Within- and between-person variation in morning testosterone is associated with economic risk-related decisions in athletic women across the menstrual cycle

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ABSTRACT

Literature suggests that women experience ovulatory shifts in risk-taking behaviours across different domains, which might be partly attributed to changes in testosterone (T). Thus, we investigated associations between menstrual variability in T concentrations and economic risk-related decisions among athletic women. Thirty-five women were monitored across three consecutive menstrual cycles. Testing occurred on day seven (D7), 14 (D14) and 21 (D21) following the onset of menses. The morning (7 to 8 am) assessment of salivary T (sal-T) and cortisol (sal-C) was followed by the economic Hawk-Dove game (11 am to 12 pm) played in pairs, where hawk decisions were used to index risk. Morning sal-T concentration increased from D7 to D14, before decreasing on D21 ($p < 0.001$), representing moderate effect size (ES) changes of 0.6 to 0.8. Morning sal-C did not vary over time. Hawk choices paralleled the sal-T results, being elevated on D14 ($p < 0.001$) with large ES changes of 1.8. Regression analyses revealed that morning sal-T concentration was positively related ($p \leq 0.01$) to the number of hawks chosen between- (beta = 0.47) and within-participants (beta = 0.10) when controlling for training hours and menstrual day. In summary, the risk-related choices of athletic women during a dyadic contest covaried with morning sal-T concentrations across the menstrual cycle. Both outcomes were positively correlated on a within- and between-person level. Confirming the major sources of T variation across the menstrual cycle, whilst discerning its relationship with other risk-related behaviours, would be worthwhile avenues for research.

1. Introduction

Evidence suggests that women experience ovulatory shifts in risk-taking behaviours across different domains. In the field of economics, for instance, women often display greater competitiveness (Buser, 2012), more competitive bidding (Pearson and Schipper, 2013), and take greater financial risks (Lazzaro et al., 2016) during high-fertile (e.g., ovulation) versus low-fertile (e.g., luteal, follicular) phases. In studies on women athletes, training motivation and competitiveness exhibited similar patterns of change, being elevated on days 13–15 of a menstrual cycle versus days 6–8 and 20–22 (Cook et al., 2018; Crewther and Cook, 2018). Similarly, aggressive risk-taking behaviours among girls of reproductive age were heightened around peri-ovulation, relative to other menstrual phases (Vermeersch et al., 2008).

Some risk-related behaviours (e.g., competitiveness in athletic activities) among women also parallel, and correlate with, menstrual changes in testosterone (T) concentrations (Cook et al., 2018; Crewther and Cook, 2018; Hahn et al., 2016). One study specifically examined the link between T and economic risk-taking in women across two menstrual-cycle phases (Reavis and Overman, 2001). The authors reported no changes in T concentrations or any T linkages with risk taking, as measured by the Iowa Gambling Task (IGT). However, the split-group design only allows between-person comparisons and they did not include the mid-cycle period, where T concentrations might be elevated among physically-active women (Ahrens et al., 2014). To our knowledge, no work has investigated the within- and between-person (over a menstrual cycle) relationships between T and risk taking in an economic domain.

A longitudinal study was conducted to examine associations between morning salivary T (sal-T) concentrations and economic risk-

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taking behaviours in athletic women. Risk was assessed in the Hawk-Dove game, a dyadic economic paradigm that models dominant (hawk) and subordinate (dove) strategies (Maynard Smith, 1982). The first aim was to characterize changes in sal-T and hawk decisions across a menstrual cycle. Our second aim was to investigate the relationship between these outcomes on a within- and between-person level. We also assessed salivary cortisol (sal-C), based on evidence linking this biomarker directly, or indirectly, to financial risk preferences (Cueva et al., 2015) and risk taking (Mehta et al., 2015).

2. Materials and methods

2.1. Participants

Thirty-five women athletes, undertaking physical training for different sports (i.e., netball, football, touch rugby, 7-aside rugby, and field hockey), were monitored with informed consent. Cohort demographics were, as follows; age (M = 22.3, SD = 1.8 years), height (M = 1.73, SD = 0.04 m), body mass (M = 69.6, SD = 3.9 kg), and body mass index (BMI) (M = 23.4, SD = 0.9 kg/m^2). The participants were free of hormone-based contraceptives (> 6 months) and they reported a normal menstrual-cycle length (M = 29.1, SD = 2.2 days). Each participant reported their average weekly training over the last two months, ranging from three to 12 h (M = 7.8, SD = 1.9). This detail was reported once at study inception. Pre-screening ensured that the participants had no injuries, health or medical conditions, including any psychiatric or endocrine disorders, and they were not taking any drugs or doping agents. Ethical approval was provided by the National Research Ethics Service, UK (reference number 10/H0808/124).

2.2. Study design

Testing occurred on day seven (D7), 14 (D14) and 21 (D21) across three consecutive menstrual cycles and thus, each athlete was scheduled to complete nine separate assessments. Day one was the self-reported start of menses (Cook et al., 2018). This three-day testing regime was adopted to capture cyclical changes in women's sal-T concentrations, rather than define actual menstrual phase or fertility status. Each participant was randomly assigned to start on one of the three days (D7, n = 11; D14, n = 13; D21, n = 11) and then proceeded, in order, through the remaining days and cycle repeats. We did not anticipate any training bias regarding the measurement of sal-T, as past-week physical activity does not affect the T changes that occur over a standardized 28-day cycle (Ahrens et al., 2014). Nevertheless, participants were asked to refrain from intense physical activity for at least 48 h before each assessment. Testing started in the morning with saliva self-collected at home between 0700 and 0800 h, thereby providing some control for circadian variation (Al-Dujaili and Sharp, 2012), before resuming with Hawk-Dove testing in the laboratory between 1100 and 1200 h. In the interim period, participants were asked not to engage in any stressful (e.g., exercise) activities.

2.3. Morning hormones

Morning saliva sampling was chosen to eliminate individual variances across the day, starting some 30–40 min after waking. Participants were asked to avoid eating, smoking, drinking, chewing gum or brushing their teeth beforehand (Hahn et al., 2016). The samples were collected by passive drool into sterile containers and kept in a commercial fridge before transfer (< 4 h) to a − 80 °C freezer. Testing was performed using enzyme-linked immunoassay kits (Salimetrics LLC, USA) with a calibration range of 6.1 to 600 pg/mL (sal-T) and 0.12 to 30 ng/mL (sal-C). The inter-assay coefficients of variation (CV) ranged from 5% to 14% for both kits. To eliminate this variance, each athlete's samples were tested within the same plate.

2.4. Hawk-Dove decision making

The Hawk-Dove game was played against an opponent from a pool of similar-aged women, but not other study participants, who were rotated across test occasions to reduce biased judgements based on a prior encounter. Each game was contested face-to-face with players choosing either a hawk or dove based on a financial outcome (see supplemental file for more details). If both players choose a hawk they make nothing, but if both choose a dove they each earn £0.50. Following a hawk-dove or dove-hawk scenario, the person choosing a hawk will make £1.00 and the player choosing a dove £0.00. Subsequently, choosing a hawk might afford greater financial gains, but it's also a riskier strategy than a dove. Overall, 10 rounds were played to better estimate general tendencies for hawk or dove strategies (Mehta et al., 2017). To reinforce these outcomes all winnings were kept. The game was completed in < 15 min and the winner pointed out verbally by a referee. The total number of hawks chosen by participants (across all 10 rounds) were recorded for analysis.

2.5. Statistical analyses

Data were analysed using a linear mixed model with random intercepts. Mixed models use maximum likelihood estimation to give unbiased results in the presence of missing data. In this study, some data loss (~15%) did occur due to unforeseen factors (e.g., work commitments, injuries). To profile menstrual changes in sal-T, sal-C (log transformed) and hawk decisions, we first conducted a one-way analysis of variance (ANOVA) with menstrual day (D7, D14, D21) as a within-subject factor. Menstrual-cycle number was tested as an additional factor, but no significant main effects or interactions emerged. Where appropriate, pairwise contrasts were applied to determine differences between specific subgroups. The ANOVA degrees of freedom were computed using Kenward-Roger approximations. Omega squared (ω^2) and Hedges g were calculated as effect size (ES) statistics. All variables are presented as estimated marginal means with a 95% confidence interval (CI).

Multilevel modelling was used to explore the relationship between menstrual changes in morning hormones and hawk decisions. First, a backwards elimination procedure was applied to identify significant predictors (of hawk choices) to be entered in Model 1, as control variables. The initial variables tested were; menstrual day and menstrual cycle (both dummy coded), age, BMI, and training hours as time-invariant predictors. To disaggregate the within- and between-person hormonal effects (Ketturat et al., 2016), the person-mean centered values for sal-T and sal-C were included in Model 2 and the person-centered values in Model 3. A marginal and conditional R^2 was calculated to assess model fit. Standardized (beta) coefficients are also provided for ES determination. Diagnostic testing of the ANOVA and regression models revealed that all statistical assumptions were met. The main analyses were conducted in r using the lmerTest package (Kuznetsova et al., 2017) with significance was set at p ≤ 0.05.

3. Results

A significant (F(2, 230) = 15.6, p < 0.001, ω^2 = 0.80) menstrual-day effect on morning sal-T concentration was observed (Fig. 1A). An elevated (p < 0.001) sal-T profile occurred on D14 versus both D7 (g = 0.61) and D21 (g = 0.80), whereas the D7 and D21 results were no different (p = 0.412, g = 0.19). As depicted in Fig. 1B, we found no menstrual-day effect on log-transformed morning sal-C (F(2, 233) = 0.537, p = 0.585, ω^2 = 0.04). The analysis of raw sal-C values converged with these results (F(2, 233) = 0.401, p = 0.670, ω^2 = 0.03). The Hawk-Dove findings (Fig. 1C) varied with menstrual day (F(2, 230) = 93.2, p < 0.001, ω^2 = 0.72), such that more hawks were chosen (p < 0.001) on D14 than either D7 (g = 1.76) or D21 (g = 1.78), but the hawk decisions on D7 and D21 did not differ from
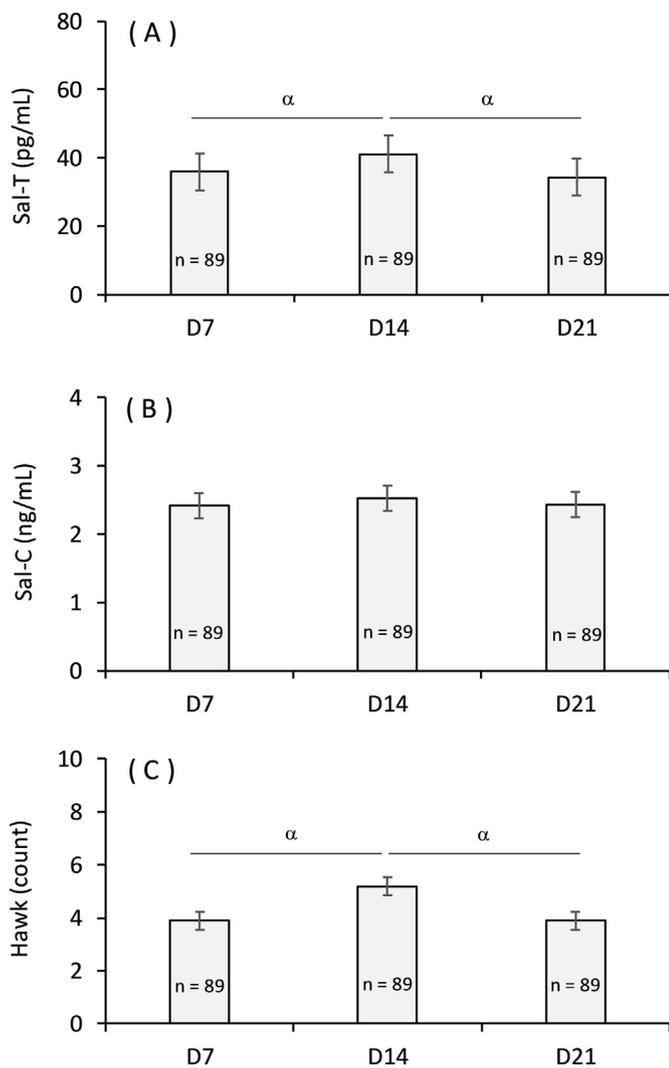
Fig. 1. Morning measures of salivary testosterone (Sal-T) (1A) and cortisol (Sal-C) concentrations (1B) and hawk decisions (1C) in athletic women across the menstrual cycle. Data are presented as estimated marginal means with a 95% CI. $^{\alpha}$Significantly different from D7 and D21 $p < 0.01$.

each other ($p = 0.994$, $g = 0.02$).

The elimination procedure identified training hours and menstrual day as significant predictors of hawk choices (Model 1, Table 1). Training hours is grand-mean centered for interpretation. Only morning sal-T was positively related ($p \leq 0.01$) to hawk decisions in Model 2 (controlling for Model 1 variables) and 3 (controlling for Model 1 and 2 variables). The beta coefficient for sal-T, after person-mean centering, was stronger (i.e., moderate ES) than that demonstrated for sal-T after person centering (i.e., weak ES). The final models showed good fit with a stronger conditional R^2 (68–70%) than marginal R^2 (44–59%). Interactions between sal-T and sal-C were also tested, but no results were statistically significant.

4. Discussion

Two sets of complementary analyses were conducted to investigate the link between menstrual variation in salivary hormones and economic risk taking in a dyadic contest. Menstrual profiling uncovered a morning rise in sal-T concentrations from D7 to D14 (moderate ES), before falling on D21 (large ES), whereas sal-C concentrations were stable over time. The observed increase in sal-T around mid-cycle or ovulation is supported by research on athletic (Cook et al., 2018; Crewther and Cook, 2018; Shultz et al., 2011) and physically-active women (Ahrens et al., 2014). More hawks were also chosen by study participants on D14 than on D7 or D21 (large ES change). This finding aligns to reports on risk-related behaviours in fields of economics (Buser, 2012; Lazzaro et al., 2016; Pearson and Schipper, 2013), adolescent medicine (Vermeersch et al., 2008), and sport science (Cook et al., 2018; Crewther and Cook, 2018).

Participants with higher sal-T on average tended to choose more hawks after controlling for menstrual day and training hours. On an individual level, a rise in sal-T concentration was also associated with more hawk decisions, although the between-person comparison produced a larger ES. Other evidence indicates that elevated, or rising, T levels among women are related to more hawk decisions (Mehta et al., 2017) and high-risk choices in the IGT (Stanton et al., 2011; van Honk et al., 2004). If it is responsible for these changes, T could also motivate economic choices to enhance one's social status, irrespective of any financial loss or gain (van Honk et al., 2016). Alternatively, the dyadic contest might provide a cue for intrasexual competitiveness (e.g., training motivation, desire to compete) among women with T, or other correlated factors, acting as key regulatory signals (Cook et al., 2018; Crewther and Cook, 2018; Hahn et al., 2016). If so, this effect could be magnified among athletic women, as a cohort who are arguably more

Table 1
Regression models with morning hormones predicting hawk decisions controlling for training hours and menstrual day.

Predictors	Model 1			Model 2			Model 3		
	B	95% CI	beta	B	95% CI	beta	B	95% CI	beta
Fixed effects									
Intercept	3.88**	3.62, 4.14		3.85**	3.61, 4.09		3.87**	3.62, 4.11	
Training hours (grand-mean centered)	0.26**	0.16, 0.35	0.46	0.13**	0.04, 0.23	0.22	0.13*	0.04, 0.23	0.22
D14 (reference = D7)	1.29**	1.08, 1.51	0.47	1.32**	1.09, 1.55	0.47	1.24**	1.00, 1.48	0.45
D21 (reference = D7)	−0.01	−0.23, 0.20	0.00	−0.01	−0.25 0.22	0.00	0.01	−0.22, 0.24	0.00
Morning sal-T (person-mean centered)				0.04**	0.03, 0.05	0.47	0.04**	0.03, 0.05	0.47
Morning sal-C (person-mean centered)				−0.12	−0.73, 0.48	−0.03	−0.12	−0.73, 0.48	−0.03
Morning sal-T (person centered)							0.01*	0.00, 0.03	0.10
Morning sal-C (person centered)							0.03	−0.08, 0.14	0.02
Random effects									
σ^2	0.53			0.55			0.54		
$\tau_{00\ ID}$	0.39			0.18			0.18		
ICC_{ID}	0.42			0.24			0.25		
Observations	267			234			234		
Marginal R^2/conditional R^2	0.438/0.675			0.587/0.688			0.594/0.696		

KEY: D7 = day 7, D14 = day 14, D21 = day 21, sal-T = salivary testosterone, sal-C = salivary cortisol, ICC = intraclass correlation coefficient.
Coefficients are significant at *$p \leq 0.01$, **$p < 0.001$.

sensitive to the rewarding properties of T (van Honk et al., 2004).

This work supports suggestions that T might function as a mediator of behaviours involving economic risk (Apicella et al., 2015), either as a trait (e.g., high T women choosing more hawks) and/or state (e.g., hawk choices vary with changing T levels) variable. However, research findings in this area are mixed, with many studies failing to establish a T association with risk-related outcomes or perceptions (Derntl et al., 2014; Mehta et al., 2015; Reavis and Overman, 2001; Vermeersch et al., 2008), partly due to heterogeneity in research design, the measures of risk employed, and moderating factors. Other steroid hormones (e.g., progesterone, estradiol) also display large menstrual variability and correlate with risk-related constructs (Buser, 2012; Derntl et al., 2014; Vermeersch et al., 2008). This could explain the prediction of risk by menstrual cycle day, before and after sal-T inclusion, and any unexplained variance yielded in this study.

Our findings must be balanced against uncontrollable factors (e.g., training regimes, dietary intake) when conducting longitudinal research on athletic women and whether the results are transferable to non-athletic populations. More complex dyadic interactions could also affect the hawk or dove decisions made, whereby the situational decisions of one player could influence the subsequent choices of their opponent. Financial gains could potentially have been a contributor, we did not keep track of this factor, being a limitation of this study. The time difference (~4 h) between morning sampling and Hawk-Dove testing is another consideration, but we anticipated little sal-T change (< 10%) over this period (Al-Dujaili and Sharp, 2012). Notwithstanding these limitations, we identified between- and within-person relationships between menstrual measures of morning sal-T and risk taking in athletic women. Confirming the different menstrual sources of T variability, whilst discerning its relationship with other risk-related behaviours, would be worthwhile avenues for research.

Declarations of interest

None.

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Appendix A. Supplementary data

The r codes for the statistical analyses can be sourced from the corresponding author. Supplementary data associated with this article can be found online at https://doi.org/10.1016/j.yhbeh.2019.04.007.

References

Ahrens, K.A., Vladutiu, C.J., Mumford, S.L., Schliep, K.C., Perkins, N.J., Wactawski-Wende, J., Schisterman, E.F., 2014. The effect of physical activity across the menstrual cycle on reproductive function. Ann. Epidemiol. 24, 127–134.

Al-Dujaili, E.A.S., Sharp, M.A., 2012. Female salivary testosterone: measurement, challenges and applications. In: Ostojic, S. (Ed.), Steroids - From Physiology to Clinical Medicine. InTech, pp. 129–167.

Apicella, C.L., Carré, J.M., Dreber, A., 2015. Testosterone and economic risk taking: a review. Adapt. Hum. Behav. Physiol. 1, 358–385.

Buser, T., 2012. The impact of the menstrual cycle and hormonal contraceptives on competitiveness. J. Econ. Behav. Organ. 83, 1–10.

Cook, C.J., Kilduff, L.P., Crewther, B.T., 2018. Basal and stress-induced salivary testosterone variation across the menstrual cycle and linkage to motivation and muscle power. Scand. J. Med. Sci. Sports 28, 1345–1353.

Crewther, B.T., Cook, C.J., 2018. A longitudinal analysis of salivary testosterone concentrations and competitiveness in elite and non-elite women athletes. Physiol. Behav. 188, 157–161.

Cueva, C., Roberts, R.E., Spencer, T., Rani, N., Tempest, M., Tobler, P.N., Herbert, J., Rustichini, A., 2015. Cortisol and testosterone increase financial risk taking and may destabilize markets. Sci. Rep. 5, 11206. https://doi.org/10.1038/srep11206.

Derntl, B., Pintzinger, N., Kryspin-Exner, I., Schöpf, V., 2014. The impact of sex hormone concentrations on decision-making in females and males. Front. Neurosci. 8, 352. https://doi.org/10.3389/fnins.2014.00352.

Hahn, A.C., Fisher, C.I., Cobey, K.D., DeBruine, L.M., Jones, B.C., 2016. A longitudinal analysis of women's salivary testosterone and intrasexual competitiveness. Psychoneuroendocrinology 64, 117–122.

Ketturat, C., Frisch, J.U., Ullrich, J., Häusser, J.A., van Dick, R., Mojzisch, A., 2016. Disaggregating within- and between-person effects of social identification on subjective and endocrinological stress reactions in a real-life stress situation. Personal. Soc. Psychol. Bull. 42, 147–160.

Kuznetsova, A., Brockhoff, P.B., Christensen, R.H.B., 2017. lmerTest package: tests in linear mixed effects models. J. Stat. Softw. 82, 1–26.

Lazzaro, S.C., Rutledge, R.B., Burghart, D.R., Glimcher, P.W., 2016. The impact of menstrual cycle phase on economic choice and rationality. PLoS One 11, e0144080.

Maynard Smith, J., 1982. Evolution and the Theory of Games. Cambridge University Press, Cambridge, UK.

Mehta, P.H., Welker, K.M., Zilioli, S., Carré, J.M., 2015. Testosterone and cortisol jointly modulate risk-taking. Psychoneuroendocrinology 56, 88–99.

Mehta, P.H., Lawless Desjardins, N.M., van Vugt, M., Josephs, R.A., 2017. Hormonal underpinnings of status conflict: testosterone and cortisol are related to decisions and satisfaction in the hawk-dove game. Horm. Behav. 92, 141–154.

Pearson, M., Schipper, B., 2013. Menstrual cycle and competitive bidding. Games Econom. Behav. 78, 1–20.

Reavis, R., Overman, W.H., 2001. Adult sex differences on a decision-making task previously shown to depend on the orbital prefrontal cortex. Behav. Neurosci. 115, 196–206.

Shultz, S.J., Wideman, L., Montgomery, M.M., Levine, B.J., 2011. Some sex hormone profiles are consistent over time in normal menstruating females: implications for sports injury epidemiology. Brit. J. Sport Med. 45, 735–742.

Stanton, S.J., Liening, S.H., Schultheiss, O.C., 2011. Testosterone is positively associated with risk taking in the Iowa Gambling Task. Horm. Behav. 59, 252–256.

van Honk, J., Schutter, D.J., Hermans, E.J., Putman, P., Tuiten, A., Koppeschaar, H., 2004. Testosterone shifts the balance between sensitivity for punishment and reward in healthy young women. Psychoneuroendocrinology 29, 937–943.

van Honk, J., Will, G.J., Terburg, D., Raub, W., Eisenegger, C., Buskens, V., 2016. Effects of testosterone administration on strategic gambling in poker play. Sci. Rep. 6, 18096. https://doi.org/10.1038/srep18096.

Vermeersch, H., T'Sjoen, G., Kaufman, J.M., Vincke, J., 2008. Estradiol, testosterone, differential association and aggressive and non-aggressive risk-taking in adolescent girls. Psychoneuroendocrinology. 33, 897–908.