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Intranasal Oxytocin, Testosterone reactivity, and Human Competitiveness.

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Abstract

Competitiveness is an essential feature of human social interactions. Despite an extensive body of research on the underlying psychological and cultural factors regulating competitive behavior, the role of biological factors remains poorly understood. Extant research has focused primarily on sex hormones, with equivocal findings. Here, we examined if intranasal administration of the neuropeptide oxytocin (OT) – a key regulator of human social behavior and cognition – interacts with changes in endogenous testosterone (T) levels in regulating the willingness to engage in competition. In a double-blind placebo-control design, 204 subjects (102 females) self-administrated OT or placebo and were assessed for their willingness to compete via an extensively-validated laboratory paradigm. Salivary T concentrations were measured throughout the task to assess endogenous reactivity. While in females, both under OT and under placebo, T-reactivity during competition were not associated with competitiveness; in males, the association between T-reactivity and competitiveness was OT dependent. That is, males under placebo, demonstrated a positive correlation between T-reactivity and the willingness to engage in competition while no association was observed in males receiving OT. The interaction between OT, T-reactivity, and sex on competitive preferences remained significant even after controlling for potential confounds such as performance, self-confidence, and risk-aversion, suggesting that this three-way interaction effect was specific to competitive motivation rather than to other generalized processes. These findings deepen our understanding of the biological processes underlying human preferences for competition and extend the evidence base for the interplay between hormones in affecting human social behavior.

1. Introduction

Human social relations can frequently be described as contests in which competing agents have the opportunity to expend scarce resources – such as effort, money, or time – in order to affect the probabilities of winning prizes (Darwin, 1871, 1859; Dechenaux et al., 2015). Winning a competition, of course, may carry considerable benefits (e.g., territory, prestige, wealth), however, losing may have considerable drawbacks; these include both the forgone resources invested in the competition, as well as the consequences of losing (e.g., physical harm, loss in status). Thus, as part of their social interactions, individuals often face a decision whether to compete or not.

The last decade has seen the blossoming of an active program of research examining differences in competitive preferences under controlled laboratory conditions. In the classic paradigm (Niederle and Vesterlund, 2007), participants are asked to choose how they will be paid for performing a task. Under a piece-rate payment, participants are paid for each correct solution, and their earnings under this scheme are solely a function of their own performance. Alternatively, under a tournament-style payment, participants are paid a larger sum, but only if their performance is better relative to all other participants in their group. Thus, by selecting a tournament payment, participants demonstrate a willingness to engage in competition. Moreover, by including additional assessments of self-confidence, risk aversion, and performence, the paradigm is able to disentangle the motivation to compete from other potentially confounding factors.

This paradigm has been widely used in the economics literature to test the hypothesis that the well-established and cross-cultural gap between males and females in wages and social position[1] may be due, not only to structural factors such as gender-bias or to differences in skills, but also due to a difference in the willingness to engage in (or shy away from) competitive environments. Indeed, research has demonstrated that sex-differences in competitive preferences can be manipulated by targeting key processes that socialize males and females differently to competitive environments (Booth et al., 2019; Boschini et al., 2019; Cassar et al., 2016; Flory et al., 2018; Gneezy et al., 2009; Knight et al., 1981; Müller and Schwieren, 2012; Zhong et al., 2018; Zhong and Fu, 2019).

Despite gains in understanding the contextual and psychological factors affecting human competitiveness, the contribution of biological factors remains poorly understood. This is a crucial next step for advancing a more integrated perspective of the processes which give rise to sex differences in human psychology and behavior (Eagly and Wood, 2013). Research in social neuroendocrinology demonstrates the essential effects of hormones in regulating emotions, cognition, and behavior (Bos et al., 2012; McCall and Singer, 2012). Traditionally, research into the biological foundations of competitive behaviors has focused on gonadal hormones (Booth et al., 2006; Carré et al., 2011; Carré and Archer, 2018; Mazur and Booth, 1998; see Eisenegger et al., 2011 for a review).

Laboratory studies find that while baseline testosterone (T) levels do not show a consistent association with competitive preferences (Apicella et al., 2011; Zhong et al., 2018), rather it is changes in T levels that serve as a better indicator (Buckert et al., 2017; Zhong and Fu, 2019). Consistent with this finding, predominant theories characterizing the social neuroendocrinology of status, notably the *challenge hypothesis* and the *biosocial model of status*, place rises in T levels as indicators of competitive engagement. While conceptually similar, the two theories make disparate predictions regarding the contexts under which T levels should rise. The challenge hypothesis proposes that T increases whenever social status is being challenged (Archer, 2006; Wingfield et al., 1990). In contrast, the biosocial model of status proposes that T increases or decreases depending on whether social status is gained or lost (Mazur, 1985).

Given that competition is inherently social, it can be reasoned that, besides testosterone, the neuropeptide hormone oxytocin (OT) – a key regulator of social approach and motivation – may also play a role in regulating competitive preferences. In the brain, oxytocin exerts varied effects on social cognition and behavior, either by its action as a neurotransmitter (Insel, 2010; Meyer-Lindenberg, Domes, Kirsch, & Heinrichs, 2011) via projections from the hypothalamus to limbic sites, or as a neurohormone via diffusion through the intracellular space to local or distant targets (Insel, 2010; Meyer-Lindenberg et al., 2011).

Despite an extensive body of research demonstrating that OT regulates social behavior and cognition, it has not yet been implicated in regulating competitive preferences. OT has been theorized to modulate the motivation component of social approach and withdrawal behaviors, via its connection to dopaminergic neurons in the nucleus accumbens, (Bethlehem et al., 2014; Gordon et al., 2011; Kemp and Guastella, 2010; Stavropoulos and Carver, 2013). This represents a shift from earlier findings which characterized OT effects as largely prosocial, based on findings that intranasal OT increases interpersonal trust and generosity, and facilitates empathy and affiliation (reviewed in MacDonald and MacDonald, 2010).

The vast majority of experiments examining the effects of intranasal OT have been conducted on males; however, recent studies suggest that the manner by which OT regulates social motivation differ between males and females. For example, OT has been shown to facilitate sex-specific strategies for interacting with the social environment, including differential sensitivity to social cues of threat or affiliation (Fischer-Shofty et al., 2010; Gao et al., 2016; Luo et al., 2017; Rilling et al., 2014; Scheele et al., 2014; Xu et al., 2018). In mice exposed to a social stressor, OT administration increases social interactions in males, but leads to greater withdrawal in females (Steinman et al., 2016). These findings of sex-specific effects of OT on social behavior and motivation, parallel the finding of sex differences in OT receptor expression (Zingg and Laporte, 2003), sexually dimorphic effects of intranasal OT on amygdala (Gao et al., 2016; Luo et al., 2017) (Gao et al., 2016; Luo et al., 2017) and putamen reactivity (Feng et al., 2015), and the role of gonadal hormones estradiol and testosterone (Johnson et al., 1991) in regulating OT expression in the brain (Dumais and Veenema, 2016).

Amidst ongoing interest in understanding the factors driving differences in competitive preferences between males and females, here we test for interacting roles between (exogenous) OT and (endogenous) T on competitive preferences. Despite the prominent roles of T and OT in modulating social behavior (Crespi, 2016), few studies have examined their possible interaction in humans. Animal models raise the intriguing possibility that OT social effects may be contingent on T levels (Winslow and Insel, 1991). In one of the few studies in humans examine these hormones together, high endogenous T levels were associated with less attentional processing of infant faces. This effect was canceled after intranasal OT administration (Holtfrerich et al., 2016). Here, we aimed to test if the association between T-reactivity and competitive behavior is moderated by exogenous administration of OT.

2. Methods

2.1. Subjects

Two hundred and four subjects (102F) participated in a double-blind, placebo-controlled, between-subject design experiment. Subjects were recruited in groups of eight or twelve, with an even number of males and females in each of the 18 total sessions. The sample size was determined using G*power 3.1.9.2 with squared f of 0.04, which is within the range that is suggested to be sufficient for detecting an effect in experiments using intranasally applied OT (Walum et al., 2016).

Subjects were recruited across multiple campus sites to capture a broad assortment of undergraduate majors across the social science, humanities, life and physical sciences. Subjects were <35 years old, had no history of psychiatric or endocrine illness, smoked less than 15 cigarettes a day, and were not taking any prescription medications that might interact with OT. For females, exclusion criteria also included current pregnancy or breastfeeding. Subjects were instructed to refrain from smoking, eating, or drinking (except water) for 2 h before the experiment, and from physical activity, alcohol, and caffeine consumption for 24 h before the experiment. Subjects received 100 NIS (~ 25$) or equivalent course credit for completing the study, and an additional fee (ranging from 0 to 58 NIS) based on their performance and decisions. The study was approved by the Helsinki Committee of the local university hospital.

2.2. Mood Assessment

To test if OT had any general effects on subjective state, subjects filled a visual analog scale (VAS) questionnaire directly before intranasal administration, and again at the conclusion of the experiment. The 8-items assessed were: working capacity, tiredness, anxiety, anger, conversation, closeness, concentration, working capacity, and sadness. Each item was scaled from 1 ("not at all") to 10 ("very much"). As was expected, the differences between the first and the second VAS scores were not affected by OT (t-tests for change scores; all p's > 0.05).

2.3. Saliva Samples and T Assays

Saliva samples were collected at four time-points during each session, but for this study, only the first three-samples were analyzed (since the fourth sample was taken after participants completed another unrelated experiment; see Procedure section 2.7. and Fig.1). T levels were measured from saliva by passive drool. Subjects were asked to spit into a small polystyrene tube. Saliva samples were frozen immediately following collection and stored at −80°C. At the end of the collection period, samples were assayed in our laboratory using competitive enzyme immunoassays for T (Salimetrics EIA, product number: 1-2402). Sample and standard reactions were run in duplicate, and the sample concentrations used in the analyses are the averages of the duplicates. Interassay coefficients of variation were 12.35% for low pools and 6.65% for high pools. The intrassay coefficient of variation was 5.76%. Samples for whom the coefficient of variation exceeded 15% between duplicates, indicating unreliable assay results, were excluded from analyses (overall eight samples; Time-1 – 4 samples, Time-2 – 1 sample, Time-3 – 3 samples). The intrassay coefficient of variation for the remaining samples was 4.81%. In addition, T concentrations could not be obtained for 14 samples due to insufficient saliva provided during the collection periods (Time-1 – 6 samples, Time-2 – 4 samples, Time-3 – 4 samples).

2.4. Drug Administration

Subjects self-administered either 24 IU of OT (three puffs of 4 IU in each nostril; Syntocinon spray; Novartis, Basel, Switzerland) or a placebo under an experimenter's supervision. The placebo included all the Syntocinon ingredients except for the active hormone. The administration of OT or placebo was randomized within sex to ensure an equal number of males and females in every condition. Both the experimenter and the subjects were blind to the drug condition, and subjects could not differentiate between OT and placebo (Fisher's exact test, p = .60). The experimental paradigm started approximately 30 m after hormone administration, of which, subjects could read

National Geographic magazines for the first 25 m. In the remaining 5 min, the second saliva sample was collected.

2.5. Competitive Preferences Paradigm

Subjects were assigned to a four-person group, and were not informed who are the other three subjects in their foursome. Next, subjects completed a standardized set of arithmetic tasks (adding five 2-digit numbers), which differed only in the mechanism by which subjects were paid for the number of problems they solved. In the first 3-rounds, subjects tried to solve as many problems as they could during 4 m per round. Subjects were allowed to use a pencil and paper for calculations, but not a calculator. Upon submitting an answer to the designated box, subjects were informed if it was correct, a counter of solved-problems was updated, and the next problem was shown. During each task, a countdown timer was shown on the screen.

The payment-schemes were as follows:

Round-1 (Piece-Rate Payment-Scheme). In this round, each subject received one NIS for every problem solved, regardless of how many problems the other subjects in the foursome solved.

Round-2 (Tournament Payment-Scheme). In this round, the subject, in each foursome, who solved the most problems received four NIS for every solution, while the remaining three subjects received nothing. In case of a tie, each one of the winners received one NIS per solved-problem.

Round-3 (Payment-Scheme Choice). In this round, before performing the task, subjects decided which payment-scheme composition will be applied to their performance. That is, each subject chose, by a slider scale, how to allocate a 100-point endowment between the piece-rate and the tournament payment-schemes[2]. For each point subjects allocated to the piece-rate scheme, they received 0.01 NIS for every solved-problem. For each point subjects allocated to the tournament-scheme, they received 0.04 NIS for every solved-problem, but only if the number of problems they solved was greater than the number of problems that each of the three other subjects solved in Round-2 (tournament)[3]. Otherwise, no payment was given for points that were allocated to the tournament-scheme. In case of a tie, subjects received 0.01 NIS per solved-problem for each point that they allocated to the tournament-scheme. Subjects' point-allocation did not affect the earnings of others, nor did it depend on how the other subjects allocated their points.

Round-4 (Past Performance). Subjects were reminded of their performance in Round-1, and were asked to decide (retroactively) which payment-scheme composition would be applied to it. For each point subjects allocated to the piece-rate scheme, they received 0.01 NIS for every problem they solved in Round-1. For each point subjects allocated to the tournament-scheme, they received 0.04 NIS for every problem they solved in Round-1, but only if the number of problems they solved in Round-1 was greater than the number of problems that each of the three other subjects solved at Round-1. Otherwise, no payment was given for points that were allocated to the tournament-scheme. In case of a tie, for each point that was allocated to the tournament-scheme, subjects received 0.01 NIS for every solved-problem. As in Round-3, subjects' point-allocation did not affect the earnings of others, nor did it depend on how the other subjects allocated their points.

Because, as opposed to Round-3, points allocated to tournament-scheme in Round-4 do not require subjects to actually engage in a competition, but rather are based on their previous performance, point allocation in this round acts as an important control for other general or unmeasured factors associated with the tournament, such as performance anxiety.

Subjects' Payment. Before Round-1, subjects were informed that their total payment would be set according to their earnings in one of four rounds which would be randomly chosen at the end of the experiment. This payment procedure ensured that decisions in a given round are not affected by the outcomes of other rounds (wealth effect).

To minimize the effect of the first round's outcomes on subjects' point-allocations in subsequent rounds, subjects were not informed regarding their performance relative to other subjects until the very end of the experimental session.

2.6. Performance, Self-Confidence, and Risk-preferences

Performance was operationalized as the number of solved-problems in Round-1 and Round-2, since only in these rounds, payment schemes were identical across all subjects. To assess subjects' confidence on their performance at the arithmetic tasks, following the four rounds, subjects were asked to guess their rank (from first to fourth) in Round-1 and Round-2. Each successful guess awarded subjects with one NIS. Subjects' risk-preferences were measured by a price list design (Zhong et al., 2018). Subjects were asked to make 10 choices between two alternatives. For every choice, option A was winning 10 NIS with a 50% chance or 0 NIS with a 50% chance, and option B was winning, with complete certainty, an increasing amount of NIS, starting with 2.5 NIS, in the first choice, increasing by 0.5 NIS on every choice, up to 7 NIS in the last choice. A later switching point (from option A to option B) indicates a preference. One randomly chosen subject in every experimental session received payment based on one of his or her choices.

2.7. Procedure

To control for diurnal rhythms in circulating OT levels, all experimental sessions were scheduled for 14:00, in keeping with the recommended guidelines for OT administration studies (Guastella et al., 2013). After signing a written consent form, subjects were seated in front of computers at cubicles, the first saliva (Time-1) sample was collected, and subjects completed the mood assessment measure. Then, subjects self-administered either OT or a placebo. Twenty-five minutes after the administration, the second saliva sample (Time-2) was collected. Approximately 30 minutes after hormone administration, the subjects completed the competitive preferences paradigm, and the self-confidence and risk-preference measures, which were followed by the collection of the third saliva sample (Time-3). After two additional unrelated experiments, subjects completed the mood assessment measure and a demographic questionnaire again, and the fourth saliva sample (Time-4) was collected. At the end of the session, subjects were directed to another room and received payment privately (see Fig. 1 for the experiment’s timeline). Subjects were not allowed to communicate with each other throughout the session.

2.8. Statistical Analyses

We conducted logit and linear regression analyses with treatment (placebo/ OT), T baseline levels and reactivity, and sex (female/male) as between-subjects variables. The willingness to engage in competition was assessed by applying a general linear model with a logit link function and the binomial distribution on the proportion of points allocated to tournament in Round-3 (ranging between 0 and 1). To account for potential heterogeneity between experimental sessions, standard errors were clustered by session (using the Huber-white sandwich with d.f. correction).

To account for known sex differences in T levels (baseline levels in our sample; Males: $M = 150.87$, $SE = 5.57$, Females: $M = 50.96$, $SE = 2.00$, t-test on logarithmized values (192) = -21.12, $p < .001$), values at Time1-Time3 were standardized for each sex separately (to $M = 0$ and $SD = 1$). Outliers were winsorized to ± 3 SDs.

T-reactivity was assessed by regressing T levels (standardized and winsorized by sex) onto T levels (standardized and winsorized by sex) at an earlier time-point and saving the unstandardized residuals (Welker et al., 2017). For example, T-reactivity from Time-2 (pre-competition) to Time-3 (post-competition) was assessed by the unstandardized residuals of regressing T levels at Time-3 onto T levels at Time-2. Since the residuals represent changes in T levels that are not explained by T levels at the earlier time-point, this reactivity assessment is statistically independent of T levels at the earlier point. For all analyses, assessing T-reactivity as the absolute change in T levels did not affect the significance of the results.

3. Results

3.1. Is the Willingness to Compete Associated with Baseline T Concentrations?

Our critical measure of willingness to compete consists of the proportion of points subjects chose to allocate to the tournament-scheme in Round-3. Baseline T levels were not a significant predictor of the willingness to compete ($b = 0.08$, $SE = 0.04$, $p = .052$), nor did baseline T levels interact with OT, sex, or the OT × sex interaction to predict the willingness to compete (all p's > 0.05).

3.2. Do T-Reactivity, OT, and Sex Interact to Affect the Willingness to Engage in Competition?

Here, as well, our main variable of interest – the willingness to compete – consists of the proportion of points subjects chose to allocate to tournament-scheme in Round-3. OT treatment, T-reactivity from pre-competition (Time-2) to post-competition (Time-3), and sex were our main variables of interest. None of these variables were by themselves significant predictors of the proportion of points allocated to the tournament (all p's > .05; see Table 1 Model 1). Rather, the interaction between OT, T-reactivity, and sex, significantly predicted tournament point-allocation ($p = .036$; see Table 1 Model 3, and Fig. 2). In females, T-reactivity did not predict tournament point-allocation, neither under placebo ($b = 0.20$, $SE = 0.40$, $p = .620$), nor under OT ($b = 0.03$, $SE = 0.31$, $p = .915$). However, in males, T-reactivity was a significant predictor of points allocated to the tournament under placebo ($b = 1.33$, $SE = 0.32$, $p < .001$), but not under OT ($b = -0.03$, $SE = 0.35$, $p = .930$).

To examine the specificity of this three-way interaction (OT × T-reactivity x sex) on competitive motivation, we tested if these interactive effects could be accounted for indirectly, via their effect on performance, self-confidence or risk-preferences. While performance ($b = 0.14$, $SE = 0.03$, $p < .001$) and confidence ($b = 0.66$, $SE = 0.09$, $p < .001$) were strongly predictive of points allocated to the tournament-scheme in Round-3, risk was only marginally so ($b = 0.20$, $SE = 0.10$, $p = .063$). Nevertheless, the OT × T-reactivity × sex interaction was still a significant predictor of points allocated to the tournament-scheme even after controlling for performance, confidence and risk-preferences ($p = .010$, see Table 1 Models 4-6).

In Round-4, subjects allocated points retrospectively based on their performance in Round-1, but do not actually engage in a competition. While tournament point-allocation in Round-4 is significantly correlated with tournament point-allocation in Round-3 (r (202) = 0.41, $p < .001$), importantly, the three-way interaction of OT x T-reactivity x sex did not predict tournament point-allocation in Round-4, when competitive performance is absent ($b = -0.96$, $SE = 0.73$, $p = .188$). Notably, even after controlling for the combined effects of self-confidence, risk, and points allocated in Round-4, the OT × T-reactivity × sex interaction still predicted tournament point-allocation in Round-3 ($p = .029$, see Table 1 Model 7). Additional analyses showed that this finding was robust to additional controls for female menstrual cycle-phase and contraceptive use (see Supplemental Material for additional analysis).

3.3. Is T-Reactivity Dependent on OT Administration and Sex?

To examine if T-reactivity was itself dependent on OT administration, we regressed T-reactivity on OT, sex, and the OT x sex interaction. T-reactivity was not affected by OT administration (Time-1 to

Time-2: $b \approx 0.00$, $SE = 0.08$, $p = .953$; Time-1 to Time-3: $b = -0.08$, $SE = 0.09$, $p = .416$; Time-2 to T ime-3: $b = -0.07$, $SE = 0.07$, $p = .307$), sex (Time-1 to Time-2: $b = -0.03$, $SE = 0.08$, $p = .753$; Time-1 to Time-3: $b = -0.03$, $SE = 0.09$, $p = .704$; Time-2 to Time-3: $b = 0.01$, $SE = 0.05$, $p = .906$), or by the OT × sex interaction (Time-1 to Time-2: $b \approx 0.00$, $SE = 0.12$, $p = .986$; Time-1 to Time-3: $b = -0.10$, $SE = 0.16$, $p = .544$; Time-2 to Time-3: $b = -0.08$, $SE = 0.12$, $p = .532$), suggesting that OT administration itself did not alter T levels over the course of the study.

3.4. Do T-Reactivity, OT, and Sex Interact to Affect How 'Rationally' Participants Allocate Points to the Tournament?

Allocating points to the tournament is only worthwhile if a player has a chance of winning. While performance in the arithmetic task varied considerably between subjects, we next asked the question, if for a given level of performance, does the OT × T-reactivity × sex interaction affect the degree to which subjects optimize their points allocated to the tournament? Put differently, does the OT x T-reactivity x sex interaction affect the amount by which subjects maximize their total monetary return? We calculated the odds, for each subject, that the number of their solved-problems exceeded the number of solved-problems in the preceding round of three other randomly chosen subjects. Thus, for any given performance, we could estimate the probability of winning the tournament, and what the optimal proportion allocated to the tournament should be. Next, we calculated the gap between the actual proportion of points that subjects allocated to the tournament to the proportion that would maximize their expected total return. This allowed us to assess the total 'money on the table' left by each subject.

For a given number of solved-problems in Round-3, the 'Money on the table' (MOT) for subject *i* was defined by:

$$MOTi = \begin{cases} Ai - Pi^3 & if\ Pi^3 < Ai \\ 0 & if\ Pi^3 = Ai \\ (Pi^3 - Ai) \times 3 & if\ Pi^3 < Ai \end{cases}$$

Where P*i* denotes the percentile rank of subject-*i*'s number of solved-problems in Round-3 within the distribution of number of solved-problems in Round-2 among all subjects in the study, and A*i* denotes the actual allocation of this subject. We regressed this 'money on the table' variable on treatment, T-reactivity, and sex. Whereas the OT × T-reactivity × sex interaction did not predict the amount of money subjects left on the table, (b = -6.83, SE = 26.61, p = .800), the OT × T-reactivity did (b = -33.60, SE = 11.28, p = .008; see Fig. 4). That is, while under placebo, T-reactivity was not related to the optimization of tournament point-allocation, given performance ($r(96) = 0.07$, p = .489), under OT, T-reactivity negatively correlated with the level that subjects optimized their point-allocation ($r(97) = -0.22$, p = .025; Difference between OT to placebo correlations = 0.30, Fishers Z-test = 2.07, p = .039; see Fig. 3). Neither OT × sex (p = .630), nor the T reactivity × sex (p = .210) interactions were significant.

3.5. Do T-Reactivity, OT, and Sex Affect the Correlation between Performance and Point-Allocation to the Tournament?

As expected, participants who solved more problems in Round-1 or Round-2 tended to allocate more points to the tournament in Round 3 (Correlation between performance in Round-1 and points allocated to tournament in Round-3: $r(202) = 0.23$, p = .001; Correlation between performance in Round-2 and points allocated to tournament in Round-3: $r(202) = 0.37$, $p < .001$). OT treatment, T-reactivity, sex, and the interaction between them were not significant predictors of the number of problems solved in Round-1 or Round-2, suggesting that these variables did not directly affect cognitive performance (all *p's* > .10; see supplementary materials). However, OT did reduce the strength of the association between performance and points allocated to the tournament. While under placebo, performance and point-allocation were moderately correlated ($r(100) = 0.46$, $p < .001$), under OT no such correlation was observed ($r(100) = 0.17$, p = .090; Difference between OT to placebo correlations = 0.29, Fishers Z-test = 2.32, p = .020; see Fig. 4).

4. Discussion

In an era of increasingly selective educational programs, vigorous races for career promotion, and a scarcity of high-paying jobs, opportunities for success come disproportionately to those who embrace competition. Academics and policymakers have raised attention to the potential role of sex differences in competitive preferences as a key factor in contributing to differences between men and women in occupational selection and career promotion. Despite intense interest in understanding the factors giving rise to individual differences in competitiveness, knowledge regarding biological mechanisms has been surprisingly elusive. Here, we show that the combination of OT administration and T-reactivity in response to a competition affecting competitive-preferences in a sex-dependent manner. In males receiving placebo, a greater rise in endogenous T levels was associated with a greater willingness to compete; however, under OT, this association was absent. In contrast, for females, T-reactivity during competition was not related to the willingness to engage in competition, both under placebo and under OT.

Previous research has shown that T plays a role in modulating behaviors and preferences that are at the core of competition, including performance (Casto et al., 2020), risk-preferences (Apicella et al., 2014), and self-confidence (Dalton and Ghosal, 2018; Eisenegger et al., 2017). In addition, several studies have shown a relationship between T-reactivity and competition (Trumble et al., 2012; van der Meij et al., 2012). Here, we demonstrate that in males under placebo, T-reactivity was associated, specifically, with the willingness to engage in a competition when controlling for potential confounds such as subjects' performance, risk-attitude, or self-confidence.

In terms of existing theory, the 'Biosocial Model of Status' could not be tested in our study, since subjects were not informed regarding the competition outcome till the very end of each session. However, our results in males under the placebo condition are consistent with the 'Challenge Hypothesis' which posits the T levels increase in response to social challenges, such as competition, regardless of the outcome of the competition (Archer, 2006; Burk et al., 2019; Wingfield et al., 1990). As opposed to males, females under placebo in our study showed no association between T-reactivity to competitiveness. This finding is consistent with previous studies showing T-reactivity during competitive tasks for males, but not for females (Klinesmith et al., 2006). It has been argued that sex differences in the association between T-reactivity and behavior may reflect sex differences in the level of social engagement with the task (Geniole et al., 2017). However, males and females in our study showed similar performance in the number of problems solved (females in our study solved an average 6.42 (*S.D.* = 2.42) of problems per task; males solved an average of 6.92 (*S.D.* =

3.28) problems per task; t(202) = -1.30, p = .214), so this does not seem to be a suitable explanation for our findings here.

Under OT, there was no association between T-reactivity to competitiveness in both sexes. In the brain, T is aromatized to estradiol, which has been shown to upregulate the expression of the OT receptor (Johnson et al., 1989) and increase OT binding affinity in several brain regions (Johnson et al., 1991; Tribollet et al., 1990). However, given that the time course of such effects is typically over the course of several hours, this seems unlikely to be an explanation here. Rather, our findings suggest that at least in males, while OT did not directly affect levels of salivary T, it canceled out effects of T-reactivity on competitiveness which were observed under placebo. This finding is consistent with the broader notion of opposing roles of OT and T in modulating human social behavior (Crespi, 2016). Our finding that under OT there was a decreased correlation between T-reactivity and money on the table suggests that OT reduced the saliency of T-reactivity as a driver of competitive performance. Interestingly, reduced attention to interoceptive signaling has been postulated as one mechanism by which OT may modulate social cognition (Yao et al., 2018).

Under placebo, males and females did not show differences in the proportion of points invested in the tournament. This is contrast to the majority of previous studies examining sex differences in competitive preferences which show that males more readily engage in competition - even in instances when it is disadvantageous, and females are more likely to shy away - even when they would gain from competing (Balafoutas and Sutter, 2012; Dasgupta et al., 2019; Niederle and Vesterlund, 2007; Saccardo et al., 2018; Zhong et al., 2018). However, several cases have also been reported in which females compete at equal rates as males, highlighting the importance of socio-cultural factors in mitigating or exacerbating these differences (Booth and Nolen, 2012; Carpenter et al., 2018; Dariel et al., 2017; De Paola et al., 2015; Khachatryan et al., 2015; Price, 2016). While perhaps surprising, the lack of sex-differences could be explained by socio-cultural factors such as gender equality. Our study was conducted in Israel, on a sample of Israeli students. The vast majority of studies that reported sex-differences in competitive preferences were conducted in countries with greater gender equality than Israel, according to the global gender gap index (Global

Gender Gap Report 2020, 2020). In contrast, studies that were conducted in countries with lower gender equality than Israel (e.g., Armenia, Italy, and United Arab Emirates), did not observe sex-differences in competitive preferences (Booth et al., 2019; Dariel et al., 2017; De Paola et al., 2015; Khachatryan et al., 2015; Lee et al., 2014). This pattern further highlights the role of social and cultural factors (Zhong and Fu, 2019) in contributing to sex differences in competitiveness, and raises an intriguing direction for future research examining the interplay of such cultural factors with biology.

More broadly, our findings support the proposition that rather than having a uniform effect on behavior, OT interacts with T in affecting competitiveness in a sex-specific manner (Casto et al., 2020; Fischer-Shofty et al., 2010). These findings deepen our understanding of the neuroendocrine processes underlying human preferences for competition, suggest a new path for the interaction between OT and T on human social behavior, and extend the evidence base for sex-dependent effects of OT on this behavior.

Author Contributions

B.R. Cherki, E. Winter, and S. Israel designed the experiment; D. Mankuta gave medical support; B.R. Cherki ran the experimental sessions; and B.R. Cherki and S. Israel analyzed the data and wrote the paper. All authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interests with respect to their authorship or the publication of this article.

Notes

1. According to the Economic Participation and Opportunity sub-index of the Global Gender Gap Index 2020 report (*Global Gender Gap Report 2020*, 2020), a gender gap in wages, management positions, etc., exists in all the 153 countries that are included in the report.
2. This linear choice measure (Saccardo et al., 2018) was preferred over the more commonly used dichotomous choice between competition or piece-rate in order to maximize statistical power.
3. To ensure that subjects' point-allocations in Round-3 were not biased by their expectations regarding the chosen compositions of the other subjects in their foursome, subjects' performance in this round was compared to the performance of the three other subjects in Round-2.

References

Apicella, C.L., Dreber, A., Gray, P.B., Hoffman, M., Little, A.C., Campbell, B.C., 2011. Androgens and competitiveness in men. J. Neurosci. Psychol. Econ. 4, 54–62. https://doi.org/10.1037/a0021979

Apicella, C.L., Dreber, A., Mollerstrom, J., 2014. Salivary testosterone change following monetary wins and losses predicts future financial risk-taking. Psychoneuroendocrinology 39, 58–64. https://doi.org/10.1016/j.psyneuen.2013.09.025

Archer, J., 2006. Testosterone and human aggression: an evaluation of the challenge hypothesis. Neurosci. Biobehav. Rev., Relationship between the Brain and Aggression 30, 319–345. https://doi.org/10.1016/j.neubiorev.2004.12.007

Balafoutas, L., Sutter, M., 2012. Affirmative action policies promote women and do not harm efficiency in the laboratory. Science 335, 579–582. https://doi.org/10.1126/science.1211180

Bethlehem, R.A.I., Baron-Cohen, S., van Honk, J., Auyeung, B., Bos, P.A., 2014. The oxytocin paradox. Front. Behav. Neurosci. 8. https://doi.org/10.3389/fnbeh.2014.00048

Booth, A., Fan, E., Meng, X., Zhang, D., 2019. Gender Differences in Willingness to Compete: The Role of Culture and Institutions. Econ. J. 129, 734–764. https://doi.org/10.1111/ecoj.12583

Booth, A., Granger, D.A., Mazur, A., Kivlighan, K.T., 2006. Testosterone and Social Behavior. Soc. Forces 85, 167–191. https://doi.org/10.1353/sof.2006.0116

Booth, A., Nolen, P., 2012. Choosing to compete: How different are girls and boys? J. Econ. Behav. Organ. 81, 542–555. https://doi.org/10.1016/j.jebo.2011.07.018

Bos, P.A., Panksepp, J., Bluthé, R.-M., Honk, J. van, 2012. Acute effects of steroid hormones and neuropeptides on human social–emotional behavior: A review of single administration studies. Front. Neuroendocrinol. 33, 17–35. https://doi.org/10.1016/j.yfrne.2011.01.002

Boschini, A.D., Dreber, A., von Essen, E., Muren, A., Ranehill, E., 2019. Gender, Risk Preferences and Willingness to Compete in a Random Sample of the Swedish Population. SSRN Electron. J. https://doi.org/10.2139/ssrn.3241415

Buckert, M., Schwieren, C., Kudielka, B.M., Fiebach, C.J., 2017. How stressful are economic competitions in the lab? An investigation with physiological measures. J. Econ. Psychol. 62, 231–245. https://doi.org/10.1016/j.joep.2017.07.004

Burk, C.L., Mayer, A., Wiese, B.S., 2019. Nail-biters and thrashing wins: Testosterone responses of football fans during World Cup matches. Physiol. Behav. 209, 112596. https://doi.org/10.1016/j.physbeh.2019.112596

Carpenter, J., Frank, R., Huet-Vaughn, E., 2018. Gender differences in interpersonal and intrapersonal competitive behavior. J. Behav. Exp. Econ. 77, 170–176. https://doi.org/10.1016/j.socec.2018.10.003

Carré, J.M., Archer, J., 2018. Testosterone and human behavior: the role of individual and contextual variables. Curr. Opin. Psychol., Aggression and violence 19, 149–153. https://doi.org/10.1016/j.copsyc.2017.03.021

Carré, J.M., McCormick, C.M., Hariri, A.R., 2011. The social neuroendocrinology of human aggression. Psychoneuroendocrinology 36, 935–944. https://doi.org/10.1016/j.psyneuen.2011.02.001

Cassar, A., Wordofa, F., Zhang, Y.J., 2016. Competing for the benefit of offspring eliminates the gender gap in competitiveness. Proc. Natl. Acad. Sci. 113, 5201–5205. https://doi.org/10.1073/pnas.1520235113

Casto, K.V., Edwards, D.A., Akinola, M., Davis, C., Mehta, P.H., 2020. Testosterone reactivity to competition and competitive endurance in men and women. Horm. Behav., 30th Anniversary of the Challenge Hypothesis 123, 104665. https://doi.org/10.1016/j.yhbeh.2019.104665

Crespi, B.J., 2016. Oxytocin, testosterone, and human social cognition. Biol. Rev. 91, 390–408. https://doi.org/10.1111/brv.12175

Dalton, P.S., Ghosal, S., 2018. Self-confidence, Overconfidence and Prenatal Testosterone Exposure: Evidence from the Lab. Front. Behav. Neurosci. 12. https://doi.org/10.3389/fnbeh.2018.00005

Dariel, A., Kephart, C., Nikiforakis, N., Zenker, C., 2017. Emirati women do not shy away from competition: evidence from a patriarchal society in transition. J. Econ. Sci. Assoc. 3, 121–136. https://doi.org/10.1007/s40881-017-0045-y

Darwin, C., 1871. The descent of man and selection in relation to sex. London, UK: John Murray.

Darwin, C., 1859. On the origin of species. London, UK: John Murray.

Dasgupta, U., Mani, S., Sharma, S., Singhal, S., 2019. Can gender differences in distributional preferences explain gender gaps in competition? J. Econ. Psychol. 70, 1–11. https://doi.org/10.1016/j.joep.2018.10.013

De Paola, M., Gioia, F., Scoppa, V., 2015. Are females scared of competing with males? Results from a field experiment. Econ. Educ. Rev. 48, 117–128. https://doi.org/10.1016/j.econedurev.2015.06.002

Dechenaux, E., Kovenock, D., Sheremeta, R.M., 2015. A survey of experimental research on contests, all-pay auctions and tournaments. Exp. Econ. 18, 609–669. https://doi.org/10.1007/s10683-014-9421-0

Dumais, K.M., Veenema, A.H., 2016. Vasopressin and oxytocin receptor systems in the brain: Sex differences and sex-specific regulation of social behavior. Front. Neuroendocrinol. 40, 1–23. https://doi.org/10.1016/j.yfrne.2015.04.003

Eagly, A.H., Wood, W., 2013. The Nature–Nurture Debates: 25 Years of Challenges in Understanding the Psychology of Gender. Perspect. Psychol. Sci. 8, 340–357. https://doi.org/10.1177/1745691613484767

Eisenegger, C., Haushofer, J., Fehr, E., 2011. The role of testosterone in social interaction. Trends Cogn. Sci. 15, 263–271. https://doi.org/10.1016/j.tics.2011.04.008

Eisenegger, C., Kumsta, R., Naef, M., Gromoll, J., Heinrichs, M., 2017. Testosterone and androgen receptor gene polymorphism are associated with confidence and competitiveness in men. Horm. Behav., Hormones and Human Competition 92, 93–102. https://doi.org/10.1016/j.yhbeh.2016.09.011

Feng, C., Hackett, P.D., DeMarco, A.C., Chen, X., Stair, S., Haroon, E., Ditzen, B., Pagnoni, G., Rilling, J.K., 2015. Oxytocin and vasopressin effects on the neural response to social cooperation are modulated by sex in humans. Brain Imaging Behav. 9, 754–764. https://doi.org/10.1007/s11682-014-9333-9

Fischer-Shofty, M., Shamay-Tsoory, S.G., Harari, H., Levkovitz, Y., 2010. The effect of intranasal administration of oxytocin on fear recognition. Neuropsychologia 48, 179–184.

Flory, J.A., Gneezy, U., Leonard, K.L., List, J.A., 2018. Gender, age, and competition: A disappearing gap? J. Econ. Behav. Organ. 150, 256–276.

Gao, S., Becker, B., Luo, L., Geng, Y., Zhao, W., Yin, Y., Hu, J., Gao, Z., Gong, Q., Hurlemann, R., Yao, D., Kendrick, K.M., 2016. Oxytocin, the peptide that bonds the sexes also divides them. Proc. Natl. Acad. Sci. 113, 7650–7654. https://doi.org/10.1073/pnas.1602620113

Geniole, S.N., Bird, B.M., Ruddick, E.L., Carré, J.M., 2017. Effects of competition outcome on testosterone concentrations in humans: An updated meta-analysis. Horm. Behav., Hormones and Human Competition 92, 37–50. https://doi.org/10.1016/j.yhbeh.2016.10.002

Global Gender Gap Report 2020, 2020. . World Economic Forum, Geneva.

Gneezy, U., Leonard, K.L., List, J.A., 2009. Gender differences in competition: Evidence from a matrilineal and a patriarchal society. Econometrica 77, 1637–1664.

Gordon, I., Martin, C., Feldman, R., Leckman, J.F., 2011. Oxytocin and social motivation. Dev. Cogn. Neurosci., Special Issue on Motivation 1, 471–493. https://doi.org/10.1016/j.dcn.2011.07.007

Insel, T.R., 2010. The Challenge of Translation in Social Neuroscience: A Review of Oxytocin, Vasopressin, and Affiliative Behavior. Neuron 65, 768–779. https://doi.org/10.1016/j.neuron.2010.03.005

Johnson, A.E., Coirini, H., Insel, T.R., McEwen, B.S., 1991. The Regulation of Oxytocin Receptor Binding in the Ventromedial Hypothalaimic Nucleus by Testosterone and Its Metabolites. Endocrinology 128, 891–896. https://doi.org/10.1210/endo-128-2-891

Johnson, A.E., Coirini, H., McEwen, B.S., Insel, T.R., 1989. Testosterone Modulates Oxytocin Binding in the Hypothalamus of Castrated Male Rats. Neuroendocrinology 50, 199–203. https://doi.org/10.1159/000125222

Kemp, A., Guastella, A.J., 2010. Oxytocin: Prosocial Behavior, Social Salience, or Approach-Related Behavior? Biol. Psychiatry 67, e33–e34.

Khachatryan, K., Dreber, A., von Essen, E., Ranehill, E., 2015. Gender and preferences at a young age: Evidence from Armenia. J. Econ. Behav. Organ., Economic Experiments in Developing Countries 118, 318–332. https://doi.org/10.1016/j.jebo.2015.02.021

Klinesmith, J., Kasser, T., McAndrew, F.T., 2006. Guns, Testosterone, and Aggression: An Experimental Test of a Mediational Hypothesis. Psychol. Sci. 17, 568–571.

Knight, G.P., Kagan, S., Buriel, R., 1981. Confounding effects of individualism in children's cooperation — Competition social motive measures. Motiv. Emot. 5, 167–178. https://doi.org/10.1007/BF00993895

Luo, L., Becker, B., Geng, Y., Zhao, Z., Gao, S., Zhao, W., Yao, S., Zheng, X., Ma, X., Gao, Z., Hu, J., Kendrick, K.M., 2017. Sex-dependent neural effect of oxytocin during subliminal processing of negative emotion faces. NeuroImage 162, 127–137. https://doi.org/10.1016/j.neuroimage.2017.08.079

MacDonald, K., MacDonald, T.M., 2010. The Peptide That Binds: A Systematic Review of Oxytocin and its Prosocial Effects in Humans. Harv. Rev. Psychiatry 18, 1–21. https://doi.org/10.3109/10673220903523615

Mazur, A., 1985. A Biosocial Model of Status in Face-to-Face Primate Groups*. Soc. Forces 64, 377–402. https://doi.org/10.1093/sf/64.2.377

Mazur, A., Booth, A., 1998. Testosterone and dominance in men. Behav. Brain Sci. 21, 353–363. https://doi.org/10.1017/S0140525X98001228

McCall, C., Singer, T., 2012. The animal and human neuroendocrinology of social cognition, motivation and behavior. Nat. Neurosci. 15, 681–688. https://doi.org/10.1038/nn.3084

Meyer-Lindenberg, A., Domes, G., Kirsch, P., Heinrichs, M., 2011. Oxytocin and vasopressin in the human brain: social neuropeptides for translational medicine. Nat. Rev. Neurosci. 12, 524–538. https://doi.org/10.1038/nrn3044

Müller, J., Schwieren, C., 2012. Can personality explain what is underlying women's unwillingness to compete? J. Econ. Psychol. 33, 448–460. https://doi.org/10.1016/j.joep.2011.12.005

Niederle, M., Vesterlund, L., 2007. Do women shy away from competition? do men compete too much? Q. J. Econ. 122, 1067–1101.

Price, C.R., 2016. Do Women Shy Away from Competition? Do Men Compete Too Much?: A (Failed) Replication. SSRN Electron. J. https://doi.org/10.2139/ssrn.1444100

Rilling, J.K., DeMarco, A.C., Hackett, P.D., Chen, X., Gautam, P., Stair, S., Haroon, E., Thompson, R., Ditzen, B., Patel, R., Pagnoni, G., 2014. Sex differences in the neural and behavioral response to intranasal oxytocin and vasopressin during human social interaction. Psychoneuroendocrinology 39, 237–248. https://doi.org/10.1016/j.psyneuen.2013.09.022

Saccardo, S., Pietrasz, A., Gneezy, U., 2018. On the Size of the Gender Difference in Competitiveness. Manag. Sci. 64, 1541–1554. https://doi.org/10.1287/mnsc.2016.2673

Scheele, D., Striepens, N., Kendrick, K.M., Schwering, C., Noelle, J., Wille, A., Schläpfer, T.E., Maier, W., Hurlemann, R., 2014. Opposing effects of oxytocin on moral judgment in males and females. Hum. Brain Mapp. 35, 6067–6076. https://doi.org/10.1002/hbm.22605

Stavropoulos, K.K.M., Carver, L.J., 2013. Research Review: Social motivation and oxytocin in autism – implications for joint attention development and intervention. J. Child Psychol. Psychiatry 54, 603–618. https://doi.org/10.1111/jcpp.12061

Steinman, M.Q., Duque-Wilckens, N., Greenberg, G.D., Hao, R., Campi, K.L., Laredo, S.A., Laman-Maharg, A., Manning, C.E., Doig, I.E., Lopez, E.M., Walch, K., Bales, K.L., Trainor, B.C., 2016. Sex-Specific Effects of Stress on Oxytocin Neurons Correspond With Responses to Intranasal Oxytocin. Biol. Psychiatry, Corticotropin-Releasing Factor, FKBP5, and Posttraumatic Stress Disorder 80, 406–414. https://doi.org/10.1016/j.biopsych.2015.10.007

Tribollet, E., Audigier, S., Dubois-Dauphin, M., Dreifuss, J.J., 1990. Gonadal steroids regulate oxytocin receptors but not vasopressin receptors in the brain of male and female rats. An autoradiographical study. Brain Res. 511, 129–140. https://doi.org/10.1016/0006-8993(90)90232-Z

Trumble, B.C., Cummings, D., von Rueden, C., O'Connor, K.A., Smith, E.A., Gurven, M., Kaplan, H., 2012. Physical competition increases testosterone among Amazonian forager-horticulturalists: a test of the 'challenge hypothesis.' Proc. R. Soc. B Biol. Sci. 279, 2907–2912. https://doi.org/10.1098/rspb.2012.0455

van der Meij, L., Almela, M., Buunk, A.P., Fawcett, T.W., Salvador, A., 2012. Men with elevated testosterone levels show more affiliative behaviours during interactions with women. Proc. R. Soc. B Biol. Sci. 279, 202–208. https://doi.org/10.1098/rspb.2011.0764

Walum, H., Waldman, I.D., Young, L.J., 2016. Statistical and Methodological Considerations for the Interpretation of Intranasal Oxytocin Studies. Biol. Psychiatry, Oxytocin and Psychiatry: From DNA to Social Behavior 79, 251–257. https://doi.org/10.1016/j.biopsych.2015.06.016

Welker, K.M., Norman, R.E., Goetz, S., Moreau, B.J.P., Kitayama, S., Carré, J.M., 2017. Preliminary evidence that testosterone's association with aggression depends on self-construal. Horm. Behav., Hormones and Human Competition 92, 117–127. https://doi.org/10.1016/j.yhbeh.2016.10.014

Wingfield, J.C., Hegner, R.E., Dufty, Alfred M., Ball, G.F., 1990. The "Challenge Hypothesis": Theoretical Implications for Patterns of Testosterone Secretion, Mating Systems, and Breeding Strategies. Am. Nat. 136, 829–846. https://doi.org/10.1086/285134

Winslow, J., Insel, T., 1991. Social status in pairs of male squirrel monkeys determines the behavioral response to central oxytocin administration. J. Neurosci. 11, 2032–2038. https://doi.org/10.1523/JNEUROSCI.11-07-02032.1991

Xu, L., Becker, B., Luo, R., Zheng, X., Zhao, W., Zhang, Q., Kendrick, K.M., 2018. Oxytocin amplifies sex differences in human mate choice. bioRxiv 416198. https://doi.org/10.1101/416198

Zhong, S., Fu, J., 2019. Visceral Influences on Gender Difference in Competitiveness. SSRN Electron. J. https://doi.org/10.2139/ssrn.3341678

Zhong, S., Shalev, I., Koh, D., Ebstein, R.P., Chew, S.H., 2018. Competitiveness and stress. Int. Econ. Rev. 59, 1263–1281. https://doi.org/10.1111/iere.12303

Zingg, H.H., Laporte, S.A., 2003. The oxytocin receptor. Trends Endocrinol. Metab. 14, 222–227. https://doi.org/10.1016/S1043-2760(03)00080-8

Table 1.

Regression analysis on the proportion of tournament point-allocation in Round-3

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OT	0.08 (0.19)	-0.20 (0.20)	-0.20 (0.20)	-0.16 (0.20)	-0.26 (0.19)	-0.19 (0.20)	-0.17 (0.21)
Male dummy	0.29 (0.19)	-0.03 (0.21)	-0.08 (0.22)	-0.13 (0.20)	-0.32 (0.22)	-0.29 (0.25)	-0.26 (0.25)
T-Reactivity	0.23 (0.20)	0.48 (0.33)	0.20 (0.40)	0.20 (0.36)	0.13 (0.29)	-0.03 (0.27)	-0.04 (0.26)
OT × Male		0.60 * (0.27)	0.63 * (0.27)	0.66 ** (0.25)	0.78 ** (0.26)	0.73 * (0.30)	0.66 * (0.26)
OT × T-Reactivity		-0.69 * (0.33)	-0.17 (0.51)	-0.08 (0.45)	-0.05 (0.42)	-0.01 (0.43)	-0.10 (0.40)
Male × T-Reactivity		0.37 (0.44)	1.13 * (0.40)	1.13 ** (0.40)	1.18 ** (0.38)	1.38 ** (0.45)	1.17 * (0.46)
OT × Male × T-Reactivity			-1.20 * (0.57)	-1.30 * (0.54)	-1.24 * (0.52)	-1.29 * (0.50)	-1.03 * (0.47)
Performance				0.14 *** (0.03)	0.05 * (0.02)	0.06 · (0.03)	0.05 · (0.03)
Confidence					0.56 *** (0.11)	0.63 *** (0.14)	0.47 ** (0.13)
Risk-preference						0.14 (0.09)	0.09 (0.09)
Points' allocation at Round-4							0.96 *** (0.26)
Constant	-0.61 *** (0.14)	-0.48 ** (0.14)	-0.47 *** (0.14)	-1.36 *** (0.22)	-2.12 *** (0.24)	-2.39 *** (0.33)	-2.27 *** (0.33)
Observations	197	197	197	197	197	181	181

Note: Factors contributing to the proportion of points that were allocated to the tournament in Round-3, were assessed via a general linear model with a logit link function and the binomial distribution. Male dummy = 1 if subject is male, 0 otherwise. Parentheses contain robust standard errors, clustered by session.

a – Sixteen subjects were excluded from analysis in models 4 and 5, due to inconsistent decisions in the risk-preference measure.

· Significant at 10%.

* Significant at 5%.

** Significant at 1%.

*** Significant at 0.1%.

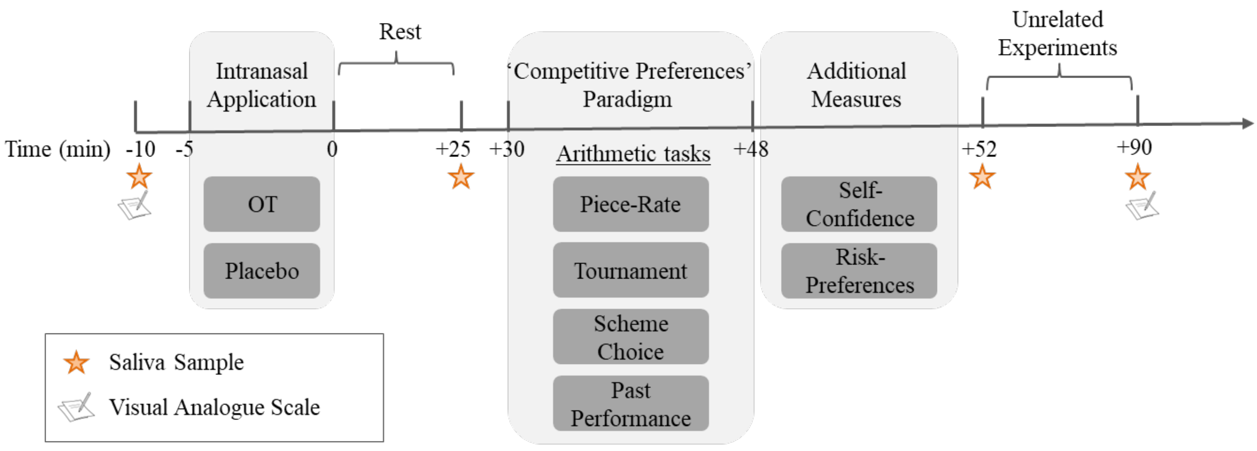

Fig. 1. Experiment Timeline

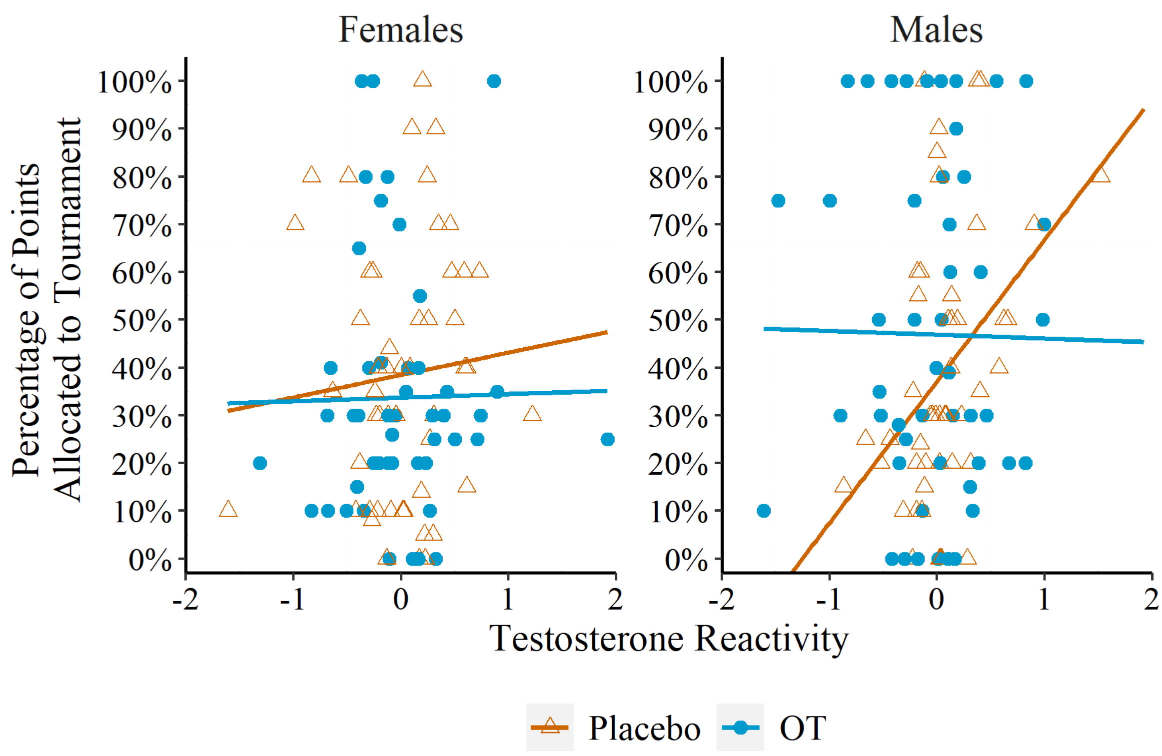

Fig. 2. Scatterplots by sex of the relationship between testosterone (T) reactivity during competition, oxytocin (OT), and the proportion of points subjects allocated to the tournament-scheme in Round-3. T-reactivity is based on residuals of predicting T levels (standardized by sex) at Time-3 (post-competition) by T levels (standardized by sex) at Time-2 (pre-competition).

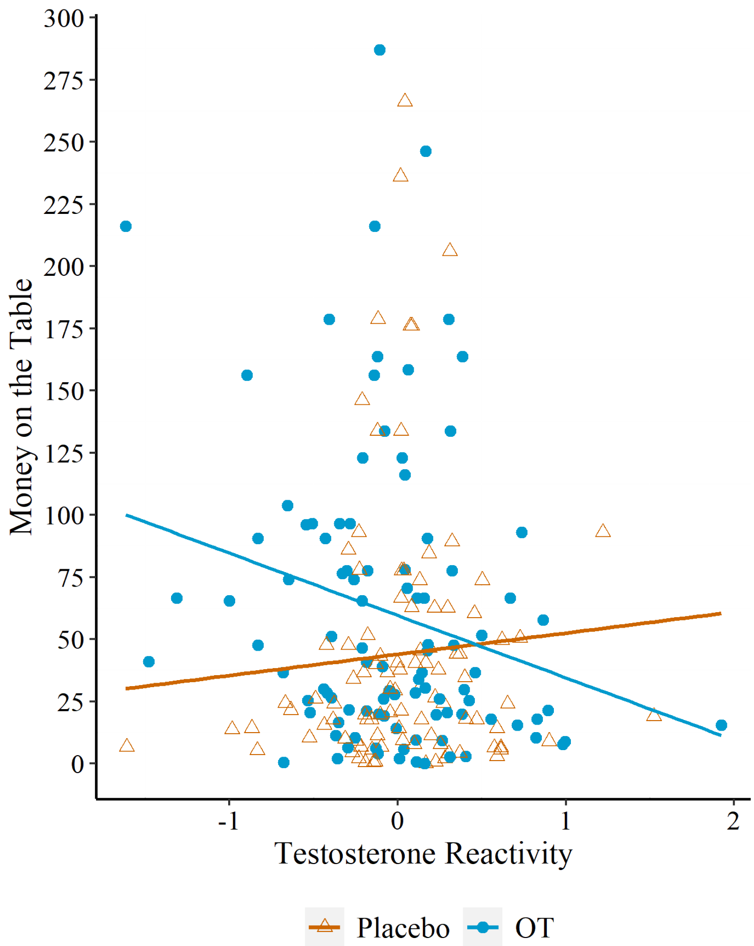

Fig. 3. Scatterplot of the association between testosterone (T) reactivity and the amount of money subjects left on the table in Round-3. T-reactivity is based on residuals of predicting T levels (standardized by sex) at Time-3 (post-competition) by T levels (standardized by sex) at Time-2 (pre-competition).

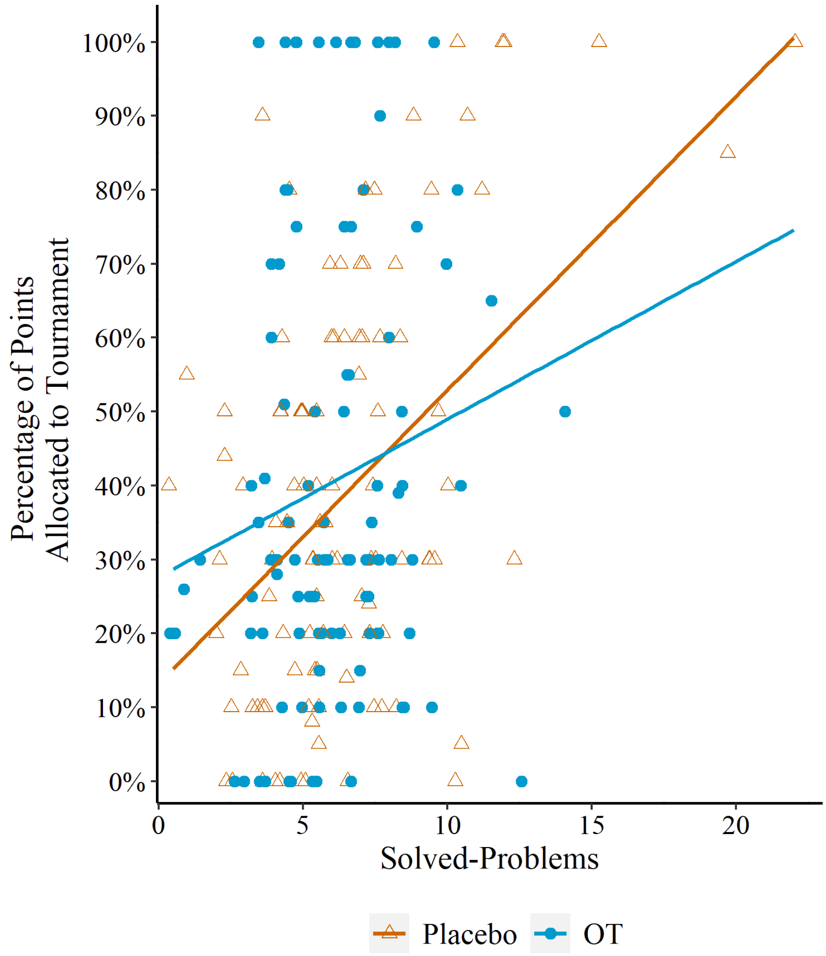

Fig. 4. Scatterplot of the relationship between the number of solved-problems (average of Round-1 and Round 2) and the proportion of points subjects allocated to the tournament-scheme in Round-3. Points are jittered with respect to the x-axis for visual propose.