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ORIGINAL ARTICLE

Effects of Neuroticism–Anxiety and Sociability Personality Traits on the Relationship Between Testosterone and Risk Propensity in Finance

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Abstract

Risky financial decisions, defined as rational calculations between expected risk and reward, are subject to various psychological and neurobiological mechanisms. In this context, the relationship between testosterone levels and risk propensity has been investigated, but the results are inconsistent. Here, the effects of some personality traits, neuroticism–anxiety and sociability, on the relationship between testosterone levels and risk propensity were examined in decisions under risk (GDT) and under uncertainty (BART). In a mixed-sex sample of 100 graduate students and experienced decision makers, we found that basal testosterone levels were positively correlated with risk propensity for decisions under risk in males with low neuroticism–anxiety scores, whereas they were negatively correlated with risk propensity for decisions under risk in males with high neuroticism–anxiety scores. However, they were not correlated in (i) decisions under uncertainty in males, independent of neuroticism–anxiety, (ii) decisions under risk or under uncertainty in males, independent of sociability, and (iii) decisions under risk or under uncertainty in females, independent of sociability and neuroticism–anxiety. These results indicate that neuroticism–anxiety, but not sociability, may affect the relationship between testosterone levels and risk propensity only in decisions under risk and only in males, and provide evidence for the complexity of this relationship in males.

Keywords: Risk propensity, Testosterone, Sociability, Neuroticism–anxiety, Personality traits

JEL classification: G41

Introduction

Financial decision making is a complex process in which the expected rewards are weighed against the associated risks (Berk & DeMarzo, 2020). Recent neuroeconomic studies suggest that financial decision making is influenced by various psychological constructs (Welker et al., 2019), social context (Zililoli & Watson, 2014), and biological factors such as hormones (Nofsinger et al., 2018), and not only by a rational cost–benefit analysis, as suggested by traditional economic decision-making theories (Tobler & Weber, 2014).

One hormone that has received attention in the context of financial decision making is the steroid hormone testosterone (Apicella et al., 2008; Herbert, 2018), which plays an important role in reproductive physiology and development, modulating a number of behavioral processes relevant to survival and reproduction, particularly in males (Apicella et al., 2015). Testosterone affects brain regions related to reward processing by increasing reward sensitivity (Welker et al., 2015), decreasing impulse control (Mehta & Beer, 2010), altering risk perception, and increasing dominance behavior (Mehta & Josephs, 2010). These effects may encourage individuals to

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take more risks, as the potential rewards become more attractive, and the perceived risks are minimized. Studies generally suggest that higher basal levels of endogenous testosterone or administered exogenous testosterone are associated with riskier financial decisions in the laboratory and in real life (Apicella et al., 2008; Coates & Herbert, 2008; Cueva et al., 2015; Nofsinger et al., 2018; Stanton, Liening, & Schultheiss, 2011; Van Honk et al., 2004). However, the results of studies are not consistent for both sexes and for all risk measures (Apicella et al., 2015). Furthermore, in one study, individuals with both lower and higher testosterone levels were more likely to make risky decisions (Stanton, Mullete-Gillman, et al., 2011). Taken together, these observations suggest a more complex relationship between testosterone and financial risk taking that is dependent on other neurobiological and psychological systems.

Risk-taking behavior has been shown to be related to personality traits such as sensation seeking, aggression, power motivation, sociability, and social contexts such as interpersonal competition (Welker et al., 2019; Zilioli & Watson, 2014; Zuckerman & Kuhlman, 2000). In finance, CEOs who are higher in extraversion and lower in conscientiousness are less likely to reduce their firm's strategic risk taking when the value of their stock options increases (Benischke et al., 2019). Individuals high in risk taking are often characterized by high extraversion and low neuroticism, agreeableness, and conscientiousness traits (Nicholson et al., 2005). Extraversion and neuroticism reflect the underlying neuropsychological mechanisms of approach and avoidance systems, which are related to reward processing (Corr, 2004; Krupić & Corr, 2017; Welker et al., 2015) and are bidirectionally linked to testosterone levels (El Ahdab et al., 2023; Enter et al., 2014). It is therefore possible that the relationship between testosterone and risk taking is affected by extraversion and neuroticism. However, we are not aware of any study that addresses the possible effects of particular personality traits on the relationship between testosterone and decision making.

Risk and uncertainty are related but distinct concepts (De Groot & Thurik, 2018). In situations involving risk, the outcome is unknown, but the probability distribution for that outcome is known. Conversely, in situations involving uncertainty, both the outcome and the probability distribution are unknown. In both cases, preferences are determined by the probability distributions of the outcomes (Platt & Huettel, 2008). In the case of risk, these probabilities are considered objective, whereas in the case of uncertainty they are subjective. The conceptual distinction between uncertainty and risk is supported by psychology and neurobiology, which indicate that they are encoded differently in the brain (Blankenstein et al., 2017; Huettel et al., 2006; Schultz et al., 2008). For example, the response of cortisol, another hormone that has received attention in the context of financial decision making, has been shown to affect decision making under risk, but not under uncertainty (Buckert et al., 2014). We are not aware of any study that addresses the possible differences in the relationship between testosterone and decision making under risk and decision making under uncertainty.

The aim of this study was to examine the effects of personality traits, specifically neuroticism–anxiety and sociability, on the relationship between basal testosterone levels and risk propensity in decisions under risk and decisions under uncertainty. We hypothesized that basal testosterone levels would be positively related to higher risk propensity in decisions under risk and decisions under uncertainty (1) only in individuals low in the neuroticism–anxiety personality trait (H1) and (2) only in individuals high in the sociability personality trait (H2).

1 Materials and methods

1.1 Participants

Participants were recruited through the university and its alumni base, consisting of graduate students and experienced decision makers. Exclusion criteria were alcohol or drug abuse, eating, drinking, smoking, chewing, flossing their teeth, taking medicine, or engaging in physical activity within 30 minutes before providing saliva samples. Participants were also required to provide signed informed consent prior to participating in the study. The research design and all related procedures were approved by the Committee for Ethics and Research at the School of Economics and Business of the University of Ljubljana and by the National Medical Ethics Committee of the Republic of Slovenia.

1.2 Study protocol

Testing was conducted in several sessions between April and September 2022 at the same times from around 7:30 to 9:30 in the morning. The data collection was partially related to another study. The experiment was conducted in two parts, with a 20-minute break in between. After a 10-minute resting period, during which participants were asked to calm down and relax, saliva samples were taken to assess their basal testosterone levels. Participants then completed either the Balloon Analogue Risk Task (BART) (Lejuez et al., 2002) or the Game of Dice Task (GDT) (Brand et al., 2004) and, after the break,

the other task. The order of the tasks was randomly assigned to each testing group to ensure that task order had no effect on performance. After completing both tasks, participants completed a general questionnaire about their sex, age, decision-making experience, education, physical activity, medical history, and the Zuckerman-Kuhlman Personality Questionnaire (ZKPQ) (Zuckerman, 2002) for the assessment of neuroticism–anxiety and sociability personality traits. To motivate real-life behavior in both tasks, one randomly selected participant from each test group received a voucher for a sports shop equal to their total earnings in BART. Participants were informed in advance about the possibility of receiving a financial reward in the amount of their total earnings in BART.

1.3 Instruments and measures

1.3.1 Sociodemographic data

A semi-structured sociodemographic questionnaire was used to obtain information on sex, age, decision-making experience (status: student or employed, short description of their work and job title), education, daily habits, including alcohol consumption (number of drinks per week), smoking (number of cigarettes smoked per day), sport activity (how often they practiced aerobic or anaerobic sports, when they had been physically active the last time and what kind of activity they had done), coffee consumption (coffee consumption on the testing day), and sleeping schedule on the day of testing (hours of sleep, wake up and bedtime). The information collected in this questionnaire was used to obtain general sociodemographic data and to assess compliance with the inclusion criteria of the study.

1.3.2 Decisions under uncertainty

Decision making under uncertainty was assessed using BART, in which participants inflate 30 balloons in a row and earn virtual five cents for each successful inflation (Lejuez et al., 2002). Each balloon can explode at any time during the process, representing the risk of losing the accumulated gains. Participants are not informed about the probability of an explosion, which is determined by a random selection of numbers from an array of 1 to 128. The selection of the number 1 indicates an explosion. Based on this algorithm, the average "explosion point" for each balloon is 64 pumps. To model excessive risk leading to decreased gains and increased threats, each additional pump increases the potential loss and decreases the relative gain of additional pumps. The average number of pumps on the balloons that did not explode (BART score) is used as the dependent variable for decisions under uncertainty, conceptualized as the risk propensity in decisions under uncertainty. A higher adjusted average number of pumps indicates a higher risk propensity in decisions under uncertainty.

1.3.3 Decisions under risk

Decision making under risk was assessed using GDT (Brand et al., 2004), in which participants are asked to increase their imaginary starting capital (€1000) within 18 throws of a single virtual dice. Before each throw, subjects have to guess which number or combination of numbers (2, 3, or 4 numbers) will be thrown. Each choice is associated with certain gains and losses depending on the probability of the choice's occurrence (a single number with a winning probability of 1:6 = €1000 gain/loss; a combination of two numbers with a winning probability of 2:6 = €500 gain/loss; a combination of three numbers with a winning probability of 3:6 = €200 gain/loss; a combination of four numbers with a winning probability of 4:6 = €100 gain/loss). The gains and losses are explicitly described in the test instructions. This allows participants to calculate the expected returns and the associated risks. The outcome of the throws is pseudorandomized to ensure that each of the six possible numbers occurs three times during the task performance, but in a balanced order. The maximum outcome is €19,000 (if the subject chooses a single number and is successful in each throw). The maximum deficit is −€17,000 (if the subject chooses a single number and is unsuccessful in each throw). To analyze the decisions, choices of one or two numbers (probability of winning is less than 50% and high gains but also high penalties) are classified as disadvantageous or risky choices. Conversely, the choices of three or four numbers (probability of winning is 50% or higher, low gains, but also low penalties) are classified as advantageous or safe choices. In GDT, the net score (GDT score) is commonly used as a measure of performance and as a dependent variable for risk propensity in the decisions under risk. It is calculated by subtracting the number of risky choices from the number of safe choices. The net score is a quantitative indicator of risk propensity, with a more negative score indicating a higher risk propensity in decisions under risk.

1.3.4 Personality traits

Personality traits were assessed using the ZKPQ, which is based on the assumption that personality traits have a strong biological–evolutionary basis and distinguishes between five personality traits: activity, aggression–hostility, impulsive sensation seeking, neuroticism–anxiety (N–Anx), and sociability (Sy) (Zuckerman, 2002). N–Anx and Sy correlate with neuroticism and extraversion from the Big Five (DeYoung & Blain, 2020) and are used to measure

individual differences in reward processing based on the underlying neuropsychological mechanisms of behavioral avoidance and approach systems, respectively (DeYoung et al., 2021). N–Anx describes being emotionally agitated, anxious, tense or worried, compulsively indecisive, lacking self-confidence, and sensitive to criticism. Sy includes the number of friends one has, and the time one spends with them, outgoingness at parties, and preference for being with others rather than being alone or pursuing solitary activities, thus measuring extraversion (Aluja et al., 2002). Each participant can score between 0 and 10 on each personality trait scale. Higher scores on the N–Anx and Sy scales indicate higher levels of neuroticism–anxiety and sociability, respectively.

1.3.5 Testosterone assay

Basal testosterone levels were determined in saliva samples collected after a 10-minute rest period prior to BART or GDT testing. Samples were analyzed according to standard procedures (Tecan, 2019). The certified laboratory used enzyme-linked immunosorbent assay (ELISA) kits to test for free testosterone. The intraassay coefficient of variation averaged 5.6%, and the interassay coefficient of variation averaged 8.7%.

1.4 Data analysis

Testosterone levels were standardized separately for men and women using *z*-scores (Mehta & Josephs, 2010). High testosterone levels in an individual indicate a high value relative to other individuals of the same sex. Personality correlates of the avoidance and approach systems, N–Anx and Sy, as well as the GDT and BART scores were transformed using a natural logarithm to better approximate the normal distributions. However, all log-transformed variables are given without the prefix *ln*, except in the tables.

The first hypothesis (H1: testosterone is positively related to risk propensity in decisions under risk and decisions under uncertainty only in individuals low in the neuroticism–anxiety personality trait) was analyzed using a moderated multiple regression model (Hayes, 2022). The dependent variables GDT and BART scores were used for the risk propensity in decisions under risk and under uncertainty, respectively. To avoid potential problems with high multicollinearity affecting the interaction term, we mean-centered the independent variable and the moderator and created an interaction term between standardized testosterone levels within sexes and N–Anx scores (Hayes, 2022). To interpret a significant interaction, we used a simple slope analysis with the PROCESS macro for R software (Hayes, 2022). We used the multiple regression model to plot risk propensity one standard deviation above (considered high testosterone) and below (considered low testosterone) the means for testosterone levels (standardized within sexes) and N–Anx scores. We calculated simple slopes to examine the relationship between testosterone levels and risk propensity, one standard deviation above (considered high N–Anx score) and below (considered low N–Anx score) the mean of N–Anx scores.

To test the second hypothesis (H2: testosterone is positively related to risk propensity in decisions under risk and in decisions under uncertainty only in individuals high in the sociability personality trait), we applied a similar approach. We mean-centered both predictors (standardized testosterone levels within sexes and Sy) to avoid potential problems with high multicollinearity associated with the interaction term. To interpret the significant interaction, we followed the approach described in the previous paragraph. The data analysis procedure (testing H1 and H2) was repeated separately for female and male participants. In these additional analyses, the testosterone levels were log-transformed with a natural logarithm to better approximate a normal distribution. The level of significance for all analyses was set at $p < .05$.

2 Results

The data were collected from 104 participants. Four participants were excluded from the analysis because testosterone data was missing due to technical issues. No participants were excluded from the analysis for violating the study protocol or not meeting the inclusion criteria. The final sample included 100 healthy participants (mean age = 28.94 +/− 7.77, range 21–49; 58 females), who were tested under two conditions: decisions made under risk and under uncertainty. Participants were further divided into two groups, students ($n = 59$, mean age = 23.59 +/− 1.98, range 21–33; 38 females) and decision makers ($n = 41$, mean age = 36.63 +/− 6.38, range 23−49; 20 females), based on their decision-making experience.

Basic demographics, basal testosterone levels, and risk propensity scores for decisions under risk and under uncertainty by sex are shown in Table 1. Independent samples *t*-tests were conducted to compare risk propensities in decisions under risk and under uncertainty, personality traits, and basal testosterone levels between females and males. No significant differences were found in Sy scores and in BART and GDT scores between females and males, although males appeared to have higher BART and GDT scores compared to females. Compared to females, males had higher basal testosterone levels ($p < .001$) and lower N–Anx scores ($p = .017$).

Table 1. Sample sizes (N), means (M) and standard deviations (SD) of age, basal testosterone levels, neuroticism–anxiety and sociability personality traits, and risk propensity scores for decisions made under risk (GDT score) and under uncertainty (BART score) by sex.

	Male			Female					
Variable	*N*	*M*	*SD*	*N*	*M*	*SD*	*t* (98)	*p*	*d*
Age (years)	42	29.69	7.89	58	28.34	7.67	0.86	.394	0.17
ln(N–Anx score)	42	1.09	0.81	58	1.41	0.70	−2.15	.017	−0.44
ln(Sy score)	42	1.50	0.71	58	1.45	0.63	0.35	.728	0.07
Testosterone (pmol/L)	42	275.82	110.51	58	90.30	58.84	9.91	.000	2.20
ln(BART score)	42	3.62	0.44	58	3.47	0.53	1.42	.122	0.29
ln(GDT score)	42	3.11	0.93	58	2.86	1.00	1.27	.104	0.26

Note. N-Anx = neuroticism-anxiety; Sy = sociability; BART = Balloon Analogue Risk Task; GDT = Game of Dice Task.

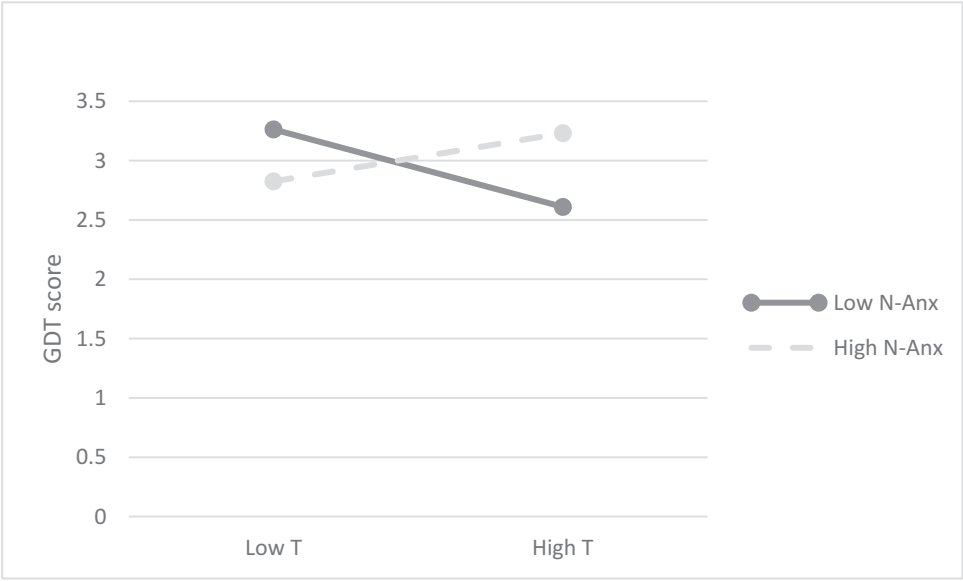

Fig. 1. Risk propensity in decisions under risk (GDT score) as a function of basal testosterone, standardized within sexes (T) and neuroticism–anxiety (N–Anx score) for the entire sample of subjects. Note. Plotted points represent conditional low and high values (+/− 1 SDs) of T levels, standardized within sexes, and N–Anx scores. GDT scores and N–Anx scores are log-transformed using a natural logarithm.

2.1 Hypothesis 1

The first hypothesis states that basal testosterone levels are positively related to higher risk propensity in decisions under risk and under uncertainty only in subjects low in the neuroticism–anxiety personality trait. In the entire sample of subjects for decisions under risk, a significant interaction effect was found between testosterone levels and N–Anx scores ($b = 0.35$, $p = .017$). The simple slope analysis revealed a significant association between testosterone levels and GDT scores only in subjects with low N–Anx scores ($b = -0.33$, $p = .032$, see Fig. 1, solid line) and that testosterone levels and GDT scores were not associated in subjects with high N–Anx scores ($b = 0.20$, $p = .156$, see Fig. 1, dashed line).

Further analysis of the male and female subsamples revealed a significant effect of the N–Anx score on the association between testosterone levels and GDT scores only in males. Testosterone levels were negatively related to GDT scores in males with low N–Anx scores ($b = -0.99$, $p = .019$) and positively related in males with high N–Anx scores ($b = 0.97$, $p = .050$), as is shown in Fig. 2. No significant main effects or effects of decision-making experience were observed. No significant effects were observed in the female subsample.

For decisions under uncertainty, we found no significant main effects of testosterone levels and N–Anx scores on BART score. Effects of the control variables (sex and decision-making experience) and the interaction between the two predictors were not significant. Furthermore, when analyzing female and male subsamples, no significant main effects or effects of the control variable (decision-making experience) were observed.

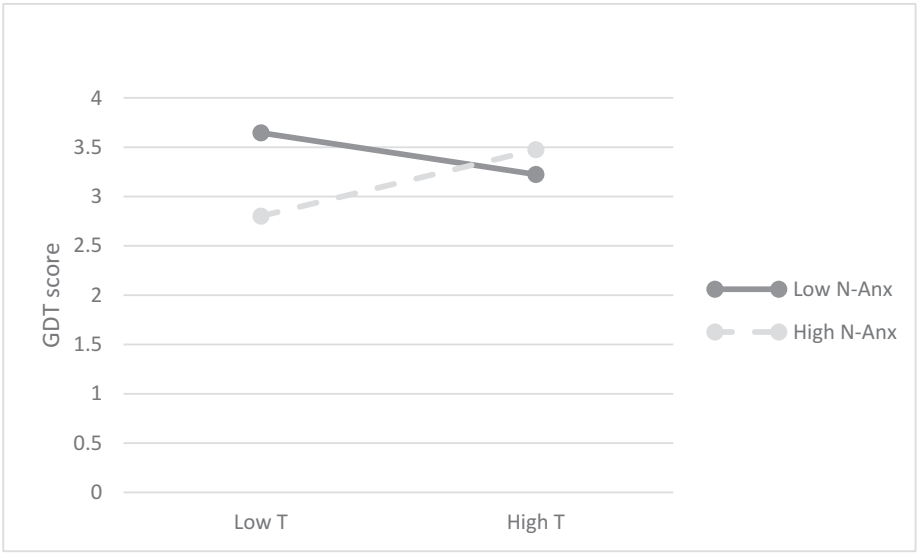

Fig. 2. Risk propensity in decisions under risk (GDT scores) as a function of basal testosterone levels, standardized within sexes (T) and neuroticism–anxiety (N–Anx scores) for males. Note. Plotted points represent conditional low and high values (+/− 1 SDs) of T levels, standardized within sexes, and N–Anx scores. GDT scores and N–Anx scores are log-transformed using a natural logarithm.

2.2 Hypothesis 2

The second hypothesis states that basal testosterone levels are positively related to higher risk propensity in decisions under risk and decisions under uncertainty only in individuals high in the sociability personality trait. In the first model, the dependent variable was the GDT score. There were no significant main effects of testosterone levels or Sy scores on GDT scores. No significant interaction was found for decisions under risk. No significant effects were observed when analyzing female and male subsamples.

In the second model, the dependent variable was the BART score. Neither testosterone levels nor Sy scores had a significant effect on risk propensity when the other predictor was conditioned on its mean. No significant interaction was found for decisions under uncertainty. Control variables for sex and decision-making experience were included in both the risk and uncertainty models, and the effects were not significant. No significant effects were observed when analyzing the female and male subsamples.

3 Discussion

In this study, we evaluated the possible effects of certain personality traits, neuroticism–anxiety and sociability, on the relationship between testosterone levels and risk propensity under two conditions, decisions under risk and decisions under uncertainty. We found that basal testosterone levels were positively correlated with risk propensity for decisions under risk in males with low neuroticism–anxiety scores, whereas they were negatively correlated with risk propensity for decisions under risk in males with high neuroticism–anxiety scores. We found no effect of sociability on the relationship between testosterone and risk propensity in decisions under risk for males. In decisions under uncertainty, we observed no effect of neuroticism–anxiety or sociability on the relationship between testosterone and risk propensity for males. We found no significant effects for females in either condition (decisions under risk or under uncertainty), regardless of the neuroticism or sociability personality trait considered.

A few studies examining the relationship between basal testosterone levels and risk propensity in decisions under risk have provided inconsistent results. One study of 21 healthy men using GDT to evaluate risk propensity found no correlation between the two (Goudriaan et al., 2010). In contrast, another study of 39 students pursuing master degrees in finance, using more real-life measures such as computerized simulations of financial trading, found a positive correlation (Nofsinger et al., 2018). However, a third study of 208 subjects using the Holt and Laury Lottery Task (Holt & Laury, 2005) found a significant relationship between basal testosterone levels and risk propensity in decisions under risk only in the gain domain (Schipper, 2023), suggesting the importance of the framing effect. The divergence in the results of these studies could be due to differences in the populations studied, lack of statistical power due to small sample numbers in some studies, the differences in methodological approach (e.g., measures used to assess risk propensity and study protocols). The finding

of our study in 100 healthy graduate students and experienced decisions makers, using GDT, that the relationship between basal testosterone levels and risk propensity in decisions under risk was significant only when the effect of neuroticism–anxiety was taken into account, supports the view of the complexity of this relationship in males.

Testosterone has been associated with avoidant personality traits such as neuroticism (Peper et al., 2018). Since basal testosterone levels were negatively correlated with N–Anx scores in our study (see Appendix, Table A1), it would be possible that basal testosterone levels were positively correlated with risk propensity for decisions under risk in males with low neuroticism–anxiety scores only because of higher basal testosterone levels. This possibility, however, is not supported by the negative correlation of basal testosterone levels with risk propensity for decisions under risk in males with high neuroticism–anxiety scores. Therefore, the mechanism of the effects of neuroticism–anxiety on the relationship between basal testosterone levels and risk propensity for decisions under risk must be more complex. Interestingly, neuroticism has not been related to risk propensity for decisions under risk (Buelow & Cayton, 2020) or other general risk-taking behaviors such as drinking, smoking, gambling, drugs, and sex (Zuckerman & Kuhlman, 2000), but only to risk propensity in decisions under risk for the gain domain (Lauriola & Levin, 2001). These discrepancies could be due to differences in methods used to measure the neuroticism trait as some studies employed the Big Five personality questionnaire (e.g., Buelow & Cayton, 2020) and others employed the Zuckerman–Kuhlman personality questionnaire (e.g., Zuckerman & Kuhlman, 2000). Taken together, these observations support the hypothesis that the relationship between basal testosterone and risk propensity is complex and depends on other neurobiological systems such as the hypothalamic–adrenal axis (Mehta et al., 2015) and mesolimbic dopaminergic system (Welker et al., 2015), social context such as interpersonal competition (Zilioli & Watson, 2014), psychological constructs such as self-construal (Welker et al., 2019), optimism about future price changes (Cueva et al., 2015), and personality traits, especially the neuroticism–anxiety trait, as is evident in our study.

In contrast to the effects of neuroticism–anxiety on the relationship between basal testosterone levels and risk propensity for decisions under risk in males, in our study we found no such effect for decisions under uncertainty in males regardless of the neuroticism–anxiety score. We are not aware of any other studies that have examined the effects of neuroticism–anxiety on the relationship between basal testosterone levels and risk propensity in decisions under uncertainty. Studies of the relationship between neuroticism and risk propensity in decisions under uncertainty have provided inconsistent results. Peper et al. (2018) found a significant relationship between neuroticism and risk propensity, while Buelow and Cayton (2020) found no significant relationship. Both studies used BART to measure risk propensity in decisions under uncertainty. Therefore, the divergence in the results between these two studies could be due to differences in the populations studied, as the first study included participants from 8 to 29 years of age, and the second included students who ranged from 17 to 19 years of age. In contrast to the second study, the first one was a longitudinal study. A few studies examining the relationship between basal testosterone levels and risk propensity in decisions under uncertainty also provided inconsistent results. In a recent study, the relationship between basal testosterone levels and risk propensity in decisions under uncertainty, as measured by BART, was not significant (Stanton et al., 2021). In addition, some other studies found a positive correlation between basal testosterone levels and risk propensity in decisions under uncertainty, as measured by BART (e.g., Goudriaan et al., 2010) and the Iowa Gambling Task (IGT) (e.g., Stanton, Liening, & Schultheiss, 2011; Van Honk et al., 2004). The divergence in the results of these studies could possibly be due to different tasks employed to evaluate risk propensity in decisions under uncertainty. Moreover, in IGT (Bechara et al., 1994), participants learn the probabilities of outcomes as they progress through the task, which makes it difficult to categorize IGT as a pure measure of risk propensity in decisions under uncertainty (De Groot & Thurik, 2018). In addition, differences in the studied populations, lack of statistical power due to small sample sizes in some studies, or the statistical approach may have also contributed to discordant results.

The differences in the effect of neuroticism–anxiety on the possible relationship between basal testosterone levels and risk propensity between decisions under risk and decisions under uncertainty could be explained by the neurobiological differences in risk and uncertainty (De Groot & Thurik, 2018). One hypothesis suggests that uncertainty could activate distinct brain systems compared to risk. Risk has been shown to activate the orbitofrontal cortex, the striatum, the insula, and the (posterior) parietal cortex, while uncertainty engages the amygdala and parts of the frontal cortex such as the inferior frontal gyrus and the (dorsal) lateral prefrontal cortex (Bach et al., 2009; Huettel et al., 2006; Krain et al., 2006; Platt & Huettel, 2008; Schultz et al., 2008). Another hypothesis suggests that risk and uncertainty activate a

common brain mechanism, albeit to different degrees, with stronger responses to decisions under risk or uncertainty. Activity in the orbitofrontal cortex and amygdala has been shown to be positively correlated with task uncertainty, while activity in the striatal system is negatively correlated (Hsu et al., 2005; Levy et al., 2010; Platt & Huettel, 2008; Schultz et al., 2008).

In our study we found no significant effects of the sociability personality trait on the relationship between basal testosterone levels and risk propensity, either in decisions under risk or in decisions under uncertainty. We are not aware of any other studies that have examined the effects of sociability on the relationship between basal testosterone levels and risk propensity in decisions under risk and under uncertainty. However, some studies that have examined the relationship between sociability/extraversion and risk propensity in both conditions provide inconsistent results. Some found a positive relationship between extraversion and risk propensity in financial decision making under uncertainty (Nicholson et al., 2005), while others found no significant relationship between extraversion and risk propensity in decisions under risk (measured with GDT) and uncertainty (measured with BART) (Buelow & Cayton, 2020). However, sociability has been found to be related to other risk-taking behaviors such as drinking and gambling (Zuckerman & Kuhlman, 2000). The divergence in the results of these studies could possibly be explained by the use of self-reported versus behavioral measures of risk propensity in decisions under uncertainty or decisions under risk in some studies. Self-reported measures are known to suffer from a number of limitations such as response biases (Wetzel et al., 2016), which could be the reason for inconsistent results. Furthermore, scores on the self-reported measures of risk propensity for decisions under uncertainty used by Nicholson et al. (2005) do not correlate with scores on BART, an established behavioral measure of risk propensity in decisions under uncertainty (Cruz-Sanabria et al., 2024). Moreover, testosterone levels have been positively associated with the approach system (El Ahdab et al., 2023) and extraversion (Smeets-Janssen et al., 2015), but negatively associated with neuroticism in males (Peper et al., 2018). Accordingly, we found a negative relationship between neuroticism–anxiety and basal testosterone levels. However, we did not find a significant association between basal testosterone levels and sociability (see Appendix, Table A1). Therefore, it is possible that the lack of a significant effect of sociability on the relationship between basal testosterone levels and risk propensity in decisions under risk and under uncertainty in our study was due to the lack of significant associations between sociability and basal testosterone levels. Overall, these findings do not support the hypothesis that the sociability trait may play a significant role in affecting the relationship between basal testosterone levels and risk propensity in both, decisions under risk and under uncertainty.

In an additional analysis of a subsample of only female participants, we found no significant effects of the neuroticism–anxiety trait on the relationship between basal testosterone levels and risk propensity for decisions under risk. We are not aware of any study comparing the effects of neuroticism–anxiety on the relationship between basal testosterone levels and risk propensity for decisions under risk between the sexes. The few studies that have examined the relationship between basal testosterone levels and risk propensities in decisions under risk in both sexes have provided inconsistent results. One study found that basal testosterone levels are positively associated with risk propensity in decisions under risk only in females (Sapienza et al., 2009), while another study found a significant positive association between the two for males and for gains only (Schipper, 2023). Yet, another study found a nonlinear relationship between basal testosterone levels and risk propensity in decisions under risk for both sexes (Stanton, Mullette-Gillman, et al., 2011). The divergence in the results of these studies could be possibly explained by findings from animal studies, which have shown that females are less responsive to androgens (e.g., testosterone) than males in terms of neuroendocrine function and sexual behavior (Yellon et al., 1989). Additionally, females produce significantly less testosterone in their bodies compared to males and exhibit less variability in testosterone levels (Wood & Newman, 1999), which was also observed in our sample (see Table 1). Furthermore, smaller variability of testosterone levels in females may reduce the statistical power to detect the psychological and behavioral effects of testosterone in females (Cohen, 1988). Given that testosterone is predominantly considered a male sex hormone, female sex hormones such as estrogen and progesterone may have a more significant impact on risk propensity in decisions under risk and under uncertainty in females than testosterone. Both estrogen and progesterone, like testosterone, affect reward processing in the brain, which could affect risk-taking behavior (Dreher et al., 2007). Although some studies have investigated these effects, the findings remain mixed (Derntl et al., 2014; Diekhof, 2018; Zethraeus et al., 2009). Taken together, these observations suggest that sex differences in hormonal responsiveness and testosterone levels may account for the inconsistent findings regarding the effect of the neuroticism–anxiety trait on the relationship between testosterone levels and

risk propensity in decisions under risk and uncertainty.

3.1 Limitations

To our knowledge, this is the first study examining the effects of personality traits, specifically neuroticism–anxiety, on the relationship between basal testosterone levels and risk propensity in decisions under risk and decisions under uncertainty. There are several strengths to our study. First, we examined the effects of certain personality traits on the relationship between basal testosterone levels and risk propensity in decisions under risk and uncertainty, which had not been done before, although there are theory-driven reasons for doing so (Welker et al., 2015). Second, following the economic distinction (Knight, 1921), we appropriately distinguished between risk propensity in decisions under risk and risk propensity in decisions under uncertainty. Furthermore, we used appropriate measures to evaluate decisions under risk and decisions under uncertainty, which is generally not done adequately in the existing literature (for more details, see De Groot & Thurik, 2018). Decisions under risk and uncertainty are characterized by known and unknown probabilities, respectively (Knight, 1921). GDT allows participants to calculate expected returns and associated probabilities, which makes it an appropriate measure of risk propensity in decision making under risk. In contrast, in BART, participants cannot predict when each balloon will explode and are thus unable to calculate expected returns and associated probabilities. This makes BART an appropriate measure of risk propensity in decisions under uncertainty. Finally, in contrast to prior research on the relationship between basal testosterone levels and risk propensity in decisions under risk and uncertainty, which has predominantly used samples of undergraduate students (Stanton, Liening, & Schultheiss, 2011) or exclusively male samples (Apicella et al., 2008), we used a mixed-sex sample of graduate students and experienced decision makers to ensure better generalizability and validity for both sexes.

However, there were some limitations in the present study. First, due to financial constraints, we were not able to offer participants real monetary rewards equivalent to the amounts simulated in the BART and GDT. This limitation impacts the ecological validity of our findings, as the simulated monetary rewards may not accurately reflect participants' real-life decision-making process under risk and under uncertainty in the financial context. Consequently, the generalizability of our results is restricted to laboratory settings and may not translate to real-life financial contexts. To address this limitation, future research should aim to externally validate BART and GDT by using real monetary incentives that mirror actual financial stakes. This approach would improve the applicability of these measures to real-life financial decision making and provide a more robust understanding of how individuals assess and respond to risk and uncertainty in financial contexts. Second, the present study tested only the associations between endogenous testosterone levels, personality traits, and risk propensity. We were therefore unable to draw any conclusions about causality. Future studies should examine the effects of exogenously administered testosterone to determine causality. Third, the study was limited to examining the effects of a single hormone, testosterone. However, it is possible that estradiol could play a role in risk taking in women (Bröder & Hohmann, 2003; Peper et al., 2018). Finally, the sample size was relatively small, which may have contributed to the non-significant results. Future studies should aim to replicate these findings in larger sample sizes. Nonetheless, we were able to partially confirm the first hypothesis and show that the neuroticism–anxiety trait affects the relationship between basal testosterone levels and risk propensity in decisions under risk, supporting the hypothesis that decision making under risk is a complex process that depends on neurobiological and psychological systems (Mehta et al., 2015; Welker et al., 2015, 2019).

4 Conclusion

The present study aimed to investigate the effects of certain personality traits (neuroticism–anxiety, sociability) on the relationship between basal testosterone levels and risk propensity in decisions under risk and decisions under uncertainty in a mixed-sex sample of graduate students and experienced decision makers. We found that the relationship between testosterone levels and risk propensity in decisions under risk was affected by neuroticism–anxiety in males. Specifically, testosterone levels were positively related with risk propensity in males low in the neuroticism–anxiety trait, whereas they were negatively correlated in those with a high neuroticism–anxiety score. However, in males, no significant correlations were observed between testosterone levels and risk propensity in decisions under uncertainty, or in females in both risk and uncertainty conditions, regardless of neuroticism–anxiety and sociability scores. These results suggest that the interaction between neurobiological factors and personality traits is important in decision making under risk in males. Furthermore, the lack of significant findings in females and in decisions under

uncertainty may indicate sex differences and context-specific effects in the neurobiological and psychological determinants of risk propensity. Further research should aim to replicate these findings in a larger sample and also consider inclusion of real-life risk-taking scenarios to enhance ecological validity.

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Declaration of competing interest

The authors have no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

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Appendix

Table A1. Pearson correlations between variables (Sex, Age, Decision-making experience, T (pmol/L), T (z-score), ln(Sy score), ln(N–Anx score), ln(BART score), and ln(GDT score)).

Variable	*N*	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. Sex	100	0.58	0.50	–								
2. Age	100	28.91	7.75	−.09	–							
3. Decision-making experience	100	0.40	0.49	−.17	**.83****	–						
4. T (pmol/L)	100	0.00	0.10	−**.74****	−.05	.01	–					
5. T (*z*-score)	100	168.22	124.57	.00	−.07	−.07	**.64****	–				
6. ln(Sy score)	100	1.47	0.66	−.04	−.06	−.07	.16	.16	–			
7. ln(N–Anx score)	100	1.28	0.76	**.21***	−**.36****	−**.36****	−**.22***	−.07	−**.22***	–		
8. ln(BART score)	100	3.53	0.49	.14	−.17	−.06	.06	−.04	−.06	.05	–	
9. ln(GDT score)	100	2.96	0.98	−.13	−.00	−.03	.05	−.05	.07	.03	.02	–

Note. T = testosterone; Sy = sociability; N–Anx = neuroticism–anxiety; BART = Balloon Analogue Risk Task; GDT = Game of Dice Task. Sex is coded such that 0 represents males and 1 represents females. Decision-making experience is coded such that 0 represents students and 1 represents decision makers. Significance is displayed at $p < .05$(*) and $p < .01$(**).