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Stress and reward: Long term cortisol exposure predicts the strength of sexual preference

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HIGHLIGHTS

- We measured *effort expended to view erotic images of women versus men.*
- This heterosexual preference declines with self-reported anhedonia.
- It increases with long term exposure to endogenous cortisol.

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ABSTRACT

Healthy individuals tend to consume available rewards like food and sex. This tendency is attenuated or amplified in most stress-related psychiatric conditions, so we asked if it depends on endogenous levels of the 'canonical stress hormone' cortisol. We unobtrusively quantified how hard healthy heterosexual men would work to consume erotic images of women versus men and also measured their exposure to endogenous cortisol in the prior two months. We used linear models to predict the strength of sexual preference from cortisol level, after accounting for other potential explanations. Heterosexual preference declines with self-reported anhedonia but increases with long term exposure to endogenous cortisol. These results suggest that cortisol may affect reward-related behavior in healthy adults.

1. Introduction

Glucocorticoid hormones (GC) – *cortisol* in humans and *corticosterone* in rodents – are released from the adrenal gland in a characteristic daily cycle under central nervous control [36]. They are best known as the canonical "stress hormones" [33]: they are released in response to punishments – actual or anticipated challenges to homeostasis. While GCs modulate punishment-related behaviors such as startle and inhibition [10,69], GCs are unlikely to mediate primary defensive responses. Rather, they may be more compensatory, protecting the organism from its own primary stress response [39]. In fact, GCs are often seen as a component of the endogenous "reward system" together with opioids, endocannabinoids, and *dopamine* (DA) [39,49]. For example, GCs are readily secreted in response to food and drug rewards [49] at similar concentrations to those seen in response to stressors. Experimental GC manipulations also potently modify reward-related behaviors, as elaborated below. Finally, at physiological levels, they have positive reinforcing effects, for a review see [49]. For example, animals will learn to make operant responses which self-administer GC intravenously [48]. Such findings make them relevant to the understanding of reward-related psychiatric symptoms: anhedonia (loss of pleasure or lack of reactivity to pleasurable stimuli), hyperhedonia, addiction, eating, and gambling disorders. Yet there is no work to date on the role of long term systemic cortisol exposure on reward processing in humans. Here we review the evidence that chronic GCs influence reward processing and introduce a new behavioral assay to assess whether trait cortisol (basal levels of endogenous cortisol) can predict how hard healthy "non-stressed" subjects will work for natural rewards.

In non-stressed rat populations, chronic experimental suppression of endogenous glucocorticoids (via adrenalectomy) diminishes preference for sweet saccharin rewards [8]. This effect is specifically mediated by a reduction of GC: GCs also increase the motivation to drink sweet water after a period of carbohydrate withdrawal [8]. GCs are also critical

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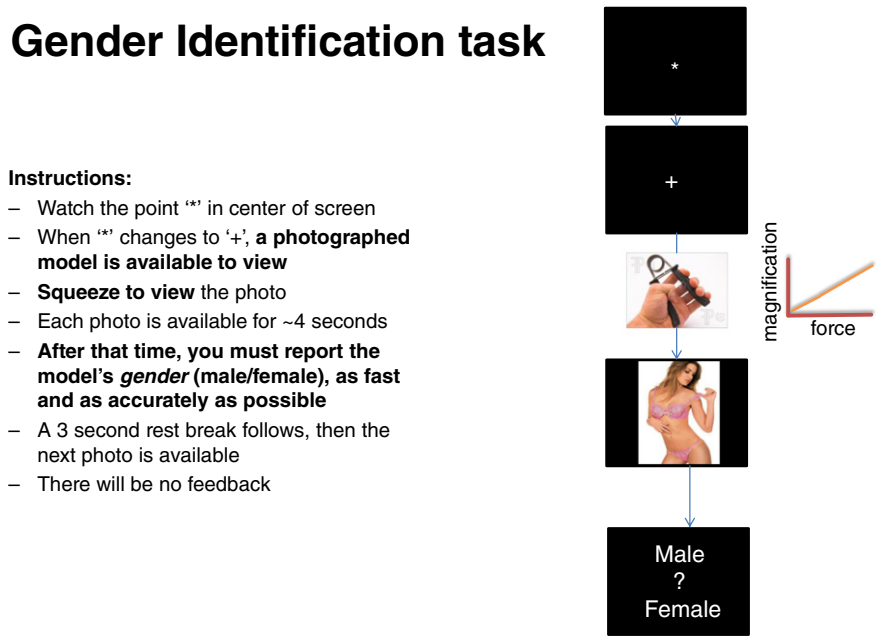

Fig. 1. The behavioral task. Instructions to subjects (left) and a time-line of one trial (right).

for the responses of rodents to rewarding drugs. Suppression of glucocorticoids, e.g. by adrenalectomy, again reduces behavioral responses to chemical rewards like morphine, amphetamine and cocaine [19,40] and decreases the work animals will exert to self-administer [39], whereas exogenous replacement of GC reverses this effect [8]. Furthermore, it has been suggested that under no-stress conditions, GCs may increase responsiveness to sexual rewards [61]. Consistent with this assumption, adrenalectomy reduces preferences for a (sexual) partner in monogamous male prairie voles, an effect reversed by GC replacement [20]. These results suggest that cortisol permits and/or drives reward-based behaviors. Puzzlingly, chronic treatment with GC leaves male rat sexual motivation unaffected [24,53] (despite reduced sexual performance [24]).

There is minimal human research into cortisol effects on reward-related behavior in healthy, non-clinical human populations [52,70]. It is not known whether basal differences in long-term cortisol exposure explain an individual's preference for natural reward. We aim to investigate this by measuring reward consumption behavior and long term systemic exposure to cortisol. We focus on objective behavioral assays [10,26,27,51,72] because behavioral and non-behavioral (questionnaire) measures of reward processing are often incongruent and therefore likely tap into different phenomena. Problems with subjective report per se include focusing illusions [34], framing effects [18], social conformity [2] and normality implications set by the questionnaire format [63]. In addition, it is often unclear how questionnaires connect to the reward protocols used in animal studies.

For ease, we focus on visually presented sexual rewards which animals will also work for [17]. While male subjects perform an unrelated task, we tracked the muscular effort they expended to magnify or 'approach' rewarding visual stimuli in real time (Fig. 1). Here, strong preferences for one class of stimuli are seen as relatively higher exertion (Fig. 2). Assuming that larger, more clearly visible, erotic images of females are more rewarding for male subjects, effortful magnification can be seen as analogous to approaching and consuming food or sexual rewards [45]. The strength with which subjects exerted muscular effort can therefore be taken as a measure of how strongly they prefer one image to another. Focusing on real-time viewing of available images, our task measures *consumption* preference in isolation from other aspects of reward processing (see Materials and methods). This is important because reward processing can be parsed into functionally distinct components[1] [6,71].

Our task thus measures consumption preferences without requiring participants to choose between alternatives, to act in the absence of the reward (i.e. to mentally *simulate* upcoming or abstract rewards at the time of acting), to learn or predict reward value [50] or to wait for temporally delayed rewards [25,28]. In this way we attempt to isolate the determinants of simple consumption preference per se, while excluding explanations based on high-order cognition (e.g. decision-making deficits).

Based on these considerations we measured individual differences in long term (prior two months) endogenous cortisol, and hypothesized that increased cortisol exposure predicts increased preference for the consumption of sexual rewards. We also expected that self-reported anhedonia predicts diminished preference for these same reward stimuli.

2. Materials and methods

2.1. Subjects

Thirty six male undergraduates (18–32 years old, median 21) were recruited by email from the University of Zurich, Switzerland. Five subjects were excluded: two lacked sufficient hair for the cortisol analysis, one had clinical-range stress-related symptoms (score of 21 in Beck's Depression Inventory, indicating moderate depression), one subject showed a behavioral pattern indicative of possible homosexual orientation (see Supplementary data), and one was a statistical outlier (Cook's distance [13] was >1 in the regression below). The study was approved by the local review board and all subjects provided written informed consent.

2.2. Behavioral measures

Fig. 1 outlines the behavioral task (see also Supplementary data). The task comprised 80 trials, with 10 male and 10 female pictures presented 4 times each, i.e. $80 = 10 \times 2 \times 4$. Trials occurred in a completely

[1] Correspondingly there is a toolbox of behavioral measures in animals, including unconditioned responses (orofacial taste reactions to palatable liquids presented intraorally [5]), choice behavior (effort-related T-mazes [58]) and progressive ratio [31].

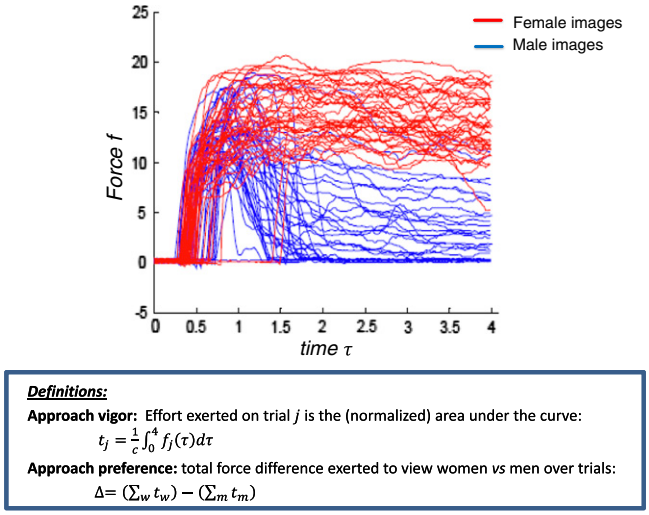

Fig. 2. Measuring preference. These curves give the time course of hand grip force as one male subject effortfully magnifies a range of different visual stimuli during the 4 s available viewing time. Red curves correspond to viewing images of females, and blue curves correspond to images of males. Approach preference was defined as the relative work exerted to view two classes of stimuli. Thus male heterosexual approach preference is simply the average force difference between viewing female versus male images. Note: The normalization constant *c* takes into account individual differences in hand strength. For each subject, *c* is their maximum effort (effort on their most effortful trial).

random order: the identity of a picture on any one trial was unpredictable. Each trial lasted around 5 s, and included a picture-viewing phase of 4 s and response phase. In the response phase subjects attempted to report the gender of the person displayed in that trial picture. Responses were registered by pressing '*i*' or '*e*' on a standard QWERTY keyboard to indicate "male" or "female". This relation was counterbalanced between subjects but fixed within subject, i.e. some subjects used '*i*' to report "male" while others used '*e*'. Subjects were incentivized by a monetary reward: 20 random trials were selected at the end and they were paid 0.2 CHF for each trial on which they responded correctly. For each subject, maximum (full screen) magnification required their personal maximum force exertion (assessed for each subject separately in a calibration test). In absolute terms, this yielded a picture which filled the 15 in. laptop screen. Around 25% of maximum force was required to accurately assess gender. We took the difference in total exertion between different classes of stimuli as a measure of consumption preference (male vs. female images: see Fig. 2) and as such the task is not a classical decision or reinforcement-learning task. Rather it measures consumption preference without forcing an explicit choice between discrete alternatives. Instead subjects must select between infinitely many effort trajectories which dynamically determine stimulus magnification over the 4 s viewing time. Presumably, in making this selection, participants optimize (with respect to the costs of energetic effort) both (1) the monetary reward resulting from the correct gender classification and (2) the sexual reward derived from viewing individual images of female vs. male models. The gain of this force–magnification relationship was calibrated for each subject separately before the experiment proper. This ensured that the range of image magnification was constant over subjects (i.e. independent of an individual's hand strength). By providing an incentive for correct gender classification of every cue, this task socially licenses viewing and diminishes possible demand or stigma effects associated with erotic images.

2.3. Apparatus and stimuli

The force gauge was custom-built (similar devices are readily available commercially). A pressure sensor was sandwiched between two parallel, rectangular sheets of metal which in turn were housed in a larger plastic box approximately 15 cm × 10 cm × 5 cm (see bottom right of Supplementary Fig. 1). It required subjects to pinch the pressure sensor between their thumb and index/middle fingers, i.e. apply positive force simultaneously, and in opposition, onto both metal plates. This pressure linearly reduced electrical resistance in a circuit, allowing current to flow more easily. This current was in turn translated into a digital signal (plastic box pictured in top of Supplementary Fig. 1) and linked to Matlab via USB. A simple Matlab function then translated the intensity of this signal to the size of the picture seen on the subject's computer screen. In the absence of any pressure, no picture is visible on the screen. The harder one pinches, the larger the picture appears. There was a linear relationship between force and picture size. The actual stimuli used in the gender classification task are given in Supplementary Fig. 2.

2.4. Subjective report measures

At the very end of the experiment, subjects rated each image used in the above behavioral task on a 5-point Likert scale (with "very un/attractive" labeled at the end points and "neutral" labeled at the mid-point). They also completed standardized questionnaire measures pertaining to dispositional "reward sensitivity" in their German language translations: Snaith–Hamilton Pleasure Scale (SHAPS) [22] measures anhedonia or participants' "ability to experience pleasure in the last few days" across four domains of hedonic experience (interest/pastimes, social interaction, sensory experience, and food/drink), and BAS1 and BAS2 are two "Behavioral Activation Scales" of the "Action Regulating Emotional System" questionnaire (ARES [29]) and measure distinct features of dispositional approach tendencies. These latter two resemble "drive" and "reward responsiveness" respectively, in Carver & White's BAS scales [11] (see Supplementary data for other details of our BIS–BAS). Additional questionnaire measures probed 'negative affect': ARES [29] measures two features of behavioral inhibition (subscales BIS1 measure "anxiety" and BIS2 "frustration", see below), and Beck's Depression Inventory (BDI) [35] assesses depressive symptoms minus the 4 items on anhedonia [9,51] (the scores on these items were subtracted).

2.5. Measurement of cortisol in hair

Due to major physiological daily fluctuations, saliva and serum are too noisy as an index of overall long-term cortisol exposure. By contrast, head hair grows at an average of 1 cm/month and reflects the overall systemic exposure to cortisol over time. We therefore quantified endogenous cortisol in hair using previously validated methods [66]. Our hair cortisol concentrations represent the integral of systemic cortisol exposure over the last 2 months of the subjects' lives. They reflect all of the stressors, physical and psychological, experienced in the last 2 months. Hair cortisol concentrations show a high degree of intra-individual stability in the absence of significant, transient stressors [67]. While our sample was recruited from a healthy student population, we did not explicitly confirm the absence of such stressors (e.g. traumatic loss) and cannot therefore be absolutely certain that our cortisol variance reflects only stable factors and not transient, exogenous factors. It should be noted that the subjects were not obese, had not been diagnosed with Cushing syndrome or used glucocorticoids within the last 3 months.

Previously published papers describe the measurement of cortisol in hair in detail [62,73]. The method involves methanol extraction of cortisol and measurement by an immunoassay. Briefly, between 10 and 20 mg of hair from the 2 cm closest to the scalp is accurately weighed and minced finely with scissors. The 2 cm closest to the scalp operationalizes the last 2 months. We chose this method of preliminary preparation as an alternative to powdering i.e. grinding the hair [15,38], a choice which does not significantly affect the concentration of cortisol

determined [67]. One milliliter of methanol is added, and the suspension is sonicated for 30 min and incubated overnight at 52 °C while gently shaking. The next day, the methanol is transferred into a clean tube and evaporated to dryness using nitrogen. For measurement of cortisol in hair we used an immunoassay (ELISA) originally developed for quantifying cortisol in saliva (reagents commercially available, ALPCO, Inc). The absolute cortisol extraction recoveries are 88% in a 100 ng/ml standard and 87% in a 2 ng/ml standard. The intraday CVs are 7.2% in a hair sample at a concentration of 64 ng/g and 6.0% in a hair sample at a concentration of 629 ng/g, and the CVs for inter-day measurements are 10.6 and 7.6% for 49 and 548 ng/ml, respectively.

We extracted hair from subjects at the end of each experimental session, immediately before debriefing and paying the subjects.

2.6. Additional control measures

Variables known to affect baseline cortisol levels, such as smoking and alcohol consumption as well as shift work employment, were collected and used as control variables in the analysis (dummy coded). 3/31 participants were smokers, 28/31 drank alcohol (with an average of 4.9 units per week) and 5/31 worked nights or did night shift work.

2.7. Statistical analyses

Our male subjects evaluated female images as attractive, and more attractive on average than male images. First, we calculated the subject specific average attractiveness ratings for female pictures, and used a one sample *t*-test to ask whether attractiveness was above "neutral" on the Likert scale ($p = 0.000002$). Second, for each subject we calculated the difference in their mean attractiveness rating for female versus male pictures, and asked whether this difference was above zero using a one sample *t*-test ($p = 0.000002$).

We used linear regression to predict the strength of an individual's consumption preference (see Fig. 2) from hair cortisol and self-reported anhedonia. The analysis included the control variables described above (smoking and alcohol consumption, shift work employment). We defined consumption preference Δ as the total force exerted to view women versus men, i.e. the strength-normalized, standardized area under the force curves in Fig. 2. By between-subject 'standardization' we mean that we subtracted the group average from each individual subject's Δ and then divided the standard deviation. We also standardized the predictor variables below. Standardization does not change the statistical significance of our tests, but aids the interpretation below. Formally, we then attempted to predict each subject's preference Δ according to the following:

$$\Delta = \beta_0 + \beta_1 \mathrm{CORT} + \beta_2 \mathrm{SHAPS} + \beta_3 \mathrm{BAS1} + \beta_4 \mathrm{BAS2} + \sum_{l=5}^{7} \beta_l N_l + \sum_{k=8}^{10} \beta_k C_k + \epsilon \quad (1)$$

By quantifying how consumption preference depends on trait cortisol and anhedonia, β_1 and β_2 probe our two hypotheses. The N_l are three questionnaire measures of negative affect: the behavioral inhibition scales [29] BIS1 and BIS2 (see Subjective report measures) and Beck's Depression Inventory [35] (excluding the 4 items examining anhedonia to minimize overlap with the *SHAPS*). The C_k are the self-reported control variables (smoking, drinking and shift work). ϵ is zero-mean Gaussian error. All statistical inference below uses the fact that under the null hypotheses, parameter estimators of this linear Gaussian regression follow a Student's *t* distribution, with $df = 20$ i.e. 31 subjects minus 11 coefficients in Eq. (1). Our statistical analysis quantifies the relation between cortisol and reward preference having first accounted for any influence of sub-clinical stress-related symptoms (BDI and SHAPS scores). This is achieved because multiple regression quantifies the partial effect of each predictor variable [54].

Alternatively, consumption preference might be operationalized in terms of the average difference in *maximum* force applied to view female versus male images (as opposed to difference in "integral" force as defined above and in Fig. 2). We disfavor this definition because it does not summarize the total energy put into viewing female versus male images: it disregards most of the force trajectory data. In the supplementary material we nevertheless include the results of a regression identical to Eq. (1), but where the dependent measure on the left-hand side was the substituted with the average difference in *maximum* force applied to view female versus male images for each subject.

We did two additional analyses, regressing the average force exerted to male and female pictures separately on cortisol. To do this we simply replace the left-hand side of Eq. (1) with the subject-specific measures on these average forces.

3. Results

On average, subjects performed the incidental gender classification task with 99% accuracy. Only one subject made more than two errors. The average reaction time (RT) to classify a given picture was 738 ms. This reaction time was defined as the latency between the onset of the response options – i.e. "male" or "female" – and the time at which subject's response was recorded. The reaction time thus does not include any of the picture viewing time. For each subject, we subtracted the average RT to classify female pictures from the average RT to classify male pictures. A one sample *t*-test on these 31 scalars revealed that subjects were 50 ms faster on average to classify male versus female pictures $p = 3.2 \times 10^{-6}$, $n = 31$. This may be because male subjects abandon viewing these less attractive pictures earlier and therefore have more time to prepare the motor response itself.

Table 1 summarizes findings from the linear regression analysis. The regression revealed a positive dependence of consumption preference on CORT ($p = 0.003$) after accounting for other control variables. Similarly there was a positive relation to self-reported "reward gratification" [29] or "reward responsiveness" [11] BAS2 ($p = 0.008$), but a negative association with anhedonia SHAPS ($p = 0.028$). Highlighting the specificity of these findings, there was no statistically discernible effect of BDI (excluding the 4 items examining anhedonia) on consumption preference. Interestingly, reward "drive" BAS1 – a general measure of how energetically individuals pursue more abstract goals – was negatively correlated with reward preference ($p = 0.007$). This finding respects the much-touted dissociation between reactive and prospective processing of rewards (see Discussion).

This pattern of significance held if we restricted the average difference Δ_i for subject *i* to be taken only over those pictures which they explicitly rated as non-aversive in the debriefing session i.e. only those male and female pictures subject *i* rated as neutral or attractive (three

Table 1
Linear regression of consumption preference on other predictors. The estimated coefficients from Eq. (1) and associated statistical inference are listed. The *r*-square associated with this regression is 0.66. This table shows that for an increase of one standard deviation in a subject's cortisol, their expected consumption preference increases by half a standard deviation. For a standard deviation increase in self-reported anhedonia, their expected preference *decreases* by 0.37 standard deviations. Cronbach's alpha values for these questionnaire measures are as follows: BIS1 (0.84), BIS2 (0.79), BAS1 (0.74), BAS2 (0.75), SHAPS-D (0.86), and BDI (0.85).

Predictor	Coefficient	SE	*t*-Statistic	*p*-Value
CORT	0.50	0.15	3.37	0.003
SHAPS	−0.37	0.16	−2.35	0.029
BAS1	−0.44	0.15	−3.01	0.007
BAS2	0.47	0.16	2.91	0.009
BIS1	−0.26	0.20	−1.07	0.30
BIS2	0.27	0.21	1.30	0.21
BDI (minus anhedonia)	−0.15	0.17	−0.91	0.37
Shiftwork	0.08	0.15	0.52	0.61
Smoker	−0.25	0.14	−1.75	0.094
Alcohol	0.07	0.15	0.45	0.66

subjects were excluded in this analysis leaving $n = 28$ because they did not rate any male image as non-aversive, and therefore Δ_i was not defined). As discussed above (final paragraph of Statistical analysis) we did two additional analyses, regressing the average force exerted to male and female pictures separately on cortisol. Cortisol had a negative impact on effort to view male images and a positive impact on effort to view female images, but neither of these was separately statistically significant.

Fig. 3 visualizes these relationships in hypotheses 1 and 2, having accounted for our control variables ($n = 31$). Firstly we separately regressed Δ and *CORTISOL* on the remaining 9 variables in Eq. (1). The resulting residuals of these regressions give the component of Δ and *CORTISOL* that is orthogonal to these 9 effects. An analogous procedure was used to examine the relationship between Δ and *SHAPS*, having controlled for the other 9 effects. These "partial" correlations are cross-plotted in Fig. 3. We (1) confirmed that the results presented above remain essentially unchanged, and statistically significant at the same level, following the exclusion of the three smokers in our sample, (2) report the correlation matrix between all predictor variables in the design matrix (see Supplementary data) and (3) performed a simple linear correlation between Δ and *CORTISOL* without accounting for any control variables or excluding any subjects (except for those with insufficient hair for cortisol analysis). This latter procedure resulted in a significant positive correlation between Δ and *CORTISOL* ($n = 34$, $r = 0.54$, $p = 0.001$).

We also calculated the 'latency difference' between viewing female and male images for each subject – how quickly they reached the maximum force for each type of trial – and substituted this dependent measure into the left-hand side of the Eq. (1). None of the predictors in Eq. (1) were significant at even the 10% level, apart from reward "drive" BAS1 ($\beta_{BAS1} = -0.49$, $p = 0.03$).

4. Discussion

In our task the magnification or "approach" of erotic images on a screen was instantaneously and dynamically proportional to the force exerted on a hand-grip (during the 4 s viewing period). We found that the strength of (heterosexual) male behavioral preference for female sexual images correlated with self-reported "reward gratification/responsiveness" [11,29]. Similarly, their preference decreased with increasing levels of anhedonic symptoms reported in daily life (lower self-reported pleasure). GCs are necessary for effortful "gratification behaviors" such as drug taking [23] and "palatable" feeding [4,8,16] and speculated to underlie stress-related increases in these same behaviors [60]. We therefore investigated whether cortisol predicts the vigor of human sexual approach. Controlling for self-report measures, behavioral preference for sexual rewards increased with long term cortisol exposure (2 months pre-test cortisol derived from a hair sample). This result is correlational and it is not possible to make a causal argument. We cannot strictly determine whether preference for female images results in chronically higher cortisol levels or whether chronically elevated cortisol levels to a preference for female images. Before offering an interpretation, we point out some further limitations of this work.

We have focused on predicting sexual preferences, testing the relationship between cortisol and the differential exertion made to view female versus male images. By this definition, an increased heterosexual preference can arise either by less force being used for male images or more force for female images, or both. These three possibilities suggest different interpretations. It is relevant here that our cortisol–preference relationship held if we restricted our analysis only to pictures which were explicitly rated as non-aversive in the debriefing session i.e. only those male and female pictures subject *i* rated as neutral or attractive. This argues against the possibility that consumption preference, as we have defined it, reflects avoidance of male pictures rather than approach of female pictures. Interestingly, we found that while cortisol had a negative impact on effort to view male images and a positive impact on effort to view female images, neither of these were separately statistically significant. This puzzling result revives – but does not resolve – the possibility that cortisol may predict both increased avoidance of male pictures and approach of female pictures. Future studies must more directly assess the role of aversion in sexual preference via alterations to the experimental design e.g. augmenting our 'gender classification' task with a third category of affectively-neutral images, thereby creating a baseline against which to measure absolute avoidance versus approach.

We operationalized consumption preference as the average difference in integral force exerted to view female versus male images. When we defined consumption preference in terms of average difference in maximum force, we found a statistically weaker relationship with cortisol, i.e. only at a trend level ($p = 0.07$). This weaker relation may reflect reduced statistical power arising from a more noisy measure

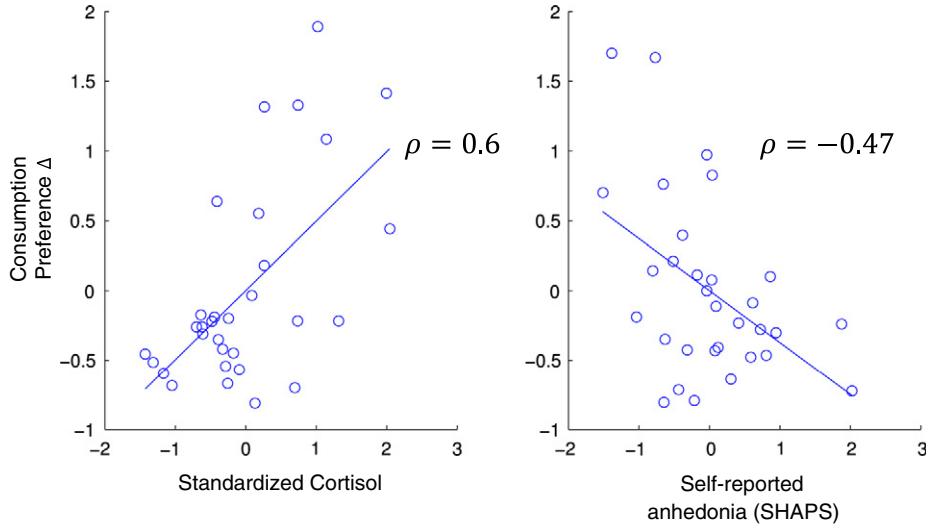

Fig. 3. Healthy male subjects' preference for female sexual stimuli increases with long term endogenous exposure to cortisol but decreases with self-reported anhedonia, having accounted for other control variables. 'Behavioral preference' is defined as the muscular effort exerted to view erotic female as opposed to male images (see Fig. 2). 'Cortisol' is measured by hair sample (see main text). Partial correlation coefficients ρ, superimposed on each subplot, provide a complementary quantification of these relationships (statistical significance reported in Table 1).

of consumption preference. In particular, on any one trial "integral force" can itself be viewed as an average (of the exertion at each discrete time point), and should therefore have lower variance than measures which do not benefit from within-trial averaging. Alternatively, this weaker relation may reflect that cortisol better predicts the physical endurance of effortful consumption: such endurance can only be captured by measures which incorporate the temporal dimension of effortful exertion, such as integral force.

Without overlooking these ambiguities, our results nevertheless suggest several implications. While chronic stress decreases sexual approach motivation in animal models [68] there has been dispute over whether this effect is mediated by GCs per se [24,53]. Our work suggests that in a healthy non-clinical population of young males, there is actually a positive relation between GCs and sexual motivation.

Our results also demonstrate that questionnaire measures may not fully explain between-subject variation in human reward responsiveness. In particular, cortisol explained between-subject variation in the preference for consuming rewards that is not explained by questionnaire measures of reward sensitivity (i.e. having statistically accounted for covariation in reward sensitivity, see Table 1). This may reflect its effect on incentive motivation perhaps even in the absence of hedonic pleasure [43].

We observed an interesting dissociation whereby behavioral preference for sexual rewards increased with self-reported "reward responsiveness" but decreased with "reward drive" (BAS2 and BAS1 respectively [29]). While these two self-report scales correlate with one another, they do not form a unitary global measure of appetitive motivation (according to structural equation modeling [56]) and frequently diverge in their relationships with behavioral and psychometric criteria [65] supporting their existence as two distinct constructs. Items of the "drive" scale tap into how energetically individuals pursue more abstract goals (e.g. "I go out of my way to get things I want"), while items of the "reward responsiveness" scale probe responses to the actual receipt of rewards e.g. "When I get something I want, I feel excited and energized" [11]. Despite evidence for a meaningful distinction, it is still relatively rare for experimentalists to infer preferences from behavioral responses at the time of reward consumption, as opposed to goal-directed efforts to attain prospective rewards [6,57,71,72]. While such a preference may be inferred from unconditioned responses (such as orofacial responses [6] to delivered food rewards), a sensitive measure in humans is more elusive, particularly for general non-food rewards. To this end we have measured the behavioral vigor with which participants approach/consume immediate, instantaneously available visual rewards. The selective coupling between self-reported "reward responsiveness" and this measure of reward reactivity suggests that our task may isolate reward responsiveness from goal-directed drive (to obtain currently absent rewards). In our regression analysis only the former positively predicted consumption preference. That the effects of self-reported "reward responsiveness" and "drive" go in different directions underscores the importance of this separation and points to an intriguing behavioral parallel to well-documented (but unintuitive) distinction between a priori "wanting" and consummatory "liking" [6]. Given new emphasis on this distinction in the clinical literature [71], our general procedure for eliciting preferences may be useful in the targeted assessment of clinically disordered reward responsiveness. One specific putative application, closely related to our work here, is a behavioral measure of socio-sexual anhedonia [12].

Previous work points to numerous plausible biological mechanisms. Each relates to an interaction between GCs and components of the biological "reward system". As mentioned above, GCs stimulate mesencephalic DA transmission acting via glucocorticoid receptors [14,39,49], both upregulating dopamine D1 receptors in the substantia nigra and ventral tegmental area[2] [14] and tyrosine hydroxylase, a DA precursor [14]. However, numerous lines of evidence suggest that DA does not uniquely or primarily mediate pleasure in the consumption of rewards [47,57,58]. For example, DA lesions disrupt feeding but not orofacial taste reactions ('pleasure [7]'). Also, engineered mice with total DA blockade can learn reward locations [55] and place preferences for morphine [30]. Thus, while DA may encode anticipated reward magnitude, approach drive, or a teaching signal for reward learning, it does not modulate immediate consumption behaviors when no work is required [47]. By contrast, DA may have a more universal role in altering effort/inertia costs [41,47,59] (e.g. increasing lever press ratio or maze distance). While many tasks confound effort and delay costs [47], our task isolates the former due to an infinitesimal temporal delay between exertion and reward. A specific question is whether DA specifically invigorates sexual exertion via its actions in nucleus accumbens and medial preoptic area [32,46]. A separate but not exclusive hypothesis is that GC acts on other aspects of the central reward system to amplify preferences. Of relevance here is the fact that GCs stimulate the release of opiates [42] which might in turn enhance consummatory pleasure independently of effort costs [6] (e.g. through their actions on GABAergic spiny neurons in the nucleus accumbens shell). It is worth noting here that GCs also modulate dopaminergic transmission in rat nucleus accumbens [3]. Finally, opioids also act at numerous levels to diminish the HPA response [21], suggesting a "sex as stress relief" hypothesis. In experimental rats, a chronic stress-induced preference for comfort food [44] (calorically dense lard and sucrose) has been interpreted as adaptive: i.e. this preference restores homeostasis by reducing HPA activity [44] via endogenous opioids [1]. It is unclear when, if ever, sexual approach resembles coping behavior [1] though interestingly, internet sex addiction [76] can be triggered by "stress". It remains for future work to ask if chronic-mild-stress-dependent increases in GC and DA promote a general preference for potent over subtle rewards, be them sexual, sweet-fat food [1] or drugs of abuse [39,64].

In conclusion, while many stress regimes compromise male libido [37], proceptive behaviors [75], gonadal hormones and erectile function [74], the specific role of GC hormones remains unclear [53]. Less still is known about the natural function of GC in healthy "unstressed" populations. Our results suggest that healthy men with higher cortisol actually have stronger heterosexual preference: they approach and consume available sexual rewards with more vigor.

[2] Interestingly not in the brain structures containing terminals of the dopaminergic neurons.

Disclosures

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Contributors

JC and HK designed the study. HK gathered the behavioral data. SVU and ER analyzed hair. JC and HK undertook the statistical analysis, and JC, OH, and EF wrote the first draft of the manuscript. All authors contributed to and have approved the final manuscript.

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Appendix A. Supplementary data

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References

[1] Adam TC, Epel ES. Stress, eating and the reward system. Physiol Behav 2007;91(4):449–58.
[2] Asch, S. (1951). Effects of group pressure on the modification and distortion of judgments. Groups, leadership and men: research in human relations. H. E. Guetzkow. New York: Russell & Russell, 1963, Copyright 1951 by Carnegie Press.
[3] Barrot M, Abrous DN, Marinelli M, Rougé-Pont F, Le Moal M, Piazza PV. Influence of glucocorticoids on dopaminergic transmission in the rat dorsolateral striatum. Eur J Neurosci 2001;13(4):812–8.
[4] Bell M, Bhatnagar S, Liang J, Soriano L, Nagy T, Dallman M. Voluntary sucrose ingestion, like corticosterone replacement, prevents the metabolic deficits of adrenalectomy. J Neuroendocrinol 2000;12(5):461–70.
[5] Berridge KC. Measuring hedonic impact in animals and infants: microstructure of affective taste reactivity patterns. Neurosci Biobehav Rev 2000;24(2):173–98.
[6] Berridge KC, Robinson TE. Parsing reward. Trends Neurosci 2003;26(9):507–13.
[7] Berridge KC, Venier IL, Robinson TE. Taste reactivity analysis of 6-hydroxydopamine-induced aphagia: implications for arousal and anhedonia hypotheses of dopamine function. Behav Neurosci 1989;103(1):36.
[8] Bhatnagar S, Bell M, Liang J, Soriano L, Nagy T, Dallman M. Corticosterone facilitates saccharin intake in adrenalectomized rats: does corticosterone increase stimulus salience? J Neuroendocrinol 2000;12(5):453–60.
[9] Bogdan R, Pizzagalli DA. Acute stress reduces reward responsiveness: implications for depression. Biol Psychiatry 2006;60(10):1147–54.
[10] Buchanan TW, Brechtel A, Sollers JJ, Lovallo WR. Exogenous cortisol exerts effects on the startle reflex independent of emotional modulation. Pharmacol Biochem Behav 2001;68(2):203–10.
[11] Carver CS, White TL. Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales. J Pers Soc Psychol 1994;67(2):319.
[12] Chapman LJ, Chapman JP, Raulin ML. Scales for physical and social anhedonia. J Abnorm Psychol 1976;85(4):374.
[13] Cook RD, Weisberg S. Residuals and influence in regression. New York: Chapman and Hall; 1982.
[14] Czyrak A, Mackowiak M, Chocyk A, Fijal K, Wêdzony K. Role of glucocorticoids in the regulation of dopaminergic neurotransmission. Pol J Pharmacol 2003;55(5):667–74.
[15] D'Anna-Hernandez KL, Ross RG, Natvig CL, Laudenslager ML. Hair cortisol levels as a retrospective marker of hypothalamic–pituitary axis activity throughout pregnancy: comparison to salivary cortisol. Physiol Behav 2011;104(2):348–53.
[16] Dallman MF, Pecoraro N, Akana SF, La Fleur SE, Gomez F, Houshyar H, et al. Chronic stress and obesity: a new view of "comfort food". Proc Natl Acad Sci 2003;100(20):11696.
[17] Deaner RO, Khera AV, Platt ML. Monkeys pay per view: adaptive valuation of social images by rhesus macaques. Curr Biol 2005;15(6):543–8.
[18] Dermer M, Cohen SJ, Jacobsen E, Anderson EA. Evaluative judgments of aspects of life as a function of vicarious exposure to hedonic extremes. J Pers Soc Psychol 1979;37(2):247.
[19] Deroche V, Piazza PV, Casolini P, Maccari S, Le Moal M, Simon H. Stress-induced sensitization to amphetamine and morphine psychomotor effects depend on stress-induced corticosterone secretion. Brain Res 1992;598(1–2):343–8.
[20] DeVries AC, DeVries MB, Taymans SE, Carter CS. The effects of stress on social preferences are sexually dimorphic in prairie voles. Proc Natl Acad Sci 1996;93(21):11980.
[21] Drolet G, Dumont ÉC, Gosselin I, Kinkead R, Laforest S, Trottier JF. Role of endogenous opioid system in the regulation of the stress response. Prog Neuropsychopharmacol Biol Psychiatry 2001;25(4):729–41.
[22] Franz M, Lemke M, Meyer T, Ulferts J, Puhl P. Deutsche Version der Snaith–Hamilton Pleasure Scale (SHAPS-D). Fortschr Neurol Psychiatr 1998;66(9):407–13.
[23] Goeders EN. The impact of stress on addiction. Eur Neuropsychopharmacol 2003;13(6):435–41.
[24] Gorzalka BB, Hanson LA. Sexual behavior and wet dog shakes in the male rat: regulation by corticosterone. Behav Brain Res 1998;97(1–2):143–51.
[25] Green L, Myerson J, Holt DD, Slevin JR, Estle SJ. Discounting of delayed food rewards in pigeons and rats: is there a magnitude effect? J Exp Anal Behav 2004;81(1):39.
[26] Grillon C. Startle reactivity and anxiety disorders: aversive conditioning, context, and neurobiology. Biol Psychiatry 2002;52(10):958–75.
[27] Grillon C. Models and mechanisms of anxiety: evidence from startle studies. Psychopharmacology (Berl) 2008;199(3):421–37.
[28] Hariri AR, Brown SM, Williamson DE, Flory JD, de Wit H, Manuck SB. Preference for immediate over delayed rewards is associated with magnitude of ventral striatal activity. J Neurosci 2006;26(51):13213–7.
[29] Hartig J, Moosbrugger H. Die "ARES-Skalen" zur Erfassung der individuellen BIS-und BAS-Sensitivität. Z Differ Diagn Psychol 2003;24(4):293–310.
[30] Hnasko TS, Sotak BN, Palmiter RD. Morphine reward in dopamine-deficient mice. Nature 2005;438(7069):854–7.
[31] Hodos W. Progressive ratio as a measure of reward strength. Science 1961;134(3483):943–4.
[32] Hull EM, Bitran D, Pehek EA, Warner RK, Band LC, Holmes GM. Dopaminergic control of male sex behavior in rats: effects of an intracerebrally-infused agonist. Brain Res 1986;370(1):73–81.
[33] Joëls M, Baram TZ. The neuro-symphony of stress. Nat Rev Neurosci 2009;10(6):459–66.
[34] Kahneman D, Krueger AB, Schkade D, Schwarz N, Stone AA. Would you be happier if you were richer? A focusing illusion. Science 2006;312(5782):1908–10.
[35] Kammer D. Eine Untersuchung der psychometrischen Eigenschaften des deutschen Beck-Depressionsinventars (BDI). Diagnostica 1983;29:48–60.
[36] Lightman SL, Conway-Campbell BL. The crucial role of pulsatile activity of the HPA axis for continuous dynamic equilibration. Nat Rev Neurosci 2010;11(10):710–8.
[37] Majzoub JA. Corticotropin-releasing hormone physiology. Eur J Endocrinol 2006;155(Suppl. 1):S71–6.
[38] Manenschijn L, Koper JW, Lamberts SW, van Rossum EF. Evaluation of a method to measure long term cortisol levels. Steroids 2011;76(10):1032–6.
[39] Marinelli M, Piazza PV. Interaction between glucocorticoid hormones, stress and psychostimulant drugs. Eur J Neurosci 2002;16(3):387–94.
[40] Marinelli M, Rougé-Pont F, Deroche V, Barrot M, De Jésus-Oliveira C, Le Moal M, et al. Glucocorticoids and behavioral effects of psychostimulants. I: Locomotor response to cocaine depends on basal levels of glucocorticoids. J Pharmacol Exp Ther 1997;281(3):1392–400.
[41] Niv Y, Daw N, Dayan P. How fast to work: response vigor, motivation and tonic dopamine. Adv Neural Inf Process Syst 2006;18:1019.
[42] O'Hare E, Shaw D, Tierney K, E-M K, Levine A, Shephard R. Behavioral and neurochemical mechanisms of the action of mild stress in the enhancement of feeding. Behav Neurosci 2004;118(1):173.
[43] Peciña S, Schulkin J, Berridge K. Nucleus accumbens corticotropin-releasing factor increases cue-triggered motivation for sucrose reward: paradoxical positive incentive effects in stress? BMC Biol 2006;4(1):8.
[44] Pecoraro N, Reyes F, Gomez F, Bhargava A, Dallman MF. Chronic stress promotes palatable feeding, which reduces signs of stress: feedforward and feedback effects of chronic stress. Endocrinology 2004;145(8):3754–62.
[45] Pfaff D, Ribeiro A, Matthews J, Kow LM. Concepts and mechanisms of generalized central nervous system arousal. Ann N Y Acad Sci 2008;1129(1):11–25.
[46] Pfaus JG, Phillips AG. Role of dopamine in anticipatory and consummatory aspects of sexual behavior in the male rat. Behav Neurosci 1991;105(5):727.
[47] Phillips PEM, Walton ME, Jhou TC. Calculating utility: preclinical evidence for cost–benefit analysis by mesolimbic dopamine. Psychopharmacology (Berl) 2007;191(3):483–95.
[48] Piazza P, Deroche V, Deminière J, Le Moal M, Simon H. Reinforcing properties of corticosterone demonstrated by intravenous self-administration. Possible biological basis of sensation-seeking. Proc Natl Acad Sci U S A 1993;90:11738–42.
[49] Piazza PV, Le Moal M. Glucocorticoids as a biological substrate of reward: physiological and pathophysiological implications. Brain Res Rev 1997;25(3):359–72.
[50] Pizzagalli DA, Iosifescu D, Hallett LA, Ratner KG, Fava M. Reduced hedonic capacity in major depressive disorder: evidence from a probabilistic reward task. J Psychiatr Res 2008;43(1):76–87.
[51] Pizzagalli DA, Jahn AL, O'Shea JP. Toward an objective characterization of an anhedonic phenotype: a signal-detection approach. Biol Psychiatry 2005;57(4):319–27.
[52] Putman P, Antypa N, Crysovergi P, Van Der Does WAJ. Exogenous cortisol acutely influences motivated decision making in healthy young men. Psychopharmacology (Berl) 2010;208(2):257–63.
[53] Retana-Marquez S, Bonilla-Jaime H, Velazquez-Moctezuma J. Lack of effect of corticosterone administration on male sexual behavior of rats. Physiol Behav 1998;63(3):367–70.
[54] Rice JA. Mathematical statistics and data analysis. Thomson Learning; 2006.
[55] Robinson S, Sandstrom SM, Denenberg VH, Palmiter RD. Distinguishing whether dopamine regulates liking, wanting, and/or learning about rewards. Behav Neurosci 2005;119(1):5.
[56] Ross SR, Millis SR, Bonebright TL, Bailley SE. Confirmatory factor analysis of the behavioral inhibition and activation scales. Personal Individ Differ 2002;33(6):861–5.
[57] Salamone J, Cousins M, Snyder B. Behavioral functions of nucleus accumbens dopamine: empirical and conceptual problems with the anhedonia hypothesis. Neurosci Biobehav Rev 1997;21(3):341–59.
[58] Salamone JD, Correa M. Motivational views of reinforcement: implications for understanding the behavioral functions of nucleus accumbens dopamine. Behav Brain Res 2002;137(1–2):3–25.
[59] Salamone JD, Correa M, Mingote SM, Weber SM, Farrar AM. Nucleus accumbens dopamine and the forebrain circuitry involved in behavioral activation and effort-related decision making: implications for understanding anergia and psychomotor slowing in depression. Curr Psychiatry Rev 2006;3:461–82.
[60] Sapolsky RM. A primate's memoir: a neuroscientist's unconventional life among the baboons. Scribner; 2002.
[61] Sapolsky RM, Romero LM, Munck AU. How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory, and preparative actions. Endocr Rev 2000;21(1):55–89.
[62] Sauvé B, Koren G, Walsh G, Tokmakejian S, Van Uum SHM. Measurement of cortisol in human hair as a biomarker of systemic exposure. Clin Investig Med 2007;30(5):E183–91.
[63] Schwarz N, Hippler HJ, Deutsch B, Strack F. Response scales: effects of category range on reported behavior and comparative judgments. Public Opin Q 1985;49(3):388–95.
[64] Sinha R, Catapano D, O'Malley S. Stress-induced craving and stress response in cocaine dependent individuals. Psychopharmacology (Berl) 1999;142(4):343–51.

[65] Smillie LD, Jackson CJ, Dalgleish LI. Conceptual distinctions among Carver and White's (1994) BAS scales: a reward-reactivity versus trait impulsivity perspective. Personal Individ Differ 2006;40(5):1039–50.
[66] Stalder T, Kirschbaum C. Analysis of cortisol in hair – state of the art and future directions. Brain Behav Immun 2012;7:1019–29.
[67] Stalder T, Steudte S, Miller R, Skoluda N, Dettenborn L, Kirschbaum C. Intraindividual stability of hair cortisol concentrations. Psychoneuroendocrinology 2012;37(5):602–10.
[68] Taylor GT, Weiss J, Rupich R. Male rat behavior, endocrinology and reproductive physiology in a mixed-sex, socially stressful colony. Physiol Behav 1987;39(4):429–33.
[69] Tops M, Boksem MAS. Cortisol involvement in mechanisms of behavioral inhibition. Psychophysiology 2011;5:723–32.
[70] Tops M, Wijers AA, Koch T, Korf J. Modulation of rotational behavior in healthy volunteers by cortisol administration. Biol Psychol 2006;71(3):240–3.
[71] Treadway M, Zald D. Reconsidering anhedonia in depression: lessons from translational neuroscience. Neurosci Biobehav Rev 2010;3:537–55.
[72] Treadway MT, Buckholtz JW, Schwartzman AN, Lambert WE, Zald DH. Worth the 'EEfRT'? The effort expenditure for rewards task as an objective measure of motivation and anhedonia. PLoS One 2009;4(8):e6598.
[73] Van Uum S, Sauve B, Fraser L, Morley-Forster P, Paul T, Koren G. Elevated content of cortisol in hair of patients with severe chronic pain: a novel biomarker for stress. Stress Int J Biol Stress 2008;11(6):483–8.
[74] Wingfield J. Modulation of the adrenocortical response to stress in birds. Perspectives in Comparative Endocrinology. Ottawa: National Research Council of Canada; 1994. 520.
[75] Wingfield J, Sapolsky R. Reproduction and resistance to stress: when and how. J Neuroendocrinol 2003;15(8):711–24.
[76] Young KS. Internet sex addiction. Am Behav Sci 2008;52(1):21–37.