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Supplementary Statistics and Results

This file contains supplementary statistical information and a discussion of the interpretation of the belief effect on the basis of additional data. We also present the results of different statistical models together with two model selection criteria, the Bayesian Information criterion (BIC) and the Akaike Information Criterion (AIC). In addition, we report the results of an additional ultimatum game experiment that serves as a robustness check for the identification of the causal impact of testosterone administration on bargaining behaviour.

The file also contains explicit mathematical models that make the assumptions behind the social status hypothesis and the relative payoff hypothesis transparent. In addition, we show that our data rule out that testosterone affects various forms of social preferences. Finally, we compare our results on the role of baseline testosterone for responders to those of Burnham (2007).

Table S1. Proposers' average offer in the ultimatum game (N = 60)

Actual treatment group	Believed treatment group		
	believed placebo group	believed testosterone group	All
Placebo	3.66	2.38	3.40
Testosterone	4.14	3.47	3.90
All	3.88	3.08	

Controlling for beliefs and selecting the best statistical model

A control for "believed testosterone" is crucial in identifying the impact of testosterone actually administered because actual and believed testosterone have opposing effects on bargaining offers. This means that even a very slight co-variation between the two variables can confound the estimate of the actual testosterone effect if one does not control for “believed testosterone”. For this reason we performed different ANOVAs in which we control for subjects beliefs. The table below presents the results of the different statistical models and shows that a model that includes an indicator variable for “actual testosterone” and “believed testosterone” (but not the interaction between the two) is superior.

Table S2. Significance levels and model selection criteria for different statistical models (ANOVAs)

Dependent variable: proposers’ mean offer	(1)	(2)	(3)	(4)
Indicator for actual testosterone treatment	p=0.100		**p=0.031**	p=0.020
Indicator for believed testosterone treatment		p=0.017	**p=0.006**	p=0.004
Interaction of actual and believed treatment				p=0.346
Akaike information criterion (AIC)	190.8	187.7	**184.7**	185.8
Bayesian information criterion (BIC)	195.0	191.9	**191.0**	194.2
	N = 60	N = 60	**N = 60**	N = 60

The table reports p-values and model selection criteria of different model specifications. The dependent variable is proposers’ mean offer in the ultimatum game. In specification (1) and (2), the only explanatory variable is an indicator variable if subjects received testosterone or if subjects believed they received testosterone, respectively. In specification (3), we include both, actual and believed, treatment as explanatory variables and in model (4), we additionally include an interaction between the actual and believed treatment indicator. **Both the Bayesian information criterion (BIC) and the Akaike information criterion single out specification (3) as the best one.** Therefore, we report the results of model (3) in the main text.

Note that it is crucial to control for the *believed* testosterone treatment in order to measure the effect of the *actual* testosterone treatment properly. The reason is that – due to the small sample size – there exists a small insignificant co-variation between the believed testosterone treatment and the actual testosterone treatment, i.e. subjects who received testosterone are slightly more likely to believe that they received testosterone. This co-variation then dampens the effect of the actual testosterone treatment if one does not control for the believed treatment effect because the belief in testosterone tends to reduce bargaining offers while actual testosterone tends to increase it.

We conducted the same ANOVAs with single ultimatum game offers instead of the mean offer per individual, and controlled for repeated measurements. This yields the same results. In addition, we also bootstrapped the standard errors in equivalent OLS-regressions; this does not change the significance of any effect reported in the paper (and reported above).

A robustness check with additional data

As a robustness check, we conducted an additional experiment with 90 female proposers and 90 female responders. This experiment was identical to the previous one, except for the fact that subjects did not take a testosterone or placebo pill. Testosterone was not mentioned in any way before or during the experiment.

This experiment enables us to check the robustness of the previous statistical results. In particular, individuals in the new experiment can all be viewed as subjects in (i) a placebo treatment who (ii) must believe they are in a placebo treatment because testosterone was never even mentioned before or during the experiment. The proposers in the new experiment should therefore make the same bargaining offers as those in the previous experiment who actually received a placebo and who believed that they received a placebo. This conjecture is indeed true (bootstrapped Mann Whitney test based on 20,000 replications, $z = 1.31$, $p = 0.191$). Therefore, we can treat the proposers in the new experiment like subjects who received a placebo and who believed that they received a placebo. By combining the data from the new and the previous experiment, we substantially increase the statistical power of our estimates.

For example, by combining the data of the new experiment with that of those subjects from the previous experiment who believed that they received a placebo, we have now sufficient data to examine the effect of actual testosterone only among subjects with a placebo belief. It turns out that the subjects in this sample who actually received testosterone made significantly higher bargaining offers than those who did not receive testosterone. (t-test: $p = 0.006$; Mann-Whitney test: $p = 0.005$; $N = 133$, both tests are bootstrapped with 20,000 replications).

Below we show the results of ANOVAs with the combined data of both experiments.

Table S3. Significance levels and model selection criteria for different statistical models (ANOVAs) with the enlarged data set

Dependent variable: proposers' mean offer	(1)	(2)	**(3)**	(4)	(5)
Indicator for actual testosterone treatment	p=0.031		**p=0.001**	p=0.003	p=0.009
Indicator for believed testosterone treatment		p=0.055	**p=0.002**	p=0.002	p=0.001
Interaction of actual and believed treatment				p=0.416	p=0.299
Indicator for additional experiment					p=0.395
Akaike information criterion (AIC)	436.92	437.93	**429.33**	430.65	431.90
Bayesian information criterion (BIC)	442.94	443.95	**438.36**	442.69	446.95
	N = 150	N = 150	**N = 150**	N = 150	N = 150

In the combined data set, AIC and BIC both select model specification (3). The basic results are similar to those of Table S2, except that now the p-values for the testosterone effect are generally lower because the larger number of observations enables us to estimate the standard errors more precisely. For example, **the effect of actual testosterone is now significant at p = 0.031 even if one does not control for testosterone beliefs (specification (1)).**

We added a new specification (5) in order to test if the results are driven solely by differences in the proposers' mean offers in the two experiments. To test this, we included an indicator variable for whether a subject participated in the additional experiment (= 1) or not (= 0). We find that the role of actual testosterone, believed testosterone and their interaction does not change in any important way and the p-value of 0.395 indicates that the additional indicator variable is not significant. Note also that AIC and BIC indicate that model (5) provides a worse description of the data than models (3) or (4).

We conducted the same ANOVAs as in Table S3 with single ultimatum game offers instead of the mean offer per individual, and controlled for repeated measurements. This yields the same results. In addition, we also bootstrapped the standard errors in equivalent OLS-regressions; this does not change the significance of any effect reported in the paper (and reported above).

Furthermore, we also used the combined data set to examine responder behaviour as well. None of the responder results described in the paper changes if we use the combined data set. In particular, the null effect of actual testosterone on responders' behaviour also holds.

Survey results on subjects' beliefs about testosterone

Eighteen months after the experiment we conducted a survey which confirmed subjects' strong beliefs in the folk hypothesis: they believed that testosterone increases contentious, selfish and aggressive behaviour. 52 percent of them even spontaneously mentioned the word "aggressive" when asked to indicate how testosterone administration affects the behaviour of individuals. Moreover, if asked whether testosterone administration would make *them* more aggressive, 68 percent agreed with this statement. We gave subjects a list of paired behavioural or intentional attributes such as "aggressive - peaceful". The subjects then could express their views about whether testosterone makes people strongly aggressive, weakly aggressive, weakly peaceful, strongly peaceful or neither aggressive nor peaceful". 80% of the subjects expressed the view that testosterone makes people strongly or weakly aggressive. The list of paired attributes also contained words such as contentious and selfish. 83% agreed that testosterone makes people more contentious and roughly 50 percent thought that it makes them more selfish (only 5 percent thought that it makes them less selfish).

Interpreting the belief effect

The data from the additional experiment (with 90 female proposers and 90 female responders) can also be used to gain further insight into the potential mechanisms associated with a testosterone belief. Recall that this experiment was identical to the main experiment, except for the fact that subjects did not take a testosterone or placebo pill. Testosterone was not mentioned in any way before or during the experiment, but after the experiment was over (i.e. after all decisions had been made), we asked subjects whether they believe they have an above average or a below average testosterone level. The answer to this question is useful for the interpretation of the testosterone effect because *only* ex-post rationalization can be operative in this setting: the subjects who made unfair offers could legitimise their behaviour by saying that they believe they have an above average testosterone level, implying a *negative* correlation between their offers and the above average testosterone belief. However, those with above average beliefs make even (insignificantly) *higher* offers (t-test, $p = 0.348$, $N = 49$). It seems, therefore, that the ex-post rationalization of unfair offers is an unlikely mechanism for the strong belief effect observed in the placebo-controlled study.

The role of endogenous baseline testosterone

An interesting question concerns the potential role of endogenous baseline testosterone levels in our experiment. If subjects in the testosterone group exhibited higher baseline testosterone levels, one could argue that the difference in baseline testosterone levels causes the effect on proposers' offers and not the exogenous administration *per se*. We therefore measured salivary testosterone levels immediately before substance administration. We find no significant difference in baseline testosterone levels in the two treatment groups (Mann-Whitney test: $p = 0.741$, $N = 59$, two-tailed). Furthermore, we also controlled for a potential impact of baseline testosterone at the *individual subject level* by controlling for baseline levels. This analysis again confirms that testosterone administration also increases proposers' offers if we control for baseline testosterone (ANOVA, main effect of testosterone, controlled for baseline testosterone values, $F = 4.18$, $p = 0.046$, two-tailed; Cohen's $f^2 = 0.23$, $N= 59$), and the impact of baseline testosterone on proposers' offers is insignificant (ANOVA, main effect of baseline testosterone values, $F = 0.92$, $p = 0.437$, two-tailed; $N= 59$). Finally, we checked whether the effect of exogenous testosterone on proposer's behaviour is a function of baseline testosterone levels in the sense that subjects with low endogenous baseline levels react particularly strongly to the exogenous administration of testosterone. However, the interaction effect between endogenous testosterone levels and the exogenous testosterone administration on proposers' offers is also insignificant (ANOVA, $F = 0.80$, $p = 0.497$, two-tailed, $N = 59$). Thus, these results show that endogenous baseline testosterone levels cannot explain the higher prevalence of fair offers – which is consistent with a recent study that relates endogenous testosterone levels to proposer behaviour in the ultimatum game[1]. Instead, it is the experimental administration of testosterone that caused the higher bargaining offers in our experiment.

Behavioural implications of social status concerns in the ultimatum game

The proposer in the ultimatum game faces the threat of a rejection if she makes an unfairly low offer. The proposer can avoid a rejection with near certainty by making a fair offer, while the rejection probability is substantial if she makes an unfair offer. If subjects with testosterone show a stronger concern for social status in the sense that they are more concerned about avoiding being vetoed (i.e., "losing their face"), they will make higher offers. *The purpose of this subsection is to show that this statement can be rigorously derived from a mathematical model that takes the psychological rejection concern into account.*

In the first step, we define the proposer's utility from an offer x if the offer is accepted (which we denote by u^a) and if the offer is rejected (which we denote by u^r). In order to do this we normalize, without loss of generality, the total sum to be divided to 1. The proposer's utility u of an accepted offer of the size $x \in [0,1]$ is defined as follows:

$$u^a = 1 - x$$

If the responder rejects the offer, both earn zero and the utility of the proposer is defined by the following expression:

$$u^r = -\varepsilon$$

where $-\varepsilon$ denotes the utility loss a status-concerned proposer experiences in case of a rejection. Thus, in contrast to a proposer who is not concerned about social status, a proposer with social status concerns has an additional utility loss because the rejection diminishes her status.

Since the proposer does not know whether the second-mover will accept or reject the offer, she has to form beliefs about the likelihood of the acceptance of an offer $p(x)$. We assume that proposer's beliefs about the likelihood that an offer will be accepted increases with the size of the offer, that is, $p'(x) > 0$, an assumption this is empirically well supported. Moreover, we assume that the relationship between the acceptance rate and the size of the offers is weakly concave, meaning that the increase in the acceptance rate does not increase with the offer size [i.e., $p''(x) \leq 0$]. We only make this assumption for convenience. A weaker assumption [that p'(x) does not increase too much with x] would also suffice.

The *expected* utility U of an offer x is defined by the utilities of acceptance and rejection that are weighed by the probabilities of acceptance $p(x)$ and rejection $(1 - p(x))$:

$$U = p(x)u^a + (1 - p(x))u^r$$

If we insert the definitions for u^a and u^r into U we get

$$U = p(x)[1 - x] + [1 - p(x)][-\varepsilon]$$

This expression for the expected utility of an offer x shows that a proposer with social status concerns (i.e. with $\varepsilon > 0$) can gain more from making offers that are accepted than a proposer who does not care about social status (i.e. $\varepsilon = 0$). The simple reason is that for a proposer with status concerns the utility of a rejected offer is lower compared to a proposer without status concerns. Thus, a proposer with status concerns has more to gain from inducing acceptance than a proposer without status concerns. Because the proposer can increase the probability of acceptance by making higher offers to the responder, a proposer with status concerns has an incentive to make higher offers than a proposer without status concerns. Thus, if testosterone increases status concerns, it follows that subjects with testosterone will make higher offers.

In the second step, we prove this claim explicitly by deriving the proposer's optimal offer, which is the offer x^* that maximizes the proposer's expected utility. For this purpose, we take the first derivative of the expected utility U with respect to x (denoted by U_x) and set it equal to zero:

$$U_x = p'(x^*)[1 - x^* + \varepsilon] - p(x^*) = 0.$$

Our assumptions guarantee that the second derivative U_{xx} is negative, which implies that the solution x^* to the above equation constitutes a global maximum of U.

In the third step, we compute how the optimal offer x^* changes if the status component ε increases. The change in the optimal offer x^* in response to a change in ε can be computed by taking the total derivative of the first order condition $U_x = 0$ and rearranging terms:

$$\frac{\partial x^*}{\partial \varepsilon} = -\frac{U_{x\varepsilon}}{U_{xx}}$$

$U_{x\varepsilon}$ and U_{xx} denote the second partial derivates of expected utility. If we insert the explicit expressions for $U_{x\varepsilon}$ and U_{xx} into the above expression we get:

$$\frac{\partial x^*}{\partial \varepsilon} = - \frac{p'(x^*)}{p''(x^*)\times\left[1 - x^* + \varepsilon\right] - 2\times p'(x^*)} > 0$$

Because $p'(x)$ is always positive and $p''(x)$ is always negative or zero, the denominator in the above expression is always negative while the numerator ($p'(x)$) is always positive. Thus, $\partial x^*/\partial \varepsilon$ is always positive. It follows that we have shown that a proposer's optimal offer x^* increases if the proposer is more concerned about social status (i.e. has a higher ε). Therefore, if testosterone administration increases status concerns by increasing ε, testosterone administration will lead to higher offers.

Behavioural implications of relative payoff preferences in the ultimatum game

A competing explanation for higher proposer offers in the ultimatum game is that subjects care for *relative payoffs*. A subject with relative payoff preferences values the payoff difference (or the payoff ratio) between herself and the relevant reference agent positively, i.e., the subject prefers to be better off in material terms than others and wants to avoid being worse off than others. Research on social preferences has documented the existence these subjects[2,3]. They prefer, for example, a material payoff allocation (8, 2) for (self, other) over an allocation (8, 5) even though their own payoff does not change across allocations. They also prefer a payoff allocation (0, 0) over the allocation (2, 8) because by choosing (0, 0) they can avoid the extra disutility from earning less than the other player.

A formal model (presented below) shows that if testosterone increases the relative payoff component of a subjects' preference, the individual may make either higher or lower offers in the ultimatum game. In other words, there is no clear prediction for proposer behaviour. The intuition behind this result is as follows: a proposer with a stronger relative payoff preference values an unequal accepted offer, say the offer (8, 2), more than a proposer with a weaker preference for being ahead. This is so because the proposer with the strong relative payoff preference derives a higher utility from being ahead in payoff terms. However, this subject also loses more utility if the offer is rejected. Therefore, it is a priori unclear whether this subject will make higher or lower offers compared to a proposer with a weaker relative payoff preference. This means that the higher offers of the proposers with testosterone could, in principle, be a consequence of a higher, testosterone-induced, relative payoff preference.

However, the existence of testosterone-induced relative payoff preferences also makes a prediction for the responders in the ultimatum game. A responder with a strong preference for relative payoffs derives less utility from an unfair offer than a responder with a weak preference because the unfair allocation gives the responder less than the proposer. Thus, if testosterone increases the strength of relative payoff preferences, responders who receive testosterone are unambiguously more likely to reject unfair offers compared to subjects who received placebo. However, as shown in the main text, the responder data do not support this prediction.

The lack of an impact of testosterone administration on rejection behaviour suggests that testosterone does not affect relative payoff preferences in the ultimatum game. In addition, this fact also suggests that testosterone has a negligible impact on various forms of social preferences such as altruism, social welfare concerns, inequity aversion, or reciprocity (see subsection on social preferences below).

A simple formal model of relative payoff preferences in the ultimatum game

The mathematical model presented below shows that if testosterone has an effect on relative payoff preferences, the following two results hold:

1) Testosterone administration has an ambiguous effect on the proposer's optimal offer, implying that the offers of subjects in the testosterone group can increase or decrease.
2) Testosterone administration unambiguously increases the rejection rate of unfair offers.

Result 1 implies that higher bargaining offers in the testosterone group are consistent with the relative payoff motive but our data on responder behaviour are not in accordance with result 2 suggesting that testosterone does not affect relative payoff preferences in the ultimatum game. As in the previous model, we will proceed in several steps. In the first, we define the proposer's utility from an offer x if the offer is accepted (denoted by u^a) and if the offer is rejected (denoted by u^r). In order to do this we normalize, without loss of generality, the total sum to be divided to 1. The proposer's utility u of an accepted offer of size $x \in [0,1]$ is defined as follows:

$$u^a = 1 - x + \sigma[(1 - x) - x],$$

where σ measures the strength of the utility gain from earning more than the partner (if $1 - 2x$ is positive), or the utility loss from earning less than the partner (if $1 - 2x$ is negative). A proposer with no relative payoff concerns has a $\sigma=0$. If the responder rejects the offer, both players earn zero and the utility of the proposer is zero:

$$u^r = 0.$$

Since the proposer does not know whether the second-mover will accept or reject the offer, she has to form beliefs about the likelihood of the acceptance of an offer $p(x)$. We assume that proposer's beliefs about the likelihood of an offer being accepted increases with the size of the offer, that is, $p'(x) > 0$, an assumption that is empirically well supported. Moreover, we assume that the relationship between the acceptance rate and the size of the offers is weakly concave, meaning that the increase in the acceptance rate does not increase with the offer size [i.e., $p''(x) \leq 0$]. This assumption is only made for convenience. A weaker assumption [that $p'(x)$ does not increase too much with x] would also suffice.

The *expected* utility U of an offer x is defined by the utilities of acceptance and rejection that are weighed by the probabilities of acceptance $p(x)$ and rejection $(1 - p(x))$:

$$U = p(x)u^a + (1 - p(x))u^r$$

If we insert the definitions for u^a and u^r into U we get

$$U = p(x)[1 - x + \sigma(1 - 2x)]$$

This expression for the expected utility of an offer x shows that a proposer who cares about relative payoffs ($\sigma>0$) can gain more from generating offers that favour her (i.e., $1 - 2x > 0$) <u>and</u> are accepted compared to a proposer who does not care about relative payoffs ($\sigma=0$).

This fact means that proposers with relative payoff concerns have a higher incentive to make offers that are accepted, inducing them to make higher offers. However, a proposer with a relative payoff concern also gains more from decreasing the offer because this increases both her material payoff and her relative payoff. Thus, two forces are at work. One force increases optimal offers while the other force decreases it. The overall effect of relative payoff concerns on bargaining offers is thus unclear.

In the second step we prove these claims explicitly by deriving the proposer's optimal offer, which is the offer x^* that maximizes the proposer's expected utility. For this purpose, we take the first derivative of the expected utility U with respect to x (denoted by U_x) and set it equal to zero:[1]

$$U_x = p'(x^*)[1 - x + \sigma(1 - 2x^*)] - p(x^*)[1 + 2\sigma] = 0.$$

In the third step, we compute how the optimal offer x^* changes if the relative payoff component σ increases. The change in the optimal offer x^* in response to a change in σ can be computed by taking the total derivative of the first order condition $U_x = 0$ and rearranging terms:

$$\frac{\partial x^*}{\partial \sigma} = -\frac{U_{x\sigma}}{U_{xx}}$$

$U_{x\sigma}$ and U_{xx} denote the second partial derivates of the expected utility. If we insert the explicit expressions for $U_{x\sigma}$ and U_{xx} into the above expression we get:

$$\frac{\partial x^*}{\partial \sigma} = -\frac{p'(x^*)[1-2x^*]-2p(x^*)}{p''(x^*)[1-x^*+\sigma(1-2x^*)]-2p'(x^*)[1+2\sigma]}$$

The sign of $\partial x^*/\partial \sigma$ is ambiguous since the sign of the numerator is ambiguous. Thus, if testosterone increases the concern for relative payoffs by increasing σ, bargaining offers may increase or decrease.

In the final step, we show the relative payoff concerns unambiguously predict an increase in the responders' rejection rate. A responder rejects an offer if her utility of accepting (U^{acc}) is lower than the utility of rejecting (U^{rej}). Because the utility of a rejection is zero, a responder rejects an offer x if her utility of accepting the offer U^{acc} obeys the inequality

$$U^{acc} = x + \sigma[x - (1 - x)] < U^{rej} = 0.$$

The above inequality is met if $\sigma > x/(1 - 2x)$, i.e., if relative payoff concerns are sufficiently high. Thus, if testosterone increases relative payoff concerns by increasing the value of σ there will be more responders for which $\sigma > x/(1 - 2x)$ holds, implying that the rejection rate in the testosterone group will be higher.

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[1] The second derivative is negative if the offer $x \leq 0.5$.

Behavioural implications of social preferences in the ultimatum game

Our experimental data show that testosterone increases bargaining offers and leaves rejection rates unaffected. Combining these two observations, we are able to rule out effects of testosterone on a number of alternative explanations for our observed main effect that testosterone increases status concerns. In particular, we can rule out that testosterone affects social welfare concerns, inequity aversion or reciprocity that have been discussed in the economics literature:

1) **Social welfare concerns:** a subject is concerned about social welfare if he or she puts a positive value on the *total* payoff of the players involved in a social interaction. Therefore, if testosterone increases concerns for social welfare this induces subjects to put a higher value on the total payoff that both players earn. This predicts that proposers make fairer offers because such offers reduce the risk of a rejection and lead to a higher total payoff. However, we should also observe a *lower* rejection rate because rejections imply a zero payoff for both parties. Therefore, responders who put a higher value on the total payoff should reject fewer offers, which we do not observe.

2) **Inequity aversion**:. one implication of inequity aversion is that subjects dislike being behind in terms of material payoffs. Thus, if testosterone increases inequity aversion, we should observe a higher rejection rate, which is not the case.

3) **Negative reciprocity**: This has been frequently invoked as an explanation for rejections of unfair offers in the ultimatum game. Negative reciprocity means that subjects punish the proposer for making an unfair offer by rejecting her offer. Apparently, however, testosterone does not seem to induce changes in negative reciprocity because it does not affect the rejection rate.

Remarks on baseline testosterone and rejection behaviour

The absence of an effect of baseline testosterone on rejection behaviour in our sample is at odds with results presented by Burnham[1]. He finds in a sample of 26 men that those 6 men who reject unfair offers have higher testosterone levels than those 20 men who accept unfair offers. However, regardless of which correlation we observe between endogenous baseline testosterone and behaviour, we can never infer from such a correlation that baseline testosterone causes the observed behaviours. For example, aggressive, antisocial or competitive behaviours in daily life may cause high endogenous testosterone. If these subjects also behave more aggressively or competitively in the experiment one observes a correlation between the experimental measure and endogenous testosterone. This was the main reason why we manipulated testosterone exogenously in our study.

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