TESTOSTERONE PRODUCTION AND COMPETITIVE FACTORS

by

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ABSTRACT

Previous research demonstrates that testosterone facilitates psychological and physiological preparedness for competitive interactions while boosting the achievement motivation that drives one to compete. Despite these benefits, testosterone production is costly, for elevated testosterone production requires greater energetic investment and can cause immunosuppression in the short term as well as accelerated aging in the long term. However, no research has yet examined whether testosterone production is sensitive to the benefits of testosterone-mediated striving and effort, relative to the costs of elevated testosterone production. This study aims to examine the hypothesis that increases in the benefits associated with elevated testosterone – manipulated by the value of a reward (low vs. high) and role of effort (vs. random chance) in determining competitive success – will result in an increase in testosterone production from pre- to post-competition. Preliminary results from 99 undergraduate students who participated in an in-lab competition revealed trends in support of the hypothesis. Specifically, those in the random condition or low-reward condition exhibited a drop in testosterone production. Those in the effort condition or high-reward condition displayed an increase in testosterone production and improved competitive performance compared to those in the random condition and low-reward condition. Overall, these preliminary findings suggest that participants' testosterone production is sensitive to contextual factors which impact how "worth it" it is to increase investment in testosterone.

Post-COVID-19 Pandemic Observations of Motivation and Striving

Post-COVID-19 pandemic observations highlight a general decrease in striving and motivation. Evidence of the pandemic's impact on striving can be seen in research examining students' online learning outcomes. Much research finds that remote learning reduces student success and academic performance (Bettinger et al., 2017; Murphy & Stewart, 2017; Spencer & Temple, 2021), compared to traditional face-to-face instruction. In particular, the shift to online learning during the COVID-19 pandemic had several negative effects on students' academic motivation, including an increased consideration of dropping out and an overall loss of learning interest (Onyema et al., 2020). Other research demonstrated similar findings, in that more time spent in online learning environments was associated with a loss of motivation to participate in class and increased feelings of fatigue (Mahdy, 2020). Notably, students reported feeling that the lack of interaction and contact between students and professors made it difficult to maintain concentration and engagement (Rapanta et al., 2021).

Given the relationship between hormones and motivation, the COVID-19 pandemic's impact on individuals' striving may be understood on a biological level. Specifically, research finds that testosterone is associated with human reward processing and motivation. For example, individuals with testosterone deficiencies exhibit greater apathy and an overall lack of motivation, compared to what is observed among people with typical testosterone levels (Amore, 2005; Shores et al., 2005; Tostain & Blanc, 2008). In line with this, one study revealed that administering a single dose of exogenous testosterone increased participants' general motivation to engage in various actions, compared to those who did not receive exogenous testosterone

(Aarts & Van Honk, 2009). Studies such as these demonstrate the causal effect that testosterone has on people's intrinsic motivation to perform.

Importantly, testosterone production – and its subsequent impact on striving – is naturally sensitive to external social cues. For example, individuals demonstrate elevations in testosterone levels when faced with a social challenge, such as being verbally insulted and physically provoked (Cohen et al., 1996) and when presented with strong cues of violence and aggression (Klinesmith et al., 2006). Notably, testosterone production is also reactive to competitive situations, both physical and mental (Geniole & Carré, 2018). Exposure to typical social cues is limited in online learning environments compared to conventional face-to-face learning. Therefore, it is possible that the reported lack of academic motivation and striving since the COVID-19 pandemic could result from online learning environments' lack of social cues that would typically prompt motivating testosterone responses in face-to-face interactions.

Testosterone's Role in Psychological and Physiological Preparedness in Competitive Environments

One important social cue which influences academic motivation and achievement is competition (Amrai et al., 2011; Sivrikaya, 2019). Testosterone is an important neuroendocrinological factor that promotes motivation to compete. Testosterone has been shown to play an important role in neuroplasticity which greatly contributes to a performance-increasing effect (Losecaat Vermeer et al., 2016). For example, increasing testosterone during a competitive social encounter is thought to promote psychological states and behaviors that would aid in achieving success against an opponent. In one study that used a competition involving mental and physical toughness, greater increases in testosterone related to better competitive endurance and overall performance while greater decreases in testosterone related to less competitive

endurance and worse overall performance, especially for men (Casto et al., 2020). This body of work demonstrates that when the cues that are typically present in social environments are absent, an individual's performance on various tasks suffers.

Testosterone Production and Sensitivity to Costs vs. Benefits

Although testosterone has been found to promote success, some research suggests that investing in testosterone production is not always worth it. Elevated testosterone levels require greater energetic investment, and high testosterone levels can cause immunosuppression in the short term (Roberts et al., 2004), as well as accelerated aging in the long term (Mohammadi-Shemirani et al., 2020). Since testosterone production is costly, the endocrine system should be sensitive to the costs and benefits of production – with the body producing more testosterone when the benefits are high relative to the costs, and less testosterone when the benefits are relatively low.

Evidence from previous research suggests that the body may be sensitive to the costs and benefits of testosterone production. For example, when more opposite-sex individuals are present in a competitive environment, participants show greater increases in testosterone during the competition, suggesting that the presence of a potential mate may increase the benefit of winning (Miller et al., 2012). Additionally, in the majority of previous studies, participants who experienced defeat demonstrated a decrease in testosterone, but in some cases, losers experienced an increase which is associated with higher levels of aggressive behavior (Carré et al., 2013) and predicted subsequent decisions to compete again (Mehta & Josephs, 2006). Similarly, while the majority of winners display an increase in testosterone, in one study, some experienced a decrease. This decrease was associated with more passive behavior (Carré et al., 2013). It was speculated that for the winners who did not display the typical increase in

testosterone, there was little benefit in producing a motivating testosterone response to re-engage in competition with someone they had already defeated. On the other hand, the losers that experienced a rise in competition-induced testosterone may have found the benefit of reclaiming lost status was worth the costs (Carré et al., 2013).

Evidence that testosterone increases when the benefits of striving are perceived to be higher is further displayed in studies examining the Status Instability Hypothesis. For example, in a study investigating clear and narrow competitive outcomes, individuals that won by a narrow margin experienced a decrease in testosterone. Within unstable hierarchies such as a "close call" win, decreases in testosterone levels may have benefited the individual by dampening their competitive motivation (Wu et al., 2017). This drop in testosterone production is thought to accompany a reduced motivation to re-engage with a dominant competitor when the costs of doing so are high, relative to the benefit. Such a drop in testosterone and motivation would have protected the vulnerable social status of competitive losers. Furthermore, in a study investigating testosterone production across successive competitions, men in unstable hierarchies as first-day winners or second-day losers experienced an increase in testosterone compared to men in stable hierarchies as double winners or double losers (Zilioli & Watson, 2014). For those in unstable hierarchies, producing a motivating testosterone response would be more beneficial to aid in reclaiming or defending their status. Conversely, those stable hierarchies have little benefit in investing in increased testosterone production because their status is already established. These findings on status motivation contribute to the theory that competition-induced increases in testosterone should be more likely to occur when the benefits of investing in testosterone production outweigh the associated costs, and less likely to occur when the benefits of producing testosterone are reduced.

Testosterone Production and Effort and Incentive

In addition to a motivation for achievement, previous research demonstrates that testosterone production may also be sensitive to an individual's perception of their role in the competitive outcome. In one study examining a basketball competition, testosterone responses correlated positively with the players' "score/time playing" ratio, a measurement of personal contribution to the win or loss. Testosterone responses correlated negatively with external attribution in winners and positively in losers. These findings indicate that testosterone changes were not directly a response to the competitive outcome but rather to the degree the individual perceives their contribution was important to the outcome (Gonzalez-Bono et al., 1999). A secondary study was conducted to build upon these findings by examining merit versus luck-based outcomes. There was a more significant increase in post-competition testosterone levels in the players who attributed the win or loss to their personal merit or ability compared to the smaller increase in testosterone observed in those that attributed their win to pure luck (Gonzalez-Bono et al., 2000). These findings offer the possibility that one's perception of the role of their personal effort and contribution in competitive environments determines whether they will display a change in testosterone production.

Past literature also suggests that testosterone production may be sensitive to reward and incentive in competitive environments. In one study, the relationship between testosterone reactivity and performance was strongest amongst the individuals that increased their chances of winning money as well as had the opportunity to gain prestige among their group (Casto et al., 2020). Conversely, in another study where there wasn't a significant reward at stake, there were no observed changes in the testosterone levels of participants in the competition regardless of outcome (Salvador et al., 1987). Based on these findings, it is possible that poor academic

performance observed during the COVID-19 pandemic may stem from reduced benefits of striving – and therefore low benefits of investment in testosterone production – due to a lack of social cues and benefits during online learning. However, no research has experimentally examined the relationship between the benefits of effort or reward on testosterone production.

Present Research

Although past research has thoroughly examined the effects of various dimensions of competition (e.g., winning or losing, narrow vs. wide margin wins), no research has examined the impact of these costs and benefits of competitive effort and reward on the biological trade-offs associated with testosterone production. The present study aims to investigate whether the value of the reward (low vs. high) and the role of effort (vs. random chance) in determining success will impact testosterone production. Based on the previous literature highlighting strengthened testosterone reactivity when the competition involves a reward, we predict that this relationship will extend to differences in the *size* of the reward: when there is a larger reward at stake, participants should perceive the benefits of obtaining the reward as greater, resulting in greater investment in testosterone production compared to when the reward is smaller. Additionally, when participants believe putting forth a greater effort will increase their likelihood of winning rather than their success being attributed to chance, we predict they will exhibit better performance in the competition as well as a greater increase in testosterone production.

Methods

Participants

I recruited 99 undergraduate participants (73 women; M_{age} = 19.90, SD = 1.43) from Texas Christian University's psychology subject pool. Participants were compensated with partial course credit. Participants were randomly assigned to one of four experimental

conditions: low reward and effort (n = 21), high reward and effort (n = 37), low reward and random chance (n = 31), or high reward and random chance (n = 10). The participants in this study were predominantly White (69.7%).

Study Preparation

Prior to their laboratory session, participants completed an online survey that included informed consent and asked eligibility screening questions and health questions. Participants who reported that they were comfortable with providing a saliva sample, did not have an endocrine condition, and did not use endocrine-related medications (e.g., T replacement, corticosteroids) were invited to participate in the laboratory study session, in line with the study's goal of understanding change in testosterone from a typical baseline. Furthermore, female participants who indicated they did not use hormonal contraceptives were invited to participate in the study. Previous research has found that individuals using hormonal contraceptives have reduced baseline testosterone levels and exhibit abnormal endocrine responses to competition (Arthur et al., 2022).

Prior to participating in the study, participants were advised to not smoke, vape, eat, drink, or perform any oral hygiene (e.g., brushing, flossing) 1 hour before their scheduled study session. Participants were screened for adherence to the study instructions upon arrival at the laboratory. Those who had complied were asked to complete the informed consent document. Those who had not were asked to reschedule their study session for a later date. This ensured that the saliva sample quality was maintained and that accurate testosterone levels could be measured.

Procedure

After being screened by a same-sex research assistant for adherence to the study requirements and providing informed consent, participants were instructed to provide their first saliva sample. Once the first sample was completed, the participants were informed that they would be competing against the other participants that week in a paper folding task. Participants were then given one of four versions of instructions, depending on the reward and winner condition. Participants in the two effort conditions were told that whoever folded the most origami frogs that week would win a gift card. Participants in the two random chance conditions were told that the winner would be randomly selected from the list of participants that week. Within the effort and random chance conditions, those in the high reward condition were told the winner would receive a $20 gift card while those in the low reward condition were told the winner would receive a $5 gift card.

After delivering the condition-specific instructions, the research assistant demonstrated how to fold the origami frogs. This task was chosen for the competitive portion of the study, because it was an easily learned skill that participants were unlikely to have prior experience with before beginning the study. Previous research has utilized similar paper-folding tasks to examine the relationship between effort and performance (Zaccaro, 1984).

Once the participant felt comfortable with the paper folding task, they completed pre-competition questions which measured their interest in the competition and encouraged them to think about the reward and effort condition before beginning (described below). After completing the pre-competition assessment, the research assistant instructed the participants to begin the 10-minute-folding period and left the room. Once the 10 minutes were complete, the research assistant returned to collect the completed and partially folded origami frogs and instructed the participant to provide their post-competition saliva sample. Participants were then

asked to complete the post-competition questionnaire measuring their perceived effort on the task (described below). Additionally, participants were asked to provide information about their parenting effort (i.e., the degree to which someone prioritizes offspring care) because parenthood is known to influence testosterone levels and reactivity (Gray et al., 2005).

Materials

Pre-competition assessment

I created a questionnaire for the purpose of this study that aimed to measure participants' interest in the competition and to prompt them to think about the implications of the reward and effort condition to heighten their level of engagement with the task before beginning. The participants were asked the first four questions on a 0-100 slider scale. Example items are *"How important is it to you to win this competition?"* and *"How confident are you in your ability to win the gift card?"* The last two items were short answers and required participants to record their strategy to win the competition and what they would plan to spend the gift card on if they won.

Post-competition assessment

The post-competition assessment was created for the purpose of this study to assess the validity of the manipulation and participants' perception of their effort after completing the competition. Participants were asked five questions on a 7-point rating scale. Example items are *"How well do you think you performed in the competition compared to others?", "How much effort did you put into your performance in the competition?",* and *"How much of an impact will your effort level have on whether you win the gift card?"*.

Parenting status

To control for the effects of fatherhood on testosterone levels, I selected items from the Parenting Effort Scale (Kruger, 2017) assessing commitment and investment in a current or future spouse and children, and whether participants have or live with any biological or non-biological children. Participants were first asked to indicate how strongly they agreed or disagreed with a series of five statements. Examples items are "I would use most of my money to support my spouse and children" and "I would be caring and emotionally supportive in a long-term relationship". Participants indicated whether each statement was true of them on a 7-point Likert scale from *Strongly Disagree* to *Strongly Agree*. Participants then were asked multiple choice questions on if they were a parent to any children, and if so, the context of that relationship.

Testosterone assay

Participants provided two 2 ml passive drool saliva samples. The first sample was collected immediately after providing informed consent, and the second sample was collected 10 min after the onset of the competitive task. Upon saliva collection, samples were centrifuged and supernatant was stored at -20° C. The samples were later thawed, centrifuged, and assayed for levels of free testosterone. Samples were assayed in duplicate using commercially available enzyme-linked immunosorbent assay (ELISA) kits (Salimetrics, Carlsbad, CA, United States) per manufacturer instructions. Assay plates were read using a plate reader at 450nm.

Results

Effects on Testosterone Production

First, I conducted assumption testing on both measures: testosterone production and competitive performance using Levene's test for homogeneity of variances. Testosterone production as a function of winner condition, $F(1, 72) = 0.97$, $p = 0.328$, and reward condition,

F (1, 72) = 0.14, p = 0.713, satisfied the assumption. Competitive performance as a function of winner condition, F (1, 97) = 0.02, p = 0.902, and reward condition, F (1, 97) = 0.01, p = 0.931, also satisfied the assumption of equal variances.

Between-subject differences in testosterone production (calculated as pre-competition testosterone - post-competition testosterone) were examined using a one-way analysis of variance (ANOVA). The results did not reveal significant effects of the winner condition on testosterone production (see Figure 1), F (1, 72) = 0.22, p = 0.64, $\eta 2$ = 0.003. Although no significant effects were found, these preliminary results were trending such that participants in the effort condition displayed increases in testosterone production in response to engaging in the competition (M = 7.11, SD = 84.31) compared to participants in the random condition who displayed decreases in testosterone production (M = -6.71, SD = 161.83). Similarly, there was not a significant effect of reward condition on testosterone production (see Figure 2), F (1, 72) = 0.60, p = 0.44, $\eta 2$ = 0.008. However, the results were trending such that participants in the high reward condition displayed increases in testosterone production (M = 12.94, SD = 95.40) while participants in the low reward condition displayed a decrease (M = -9.94, SD = 148.00). Overall, these findings suggest that although there was no statistically significant effect of either the effort conditions or reward conditions on testosterone production in response to the competition, preliminary findings are trending in support of the hypothesis.

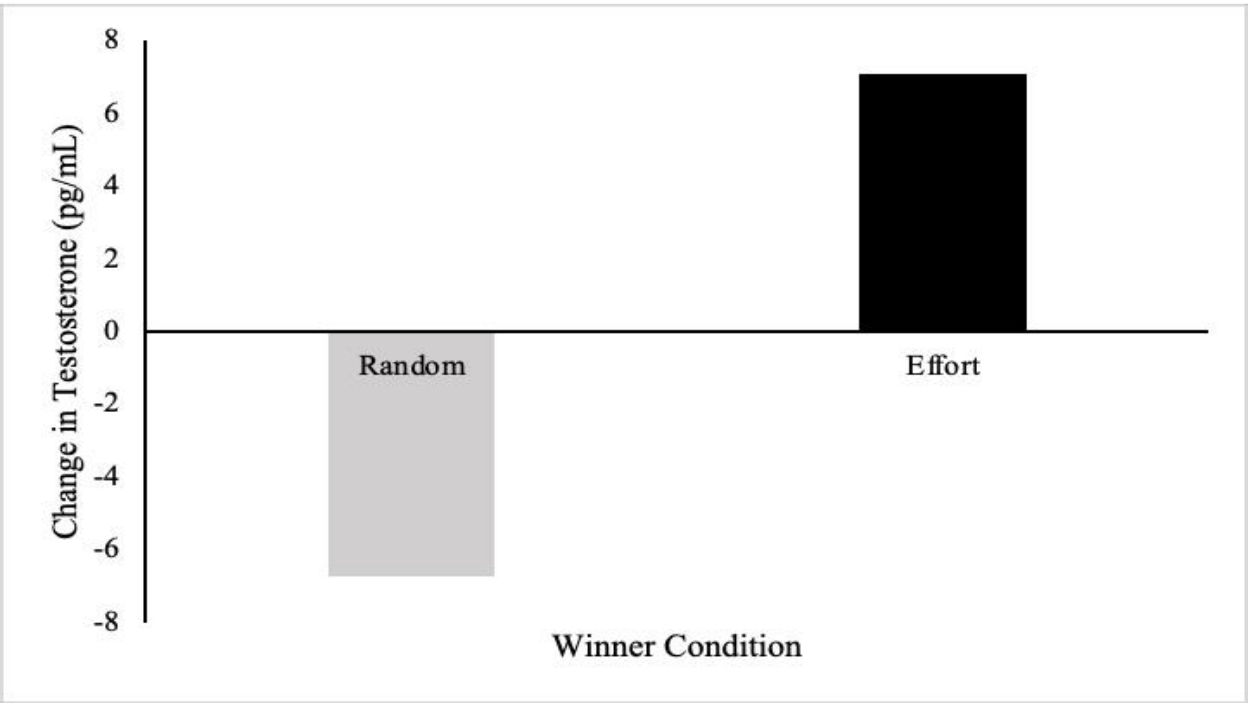

Figure 1: The effects of the winner conditions (random vs. effort) on testosterone production. Positive values reflect increases in testosterone production while negative values reflect decreases in testosterone production from pre- to post-competition.

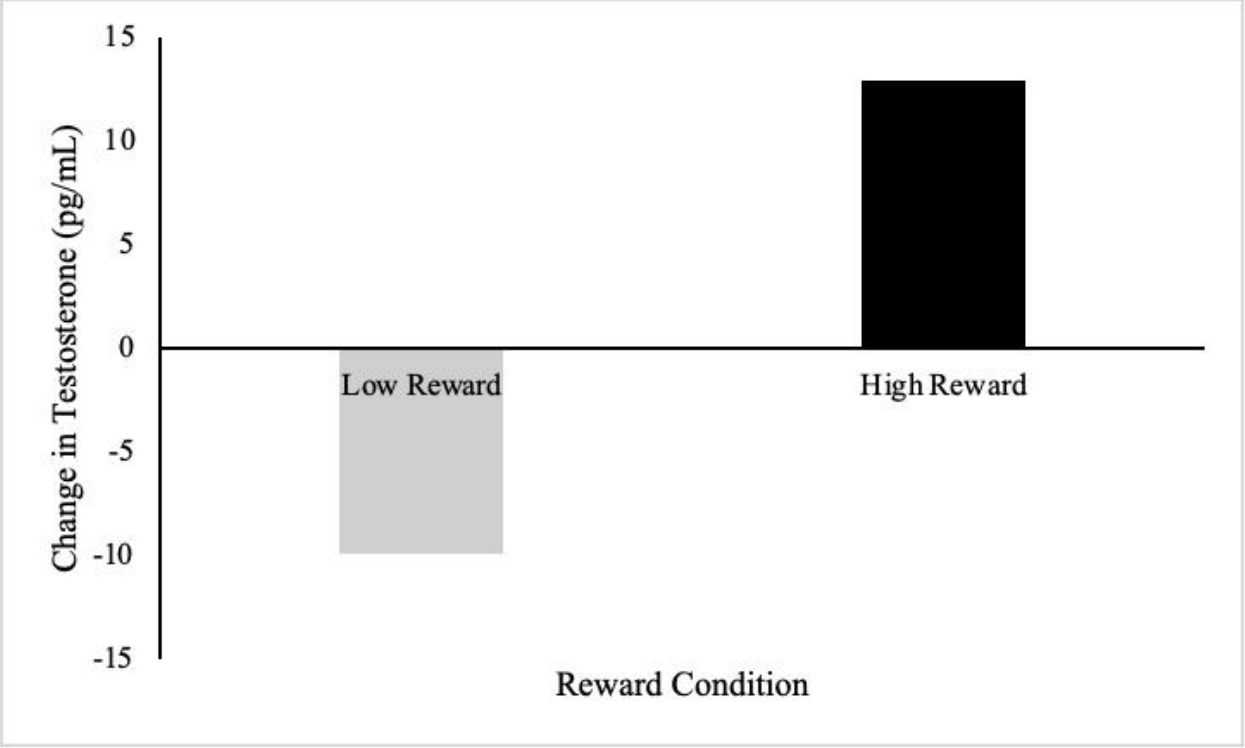

Figure 2: The effects of the reward conditions (low reward vs. high reward) on testosterone production. Positive values reflect increases in testosterone production while negative values reflect decreases in testosterone production from pre- to post-competition.

Effects on Performance

Between-subject differences in performance (measured as the number of origami frogs folded during the 10-minute competition period) were examined using a one-way ANOVA. The results revealed significant effects of the winner condition on performance (see Figure 3), F (1, 97) = 16.92, p = 0.000, $\eta 2$ = 0.15, such that participants in the effort condition folded more origami frogs (M = 14.91, SD = 5.26) compared to participants in the random condition (M = 10.63, SD = 4.84). Similarly, there was a significant effect of reward condition on performance (see Figure 4), F (1, 97) = 8.26, p = 0.005, $\eta 2$ = 0.08, indicating that participants in the high reward condition folded more origami frogs (M = 14.75, SD = 5.68) than the participants in the low reward condition (M = 11.68, SD = 4.92). Overall, these results suggest that both the effort and reward conditions have a significant effect on participant performance. When the benefits of investing in testosterone performance were relatively high (i.e., when the reward was high, when winning was determined by effort), people demonstrated better performance on the competitive task.

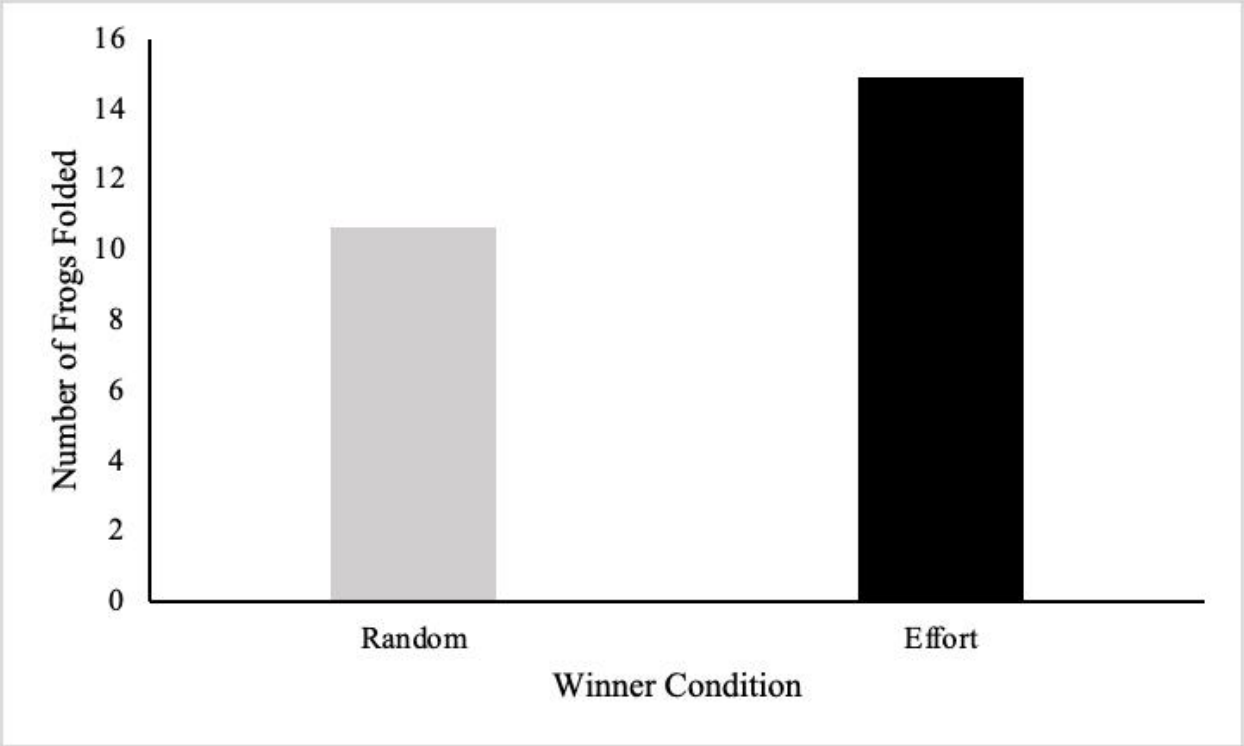

Figure 3: The effects of the winner conditions (random vs. effort) on performance.

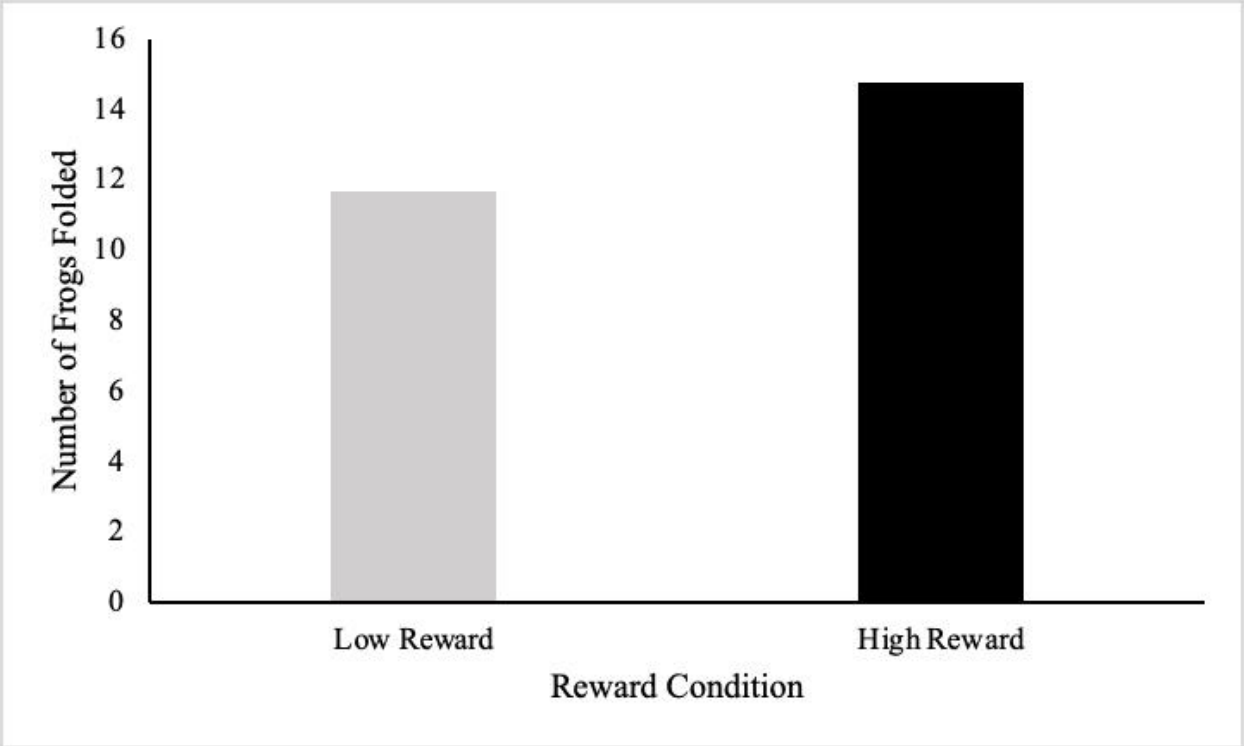

Figure 4: The effects of the reward conditions (low reward vs. high reward) on performance.

Discussion

Previous literature has thoroughly investigated the effects of various dimensions of competition on testosterone production. Specifically, testosterone reactivity has been shown to be strongest when rewards and incentives are present (Casto et al., 2020). Additionally, testosterone production is greatest when individuals are motivated to defend their status (Carré et al., 2013; Wu et al., 2017; Zilioli & Watson, 2014) and when they attribute their success to their merit (Gonzalez-Bono et al., 2000) and personal contribution (Gonzalez-Bono et al., 1999). The current study aimed to expand on previous research by examining the previously unexplored impact of the costs and benefits of competitive effort and reward on the trade-offs associated with testosterone production.

Due to an insufficient sample size, the current research can only establish preliminary findings that point toward testosterone production's sensitivity to the benefits of production. The results for the effect of each condition (winner and reward) on testosterone production were trending in support of my hypothesis that testosterone production increases when it's considered more "worth it" to do so. Specifically, participants who believed winning was based on their effort displayed greater testosterone production from baseline to post-competition levels than participants that thought winning was based on chance. Further, participants competing for a chance-based outcome displayed a decrease in testosterone from baseline to post-competition levels.

In addition to increased testosterone production, participants competing for an effort-based outcome also performed significantly better (i.e., folded more origami frogs) on the competitive task compared to those in the random-winner condition. Following a similar pattern, participants competing for the larger reward also displayed a non-significant but observable

increase in post-competition testosterone levels and performed significantly better than the participants competing for a smaller reward who displayed a decrease in testosterone and worse performance. While we are unable to draw formal conclusions from these preliminary findings, increased testosterone and greater performance in the more "worth it" conditions (i.e., effort and high reward) suggest increased motivation and striving in circumstances when the benefits outweigh the biological costs of investing in testosterone production. Participants that perceived the prospect of obtaining a larger reward and the feeling associated with an effort-based win was worth striving for likely experienced an elevated testosterone response to further their chances of success.

This interpretation of the results could provide implications for the broader context of online learning. When students transitioned to online learning during the COVID-19 pandemic, there was a decrease in exposure to various social cues compared to what is typically present in in-person settings. Consequently, students may have perceived less of a benefit in investing in elevating testosterone production in relation to the costs. Therefore, students could have felt less motivated to put forth significant amounts of effort towards striving and success, contributing to the observed decline in academic performance (Bettinger et al., 2017; Murphy & Stewart, 2017; Spencer & Temple, 2021). The findings from this study accompanied by further research may provide an understanding of virtual learning's biological and psychological effects. Such information could be valuable for educators when creating enriching, engaging, and effective online curriculums going forward.

Limitations and Future Directions

While the current research is well designed to assess impact of the costs and benefits of competitive factors on the biological trade-offs associated with testosterone production, the

sample size of 99 participants is considered underpowered for complex mediation and moderation analyses. Future research, as well as ongoing data collection in the current study, should replicate these findings with an adequately powered sample to provide a more detailed and informative picture of the relationship between effort, incentive, testosterone production, and performance. Additionally, my sample consisted of significantly more women than men (73 women vs. 26 men). Some research finds that the effects of competition on testosterone production is significantly more robust in men than in women (Casto et al., 2020). Future research should address this limitation by recruiting a more balanced sample with enough statistical power to compare men and women's testosterone production and performance in relation to the winner and reward conditions. Those findings could be used to expand on previous literature highlighting sex differences in competition-related testosterone production (Kivlighan, 2005).

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