(1.54)	(1.66)	(1.62)	(0.55)	(0.86)	(1.11)
Disbelief in payment timing	-0.13	-0.22	-0.20	-0.14	-0.02	-0.12	-0.14
	(0.20)	(0.24)	(0.25)	(0.25)	(0.12)	(0.15)	(0.17)
Constant	16.56***	15.27***	14.38***	13.37***	18.71***	18.28***	16.09***
	(1.25)	(1.44)	(1.51)	(1.44)	(0.56)	(0.74)	(1.03)
N	78	78	78	78	78	78	78
Rapid vs. Slow χ^2	0.00	0.66	0.57	0.52	2.41	1.07	0.73
Rapid vs. Slow p	0.97	0.42	0.45	0.47	0.12	0.30	0.39
Joint sig. (treatments) χ^2	2.86	3.97	3.45	2.81	4.44	5.66	4.62
Joint sig. (treatments) p	0.24	0.14	0.18	0.25	0.11	0.06	0.10
	Indifference points for (t,T) With full set of controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-1.89	-2.62*	-2.80*	-2.65	-1.58**	-2.17**	-2.29*
	(1.26)	(1.56)	(1.65)	(1.61)	(0.81)	(1.02)	(1.17)
Slow cort group	-2.74**	-2.65*	-2.60	-2.36	-0.22	-0.81	-1.90*
	(1.29)	(1.50)	(1.67)	(1.61)	(0.53)	(0.91)	(1.12)
Disbelief in payment timing	-0.18	-0.28	-0.24	-0.18	-0.06	-0.13	-0.18
	(0.22)	(0.25)	(0.27)	(0.28)	(0.12)	(0.16)	(0.19)
Constant	16.39***	15.06***	14.38***	13.49***	18.77***	18.41***	16.09***
	(1.24)	(1.47)	(1.56)	(1.54)	(0.62)	(0.79)	(1.08)
N	78	78	78	78	78	78	78
Rapid vs. Slow χ^2	0.40	0.00	0.01	0.03	3.14	1.46	0.10
Rapid vs. Slow p	0.53	0.99	0.91	0.87	0.08	0.23	0.75
Joint sig. (treatments) χ^2	4.87	4.09	3.71	3.56	4.01	4.52	4.75
Joint sig. (treatments) p	0.09	0.13	0.16	0.17	0.13	0.10	0.09

Notes: Seemingly unrelated regression estimates of differences in indifference points between the three threatment groups. t indicates the *early* date, with 0 being "tomorrow" and 6 being six months from "tomorrow;" T indicates the delay of the *later* date in months from "tomorrow". Indifference points indicate the point at which an individual is indifferent between the observed amount at the earlier date and €20 at the later date. "Disbelief in payment timing" measures on a scale from 1 to 9 the degree to which participants did not believe that the payment would be paid out at the time indicated in the task. Negative affect is standardized and measured by PANAS; State anxiety is standardized and measured by the State-Trait Anxiety Index. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, tests of joint significance for the rapid cort and slow cort groups, and tests of joint significance of the control variables. *$*p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table A.7: Impatience restricted to participants who did not correctly guess their treatment

	Indifference points for (t,T) Without controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-2.35*	-3.39**	-3.22*	-3.00*	-1.21	-1.99*	-2.53**
	(1.35)	(1.68)	(1.69)	(1.74)	(0.79)	(1.11)	(1.21)
Slow cort group	-2.58*	-2.54	-2.46	-2.05	-0.02	-0.06	-1.62
	(1.56)	(1.80)	(1.95)	(1.95)	(0.58)	(0.76)	(1.29)
Constant	16.77***	15.38***	14.75***	14.05***	18.77***	18.03***	16.29***
	(0.97)	(1.14)	(1.18)	(1.12)	(0.35)	(0.42)	(0.77)
N	52	52	52	52	52	52	52
Rapid vs. Slow χ^2	0.02	0.21	0.15	0.21	1.93	2.53	0.43
Rapid vs. Slow p	0.88	0.65	0.70	0.65	0.16	0.11	0.51
Joint sig. (treatments) χ^2	4.00	4.44	3.88	3.17	2.45	3.28	4.62
Joint sig. (treatments) p	0.14	0.11	0.14	0.21	0.29	0.19	0.10
	Indifference points for (t,T) With controls						
	(0,3)	(0,6)	(0,9)	(0,12)	(6,9)	(6,12)	Average
Rapid cort group	-2.84**	-3.74**	-3.77**	-3.50*	-1.09	-2.09*	-2.84**
	(1.41)	(1.80)	(1.87)	(1.95)	(0.81)	(1.14)	(1.31)
Slow cort group	-2.69*	-2.79	-2.79	-2.40	-0.03	-0.12	-1.80
	(1.48)	(1.76)	(1.90)	(1.91)	(0.58)	(0.77)	(1.26)
Constant	16.97***	15.58***	15.05***	14.34***	18.73***	18.08***	16.46***
	(0.99)	(1.17)	(1.21)	(1.17)	(0.35)	(0.41)	(0.79)
N	52	52	52	52	52	52	52
Rapid vs. Slow χ^2	0.01	0.25	0.22	0.26	1.47	2.49	0.50
Rapid vs. Slow p	0.92	0.62	0.64	0.61	0.23	0.11	0.48
Joint sig. (treatments) χ^2	5.14	4.92	4.59	3.64	1.90	3.41	5.16
Joint sig. (treatments) p	0.08	0.09	0.10	0.16	0.39	0.18	0.08

Notes: Seemingly unrelated regression estimates of differences in indifference points between the three threatment groups. The sample is restricted to participants who did not correctly guess their treatment assignment. t indicates the *early* date, with 0 being "tomorrow" and 6 being six months from "tomorrow;" T indicates the delay of the *later* date in months from "tomorrow". Indifference points indicate the point at which an individual is indifferent between the observed amount at the earlier date and €20 at the later date. Negative affect is standardized and measured by PANAS; State anxiety is standardized and measured by the State-Trait Anxiety Index. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, tests of joint significance for the rapid cort and slow cort groups, and tests of joint significance of the control variables. *$*p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table A.8: Beta Delta models

	Relative indifference points				
	(1) $\alpha = 1.00$	(2) $\alpha = 0.95$	(3) $\alpha = 0.90$	(4) $\alpha = 0.85$	(5) $\alpha = 0.80$
Annual discount factor: Placebo	0.77***	0.77***	0.77***	0.77***	0.77***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Δ Annual discount factor: Rapid cort group	-0.15**	-0.14**	-0.12*	-0.11*	-0.10
	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)
Δ Annual discount factor: Slow cort group	-0.04	-0.03	-0.02	-0.01	-0.00
	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)
Present bias: Placebo	0.84***	0.84***	0.84***	0.84***	0.84***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Δ Present bias: Rapid cort group	-0.05	-0.05	-0.04	-0.03	-0.02
	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)
Δ Present bias: Slow cort group	-0.06	-0.06	-0.05	-0.04	-0.03
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Discount factor: Rapid vs. Slow, F	1.98	1.94	1.91	1.87	1.84
Discount factor: Rapid vs. Slow, p	(0.16)	(0.17)	(0.17)	(0.18)	(0.18)
Present bias: Rapid vs. Slow, F	0.03	0.03	0.04	0.04	0.04
Present bias: Rapid vs. Slow, p	(0.87)	(0.86)	(0.85)	(0.84)	(0.83)
Joint sig. (treatments), F	1.50	1.29	1.09	0.92	0.76
Joint sig. (treatments), p	(0.21)	(0.28)	(0.37)	(0.46)	(0.55)
Annual discount factor (placebo) = 1, F	42.49	42.49	42.49	42.49	42.49
Annual discount factor (placebo) = 1, p	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Present bias (placebo) = 1, F	10.03	10.03	10.03	10.03	10.03
Present bias (placebo) = 1, p	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Annual discount rate: Placebo	0.31	0.31	0.31	0.31	0.31
Annual discount rate: Rapid cort	0.63	0.59	0.56	0.52	0.49
Annual discount rate: Slow cort	0.38	0.37	0.35	0.33	0.31

Notes: Non-linear regression estimates of differences in discounting parameters, annual discount factor (δ) and present bias (β), between the three treatment groups. Δ indicates the difference in a parameter between the placebo group and a treatment group. α is the CRRA risk aversion parameter, $U(x) = x^{\alpha}$. Positive and negative affect are measured by PANAS, state anxiety is measured by the State-Trait Anxiety Index, anxiety sensitivity is measured by the Anxiety Sensitivity Index, and debt is a dummy for whether the participants had debt. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups separately for impatience and present bias, tests of joint significance of the rapid cort and slow cort groups, and tests of the annual discount factor and the present bias coefficient for the placebo group against unity (corresponding to no discounting and no prosent bias). The lower panel of the table alse reports the annual discount rate for each treatment group, calculated as $\frac{1-\delta}{\delta}$. *$p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table A.9: Changes in psychological variables over the course of the experiment

	(1) Δ Positive affect (P2-P1)	(2) Δ Negative affect (P2-P1)	(3) Δ State anxiety (P2-P1)	(4) Impulsiveness post-P2
Rapid cort group	-2.61*	1.18**	3.57***	2.74
	(1.32)	(0.56)	(1.20)	(2.60)
Slow cort group	-1.02	0.61	-1.26	2.21
	(1.06)	(0.67)	(1.83)	(2.42)
Constant	-0.78	-1.33***	-1.30	65.19***
	(0.75)	(0.38)	(0.80)	(1.90)
N	78	78	78	78
Rapid + Constant	-3.38***	-0.15	2.27**	67.92***
(s.e.)	(1.09)	(0.41)	(0.89)	(1.77)
Slow + Constant	-1.80**	-0.72	-2.56	67.40***
(s.e.)	(0.75)	(0.55)	(1.65)	(1.50)
Rapid vs. slow F	1.44	0.69	6.65	0.05
Rapid vs. slow p	0.23	0.41	0.01	0.82
Joint sig. F	1.97	2.24	5.74	0.63
Joint sig. p	0.15	0.11	0.00	0.54

Notes: OLS estimates of change in (1) positive affect, (2) negative affect, and (3) STAIS regressed on treatment. Positive and negative affect are measured by PANAS, state anxiety is measured by the State-Trait Anxiety Index, impulsiveness is measured by Barratt Impulsiveness Scale. For each metric the difference is calculated by subtracting the value of the metric after pill 2 from the value of the metric before pill 1. Impulsiveness was only measured after pill 2. The lower panel of the table reports the result of Wald tests of equality between the rapid cort and slow cort groups, tests of joint significance for the rapid cort and slow cort groups, and tests of joint significance of the control variables. *$*p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*

Table A.10: Potential mechanisms

	(1) Average	(2) Average	(3) Average	(4) Average
Δ Positive affect (P2-P1)	0.11			
	(0.09)			
Δ Negative affect (P2-P1)		-0.10		
		(0.22)		
Δ State Anxiety (P2-P1)			-0.12	
			(0.07)	
Behavioral inhibitions (P2)				-0.05
				(0.06)
Constant	14.58***	14.29***	14.30***	17.68***
	(0.52)	(0.50)	(0.46)	(3.81)
N	78	78	78	78
R squared	0.01	0.00	0.03	0.01
Adjusted R squared	0.00	-0.01	0.02	-0.00

Notes: OLS estimates of the relationship between (changes in) psychological variables, positive affect, negative affect, state anxiety, and behavioral inhibitions, over the duration of the experiment and average indifference points for each participants across (t,T) combinations. *$p < 0.10$, ** $p < 0.50$, *** $p < 0.01$*