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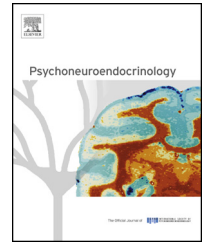
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SHORT COMMUNICATION

No evidence for an effect of testosterone administration on delay discounting in male university students

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Summary Intertemporal choices between a smaller sooner and a larger delayed reward are one of the most important types of decisions humans face in their everyday life. The degree to which individuals discount delayed rewards correlates with impulsiveness. Steep delay discounting has been associated with negative outcomes over a wide range of behaviors such as addiction. However, little is known about the biological foundations of delay discounting. Here, we examine a potential causal link between delay discounting and testosterone, a hormone which has been associated with other types of impulsive behavior. In our double-blind placebo-controlled study 91 healthy young men either received a topical gel containing 50 mg of testosterone ($N = 46$) or a placebo ($N = 45$) before participating in a delay discounting task with real incentives. Our main finding is that a single dose administration of testosterone did not lead to significant differences in discount rates between the placebo and the testosterone group. Within groups and in the pooled sample, no significant relationship between testosterone and discount rates was observed. At the same time, we do replicate standard findings from the delay discounting literature such as a magnitude-of-rewards effect on discount rates. In sum, our findings suggest that circulating testosterone does not have a significant effect on delay discounting in young men.

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1. Introduction

Time preferences are a fundamental building block of human behavior. Many decisions humans face involve intertemporal trade-offs, in which present goods have to be weighed against future goods. Typically, rewards to be received in the future are valued less than rewards of equal size received today (Frederick et al., 2002). Delay discounting refers to the subjective depreciation of rewards received in the future, where the depreciation increases with the delay of receiving the reward. The discount rate k captures the rate at which this depreciation occurs, low k individuals are thus more willing to delay gratification. Individual discount rates vary substantially and have been proposed as a measure of impulsiveness (Kirby et al., 1999). Higher discount rates have been associated with unfavorable outcomes in a wide range of important dimensions including substance abuse (e.g. Kirby et al., 1999) and gambling (Dickson et al., 2003).

Little is known, however, about the sources of heterogeneity in delay discounting. Recent evidence suggests the hormone testosterone may lead to steeper discounting of the future. Several studies reported a positive correlation between circulating levels of testosterone and other types of impulsive behavior, e.g., in the IOWA gambling task (Van Honk et al., 2004), or the ultimatum game (Burnham, 2007). In addition, two recent studies found that exposure to sexual cues induced men to discount the future steeper (Wilson and Daly, 2004; van den Bergh et al., 2008). Elevated testosterone levels in response to sexual cues could be one underlying reason for the higher discount rates (Lucas and Koff, 2010). Only one study investigated a potential correlation of endogenous testosterone levels and delay-discounting of (hypothetical) rewards (Takahashi et al., 2006). This study found a significant non-linear relationship between endogenous salivary testosterone level and discount rate, i.e., a positive correlation for individuals with a low k and a negative correlation for individuals with a high k . However, due to potential behavior-hormone feedback this type of evidence precludes causal inference. To date no study investigating a causal link between testosterone and delay discounting exists. We therefore conducted a double-blind placebo controlled experiment with real incentives to study the effect of a single dose administration of testosterone on delay discounting. More specifically, we tested the hypothesis that testosterone leads to steeper discounting of the future, i.e., a higher discount factor k .

2. Materials and methods

2.1. Subjects

91 healthy men (age 24.32 ± 2.73 years) gave written informed consent prior to participation in the study. Subjects were recruited via the volunteer database of the BonnEconLab and through posters on campus. Before deciding whether to participate subjects could visit a website with information about the experiment (timing, payment, side effects, exclusion criteria). All subjects were screened to exclude benign prostate hypertrophy, prostate cancer, heart failure, renal failure, hepatic failure, epilepsy or migraine history, and exogenous uptake of cortisone or ACTH. No adverse events

occurred. The study was approved by the ethics committee of the medical department of the University of Bonn.

2.2. Measuring individual discount rates

We used the well-established monetary choice questionnaire (Kirby et al., 1999) to elicit individual discount rates. In this delay discounting task subjects have to make 27 consecutive choices between a smaller immediate reward (SIR, range: 11–80 euro) and a larger delayed reward (LDR, range: 25–85 euro) to be received in X days (range: 7–186 days). Questions had the following form: “Which payment do you prefer—SIR today or LDR in X days?” Subjects had an incentive to respond truthfully since there was a 1-in-6 chance that one of the 27 decisions was randomly chosen and actually paid. Dollar amounts from Kirby et al. (1999) were converted into Euro at a rate of 1:1. Assuming a hyperbolic discounting function $V = A/(1 + kD)$, where V is the present value of the delayed reward A at delay D , a value of k , at which the immediate reward is equal to the discounted delayed reward can be determined for each of the 27 choices. In our case, k assumes 9 different values ranging from 0.00016 to 0.25. For each value of k , there are three different versions of a question using different reward sizes (small, medium, and large) in order to assess potential effects of reward size on delay discounting. Estimation of the discount rate k follows the procedure described in Kirby et al. (1999). We estimate the discount rate k for every individual by determining the switching point at which an individual begins to prefer larger, delayed rewards over smaller, immediate rewards for each of the three reward sizes. We obtained the overall discount rate k for every individual by taking the geometric mean of the k s for the different reward sizes.

2.3. Experimental procedure

The study used a double-blind, placebo-controlled design. There was no deception in any part of the experiment. Each session of the study took place on two consecutive days. On day 1, subjects reported individually to the Institute for Empirical Research in Economics at the University of Bonn between 10 am and 1 pm. After receiving general instructions, subjects were randomly assigned to the testosterone or the placebo group and a medical research assistant applied a topical gel containing 50 mg of testosterone (Testogel[®], Jenapharm GmbH&Co. KG, Jena, Germany) or a placebo gel on their upper right arm (Testosterone: $N = 46$; Placebo: $N = 45$). Afterwards participants had to wait until the gel was fully absorbed (approx. 10 min) before leaving the institute. Subjects were asked to refrain from showering or swimming for at least 6 h after the transdermal application, to avoid drinking alcohol until the end of the experiment and to obtain enough sleep. The testosterone was allowed to load for 21–24 h prior to the decision task. On day 2 subjects reported to the BonnEconLab at 10 am to participate in the discounting task described above and several unrelated experiments. They were seated in separate cubicles closed off with curtains and read self-paced instructions for the experiments. All experiments were programmed with ztree (Fischbacher, 2007).

After the experiments, a blood sample was taken from each subject in a separate room before they received their

payment in cash. If a subject had chosen a delayed reward the reward was mailed to the subject one day before the agreed day given that most letters in Germany reach their destination over night. The sessions on day 2 lasted on average 150 min including blood sampling and payment procedures.

2.4. Testosterone measurement

The blood samples were stored at the hormone laboratory of the gynecologic clinic at the University of Bonn and processed within a day after collection for measurement of total testosterone using a one-step Chemiluminescent Microparticle Immunoassay (ARCHITECT Testosterone, Abbott Laboratories, Wiesbaden, Germany). The intraassay and the interassay coefficients were 1.9% and 3.7% respectively, with a lower detection limit of 0.14 ng/mL.

2.5. Questionnaires

After the experiment, subjects answered several questionnaires on socio-demographic characteristics and personality variables. For a subset of subjects ($N = 51$) we also elicited at the end of the questionnaires whether they believed they had received testosterone or placebo.

2.6. Statistical analysis

Non-parametric Mann–Whitney U -tests were used to test for differences in discount rates between the two groups. Friedman tests were used to test whether discount rates depended on reward size. Post hoc analysis for these tests was carried out using Wilcoxon Signed Rank tests with Bonferroni correction for multiple comparisons. Spearman rank order correlations were used to test for associations between testosterone level and discount rates. A χ^2 test was used to test for an association of actual and perceived

testosterone administration. All tests are two-tailed. Ordinary least square regressions with log-normalized k s were used to replicate the analyses in [Takahashi et al. \(2006\)](#).

3. Results

3.1. Testosterone levels

In the treatment group the mean level of testosterone was 7.78 ± 2.07 ng/l, compared to 6.79 ± 2.04 ng/l in the control group. The difference between the two groups is significant ($p < 0.05$, two-sample U -test). There was no correlation between actual and perceived testosterone administration (Pearson's χ^2 test, $p = 0.94$).

3.2. Discount rates

Subjects in the treatment group had a mean discount rate k of $0.0295 \pm .0468$, while the mean k was $0.0203 \pm .0254$ in the control group ([Fig. 1](#)). The difference in discount rates between the two treatment groups is not statistically significant ($p = 0.538$, two-sample U -test). We also do not find a significant difference in discount rates between the two treatments for any of the three different reward size categories (two sample U -tests, all $p > 0.525$). We also tested for a correlation between testosterone levels and discount rates in the pooled sample, and separately for each treatment. In contrast to our hypothesis, the correlation coefficients are negative and none of these correlations is significant (Spearman correlation, pooled: $r = -0.15$, $p = 0.149$; placebo: $r = -0.10$, $p = 0.500$; testosterone: $r = -0.17$, $p = 0.256$). The same result holds when testing for correlations in the different reward size categories separately.

In line with previous studies (e.g. [Kirby et al., 1999](#)), we do find a magnitude effect on discount rates in both treatments (Friedman test, placebo: $\chi(2) = 15.83$, $p < 0.001$; testosterone: $\chi(2) = 19.70$, $p < 0.001$). Post hoc analysis with

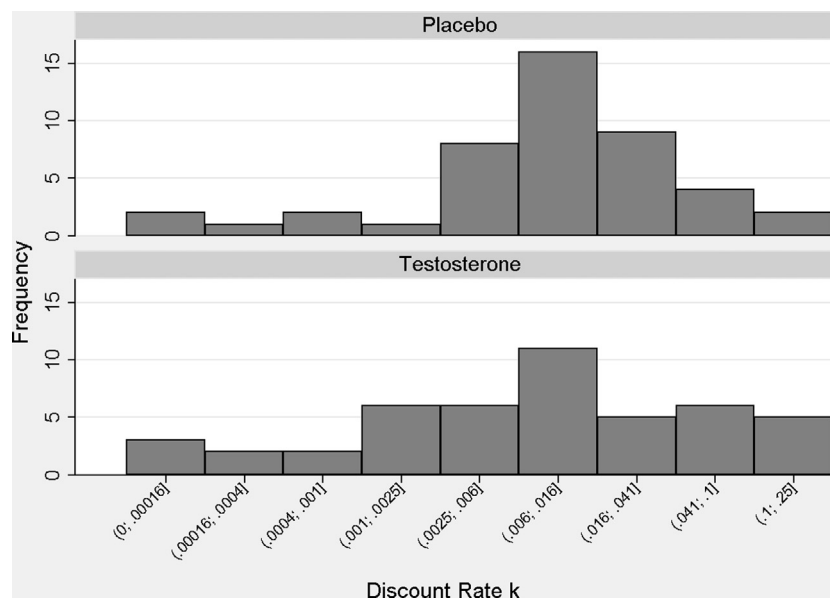


Figure 1 Frequency of discount rates in the placebo and the testosterone group for the ranges defined by the monetary choice questionnaire.

Wilcoxon Signed-Rank tests (Bonferroni corrected level of significance $p = 0.017$) revealed higher discount rates for small and medium delayed rewards compared to large delayed rewards, but not (or only by trend) for small compared to medium rewards (placebo: small vs. medium: $p = 0.042$, medium vs. large $p = 0.002$; testosterone small vs. medium: $p = 0.026$, medium vs. large $p < 0.001$).

Takahashi et al. (2006) regressed testosterone levels on $\ln(k)$ and $\ln(k)^2$ and observed a significant invert U-shaped relation. We replicate their analysis for our data (OLS regressions for pooled data and each treatment separately) but do not find a significant relationship ($p > 0.449$ for all coefficients).

4. Discussion

The present study examined a potential causal link between circulating testosterone and delay discounting. The main finding of our placebo-controlled study is that there is no significant difference in discount rates between the placebo and the testosterone group. We also did not find any significant linear or quadratic-relationship between testosterone levels and discount rates in either group or the pooled sample. Our study thus offers no support for the hypothesis that circulating testosterone influences delay discounting.

Our study differs from previous testosterone administration studies on decision making in several methodological aspects. Most notably, most of these studies use female samples and sublingual testosterone administration. While for women an optimal delay between peak serum levels and behavioral testing of 4 h has been suggested based on neurophysiological evidence (Tuiten et al., 2000), little is known about the optimal delay between t_{\max} and behavioral testing in men. The only previous study on the influence of testosterone administration on social behavior in men (Zak et al., 2009) finds a behavioral effect after 16 h. Based on the pharmacokinetics of testosterone administration using a topical gel in healthy men (Chik et al., 2006; Eisenegger et al., 2012) the delay between t_{\max} and behavioral testing in our study was at least 5–7 h. Methodological differences compared to those studies reporting positive findings in other domains of decision making might thus be a potential alternative explanation for the absence of a treatment effect.

However, there are several reasons to believe that our findings are valid. First of all, we do observe a behavioral effect of testosterone administration in another task played with the same subjects in the same experimental session (Wibral et al., 2012). The incidence of self-serving lying in a die-rolling paradigm is much lower in the testosterone group compared to the placebo group. Second, our results regarding discount rates are comparable to previous studies. We do observe the characteristic magnitude effect of rewards in the testosterone as well as the placebo group. The levels of k observed in our sample are in line with a previous study also using a sample of young men (Takahashi et al., 2006). Third, while it is possible that our sample size is still too small to pick up an effect, it is substantially larger than samples used in recent single-dose administration studies on the behavioral effects of testosterone and the sample which Takahashi et al.

(2006) use to investigate the relation between testosterone and discount rates ($N = 75$). Finally, we use blood samples for assessing testosterone levels, which should reduce measurement error (Millet, 2004). While we only measure total testosterone the findings in Eisenegger et al. (2012) suggest that testosterone administration also raises free testosterone and does not induce secondary changes in SHBG.

An interesting question for further research is whether our null finding will also hold in a setup in which delay discounting is relevant for social status. The most convincing evidence for an influence of testosterone on decision making stems from situations involving a challenge to social status (Eisenegger et al., 2011). It is therefore possible that testosterone affects delay discounting in such a context.

One limitation of the current study is that only male university students were tested. It is possible that different results might have been obtained in a female or a more diverse male sample. It is also possible that cognitive ability mediates the influence of testosterone on delay discounting. Higher intelligence has been associated with lower discount rates (Shamosh and Gray, 2008; Dohmen et al., 2010). One hypothesis is that intelligence influences the integration of the appraisal of sooner and later rewards into a decision (Shamosh and Gray, 2008). On a neural level, delay discounting seems to involve a valuation network including the orbitofrontal cortex and the ventral striatum, and a cognitive control network (Peters and Büchel, 2011). Recent evidence suggests that a higher testosterone level affects activity in parts of the valuation network in a way that would lead to steeper discounting (e.g., Hermans et al., 2010). It remains possible that testosterone influences delay discounting via an effect on the appraisal of rewards. This effect, however, could be overridden by the influence of cognitive ability in our sample of university students with high cognitive ability. In conclusion, the present study indicates that circulating testosterone does not have a significant effect on delay discounting in male university students.

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Conflict of interest

The authors report no conflict of interest. The authors alone are responsible for the content and writing of the paper.

Contributors

TD, AF, BW, and MW designed the study. AB, GO, and MW analyzed the data. DK analyzed the blood samples. AB, AF, GO, BW, and MW wrote the paper. All authors contributed to and have approved the final manuscript.

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