Low- and High-Testosterone Individuals Exhibit Decreased Aversion to Economic Risk
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Testosterone has been positively associated with aggressive, risky behaviors in a wide range of real-world domains (Mazur & Booth, 1998). Trial lawyers, who take constant risks in the courtroom, have higher testosterone levels than non-trial lawyers (Dabbs, Alford, & Fielden, 1998). Among criminals, testosterone is positively associated with the likelihood of having committed a violent crime (Dabbs, Frady, Carr, & Besch, 1987). In a sample of more than 4,000 veterans of the U.S. Army, testosterone was positively associated with alcohol abuse, drug use, violence, illicit behavior, and sexual promiscuity (Mazur, 1995). More than 50 other studies have also shown that testosterone is positively associated with interpersonal dominance and aggression, both of which engender associated social and physical risks (Archer, 2006; Mazur & Booth, 1998; Stanton & Schultheiss, 2009). The associations of testosterone with aggressive, dominating, and risky behaviors suggest that increased levels of this hormone lead to a generalized decrease in risk aversion. However, it remains to be shown whether and how testosterone levels shape risk taking in economic contexts.

The few studies that have examined the link between testosterone levels and economic decision making have yielded inconsistent results. Notably, these studies have varied in whether testosterone was measured endogenously or manipulated exogenously, in whether and how choices involved real economic incentives, and in whether one or both genders were included in the study sample (Apicella et al., 2008; Sapienza, Zingales, & Maestripieri, 2009; van Honk et al., 2004; Zethraeus et al., 2009).

In a study reported by Apicella et al. (2008), endogenous testosterone levels in men were positively correlated with choosing to make a risky investment in a single-trial gamble. Participants could gamble any percentage of a $250 endowment; a successful coin toss would multiply whatever was bet by 2.5, whereas failure meant loss of the bet amount. In contrast to received wisdom regarding testosterone and risk, the present data provide the first robust evidence for a nonlinear association between economic preferences and levels of endogenous testosterone.
contrast, Sapienza et al. (2009) used an incentive-compatible algorithm (Holt & Laury, 2002) in which subjects chose between a 50/50 gamble with $0 and $200 outcomes and varying guaranteed payments ($50–$120). In this study, endogenous testosterone levels were not associated with men’s risk preferences but were negatively correlated with risk aversion in women.

Alternatively, exogenous administration allows examination of how changes in testosterone levels affect decision making. Results have been similarly inconclusive: Although van Honk et al. (2004) found that testosterone induces reduced risk aversion in a gambling task with hypothetical rewards, Zethraeus et al. (2009) failed to find an effect of testosterone administration in a task using an incentive-compatible version of Holt and Laury’s (2002) algorithm. Because testosterone administration effectively pushes all participants into a supraphysiological range of testosterone concentration (Tuiten et al., 2000), it may mask underlying associations between endogenous testosterone levels and risk preferences, such as potential nonlinear effects within the normal physiological range. Thus, it remains unclear what influence, if any, testosterone levels exert on economic risk preferences.

In the study reported here, we investigated the relationship between endogenous testosterone levels and economic decision making in a large sample of men and women. We examined individual choice preferences using three canonical, incentive-compatible paradigms: risk preference, ambiguity preference, and loss aversion (Fig. 1). Our approach and sample size allowed us to address many of the challenges raised by previous work: We included both genders simultaneously, compared linear and nonlinear models, and used incentive-compatible tasks to examine economic preferences.

Method

Participants

Data were collected in Durham, North Carolina, from 298 participants (142 men, 156 women; age range = 18–48 years, $M = 22.1$ years, $SD = 4.2$ years). All participants provided informed consent under a protocol approved by the Duke University Medical Center Institutional Review Board.

Procedure

Participants were tested between 1:00 p.m. and 5:15 p.m. During a single session, participants completed economic decision-making tasks, provided a saliva sample, and completed questionnaires unrelated to this report.

Economic decision-making tasks

The risk preference of each subject was determined through 120 trials in which the subject selected between a certain outcome and a risky gamble (Fig. 1, top panel). Across trials, the values of the certain outcome were $3, 4, 5, 6,$ and $7$. Each certain outcome was used in 24 trials; the accompanying risky gambles were randomly selected (without replacement) from a set determined by three possible probabilities of winning (25%, 50%, and 75%) and eight ratios of the expected value of the gamble ($EV_g$) to the value of the certain option ($V_C$). The included $EV_g/V_C$ ratios were 0.5, 1.0, 1.3, 1.6, 1.9, 2.2, 2.5, and 3.0.

The ambiguity preference of each subject was measured in an additional 35 trials (intermixed with the risk-preference trials) in which participants selected between a certain outcome ($3, 4, 5, 6,$ or $7$) and a gamble with an unknown probability of winning (Fig. 1, middle panel). The expected value of the ambiguous gamble was calculated using a probability of
.5. The included $E V_C / V_C$ ratios were 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0 (see the Supplemental Material available online for additional details about this task).

Loss aversion was measured using a task based on a previous study by Tom, Fox, Trepel, and Poldrack (2007). Subjects were endowed with $20 and then presented with 64 trials; on each trial, they were offered a gamble in which they could lose part or all of their endowment or could gain a larger amount (Fig. 1, bottom panel). Trials were constructed from the factorial combination of losses ranging from $6 to $20 ($2 increments) and gains ranging from $12 to $40 ($4 increments).

No feedback was provided until the end of the experimental session; this eliminated the possibility of intertrial changes in preferences based on outcomes.

Testosterone measurement
Saliva samples were collected and stored using standard methods and were assessed with solid-phase Siemens Healthcare Diagnostics (Los Angeles, CA) Coat-A-Count125 I radioimmunoassay for testosterone (see the Supplemental Material for details on the assay protocol; Schultheiss & Stanton, 2009). For samples of known concentration (45 pg/mL and 115 pg/mL), inter assay coefficients of variation (CVs) were 14.1% and 5.2%, respectively. Analytical sensitivity, or the lower limit of detection, was 1.2 pg/mL.

Mean salivary testosterone concentrations were 86.5 pg/mL ($SD = 26.0$) for men and 14.2 pg/mL ($SD = 7.0$) for women; the effect of gender was significant, $t(283) = 32.3, p < .001$. Because of this gender difference, we used z scores for testosterone levels (i.e., each individual’s testosterone level relative to the distribution for his or her gender) in all subsequent analyses (Mehta, Jones, & Josephs, 2008).

Gender effects on risk and ambiguity preferences and on testosterone levels
Women were significantly more risk averse than men, $t(271) = −2.35, p = .02$ (risk premium for men: $M = 38\%, SEM = 5\%$; risk premium for women: $M = 54\%, SEM = 5\%$) and also more ambiguity averse than men, $t(214) = −2.92, p = .004$ (ambiguity premium for men: $M = 135\%, SEM = 11\%$; ambiguity premium for women: $M = 183\%, SEM = 12\%$).

Mean salivary testosterone concentrations were 86.5 pg/mL ($SD = 26.0$) for men and 14.2 pg/mL ($SD = 7.0$) for women; the effect of gender was significant, $t(283) = 32.3, p < .001$. Because of this gender difference, we used z scores for testosterone levels (i.e., each individual’s testosterone level relative to the distribution for his or her gender) in all subsequent analyses (Mehta, Jones, & Josephs, 2008).

Effects of testosterone on risk and ambiguity preferences
To examine the effects of endogenous testosterone on risk and ambiguity preferences, we used regression models to which we progressively added a priori independent variables. Model 1 included only testosterone as a linear predictor variable, Model 2 added testosterone as a quadratic predictor, and Model 3 added gender. Risk and ambiguity preferences were analyzed in separate models.

Neither risk preference nor ambiguity preference had a significant linear relationship with testosterone (Model 1; Tables 1 and 2). In the next step (Model 2), we found highly significant U-shaped relationships between endogenous testosterone level and risk and ambiguity preferences (Fig. 2, Tables 1 and 2): Whereas individuals with intermediate levels of testosterone were risk and ambiguity averse, as is typically found, individuals with high or low levels of testosterone (i.e., individuals with testosterone levels more than 1.5 SDs above or below the mean within their gender) were risk and ambiguity neutral (see the Supplemental Material for additional analyses using other regression models and covariates).
When gender was included as an additional factor (Model 3), the quadratic effect of testosterone on risk preference and on ambiguity preference was still significant, as was the effect of gender itself (Tables 1 and 2). When we separated the analyses by gender, the quadratic relationship between testosterone and risk preference was similar for women ($\beta = -0.17, p = .05$) and men ($\beta = -0.21, p = .02$). Although the quadratic relationship between testosterone and ambiguity preference was not significant in each gender independently, the beta coefficients for men ($\beta = -0.15, p = .12$) and women ($\beta = -0.13, p = .22$) were of similar magnitude to the coefficient for the whole sample.

**Effects of testosterone on loss aversion**

We also examined the relation between testosterone and loss aversion, the relative weighting of possible economic losses and gains (Tversky & Kahneman, 1992). We calculated loss aversion ($\lambda$) for each individual participant as follows: the unstandardized logistic regression coefficient for loss divided by the unstandardized regression coefficient for gain (Tom et al., 2007). Men and women did not differ in their loss aversion, $t(269) = 1.3, p = .2$ (men: median $\lambda = 1.9$, 25th–75th percentile = 1.4–3.1; women: median $\lambda = 1.9$, 25th–75th percentile = 1.4–4.0).

Testosterone had no linear association with loss aversion ($r = -.03, p = .62$) and no quadratic association with loss aversion, both when testosterone was the only predictor ($\beta = 0.07, p = .30$) and when gender was added to the regression model ($\beta = 0.06, p = .36$).

**Discussion**

Despite the common view that high testosterone levels lead to risky decisions across numerous domains, we found that testosterone has a quadratic relationship with economic risk preferences: Individuals with low and high levels of testosterone (within their gender) were risk and ambiguity neutral, whereas individuals with intermediate levels of testosterone were risk and ambiguity averse. Moreover, our study provides the first data documenting the effects of testosterone on ambiguity preferences. The parallel U-shaped effects for risk and ambiguity suggest that testosterone levels are associated with preferences for economic uncertainty, regardless of whether probability is known (risk) or unknown (ambiguity). Even though women and men differed both in their risk and ambiguity premiums and in their testosterone levels, testosterone levels had similar effects on risk premiums and on ambiguity premiums within each gender independently. Notably, the within-gender differences in risk and ambiguity premiums between individuals with intermediate testosterone levels (< 0.5 SD from the mean) and those with extreme levels of testosterone (> 1.5 SD from the mean) were approximately twice as large as the between-gender difference in risk and ambiguity premiums.

Note that there were no linear effects of testosterone. In contrast, Apicella et al. (2008) found that endogenous testosterone was positively associated with risk taking in men, and Sapienza et al. (2009) found that endogenous testosterone was negatively associated with risk aversion in women, but not in men. Differences between our study and past studies could

### Table 1. Regression Models Examining the Linear and Nonlinear Relationships Between Testosterone and Risk Preference

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Model</th>
<th>Testosterone (linear)</th>
<th>Testosterone (quadratic)</th>
<th>Gender</th>
<th>Regression statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model 1</td>
<td>$-0.05 (.44)$</td>
<td></td>
<td></td>
<td>$F(1, 256) = 0.59, p = .44$</td>
</tr>
<tr>
<td></td>
<td>Model 2</td>
<td>$-0.02 (.74)$</td>
<td>$-0.19 (.002)$</td>
<td></td>
<td>$F(2, 255) = 5.00, p = .002$</td>
</tr>
<tr>
<td></td>
<td>Model 3</td>
<td>$-0.01 (.84)$</td>
<td>$-0.18 (.003)$</td>
<td></td>
<td>$F(3, 254) = 5.35, p = .001$</td>
</tr>
</tbody>
</table>

Note: The table reports standardized beta coefficients, with the corresponding p values in parentheses. Gender was dummy-coded (male = 0, female = 1).

### Table 2. Regression Models Examining the Linear and Nonlinear Relationships Between Testosterone and Ambiguity Preference

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Model</th>
<th>Testosterone (linear)</th>
<th>Testosterone (quadratic)</th>
<th>Gender</th>
<th>Regression statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model 1</td>
<td>$-0.03 (.64)$</td>
<td></td>
<td></td>
<td>$F(1, 202) = 0.22, p = .64$</td>
</tr>
<tr>
<td></td>
<td>Model 2</td>
<td>$0.01 (.94)$</td>
<td>$-0.16 (.03)$</td>
<td></td>
<td>$F(2, 201) = 2.68, p = .07$</td>
</tr>
<tr>
<td></td>
<td>Model 3</td>
<td>$0.01 (.85)$</td>
<td>$-0.15 (.03)$</td>
<td></td>
<td>$F(3, 200) = 4.69, p = .003$</td>
</tr>
</tbody>
</table>

Note: The table reports standardized beta coefficients, with the corresponding p values in parentheses. Gender was dummy-coded (male = 0, female = 1).
Fig. 2. Risk and ambiguity premiums as a function of testosterone level. Endogenous testosterone levels were standardized within each sex independently. The top row shows results for (a) risk and (b) ambiguity for the sample overall; error bars represent standard errors. The scatter plots in the bottom row show the relationship between endogenous testosterone levels and (c) risk and (d) ambiguity premiums for individual male and female participants; the curves are quadratic-fit regression lines.

Contribute to the inconsistency in the findings. For example, Apicella et al. used a single-trial task that had limited incentive compatibility (only a single, randomly picked subject out of the entire sample population would be paid). Sapienza et al. recruited a sample of graduate business-school students who were trained at risk calculation and whose risk preferences may not be representative of the greater population. Yet, given the current results, it is notable that Sapienza et al. suggested that testosterone could have nonlinear effects even though they did not test for specific nonlinear effects in their data. The nonlinear relation we found may also account for reported effects of testosterone administration (van Honk et al., 2004), in that supraphysiological testosterone levels would move most participants from risk averse to risk neutral in their preferences, overshadowing the underlying U-shaped association that exists within the normal physiological range (van Honk et al., 2004; Zethraeus et al., 2009).

Our finding that high levels of testosterone are related to risk-seeking economic choices is consistent with the literature on the relationship between testosterone and risk in other domains (Mazur & Booth, 1998). More striking is the finding that individuals with low testosterone levels are also more risk seeking than are those with intermediate levels. From a neurobiological perspective, the U-shaped association could arise through several mechanisms. One possible contributor is suggested by studies showing that androgen receptor density can vary with testosterone levels (Doumit, Cook, & Merkel, 1996). Androgens bind not only to androgen receptors but also to neurotransmitter receptors (e.g., the GABA-A receptor) that have been associated with decision preferences in humans (Lane & Gowin, 2009). Depending on the brain region, androgens can either amplify or diminish the effects of GABA (Jorge-Rivera, McIntyre, & Henderson, 2000, 2007; Masonis & McCarthy, 1996), and this could contribute to GABA-mediated, curvilinear associations between testosterone and behavior. Curvilinear associations with testosterone may reflect biological optimization, which has been previously reported for testosterone in both cognitive domains (e.g., spatial cognitive abilities; Moffat &
Hampson, 1996) and physiological domains (e.g., cardiovascular health; Laughlin, Goodell, & Barrett-Connor, 2010). Because the extent to which specific economic risk preferences are optimal is likely to vary across contexts (e.g., risk seeking may become adaptive when resources are scarce), the greater variability in preferences among individuals with intermediate levels of testosterone (see Figs. 2c and 2d) could itself reflect that adaptive flexibility.

Beyond the administration of testosterone, a variety of real-world events are known to change testosterone levels; consequently, such events could drive transient changes in risk preferences. For instance, winning or losing a sports match as an athlete (Booth, Shelley, Mazur, Tharp, & Kittok, 1989) or a political election as a voter (Stanton, Beehner, Saini, Kuhn, & LaBar, 2009) can change one’s testosterone levels, as can watching a dramatic action movie (Schultheiss, Wirth, & Stanton, 2004). Studying the effects of transient changes in testosterone that accompany such events would facilitate a broader understanding of the effects of testosterone on real-world economic decisions.

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

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Supplemental Material
Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

References


