Acute Cortisol Predicts Willingness to Compete In Public

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Abstract

Competing with other people in public can impact one’s social reputation. Accordingly, the prospect of entering public contests can cause an acute biological “stress” response. It is unknown whether this stress response alters motivation to enter ongoing contests. Using real multiplayer contests from behavioral economics, we quantified participants’ "public competitiveness" by comparing their willingness to enter private IQ contests versus equivalent public IQ contests which exposed their relative IQ rank. We asked (a) whether an experimentally-stressed group, with higher average cortisol, was more or less avoidant than a control group on this measure, and (b) whether the magnitude of an individual’s cortisol response predicted their public competitiveness. In line with (b), we found that higher cortisol responses to the experimental context specifically predicted higher public competitiveness, independently of stress treatment. The stress treatment itself had no measurable effect. Future research should explore whether individual differences in cortisol do indeed act causally to increase boldness in socially-evaluated contests.

Cortisol Responses Predict Higher Competitive Behavior in Real Human Contests

The prospect of entering a public contest evokes a number of behavioral

(Bandler & Shipley, 1994; Biondi & Picardi, 1999; Joels & Baram, 2009) and endocrine

(Campeau, Liberzon, Morilak, & Ressler, 2011; Hellhammer, Wüst, & Kudielka, 2009; Kudielka, Hellhammer & Wüst, 2009; Quinn, Ramamoorthy, & Cidlowski, 2014) responses. Most prominently, endocrine cortisol responses reflect activation of the hypothalamic-pituitary-adrenal (HPA) axis

(Joels & Baram, 2009; Kudielka, Hellhammer, & Wüst, 2009), which plays a key role in energy mobilization and stress physiology. Yet to date it is not known whether the endocrine response to an imminent contest can act on the central nervous system to influence behavioral responses to the contest

(Andrews et al., 2007; Boyle, Lawton, Arkbage, Thorell, & Dye, 2013; Dandeneau, Baldwin, Baccus, Sakellaropoulo, & Pruessner, 2007; Rohleder, Beulen, Chen, Wolf, & Kirschbaum, 2007).

It is known that threats to social status, such as contests,are a particularly potent trigger of a cortisol response in humans

(Kemeny, Gruenewald, & Dickerson, 2004). Contests challenge one’s social status by publically assessing the abilities, competencies, or traits on which a positive social image is based

(Denson, Creswell, & Granville-Smith, 2012; Kemeny et al., 2004). From this perspective, cortisol is seen as one component of a coordinated psycho-biological response to social-evaluative threats such as public evaluation

( Dickerson & Kemeny, 2004; Het & Wolf, 2007; Kirschbaum, Pirke, & Hellhammer, 1993; Von Dawans, Fischbacher, Kirschbaum, Fehr, & Heinrichs, 2012; Von Dawans, Kirschbaum, & Heinrichs, 2011). The term "socio-evaluative challenge" may be more appropriate than “socio-evaluative threat”, because it highlights that contests might be perceived as either thrilling or threatening.[[1]](#footnote-1)

 Despite this causal relation between social evaluation and the acute cortisol stress response, to our knowledge there is no converse evidence that acute cortisol impacts behavioral responses to social evaluation, such as the choice to enter public contests. Interestingly, an increased secretion of cortisol is associated with lower levels of competitive behavior in some non-human animal species, as assessed via the frequency of submissive displays

(Haller, Kiem, & Makara, 1996; Shively, Laber-Laird, & Anton, 1997). While human submissive behaviors such as eye gaze avoidance

(Allan & Gilbert, 1997; Keltner, 1995) may serve a similar evolutionary function

(Keltner, 1995, 1996), it is unclear how they relate to cortisol and whether this relation is indeed specific to social-evaluative challenges, as suggested by the social self preservation theory (Bosch et al., 2009; Boyle, Lawton, Arkbage, Thorell, & Dye, 2013; Gruenewald, Kemeny, Aziz, & Fahey, 2004; Kemeny et al., 2004; Smith & Jordan, 2014).[[2]](#footnote-2)

We therefore asked whether a randomized stressor and/or the endogenous cortisol response impacted participants’ willingness to risk their social reputation by competing in public. If a participant in our experiment consented to enter a public contest, their rank in an IQ challenge was announced in public by projecting their photo and IQ rank onto the wall. We contrasted participants’ willingness to enter such contests with their willingness to enter private contests, in which they received only private feedback about their rank. As an additional factor, participants knew that some contests were ability-matched, while some were not[[3]](#footnote-3), see Figure 1. Our experiment addressed two related questions. We first looked for evidence of stress-induced avoidance of public contests, where social reputation was at stake, relative to private contests, where it was not. We hoped to assess stress-induced changes in participants’ sensitivity to social evaluation. Analogously, we also asked whether participants’ cortisol responses predicted their relative aversion to public contests.

**Materials and Methods**

### Participants

Participants were recruited from a pool of students across universities in Zurich. They were contacted by email and assessed using our exclusion criteria of any history of psychiatric or somatic disorder, including allergies, before receiving preparatory instructions (see below). Three of the 135 participants were excluded from analysis because they failed to fulfill either the choice or cortisol dependent measures. Participants were randomly assigned to stress versus control treatments. The remaining 132 participants (18-50 years, median age 23 years) consisted of 66 women and 66 men. The study was approved by the local ethics committee and conducted in accordance with the Declaration of Helsinki. Participants were not deceived in any part of this study. They were naive to laboratory stressors, following

Schommer, Hellhammer, and Kirschbaum (2003). To control for HPA axis reactivity, participants were instructed to refrain from eating or drinking anything but water in the three hours before the experiment, and to abstain from alcohol, excessive exercise, caffeine, and smoking in the six hours before the experiment. They were also asked not to brush teeth or chew gum 30 minutes prior to the experiment, and to go to bed at a reasonable time (i.e. around midnight) and get at least six hours of sleep the night before the study.

### Measures

#### Main variables of interest. We recorded participants’ choice to enter or avoid different types of competition. To assess the stress response, we also measured salivary cortisol 5 minutes prior to (baseline), 25 minutes after (peak cortisol[[4]](#footnote-4)), and 70 minutes after stressor onset and collected self-reported affect ratings on a Visual Analog Scale (VAS) immediately after the stressor offset (Aitken 1969). We recorded their performance in an N-back test. Immediately after their competitive choices but before their actual competitive performance, we recorded their belief about their relative performance. This allowed us to control for their self-confidence when assessing the effect of stress on the tendency to avoid social competition. Please see supplementary material for details of our additional measures. We did not take additional biological measures, such as testosterone, but did take other novel behavioural indices of risk preference that we may report elsewhere.

### Design and Procedure

**Stress induction.** On each day of testing, a group of 25 or 30 participants completed informed consent before all were assigned to either the “Stress” or “No stress” treatment of a socially evaluated cold pressor test (SECPT;

(Schwabe, Haddad, & Schachinger, 2008). We used a modification of the SECPT to treat a larger group [[5]](#footnote-5) (see

Minkley, Schröder, Wolf, & Kirchner, 2014 for the recent validation of a similar procedure). This procedure satisfies many conventional criteria for a stressor

(Dickerson & Kemeny, 2004; Minkley et al., 2014).

In both stress treatments, all participants sat in front of a water bucket. Participants were collectively asked to “place your hand in the water up to the wrist and leave it submerged until further instruction or for as long as you can endure it”. The “Stress” and “No Stress” treatments were identical but for the following two details: the temperature of water during a pressor task and the behavior of two experimenters during that pressor task. In the “No Stress” treatment, the water was comfortably warm (34-37○ C) and experimenters E1 and E2 stood stationary in the positions indicated in Supplemental Figure 8 with eyes directed downwards onto handheld stopwatches. In the “Stress” treatment, the water was uncomfortably cold (2-4○ C) and experimenters E1 and E2 walked among the participants, alternately directing their eye-gaze between participants’ faces and hands to inspect each participant’s compliance and a hand-held clipboard onto which they made notes with a pen.

 In both treatment conditions, experimenter 3 walked down each row of participants and took a photograph of each participant. These photographs were used later in the experiment. Participants were then asked to report seven attributes of their state affect on a short visual analog questionnaire, similar to that described by

Schoofs, Wolf, Smeets, et al. (2009).

**Behavioral task.**

*Overview.* Before the main decision task, each participant completed two N-back tasks for performance-dependent pay. Payment was first based on their absolute performance, then on their relative performance, relative to four randomly selected opponents.[[6]](#footnote-6) In the former case, they were paid proportionally to their personal percentage correct. In the latter case, the top-scorer in each group of five received a large bonus, while other group members received no pay at all. This large bonus ensured that the *expected value* or averagepayment in the relative payment scheme (high-risk/high-return competition) was comparable to that in the absolute payment scheme (low-risk/low-return non-competition). Because participants could not choose how they would be paid in these two N-back tasks, we refer to these tasks as forced-contest and forced non-contest.

 At peak cortisol response, 25 minutes post stressor onset, participants then freely chose in advance how to be paid for each of four potential upcoming N-back tasks. For each potential upcoming task, they selected between the absolute payment scheme (low-risk/low-return) and relative payment scheme (high-risk/high-return) detailed above. While these two financial payment options were constant throughout the four contests, the four contests differed along two non-pecuniary dimensions: they were ability-matched and/or publicized according to a 2 x 2 factorial design (see Figure 1b). According to our hypothesis, these independent variables should influence competitive behavior (see Introduction). Following standard practice in behavioral economics, after participants had made their choices, we then randomly selected only one of the four potential N-back contests to actually be played.[[7]](#footnote-7) After their choices, but before the final N-back test, participants reported how they expected to perform in a mixed-ability contest by indicating their expected rank from one to five in this ambiguous hierarchy. This provided some measure of their self-confidence. They were instructed that they would win 5 CHF if they were correct, incentivizing them to disclose their expected rank honestly. See the appendices for a comprehensive description of the task specifics.

### Cortisol analysis. Saliva samples were frozen at -4 degrees Celsius until they were analyzed at the laboratory of Prof. Clemens Kirschbaum (TU Dresden, Germany). See appendices for more details.

### Statistical Methods

**General.** Uncertainty about our inferences is depicted in 95% CIs, under the assumptions detailed below. All analyses were performed with the R software package

(RCoreTeam, 2014). Our sample sizes were chosen to ensure that we had 80% power to identify a 0.1 difference between stress and no stress conditions in the public contest condition. Our calculation assumed that the no stress competition rate would be 0.3 in this condition, which implies a standard deviation (i.e. Bernoulli variance) of 0.21.

**Effect of stress on self-reported affect, cortisol, guessed rank in the N-back contest, and actual N-back performance.** For each participant, the cortisol response was calculated as the difference between salivary cortisol at the 25 minute post-stress peak and five minute pre-stress baseline. Conversely, thecortisol recovery was calculated as the difference between the final cortisol level at 70 minutes and the 25 minute peak. No participants were excluded from the analyses of cortisol effects. We used a two-sample t-distribution (assuming unequal variances) to infer the effect of stress on these cortisol variables, self-reported affect, guessed rank, and final N-back performance. Our conclusions were unaffected by this parametric assumption: they were the same under non-parametric two-sample rank sum tests.

**Effect of stress and cortisol on competitive choice behavior.** Our central goal was to contrast social avoidance (public competitiveness) at different levels of stress and cortisol. We did not use a standard mixed effects ANOVA to model the effect of our Stress x Publicity x Ambiguity treatments on competitive choices, because these choices were binary not Gaussian (enter contest or not). In the appendix we use a mixed-effects logistic regression – a special case of the generalized linear mixed model – to model both the causal effect of our treatments on choice behavior, as well as the predictive relation between cortisol on choice behavior. Here we present a simpler “summary statistic” approach, which yields the same conclusions. In this summary statistic approach, we first estimated within-participantsocial avoidance by contrasting each participant’s choice to enter different contests in Figure 1b. Then, treating these within-participant summaries as raw data, we examined their between-participant variation as a function of stress (or cortisol), as follows.

A summary of each participant’s social or “public” avoidance  is created by contrasting (i.e. subtracting) their average participation in the two private contests versus the two public contests. This main effect of publicity is

 

 where  equals  if the participant entered the contest depicted in cell  of Figure 1b and  otherwise, and so on. For example, a publicity-averse participant may compete in cells  and  but not  and , giving them , while a publicity-seeking participant competing with the opposite pattern will receive . If stress reduces social avoidance, then on average where \* indicates a stressed participant.

We also considered two secondary hypotheses. Because social evaluation may be most threatening when it exposes otherwise unknown information about one’s social rank[[8]](#footnote-8), we also tested the interaction effect of publicity with ambiguity:



This quantity is higher for a given participant if mixed-ability contests trigger more social avoidance than matched-ability contests. If stress reduces social avoidance more in mixed-ability contests than match-ability contests,  should be lower under stress. Finally, for completeness, we quantified the main effect of competitive ambiguity aversion, by contrasting participation in matched-ability versus mixed-ability contests:

 

For each participant, the summary statistics defined above () take on one of a discrete, ordered set of values (-1,-1/2,0,1/2,1). We therefore used ordered logistic regression to test whether they were affected by stress treatment. Each of these three regressions contained an intercept and a dummy variable which indexed participants in the stress treatment. The dummy variable captures the effect of stress treatment versus control. Analogously, we used ordered logistic regression to test whether these summary statistics were related to the cortisol response , across subjects.

**Results**

**Stress and Cortisol, Self-Reported Affect, Pre-Choice Guessed Rank and Post-Choice N-Back Performance**

The impact of stress treatment on salivary cortisol is given in Figure 2a and Table 1 in nmol/l. The cortisol response and the cortisol recovery were greater in the stress treatment condition, particularly for male participants. There were no baseline differences in cortisol between the stress and non-stress treatments. A difference emerged at the peak 25 mins post-stressor, and no difference was visible after at 70 minutes post-stressor onset.

Despite cortisol's circadian afternoon decline, both stress treatment groups showed a significantly positive cortisol response (i.e., an increase in cortisol from the baseline to the peak measurement), but this occurred significantly more often among men in the stress treatment. Interestingly, separate one-sample t-tests revealed a positive cortisol response in both women and men, in both stress and no stress treatment conditions (p = 0.041 non-stressed women; p = 0.0014 stressed women; p = 0.0095 non-stressed men; p < 4 x 10-8 stressed men). It thus seems that our procedure elicited a baseline cortisol response in all participants, and that the cold pressor augmented this response in the stress treatment, particularly for men, see Figure 2a and Dickerson and Kemeny (2004). This common baseline component of the cortisol response made it more challenging to detect a main effect of stress-related cortisol on choice behavior (i.e. increased the false negative error probability of our statistical tests).

We then examined variation in the cortisol response with both the stress treatment and participant-specific covariates. These covariates included a gender dummy; risk preferences (assessed via questionnaire); BIS/BAS personality; Perceived Stress Scale; participants’ belief about their rank; state affect after the stressor such as self-reported irritation, anxiety, sadness, and happiness; and two dummies for smoking and drinking behavior. Only gender and stress treatment predicted the cortisol response in this linear Gaussian regression model (see Figure 4a). This analysis confirmed that men had a stronger cortisol response than women

(Kirschbaum, Wüst, & Hellhammer, 1992). Henceforth we included gender in models of the effect of stress and cortisol, permitting us to identify whether gender moderated these effects. We did not assess gonadal hormones and cannot directly comment on the role of sex hormones, nor on their potential interaction with cortisol. For a brief consideration of the role of the menstrual cycle and hormonal contraceptives, please see the appendices.

The impact of stress treatment on self-reported affect is shown in Figure 2b and Table 2. The stress treatment was perceived as more unpleasant. Stressed participants were also more annoyed. The remaining effects were not distinguishable from zero. There were 17 smokers. A two-sample t-test revealed that smokers did not differ from non-smokers on any self-reported affect rating (p values ranging from 0.259 to 0.788), suggesting that 6 hours of nicotine abstinence did not measurably impact mood. Smokers did not significantly differ from non-smokers in the magnitude of their cortisol response, as assessed with a two-sample t-test (p = 0.21).

As with previous reports (Schoofs, Preuß & Wolf 2008), we found an effect of stress treatment on N-back performance during the training phase (0-25 mins post stressor). This effect had washed out at 25 minutes post treatment. Specifically, stressed participants performed worse in both training N-back tasks (p = 0.079, p = 0.0037), but evidenced recovery by the final, post-choice performance (p = 0.468). In terms of the mean and standard errors, in the first N-back task, non-stressed subjects averaged 83% correct answers while the performance of stressed subjects was 3% worse (-2.8%, SE 1.58). In the second N-back test, the non-stressed subjects averaged 85% correct answers, and stressed subjects now performed significantly 5% worse (-5.04%, SE 1.7). By the final performance, non-stressed subjects averaged 85% correct and the stressed subjects’ performance was just 1% worse (-1.4%, SE 1.9).

As reported above, our stress treatment did not influence participants’ final competitive performance, see Figure 2d. In the context of competitive choice behavior, it is perhaps more relevant to ask whether stress influenced their beliefs about relative performance. We found that our stress treatment did not influence participants’ beliefs about their relative competitive performance, as shown in Figure 2c. This suggests that participants may have expected stress to affect everyone’s absolute N-back performance equally (or not at all), thereby leaving everyone’s *relative* performance unchanged. On average, participants seemed aware of the quality of their performance: their guessed relative rank in the group strongly correlated with their final N-back performance, as assessed with a Wilcoxon rank-sum test with continuity correction (W = 13576.5, p < 0.001).

**Stress, Cortisol, and Choice**

 Figure 3a gives the fraction of people who compete in each cell of the factorial design. It shows that, regardless of stress or ambiguity level, people strongly avoided public contests (conditions C,\*C, D,\*D of Figure 1b, where \* indexes the stress treatment participants) relative to private contests (A,\*A,B,\*B). This confirms that our task measures social avoidance.

Regarding our summary-statistic regression analyses (see **Statistical methods**), Figure 3b indicates that stress has no influence at all on social avoidance, ambiguity avoidance or their interaction at 25 minutes post-stressor. We then asked whether gender moderated any stress effect. We therefore included gender as a factor in the three summary-statistic analyses of the effect of stress on competitive choice. We found that in no case did gender modulate the impact of stress on choice behavior; in all cases the 95% confidence intervals for the gender x stress parameter generously included zero (p values > .5).

We then replaced the stress treatment dummy variable in these regressions with participants’ measured cortisol response and repeated the three summary-statistic regressions. This revealed that individuals’ cortisol response predicted lower aversion to public contests (p = 0.005), as in Figure 3d. Figure 3c illustrates this relation. It is evident from Figure 3c that only one participant out of the 21 showing a high cortisol response (i.e. greater than 15 nmol/l) also showed high publicity aversion (i.e. Publicity (P) = 1).[[9]](#footnote-9) We then included gender as a factor in these three summary-statistic analyses of the relation between cortisol response and competitive choice. As with the stress treatment above, we found that in no case did gender modulate the impact of stress on choice behavior.

We then asked whether gender jointly interacted with stress and cortisol to impact competitive behavior, and found a similar (null) pattern. We conducted analogous analyses within the framework of generalized linear mixed model regression in the supplementary material, and again found no evidence whatsoever for the claim that gender modulated the effect of stress or cortisol response, or their interaction, on competitive behavior. We then stratified the regression of cortisol response on public competitiveness by gender, in order to confirm that this relation held separately for women (p = 0.0431) and men (p = 0.0723). In summary, while our female participants' cortisol response was less dependent on stress treatment (see above), it was equally predictive of social avoidance across stress treatment conditions.

We wanted to know whether our observed relation between cortisol and public competitiveness persisted after accounting for other factors known to influence either cortisol or competitiveness. We therefore augmented the summary statistic regressions above with other participant-specific covariates: stress treatment dummy; participants’ belief about their rank; post-treatment state affect such as self-reported irritation, anxiety, sadness, or happiness; gender dummy; risk preferences as assessed by questionnaire above; personality in the form of BIS/BAS assessed by questionnaire above; self-reported chronic stress level and two dummies for smoking and drinking behavior. We did this in order to hold any (linear) contribution of these variables constant while inferring the relationship of interest: the cortisol-behavior relationship[[10]](#footnote-10). To facilitate comparison between different effects, all variables, apart from the dummies, were standardized in that we subtracted the mean and divided by the standard deviation. Cortisol remained highly predictive of social avoidance after accounting for these covariates in the regression; the estimated effect was -0.52 with a 95% CI [-0.92,-0.13] as seen in Figure 4b. For completeness, analogous plots depict the relationship between each covariate and ambiguity aversion as in Figure 4c and the interaction between ambiguity and publicity, as in Figure 4d.

While we have focused on the predictive effect of the cortisol response , it may interest some readers that we found no statistically significant predictive relation between competitive behavior and baseline cortisol.

## Discussion

Remarkably little is known about the effect of acute stress or cortisol on human competitive behavior. In particular, it is unclear whether these factors specifically influence the decision to enter or avoid contests which specifically challenge social standing. Our paradigm isolates this type of social avoidance. We designed a public IQ contest to maximally challenge reputation, thereby ensuring that avoidance would reflect participants’ reputation concerns. We demonstrated that the prospect of social evaluation indeed triggered a specific avoidant social behavior: We observed a strong drop in the probability of public competing in both ability-matched and ambiguous contests (Figure 3d).

We found no main effect of our experimental stressor on this form of social avoidance. Independently of the stress treatment, however, we observed that cortisol responses predicted lower avoidance. This means that participants with higher cortisol responses were bolder in the face of public feedback, and they were less avoidant of contests that publicly exposed their personal traits, such as physical appearance and relative cognitive ability, relative to contests with private feedback. This was true when accounting for participants’ gender and personality, as well as other variables known to influence either HPA responses or competitiveness. It is worth emphasizing that cortisol specifically predicted a reduced aversion to publicity. Our main result can be thought of as an interaction between cortisol and publicity (see Figure 3d). In contrast, we observed no overall correlation between cortisol and the total number of choices to compete. The specificity of this effect suggests a specific role for cortisol in social behavior

(Hasegawa, Toda, & Morimoto, 2008; Lundberg, Hedman, Melin, & Frankenhaeuser, 1989; Montoya, Terburg, Bos, & Van Honk, 2012; Rimmele et al., 2009; Salvador, 2005).

We cannot make any causal claims about the role of cortisol because it was not directly under experimental control. Our predictive relationship between cortisol and competitive choice behavior may reflect some hidden variable which predisposes some participants both to a responsive HPA axis and a tendency for public competition. While our analysis uses covariates to account for some high-level hidden variables such as personality and risk preferences, it remains possible that changes in structures that precede cortisol secretion, such as PFC, amygdala, hippocampus, or hypothalamus, are ultimately responsible for increased competitiveness.

Alternatively, our predictive relationship between cortisol and competitive choice behavior may indeed reflect a causal effect of cortisol on social avoidance, perhaps by cortisol entering the CNS and changing behavior. This would imply that, while social evaluation triggers cortisol

(Kirschbaum, Pirke, & Hellhammer, 1993), cortisol may in turn trigger social evaluation by reducing social avoidance. Such an effect might be mediated by fear-reducing effects of phasic cortisol

(Putman et al., 2007), if high responders experience less fear about the public revelation of their status. A potential mechanism for cortisol effects on the CNS has been suggested by

Putman and Roelofs (2011), who argue that the fear-relieving properties of cortisol could be due to the adaptive regulation of early cognitive processing of threatening information. By this account, automatic processing of goal-irrelevant threatening information is inhibited and automatic approach–avoidance responses are facilitated. Thus cortisol would lead to both reduced fear and heightened reward orientation. This appears consistent with Soravia et al. (2006), who demonstrated that exogenous cortisone buffered stimulus-induced phobic fear, and with van Peer et al. (2010) who showed that exogenous cortisol reduced motivated attention to social threat in patients. Note, however, that (exogenous) cortisol-induced alterations to the cognitive processing of specific fear-related stimuli may be unrelated to self-reported levels of anxiety (Grillon, Heller, Hirschhorn, Kling, Pine, et al., 2011). While Schelling and De Quervain have used cortisol administration in patients to reduce fear memories in post-traumatic stress disorder (De Quervain & Margraf, 2008; De Quervain et al., 2011; Schelling et al., 2004),e the generality of these findings warrants further investigation (Elnazer & Baldwin, 2014), as does the possibility of gender differences (Jackson, Payne, Nadel, & Jacobs, 2006).

If cortisol does play a causal role in social avoidance and dominance behavior, one might expect it to interact with other variables, including another endocrine process. The prominent dual-hormone hypothesis, for example, proposes that cortisol interacts with testosterone to influence dominance and avoidance behavior in social situations (Bedgood, Boggiano, & Turan, 2014; Mehta & Josephs, 2010; Zilioli & Watson, 2012), although Geniole, Busseri, and McCormick (2013) have recently questioned this notion. This question should be explicitly addressed in future work.

Our results prompt several new questions which we now briefly consider. First, why did stress not raise cortisol levels in women? Second, which aspect of the study resulted in a cortisol increase in all participants? Third, how do the findings fit with previous research on stress and risk taking and stress and decision making? Regarding our first question, our observed gender differences in cortisol response to stress resonate with previous accounts (e.g., Lovallo et al., 2006; Uhart et al., 2006). We can only speculate that the profound gender asymmetry in cortisol responses that we observed reflects some feature of our specific group stress protocol. If so, this would spark a host of new and intriguing empirical questions. Regarding our second question, we cannot be sure which aspect of the study resulted in a cortisol increase in all participants. In general, the situational characteristics that lead to activation of the HPA axis include novelty, predictability, controllability, anticipation of negative consequences, ego-involvement, cognitive challenge and reward anticipation (e.g., Dickerson & Kemeny, 2004; Pruessner, 1997). This creates a few possibilities. First, everyone in our task had a cognitive challenge, which may have triggered a slight cortisol increase. Furthermore, our instructions to subjects at the onset of our experiment may have affected the results. Participants were told that they faced a novel task, which introduced a level of unpredictability, and that their IQ performance would be measured. The latter may have invoked a threat to ego, either through fear of social evaluation or self-evaluation. Regarding our third question, there is indeed evidence that stress, and cortisol in particular (Pabst et al., 2013), may increase financial risk-taking, potentially by increasing the saliency of potential rewards (Coates et al., 2010; Lighthall et al., 2009; Putman et al., 2010; Van den Bos et al., 2009). This seems consistent with the idea that a cortisol increase might facilitate bold, competitive behavior in our task. From this perspective, two things are notable about our work. First, our task explicitly taps into *social* risk-taking. Financial risks were constant across our public and private contests; any differential participation across these contests cannot therefore be reduced to financial risk-taking. Instead, we believe that our experiment measures the social risk-taking that arises when people balance the potential glory arising from public success against the potential humiliation that accompanies social defeat. Second, unlike some of these other non-social risk tasks, we did not observe a treatment effect of stress at 25 minutes post-stressor. Rather, individual differences in cortisol response to our novel ego challenge appear to be more important.

Our focus has been on the relationship between competitive behavior and cortisol response. We now briefly consider what might have been expected in terms of the basal cortisol level. In particular, converging lines of circumstantial evidence might lead one to predict more aggressive social competition among those with lower baseline cortisol. For example, it is suggestive that depressive and anxious symptoms entail both high basal cortisol levels and low competitive behavior (Halbreich et al., 1985; Vreeburg et al., 2010). Conversely, low basal cortisol has been implicated in overly aggressive behavior (Oosterlaan et al., 2005), as found in oppositional defiant disorder (ODD) and conduct disorder (CD; Karyawasam et al., 2003; McBurnett et al., 2000; Moss et al., 1995; Pajer et al., 2001; Scerbo & Kolko, 1994; Shoal et al., 2003; Van Goozen et al., 1998; Vanyukov et al., 1993; Van de Wiel et al., 2004). From these associations alone, it is obviously unclear whether or how basal cortisol causally impacts aggressive/competitive behavior. Various causal and non-causal speculations have nonetheless arisen to explain this association. First, cortisol may be regarded as a peripheral indicator of autonomic activity (Oosterlaan et al., 2005). Several studies have found evidence for reduced autonomic activity in children, adolescents and adults with antisocial behavior, including lowered heart rate and skin conductance (e.g. Pliszka, 1999). Activity in the sympathetic branch of the autonomic nervous system goes hand in hand with the release of cortisol from the HPA axis. Thus, low basal cortisol concentrations may reflect lower autonomic activity. Second, some previous research suggests that basal testosterone is moderately positively correlated with basal cortisol (e.g., Mehta et al., 2008). This may be relevant because of the likely role of testosterone in social dominance behaviors and competitive behaviors. Perhaps more relevant still, one influential recent perspective on social aggression emphasizes the testosterone–cortisol ratio as a hormonal risk factor (Montoya et al., 2012; Pompa et al., 2008). By this account the interaction between the basal value of testosterone and cortisol levels is critical. The intimate interactions between social competitive behavior, the hypothalamic-pituitary-gonadal (HPG) axis and the hypothalamic-pituitary-adrenal (HPA) stress axis are also seen in the fact that transient changes in testosterone after social victory or defeat in contests depends on basal cortisol (Zilioli & Watson, 2012).

We briefly note some other extensions of the current study, which future work might address. First, the socio-evaluative stress response also includes inflammatory cytokines, which are known to interact with HPA function. Future work should therefore assess whether our observed effects can in fact ultimately be traced back to the cytokine system

(Dickerson, Kemeny, Aziz, Kim, & Fahey, 2004). Second, we have focused on a behavioral measure of social avoidance and found that participants were generally avoidant of public contests in comparison to private contests. We leave it to future work to identify the role of the emotion of shame in guiding and modulating social competitive behavior

(Dickerson, Gruenewald, & Kemeny, 2004; Dickerson & Kemeny, 2004). Additionally, we have discussed the role of fear in cortisol-dependent changes in public competitiveness. Another possibility for future work, which we have alluded to above, is to explore whether participants become more sensitive to social rewards such as high status or less sensitive to social penalties such as shame

(Putman, Antypa, Crysovergi, & Van Der Does, 2010).

Note that we have modelled our group stress test on the widely-used socially evaluated cold pressor test (SECPT), which, like other stress induction manipulations, intentionally confounds or combines a raft of stressful elements like temperature and social eye-gaze evaluation in order to maximize group differences in cortisol. Of course, this strategy is at odds with dissecting the individual impact of each of these elements on the dependent variable. For this, one must resort to other aspects of the experimental design. For example, our cold water stress treatment was intended to increase cortisol. Our warm water treatment was intended to buffer against cortisol by providing participants with thermal comfort. While there are fascinating clues that our temperature manipulation might alter competitive behaviour independently of the cortisol stress system (IJzerman & Semin, 2009; Sassenrath et al., 2013; Williams & Bargh, 2008), we simply aimed to use temperature as a tool to manipulate cortisol. For this reason, our dependent measure was taken 25 minutes after thermal stimulation, much later than standard socio-thermal tasks, and at peak cortisol. An identical rationale applies to the eye-gaze element of our stress induction, which might otherwise be considered a confound (Nettle et al., 2013). As suggested by a reviewer, this alone may not have entirely excluded the possibility that temperature or eye-gaze, as opposed to the stress response to temperature or eye-gaze, confounded our treatment effect. This possibility does not concern us because we observed no treatment effect. In other words, the absence of a significant treatment effect on competitive behaviour in our study implies that neither temperature nor social-gaze, nor the stress response to these, significantly influenced our dependent measure. The benefit of our null result, therefore, is that we can more confidently exclude these theoretical confounds. These potential confounds should nonetheless be carefully considered in future work. In contrast, we observed that treatment-independent individual differences in cortisol responses to the experimental context predicted competitive behaviour.

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**References**

Aitken, R. C. B. (1969). Measurement of feelings using visual analogue scales. *Proceedings of the*

 *Royal Society of Medicine*, *62*, 989 - 993.

Allan, S., & Gilbert, P. (1997). Submissive behaviour and psychopathology. *British Journal*

*of Clinical Psychology*, *36*(4), 467–488.

Andrews, J., Wadiwalla, M., Juster, R. P., Lord, C., Lupien, S. J., & Pruessner, J. C. (2007). Effects

 of manipulating the amount of social-evaluative threat on the cortisol stress response in

 young healthy men. *Behavioral Neuroscience*, *121*(5), 871-876.

Bandler, R., & Shipley, M. T. (1994). Columnar organization in the midbrain periaqueductal gray:

 Modules for emotional expression? *Trends in Neurosciences*, *17*(9), 379–389.

Bedgood, D., Boggiano, M. M., & Turan, B. (2014). Testosterone and social evaluative stress: The

 moderating role of basal cortisol. *Psychoneuroendocrinology*, *47*, 107-115.

Biondi, M., & Picardi, A. (1999). Psychological stress and neuroendocrine function in humans:

 The last two decades of research. *Psychotherapy and Psychosomatics*, *68*(3), 114-150.

Böhnke, R., Bertsch, K., Kruk, M. R., Richter, S., & Naumann, E. (2010). Exogenous cortisol

 enhances aggressive behavior in females, but not in males. *Psychoneuroendocrinology*,

 *35*(7), 1034-1044.

Bosch, J. A., de Geus, E. J. C., Carroll, D., Goedhart, A. D., Anane, L. A., van Zanten, J. J. V., …Edwards, K. M. (2009). A general enhancement of autonomic and cortisol responses during social evaluative threat. *Psychosomatic Medicine*, *71*(8), 877–885.

Boyle, N. B., Lawton, C., Arkbage, K., Thorell, L., & Dye, L. (2013). Dreading the boards: Stress

 response to a competitive audition characterized by social-evaluative threat. *Anxiety,*

 *Stress & Coping*, *26*(6), 690-699.

Buser, T. (2012). The impact of the menstrual cycle and hormonal contraceptives on

 competitiveness. *Journal of Economic Behavior & Organization*, *83*(1), 1-10.

Campeau, S., Liberzon, I., Morilak, D., & Ressler, K. (2011). Stress modulation of cognitive and

 affective processes. *Stress*, *14*(5), 503-519.

Chen, Y., Katuščák, P., & Ozdenoren, E. (2012). Why canʼt a woman bid more like a man? *Games*

 *and Economic Behavior*, *77*(1), 181-213.

Coates, J. M., Gurnell, M. & Sarnyai, Z. (2010). From molecule to market: Steroid hormones and

 financial risk-taking. *Philosophical Transacations of the Royal Society B*, *365*, 331–343.

Cohen, S. (1988). *Perceived stress in a probability sample of the United States*. New York: Sage Publications.

 Inc.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal*

 *of Health and Social Behavior*, *24*(4), 385-396.

Dandeneau, S. D., Baldwin, M. W., Baccus, J. R., Sakellaropoulo, M., & Pruessner, J. C. (2007).

 Cutting stress off at the pass: Reducing vigilance and responsiveness to social threat by

 manipulating attention. *Journal of Personality and Social Psychology*, *93*(4), 651-666.

Datta Gupta, N., Poulsen, A., & Villeval, M. C. (2005). Male and female competitive behavior-

 Experimental evidence. *GATE Working Paper* No. WP 05-12.

Dawans, B. von, Fischbacher, U., Kirschbaum, C., Fehr, E., & Heinrichs, M. (2012). The social

 dimension of stress reactivity acute stress increases prosocial behavior in humans.

 *Psychological Science*, *23*(6), 651–660.

Dawans, B. von, Kirschbaum, C., & Heinrichs, M. (2011). The Trier Social Stress Test for Groups

 (TSST-G): A new research tool for controlled simultaneous social stress exposure in a

 group format. *Psychoneuroendocrinology*, *36*(4), 514–522.

Dayan, P., & Seymour, B. (2008). Values and actions in aversion. In Glimcher, P.W., Camerer C.F., Fehr, E.F. and Poldrack R.A, *Neuroeconomics: Decision Making and the Brain*, London: Elsevier.

Denson, T. F., Creswell, J. D., & Granville-Smith, I. (2012). Self-focus and social evaluative threat

 increase salivary cortisol responses to acute stress in men. *Journal of Behavioral*

 *Medicine*, *35*(6), 624–633.

Dickerson, S. S., Gruenewald, T. L., & Kemeny, M. E. (2004). When the social self is threatened:

 Shame, physiology, and health. *Journal of Personality*, *72*(6), 1191–1216.

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical

 integration and synthesis of laboratory research. *Psychological Bulletin*, *130*(3), 355-391.

Dickerson, S. S., Kemeny, M. E., Aziz, N., Kim, K. H., & Fahey, J. L. (2004). Immunological effects

 of induced shame and guilt. *Psychosomatic Medicine*, *66*(1), 124–131.

Eckel, C. C., & Grossman, P. J. (2008). Men, women and risk aversion: Experimental evidence.

 *Handbook of Experimental Economics Results*, *1*, 1061–1073.

Elnazer, H. Y., & Baldwin, D. S. (2014). Investigation of cortisol levels in patients with anxiety

 disorders: A structured review. *Current Topics in Behavioral Neuroscience*, *18*, 191-216.

Gelman, A., & Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models*.

 Cambridge: Cambridge University Press.

Geniole, S. N., Busseri, M. A., & McCormick, C. M. (2013). Testosterone dynamics and

 psychopathic personality traits independently predict antagonistic behavior towards the

 perceived loser of a competitive interaction. *Hormones and Behavior*, *64*(5), 790-798.

Gilbert, P. (2000). Varieties of submissive behavior as forms of social defense: Their evolution

 and role in depression. In Gilbert, P., Sloman, L. (2000) *Subordination and defeat: An evolutionary approach to mood (3-45). Matwah, NJ, US: Lawrence Erlbaum Associates Publishers.*

 *disorders and their therapy*, 3–45.

Grillon, C., Heller, R., Hirschhorn, E., Kling, M. A., Pine, D. S., Schulkin, J., & Vythilingam, M.

(2011). Acute hydrocortisone treatment increases anxiety but not fear in healthy volunteers: A fear-potentiated startle study. *Biological Psychiatry*, *69*(6), 549-555.

Gruenewald, T. L., Kemeny, M. E., Aziz, N., & Fahey, J. L. (2004). Acute threat to the social self:

 Shame, social self-esteem, and cortisol activity. *Psychosomatic Medicine*, *66*(6), 915–924.

Halbreich, U., Asnis, G. M., Shindledecker, R., Zumoff, B., & Nathan, R. S. (1985). Cortisol

secretion in endogenous depression: I. Basal plasma levels. *Archives of General*

*Psychiatry*, *42*(9), 904-908.

Haller, J., Kiem, D. T., & Makara, G. B. (1996). The physiology of social conflict in rats: What is

 particularly stressful? *Behavioral Neuroscience*, *110*(2), 353-359.

Hartig, J., & Moosbrugger, H. (2003). Die “ARES-Skalen” zur Erfassung der individuellen BIS-und

 BAS-Sensitivität. *Zeitschrift für Differentielle und Diagnostische Psychologie*, *24*(4), 293–

 310.

Hasegawa, M., Toda, M., & Morimoto, K. (2008). Changes in salivary physiological stress

markers associated with winning and losing. *Biomedical Research*, *29*(1), 43-46.

Hellhammer, D. H., Wüst, S., & Kudielka, B. M. (2009). Salivary cortisol as a biomarker in stress

 research. *Psychoneuroendocrinology*, *34*(2), 163-171.

Het, S., & Wolf, O. T. (2007). Mood changes in response to psychosocial stress in healthy young

women: Effects of pretreatment with cortisol. *Behavioral Neuroscience*, *121*(1), 11-20.

Houston, A. I., & McNamara, J. M. (1988). Fighting for food: A dynamic version of the Hawk

 -Dove game. *Evolutionary Ecology*, *2*(1), 51–64.

Ijzerman, H., & Semin, G. R. (2009). The thermometer of social relations mapping social

 proximity on temperature. *Psychological Science*, *20*(10), 1214-1220.

Jackson, E. D., Payne, J. D., Nadel, L., & Jacobs, W. J. (2006). Stress differentially modulates fear

 conditioning in healthy men and women. *Biological Psychiatry*, *59*(6), 516-522.

Jaeggi, S. M., Studer-Luethi, B., Buschkuehl, M., Su, Y. F., Jonides, J., & Perrig, W. J. (2010). The

 relationship between n-back performance and matrix reasoning-implications for training

 and transfer. *Intelligence*, *38*(6), 625–635.

Joels, M., & Baram, T. Z. (2009). The neuro-symphony of stress. *Nature Reviews Neuroscience*,

 *10*(6), 459–466.

Kariyawasam, S. H., Zaw, F., & Handley, S. L. (2002). Reduced salivary cortisol in children with

 comorbid attention deficit hyperactivity disorder and oppositional defiant disorder.

 *Neuroendocrinology Letters*, *23*(1), 45-48.

Keltner, D. (1995). Signs of appeasement: Evidence for the distinct displays of embarrassment,

 amusement, and shame. *Journal of Personality and Social Psychology*, *68*(3), 441-454.

Keltner, D. (1996). Evidence for the distinctness of embarrassment, shame, and guilt: A study of

 recalled antecedents and facial expressions of emotion. *Cognition & Emotion*, *10*(2),

 155–172.

Kemeny, M. E., Gruenewald, T. L., & Dickerson, S. S. (2004). Shame as the emotional response to

 threat to the social self: Implications for behavior, physiology, and health. *Psychological*

 *Inquiry,* *15*(2), 153-160.

Kirschbaum, C., Pirke, K. M., & Hellhammer, D. C. (1993). The “Trier Social Stress Test” - A tool

 for investigating psychobiological stress responses in a laboratory setting.

 *Neuropsychobiology*, *28*(1-2), 76–81.

Kirschbaum, Clemens, Wüst, S., & Hellhammer, D. (1992). Consistent sex differences in cortisol

 responses to psychological stress. *Psychosomatic Medicine*, *54*(6), 648–657.

Kudielka, B. M., Hellhammer, D. H., & Wüst, S. (2009). Why do we respond so differently?

 Reviewing determinants of human salivary cortisol responses to challenge.

 *Psychoneuroendocrinology*, *34*(1), 2-18.

Lighthall, N. R., Mather, M. & Gorlick, M. A. (2009). Acute stress increases sex differences in risk

 seeking in the balloon analogue risk task. *PLoS One* 4(7), e6002, doi:

 10.1371/journal.pone.0006002.

Lovallo, W.R. & Thomas, T.L. (2000). Stress hormones in psychophysiological research. In

 Cacioppo, J.T., Tassinary, L.G. & Berntson, G.G (Eds.), *Handbook of Psychophysiology*, 2nd

 ed., (342–367). Cambridge: Cambridge University Press.

Lundberg, U., Hedman, M., Melin, B., & Frankenhaeuser, M. (1989). Type A behavior in healthy

 males and females as related to physiological reactivity and blood lipids. *Psychosomatic*

 *Medicine*, *51*(2), 113–122.

MacLean, P. D. (1990). *The triune brain in evolution: Role in paleocerebral functions*. New York: Springer.

McBurnett, K., Lahey, B. B., Rathouz, P. J., & Loeber, R. (2000). Low salivary cortisol and

 persistent aggression in boys referred for disruptive behavior. *Archives of General*

 *Psychiatry*, *57*(1), 38-43.

McGonagle, K. A., & Kessler, R. C. (1990). Chronic stress, acute stress, and depressive symptoms.

 *American Journal of Community Psychology*, *18*(5), 681–706.

Mehta, P. H., Jones, A. C., & Josephs, R. A. (2008). The social endocrinology of dominance: Basal

 testosterone predicts cortisol changes and behavior following victory and defeat. *Journal*

 *of Personality and Social Psychology*, *94*(6), 1078-1093.

Mehta, P. H., & Josephs, R. A. (2010). Testosterone and cortisol jointly regulate dominance:

 Evidence for a dual-hormone hypothesis. *Hormones and Behavior*, *58*(5), 898-906.

Minkley, N., Schröder, T. P., Wolf, O. T., & Kirchner, W. H. (2014). The socially evaluated cold-

 pressor test (SECPT) for groups: Effects of repeated administration of a combined

 physiological and psychological stressor. *Psychoneuroendocrinology*, *45*, 119–127.

Montoya, E. R., Terburg, D., Bos, P. A., & Van Honk, J. (2012). Testosterone, cortisol, and

 serotonin as key regulators of social aggression: A review and theoretical perspective.

 *Motivation and Emotion*, *36*(1), 65–73.

Moss, H. B., Vanyukov, M. M., & Martin, C. S. (1995). Salivary cortisol responses and the risk for

 substance abuse in prepubertal boys. *Biological Psychiatry*, *38*(8), 547-555.

Nettle, D., Harper, Z., Kidson, A., Stone, R., Penton-Voak, I. S., & Bateson, M. (2013). The

 watching eyes effect in the Dictator Game: It's not how much you give, it's being seen to

 give something*. Evolution and Human Behavior*, *34*(1), 35-40.

Niederle, M., & Vesterlund, L. (2007). Do women shy away from competition? Do men compete

 too much? *The Quarterly Journal of Economics*, *122*(3), 1067–1101.

Oosterlaan, J., Geurts, H. M., Knol, D. L., & Sergeant, J. A. (2005). Low basal salivary cortisol is

 associated with teacher-reported symptoms of conduct disorder. *Psychiatry Research*,

 *134*(1), 1-10.

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory

 paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain*

 *Mapping*, *25*(1), 46–59.

Pabst, S., Brand, M., & Wolf, O. T. (2013). Stress effects on framed decisions: There are

 differences for gains and losses. *Frontiers in Behavioral Neuroscience*, *7*, 142. doi:

 10.3389/fnbeh.2013.00142.

Pajer, K., Gardner, W., Rubin, R. T., Perel, J., & Neal, S. (2001). Decreased cortisol levels in

 adolescent girls with conduct disorder. *Archives of General Psychiatry*, *58*(3), 297-302.

Piazza, P.V., & Le Moal, M., (1997). Glucocorticoids as a biological substrate of reward:

 Physiological and pathophysiological implications. *Brain Research Reviews*, *25*(3), 359-72.

Pliszka, S. R. (1999). The psychobiology of oppositional defiant disorder and conduct disorder. In

 Juay, U. C. & Hogan, A. E. (1999) *Handbook of disruptive behavior disorders* (371-395).New York: Kluwer Academic Publishers.

Popma, A., Vermeiren, R., Geluk, C. A., Rinne, T., van den Brink, W., Knol, D. L., . . . Doreleijers,

 T. A. (2007). Cortisol moderates the relationship between testosterone and aggression in

 delinquent male adolescents. *Biological Psychiatry*, *61*(3), 405-411.

Putman, P., Antypa, N., Crysovergi, P., & Van Der Does, W. A. J. (2010). Exogenous cortisol

 acutely influences motivated decision making in healthy young men.

 *Psychopharmacology*, *208*(2), 257–263.

Putman, P., Hermans, E. J., Koppeschaar, H., van Schijndel, A., & van Honk, J. (2007). A single

 administration of cortisol acutely reduces preconscious attention for fear in anxious

 young men. *Psychoneuroendocrinology*, *32*(7), 793-802.

Putman, P., Hermans, E. J., & Van Honk, J. (2010). Cortisol administration acutely reduces

 threat-selective spatial attention in healthy young men. *Physiology & Behavior*, *99*(3),

 294-300.

Putman, P., & Roelofs, K. (2011). Effects of single cortisol administrations on human affect

 reviewed: Coping with stress through adaptive regulation of automatic cognitive

 processing. *Psychoneuroendocrinology*, *36*(4), 439–448.

De Quervain, D. J. F., & Margraf, J. (2008). Glucocorticoids for the treatment of post-traumatic

 stress disorder and phobias: A novel therapeutic approach. *European Journal of*

 *Pharmacology*, *583*(2), 365-371.

De Quervain, D. J. F., Bentz, D., Michael, T., Bolt, O. C., Wiederhold, B. K., Margraf, J., & Wilhelm,

 F. H. (2011). Glucocorticoids enhance extinction-based psychotherapy. *Proceedings of the*

 *National Academy of Sciences*, *108*(16), 6621-6625.

Quinn, M., Ramamoorthy, S., & Cidlowski, J. A. (2014). Sexually dimorphic actions of

 glucocorticoids: Beyond chromosomes and sex hormones. *Annals of the New York*

 *Academy of Sciences*, *1317*(1), 1-6.

RCoreTeam. (2014). *R: A Language and Environment for Statistical Computing*. Vienna, Austria:

 R Foundation for Statistical Computing. Retrieved from http://www.R-project.org

Rimmele, U., Seiler, R., Marti, B., Wirtz, P. H., Ehlert, U., & Heinrichs, M. (2009). The level of

 physical activity affects adrenal and cardiovascular reactivity to psychosocial stress.

 *Psychoneuroendocrinology*, *34*(2), 190–198.

Rohleder, N., Beulen, S. E., Chen, E., Wolf, J. M., & Kirschbaum, C. (2007). Stress on the dance

 floor: The cortisol stress response to social-evaluative threat in competitive ballroom

 dancers. *Personality and Social Psychology Bulletin*, *33*(1), 69–84.

Salvador, A. (2005). Coping with competitive situations in humans. *Neuroscience &*

 *Biobehavioral Reviews*, *29*(1), 195-205.

Sassenrath, C., Sassenberg, K., & Semin, G. R. (2013). Cool, but understanding… Experiencing

 cooler temperatures promotes perspective-taking performance. *Acta Psychologica*,

 *143*(2), 245-251.

Scerbo, A. S., & Kolko, D. J. (1994). Salivary testosterone and cortisol in disruptive children:

 Relationship to aggressive, hyperactive, and internalizing behaviors. *Journal of the*

 *American Academy of Child & Adolescent Psychiatry*, *33*(8), 1174-1184.

Schelling, G., Kilger, E., Roozendaal, B., De Quervain, D. J. F., Briegel, J., Dagge, A., . . .

 Kapfhammer, H. P. (2004). Stress doses of hydrocortisone, traumatic memories, and

 symptoms of posttraumatic stress disorder in patients after cardiac surgery: A

 randomized study. *Biological Psychiatry*, *55*(6), 627-633.

Schelling, G., Roozendaak, B., & De Quervain, D. J. F. (2004). Can posttraumatic stress disorder

 be prevented with glucocorticoids? *Annals of the New York Academy of Sciences*,

 *1032*(1), 158-166.

Schommer, N. C., Hellhammer, D. H., & Kirschbaum, C. (2003). Dissociation between reactivity

 of the hypothalamus-pituitary-adrenal axis and the sympathetic-adrenal-medullary

 system to repeated psychosocial stress. *Psychosomatic Medicine*, *65*(3), 450–460.

Schoofs, D., Preuß, D., & Wolf, O. T. (2008). Psychosocial stress induces working memory

 impairments in an N-back paradigm. *Psychoneuroendocrinology*, *33*(5), 643-653.

Schoofs, D., Wolf, O. T, & Smeets, T. (2009). Cold pressor stress impairs performance on working memory tasks requiring executive functions in healthy young men. *Behavioral Neuroscience*, *123*(5), 1066-1075.

Schwabe, L., Haddad, L., & Schachinger, H. (2008). HPA axis activation by a socially evaluated

 cold-pressor test. *Psychoneuroendocrinology*, *33*(6), 890–895.

Shively, C. A., Laber-Laird, K., & Anton, R. F. (1997). Behavior and physiology of social stress and

 depression in female cynomolgus monkeys. *Biological Psychiatry*, *41*(8), 871–882.

Shoal, G. D., Giancola, P. R., & Kirillova, G. P. (2003). Salivary cortisol, personality, and aggressive

 behavior in adolescent boys: A 5-year longitudinal study. *Journal of the American*

 *Academy of Child & Adolescent Psychiatry*, *42*(9), 1101-1107.

Smith, T. W., & Jordan, K. D. (2014). Interpersonal motives and social‐evaluative threat: Effects

 of acceptance and status stressors on cardiovascular reactivity and salivary cortisol

 response. *Psychophysiology*, *52*(2), 269-276.

Soravia, L. M., Heinrichs, M., Aerni, A., Maroni, C., Schelling, G., Ehlert, U., . . . De

 Quervain, D. J. F. (2006). Glucocorticoids reduce phobic fear in humans. *Proceedings of*

 *the National Academy of Sciences*, *103*(14), 5585-5590.

Taylor, V. A., Ellenbogen, M. A., Washburn, D., & Joober, R. (2011). The effects of glucocorticoids

 on the inhibition of emotional information: A dose–response study. *Biological*

 *Psychology*, *86*(1), 17-25.

Uhart, M., Chong, R.Y., Oswald, L., Lin, P-I. & Wand, G.S. (2006). Gender differences in

 hypothalamic-pituitary-adrenal (HPA) axis reactivity. *Psychoneuroendocrinology*, *31*,

 642–652.

Ulrich-Lai, Y. M., & Herman, J. P. (2009). Neural regulation of endocrine and autonomic stress

 responses. *Nature Reviews Neuroscience*, *10*(6), 397–409.

Van den Bos, R., Harteveld, M. & Stoop, H. (2009) Stress and decision-making in humans:

 Performance is related to cortisol reactivity, albeit differently in men and women.

 *Psychoneuroendocrinology,* *34*, 1449–1458.

Van Den Bos, W., Golka, P. J., Effelsberg, D., & McClure, S. M. (2013). Pyrrhic victories: the need

 for social status drives costly competitive behavior. *Frontiers in Neuroscience*, *189*, doi:

 10.3389/fnins.2013.00189.

Van de Weil, N. M. H., van Goozen, S. H., Matthys, W., Snoek, H., & van Engeland, H. (2004).

 Cortisol and treatment effect in children with disruptive behavior disorders: A

 preliminary study. *Journal of the American Academy of Child & Adolescent Psychiatry*,

 *43*(8), 1011-1018.

van Goozen, S. H., Matthys, W., Cohen-Kettenis, P. T., Gispen-de Wied, C., Wiegant, V. M., & van

 Engeland, H. (1998). Salivary cortisol and cardiovascular activity during stress in

 oppositional-defiant disorder boys and normal controls. *Biological Psychiatry*, *43*(7),

 531-539.

van Peer, J. M., Spinhoven, P., & Roelofs, K. (2010). Psychophysiological evidence for cortisol-

 induced reduction in early bias for implicit social threat in social phobia.

 *Psychoneuroendocrinology*, *35*(1), 21-32.

Vanyukov, M. M., Moss, H. B., Plail, J. A., Blackson, T., Mezzich, A. C., & Tarter, R. E. (1993).

 Antisocial symptoms in preadolescent boys and in their parents: Associations with

 cortisol. *Psychiatry Research*, *46*(1), 9-17.

Vreeburg, S. A., Zitman, F. G., van Pelt, J., DeRijk, R. H., Verhagen, J. C., van Dyck, R., …&Penninx, B. W. (2010). Salivary cortisol levels in persons with and without different anxiety disorders.

 *Psychosomatic Medicine*, *72*(4), 340-347.

Williams, L. E., & Bargh, J. A. (2008). Experiencing physical warmth promotes interpersonal

 warmth. *Science*, *322*(5901), 606-607.

Zilioli, S., & Watson, N. V. (2012). The hidden dimensions of the competition effect: Basal

 cortisol and basal testosterone jointly predict changes in salivary testosterone after social

 victory in men. *Psychoneuroendocrinology*, *37*(11), 1855-1865.

## Appendix

## Table legends

**Table 1.** The differential effect of stress on cortisol. The first three rows give the difference between measured salivary cortisol in the stress treatment and the no stress treatment, at each of the three measured time points (baseline, peak, endline). The fourth row gives the effect of stress treatment on *cortisol responses*, defined for each participant as the difference between peak salivary cortisol (25 minutes post-stressor) and baseline salivary cortisol (5 minutes before stressor onset). Analogously, the fifth row shows the effect of stress treatment on cortisol recovery in terms of the difference between endline and peak.

**Table 2.** The differential effect of stress on affect. The stress treatment caused higher self-reported annoyance and unpleasantness in participants, and lower levels of happiness.

## Figure legends

**Figure 1.** Contests and choices. (a) Contests involved performance on the N-back test, which involves holding sequences of random letters of the Roman alphabet in memory. We chose the N-back because it correlates with IQ and therefore has value for one’s social status. (b) These decision screens were each presented once in random order, and participants had unlimited time to make their decision. In each case they decided whether or not to enter the N-back contest. Contests varied in publicity and ambiguity. By contrasting participation across rows, we estimated publicity or social avoidance. We asked whether this avoidance varied with stress treatment or cortisol response (see main text). By examining row by column interactions, we estimated social avoidance was higher in ambiguous (mixed ability) public contests.

**Figure 2.** Effect of stress on (a) cortisol response, (b) self-reported affect, (c) pre-choice guessed rank and (d) post-choice N-back performance. (a) Cortisol significantly increased in both Stress and No stress treatments, but was larger in the Stress treatment, particularly among men. Both treatments showed a cortisol recovery between 25 and 70 minutes. This recovery was steeper in the Stress treatment. (b) Self-reported unpleasantness and annoyance were larger in the Stress treatment. (c) Stress did not cause detectable changes in the distribution of participants’ predicted rank in the N-back contest. (d) Stress treatment did not cause detectable changes in post-choice N-back performance at peak cortisol.

**Figure 3.** Stress and cortisol on competitive behavior. (a) The fraction of people who chose to compete in each treatment of the publicity x ambiguity x stress design. The publicity x ambiguity treatments are denoted A = private/unambiguous, B = private/ambiguous, C = public/unambiguous, D = public/ambiguous, following Figure 1b. The stress treatment is prefixed with an asterisk \*. There was strong evidence for social avoidance. No other effects were discernible. (b) An ordered logistic regression confirmed that stress treatment had approximately zero effect on social avoidance, ambiguity aversion or their interaction. (d) An ordered logistic regression revealed that cortisol response predicted lower social avoidance. (c) This plot visualizes the relationship between cortisol response and social avoidance.

**Figure 4.** Multiple regression of cortisol response and choice behavior on various participant indices. The relationship between social avoidance and cortisol response persists after accounting for additional participant-specific variables, such as participants’ belief/prediction about their rank, their affective response to the stressor, and so on. (a) The partial regression effects of various participant-specific variables on cortisol response, as estimated using simple Gaussian linear regression. This shows that cortisol response predicts lower social avoidance, even after accounting for other participant-specific variables. (b) The partial regression effects of these variables, and of cortisol response, on social avoidance. These parameters were estimated using ordered logistic regression. (c) and (d) For completeness, these two plots give the equivalent relationships for ambiguity aversion and the interaction between ambiguity and social avoidance. Only the dependent variable distinguishes these two models from that depicted in Figure 4b.

**Figure 5.** Panel (a) provides the 8 estimated parameters in Equation 2 of our GLMM. Error bars represent 95% confidence intervals. Panel (b) shows the same analysis, but the stress dummy  was replaced with participants’ measured cortisol response . Again, cortisol predicted higher participation in public contests relative to private contests (top row of Panel 8b).

**Supplemental Figure 6.** Any participant electing to enter a public contest would have their photograph and rank (within their group of five) projected onto the wall of the testing room.

**Supplemental Figure 7.** Timeline of each experimental session.

**Supplemental Figure 8.** The SECPT-G testing room. Participants were individually welcomed by an assistant, who instructed them of the ground rules for this experiment including that communication and mobile phones were forbidden. This assistant then conveyed each participant into the SECPT-G testing room, depicted here, where they were welcomed and instructed by a different individual, experimenter 1 (E1). Two additional experimenters - E2/E3 - were present, but did not speak, nor were introduced. E1 was always male, and E2/E3 were always one male and one female

(Schwabe et al., 2008)­. They each carried a clipboard and notepad.

1. Interestingly, while the literature has been preoccupied with cortisol responses to socio-evaluative threat or stress, the cortisol system also potently responds to prospective rewards (see Piazza & Moal 1997 Brain Research Reviews for an overview). Nearly two decades ago, Piazza & Le Moal (1997) introduced the idea that cortisol might aid in obtaining rewarding outcomes in the face of threat by amplifying the rewarding effects of positive reinforcers, allowing for a flexible adaptation to situations that present both aversive and rewarding elements. [↑](#footnote-ref-1)
2. Related work might suggest that acute cortisol may *reduce* aversion to challenges or threats, as measured by reductions of fear for specific stimuli and suppression of fear-related memory (Schelling et al., 2004; Schelling, Roozendaal, & De Quervain, 2004; Soravia, Heinrichs, Aerni, Maroni, Schelling, et al., 2006; Jackson, Payne, Nadel, & Jacobs, 2006; [Putman, Hermans, Koppeschaar, van Schijndel, & van Honk, 2007](#_ENREF_1); Putman, Hermans, & van Honk, 2010; van Peer, Spinhoven, & Roelofs, 2010; Taylor, Ellenbogen, Washburn, & Joober, 2011; De Quervain & Margraf, 2008; De Quervain et al., 2011) [↑](#footnote-ref-2)
3. Contests that were not ability-matched were termed *ambiguous*: Even if an individual were certain of his absolute ability, his competitor’s ability, and hence his relative ability, it was still categorized as ambiguous. [↑](#footnote-ref-3)
4. By "peak" cortisol, we mean the maximum cortisol measurement of our three samples. This maximum typically fell at 25 mins, in agreement with prior findings that the peak cortisol is roughly around this point in time. [↑](#footnote-ref-4)
5. This modification arose because the standard Socially Evaluated Cold Pressor Test (SECPT) by (Schwabe et al., 2008) is applied to one person at a time. Other existing stress tests may be applied to small groups of participants simultaneously, e.g. the Trier Social Stress Test (Dawans et al., 2011). Yet we required a larger group for our purposes. Our larger sample size enabled us to reliably construct sub-groups of participants with matched abilities on an N-back test, which were necessary for the design of our study (see below). [↑](#footnote-ref-5)
6. Relative payment schemes are competitive in the sense that they induce a conflict of interest between participants: if one participant wins money, the others cannot win money. This situation was known to our subjects a priori. In contrast, in absolute payment schemes there is no conflict of interest: everyone can win (or lose) independently of other people’s performance. [↑](#footnote-ref-6)
7. Thus participants who had chosen not to compete in the selected contest (absolute payment) were destined to be paid proportionally to their percentage correct and to remain anonymous. In contrast, participants who had chosen to enter the selected contest (relative payment) received the bonus if and only if they were the top scorer in their group, but also received any non-pecuniary outcomes of the contest. For example, if the selected contest was public, then their rank was publicized. [↑](#footnote-ref-7)
8. This hypothesis arises from considering participants’ second order beliefs, in particular their beliefs about how their performance will be evaluated by others. If participants believe that observers will discount their success/failure in the contest to chance rather than ability, the reputation stakes are lower. By this reasoning, our participants should feel lower reputation stakes in the matched contests because observers know that success only rests on chance in these matched contests: by construction all contestants have an equal chance of winning a priori. [↑](#footnote-ref-8)
9. This relationship between cortisol and behavior remained statistically significant at the same level when we included day of testing as a factor in the regression. [↑](#footnote-ref-9)
10. In other words, we ensure that any cortisol-behavior relationship does not reduce to any linear combination of these other variables. This approach to statistical control is the parametric equivalent of non-parametric 'stratification' methods. [↑](#footnote-ref-10)