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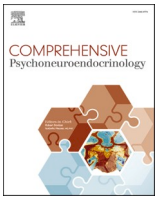

Hormone and enzyme reactivity before, during, and after a music performance: Cortisol, testosterone, and alpha-amylase

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ABSTRACT

Performance anxiety is common in a wide range of settings. This study was designed to explore the hormonal correlates of a music performance recital – a setting commonly associated with extreme and often unsettling anxiety linked to the anticipation of performing. Thirty-nine college undergraduate participants (24 women and 15 men) were recruited from students enrolled in an undergraduate music performance course. Each gave a saliva sample on a neutral non-performance day and gave additional samples immediately before and 10 and 30-min after each of two solo music recitals. Samples were subsequently assayed for cortisol, alpha-amylase, and testosterone. For women, pre-performance salivary cortisol levels were significantly elevated relative to neutral-day baseline (presumably in anticipation of performing) and continued to rise in association with the performance phase of the recital. Pre-performance alpha-amylase was significantly higher than neutral-day baseline. Testosterone increased in connection with the performance phase of the recital, but not during the anticipation phase. For all three products, patterns for men were generally similar to those for women, though not as statistically robust, perhaps owing to the smaller sample size. Increases in cortisol and alpha-amylase, from neutral-day to immediately pre-performance on recital day, suggest an effect related to the psychological anticipation of the recital. Cortisol and testosterone (but not alpha-amylase) increased in association with the performance phase of the recital. Phase-related changes in these products appears to reflect a coordinated response to the stress of a music recital and perhaps, more generally, to social-evaluative threat.

1. Introduction

Performance anxiety is extreme nervousness experienced in anticipation of or during participation in an activity in front of an audience. The feeling is common in a wide range of settings including, sport, public speaking, academics, and the performing arts including theater, dance, and music ([1] for a review). The incidence rates in music are high – in one study of students training in a major American university's music school [2], over 60% of respondents reported moderate to marked distress in association with performing and over 40% reported moderate to marked impairment in performance due to anxiety. Symptoms included poor concentration, rapid heart rate, trembling, and shortness of breath. Music performance anxiety is not restricted to relatively inexperienced amateurs. In a poll of professional orchestras in the Netherlands [3], 59% of the respondents said they had been affected by "stage fright," with 10% of the respondents suffering anticipatory anxiety beginning weeks before significant performances.

Nearly all music performers report that auditions are particularly stressful, in part because they involve scrutiny and evaluation by individuals whose opinions and recommendation can have a direct effect on career progress [4]. The physical symptoms of music performance anxiety make it likely that, as with other psychological stressors, there are endocrine correlates (e.g., [5,6]).

Dickerson and Kemeny [7] convincingly make the case that performance tasks that carry the possibility of being negatively judged by others can provoke a rise in cortisol levels. A case in point is the Trier Social Stress Test (TSST [8], which involves preparing and delivering a speech to a critical-looking and sometimes questioning audience of evaluators – part of a standard laboratory protocol for reliably inducing "social" stress in participants. Increases in salivary cortisol are seen in the majority of participants [9].

For many people, being evaluated by others results in an increase in

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testosterone as well as cortisol (e.g., Refs. [10,11]). In the TSST, and a variety of other settings, cortisol and testosterone are positively "coupled" – increases and decreases in one hormone are associated with corresponding increases and decreases in the other (e.g., Ref. [12] for a review). Salivary alpha-amylase levels also rise in reaction to the TSST [13,14], perhaps reflecting an increase in adrenergic "sympathetic drive" [15].

The psychological stress of a music recital can be conceptualized as occurring in three distinct phases: what is experienced in anticipation of the recital, what is experienced during the performance, and what is experienced in the immediate aftermath of the performance. Thus, for a music recital there can be hormone changes that anticipate the recital, changes that occur in connection with the actual performance, and changes that follow the completion of the performance that reflect the recovery of hormone levels to pre-stress baseline. Individuals can show an increase in cortisol in *anticipation* of a stressor [16–18]. Alpha-amylase is one of the major protein components of saliva and has been proposed as marker for the activation of the sympathetic nervous system [19,20]. Alpha-amylase, like cortisol, can also increase in anticipation of a laboratory social stressor [16,20]. Although social stress can produce an increase in testosterone, a robust anticipatory increase in testosterone in response to social stress in the laboratory has yet to be demonstrated [10].

Taking as a given that a music performance in front of an audience would, at least for some individuals, involve social-evaluative stress, the present study was designed to explore how this stressor affects levels of cortisol, alpha-amylase, and testosterone in relation to each of the three phases of a solo music recital.

2. Methods

2.1. Participants

Thirty-nine University of Alabama at Birmingham students (24 women and 15 men), part of a larger cohort of students enrolled in studio lessons which included a once-weekly performance class, served as participants, each providing a total of seven saliva samples collected on three different days in connection with two solo musical performances and a non-performance day. The research was approved by the university's Institutional Review Board and students gave written informed consent prior to participation. The data in this report includes only values for participants who completed all phases of the study. Participants ranged in age from 18 to 30 years (mean age for women = 20.2 years; mean age for men = 20.1 years) and each was paid $40 for participation.

The course consists of weekly one-on-one lessons lasting either 30 or 60 min, each one followed by a 1-h "performance" class during which some of the students perform a solo piece prepared for the occasion. Course enrollees were music majors and non-majors. Some students were singers (14 women and 10 men), while others (10 women and 4 men) performed on either percussion instruments, clarinet, or flute. Classes were defined by instrument, meaning that voice students met in class with other voice students, clarinet students met with other clarinet students and so on. These are known as studios, e.g., voice studio. The venue for the performance was determined by instrument, with different rooms assigned to different instruments based on the number of students and size of room required for the instrument. The audience for the performances was comprised of the course instructor, other students in the class and an occasional guest, with attendance ranging from 8 to 40 persons. Individual performances were typically between 3 and 5 min in duration. Twenty-four of the 39 participants gave vocal recitals; the remaining 15 participants were split equally between clarinet, flute, and percussion instruments.

2.2. Informed consent and the collection of saliva samples

Informed consent was obtained during regular class time, 12:20–1:10 PM by one of the authors (KHW). Students were informed of the scope, requirements, and timeline of the study, and were advised that they could opt out at any time.

All performances were scheduled for 12:20–1:10 on either Mondays or Fridays, depending on the studio. For any given participant, the day and venue were the same for each recital. Everyone enrolled in the course was required to perform several times per semester, as the same material would eventually be performed during finals week for a jury panel of faculty. The performances in this study were not formally judged, as it was understood that all performances before final exams are works in progress. After each in-class performance, the course instructor typically provided constructive feedback in private. While the quality of the performances did not determine the student's grade, students were aware that clear lack of preparation would affect their final grade.

For any given student, the first (neutral-day) saliva sample was obtained in class when the student was not scheduled to perform. Subsequent saliva samples were collected 5 min before and 10 and 30 min after the completion of the performance for each of two recitals (samples 2, 3, and 4, and samples 5, 6, and 7, respectively). Depending on the student, recitals were spaced at intervals of between 1 and 3 weeks. Recitals were scheduled so that recital-day samples would be collected at the same time of day as for neutral-day baseline samples. Fig. 1 shows the timeline for the collection of saliva samples.

Saliva samples (approximately 1 ml each) were obtained by passive drool delivered via a straw into a test tube. Within a few minutes after collection, samples were frozen and stored at −20 °C.

At the completion of the study, samples were shipped on dry ice to the Behavioral Immunology and Endocrinology Laboratory the University of Colorado (Denver) to be assayed for cortisol, alpha-amylase, and testosterone using kits by Salimetrics (Carlsbad, CA). The mean intra-assay and inter-assay coefficients of variability for cortisol, alpha-amylase, and testosterone were 10.60% and 1.71%, 7.62% and 3.54%, and 9.34% and 2.00%, respectively.

3. Statistical analyses

The SPSS statistical package was used for calculation of independent and paired *t*-tests (two-tailed), repeated measures ANOVA, and within-subjects post-hoc contrasts for hormone levels across the seven different sampling times. Pearson zero-order correlations were used to relate hormone reactivity for the first and second performances and within-individual relations between levels cortisol, alpha-amylase, and testosterone. In all cases, $p \leq .05$ was required for statistical significance. Effect sizes, Cohen's d (*d*) and partial eta squared (η_p^2), were calculated for *t*-tests tests and ANOVAs respectively. Analysis of log-transformed data produce the same results as the raw data. In keeping with procedures in descriptive reports of hormone levels associated with athletic competition (e.g. Refs. [21,22]), raw data are used for all figures and statistical analyses in this report.

4. Results

4.1. Baseline hormone levels for men and women

Neutral-day baseline hormone means for women and men are shown in Table 1. Baseline means for cortisol and alpha-amylase for men and women were similar. Mean baseline testosterone level for men was almost twice that for women, undoubtedly owing to the strong hormonal contribution of the testes.

Baseline values for one product were not significantly correlated with baseline values for either one of the other products.

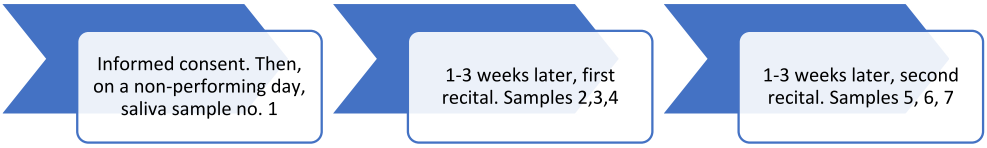

Fig. 1. Timeline for informed consent and collection of neutral-day and recital-days collection of saliva samples.

Table 1
Mean (SEM) neutral-day baseline hormone/enzyme values for men and women.

	Women (N = 24)	Men (N = 15)
Cortisol (μg/dl)	.156 (.015)	.135 (.017)
Alpha-amylase (U/ml)	104.4 (11.5)	106.2 (18.3)
Testosterone (pg/ml)	44.4 (3.2)	118.9* (9.3)

*Significantly higher than the mean for women (t (37) = 8.9, p < .001, Cohen's d = 2.69).

4.2. *Effects of music performance on salivary levels of cortisol, alpha-amylase, and testosterone*

For each hormone, repeated measures ANOVAs, separately calculated for men and women, were used to compare hormone levels for samples obtained at seven different times (neutral-day baseline, before and 10 and 30 min after the first of two musical performances, and before and 10 and 30 min after the second musical performance).

For cortisol (Fig. 2) there was a significant main effect for Time for both women and men (Women: F(6) = 6.3, p < .001, η_p^2 = 0.216; Men: F (6) = 12.0, p < .001, η_p^2 = 0.461). Fig. 2 shows mean cortisol levels for women and men at each of the time points sampled. Post-hoc contrasts showed that for both men and women, cortisol levels rose in connection with the recital and remained significantly elevated above neutral day baseline for at least 30 min after the end of the performance.

For women: Contrasts between baseline (sample 1) and pre-performance (saliva samples 2 and 5) cortisol levels – reflecting hormone changes during the anticipation phase of the recital – were significant for both performances (first performance: p = .004; second performance: p = .032). Contrasts between pre-performance and 10-min post-performance cortisol levels (samples 3 and 6) – those most closely temporally linked to the performance phase – were also significant for both performances (first performance: p < .001; second performance: p = .006). Cortisol levels fell after the conclusion of the performances, but remained elevated relative to baseline for at least 30 min after that (Fig. 2).

For men: Means for baseline and pre-performance cortisol levels were similar and not significantly different. Cortisol rose in connection with the performance phase of each recital (first performance: p = .001; second performance: p < .001) and remained significantly elevated relative to baseline level for at least 30 min after that (Fig. 2).

For alpha-amylase (Fig. 3) there was a significant main effect for Time for women (F(6) = 2.3, p = .036, η_p^2 = 0.092) but not for men (F (6) = 1.24, p = .30, η_p^2 = 0.081). For women: contrasts between baseline (sample 1) and pre-performance (saliva samples 2 and 5) alpha-amylase levels – anticipation phase – were significant for each performance. Contrasts between pre-performance and 10-min post-performance levels (samples 3 and 6) – those most closely temporally linked to the performance phase – were not significant. For both performances, alpha-amylase decreased from anticipation phase peaks and were at baseline levels within 30 min after the conclusion of the performance. For men, the pattern for both performances was generally similar to that for women, but none of the contrasts was statistically significant.

With respect to testosterone, whether for men or women, the main effect for Time did not reach statistical significance (see Fig. 4). For women: contrasts between baseline and pre-performance (saliva samples 2 and 5) testosterone levels were not significant for either performance. The contrast between the pre-performance testosterone mean and 10-min post-performance testosterone mean was significant for the first performance (p = .003) but not the second performance (p = .203). Peak levels of testosterone were seen in connection with the performance phase of the recital – the contrasts between baseline and samples

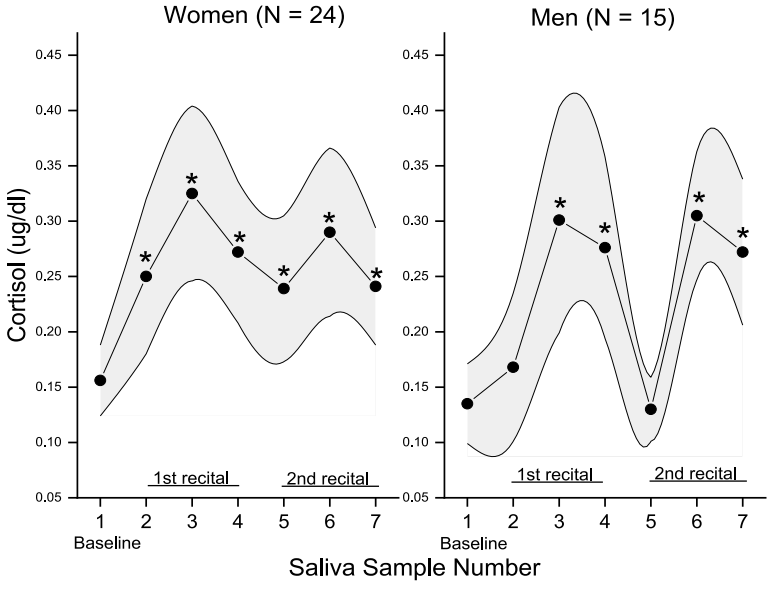

Fig. 2. Mean cortisol level for neutral-day baseline and recital day-samples. Shading shows 95% confidence intervals for the means. Asterix (*) indicates means significantly different (p ≤ .05) from neutral-day baseline. Significance levels ranged from p < .001 to p < .04.

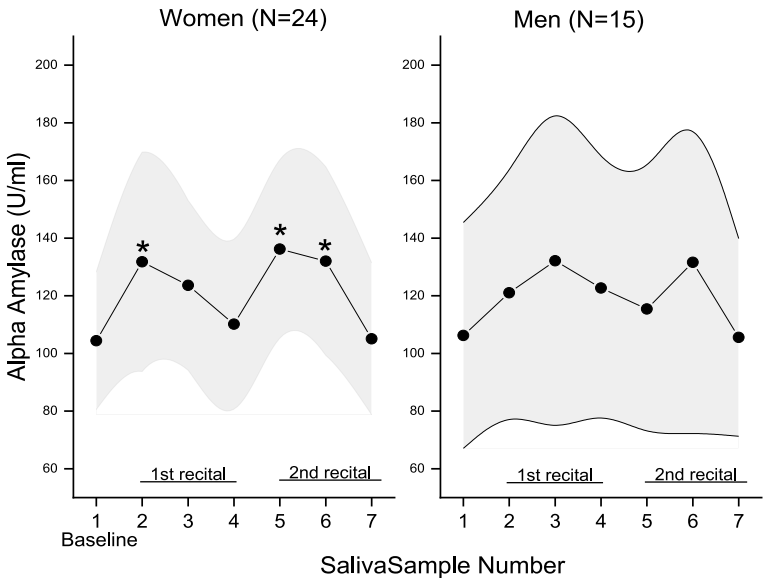

Fig. 3. Mean alpha-amylase level for neutral-day baseline and recital day-samples. Shading shows 95% confidence intervals for the means. Asterix (*) indicates means significantly different ($p \leq .05$) from neutral-day baseline. Significance levels ranged from $p = .05$ to $p = .02$.

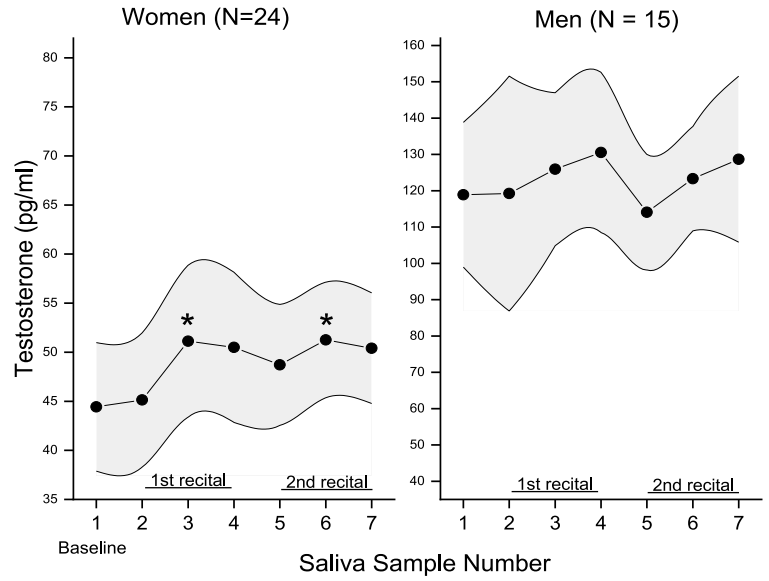

Fig. 4. Mean testosterone level for neutral-day baseline and recital day-samples. Shading shows 95% confidence intervals for the means. Asterix (*) indicates mean is significantly different ($p \leq .05$) from neutral-day baseline.

3 and 6 were statistically significant ($p = .050$ and $p = .049$, respectively). On average, testosterone remained relatively high for at least 30 min after the end of each performance, albeit at levels that were not significantly different from neutral-day baseline. For men: the pattern of change in testosterone was similar to that for women, but none of the within-group contrasts were statistically significant.

4.3. The effects of music performance on cortisol, testosterone, and alpha-amylase are correlated for the two performances

Each participant gave two recitals and consideration of changes in product levels for each provides information about the stability of individual differences in hormone reactivity associated with music performance. Highest hormone levels for men and women were typically seen for the saliva samples obtained either 10 min or 30 min after the completion of each performance. To compare hormone changes between the two performances, for each participant we took the peak hormone level without regard to sample number for each recital and calculated that value as percent change from neutral-day baseline value. Expressed in this way, whether for cortisol, alpha-amylase, or testosterone, individual differences in hormone reactivity are conserved from one music performance to the next. The significant relationships between hormone reactivity for the first and second recitals for cortisol, alpha-amylase, and testosterone are shown in Fig. 5.

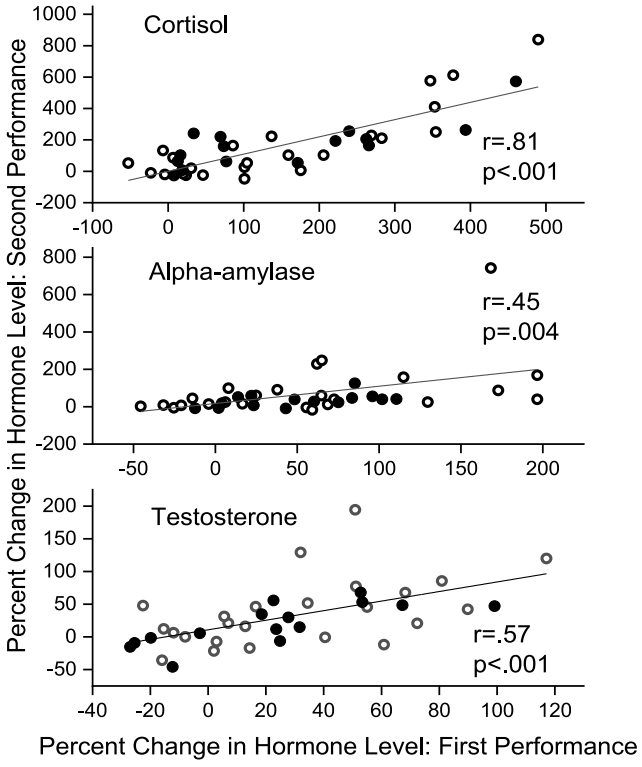

Fig. 5. Correlations between hormone reactivity for the first and second music performances for men and women combined. Each data point represents values for a single individual. Women (N = 24) are indicated by open circles; filled circles indicate men (N = 15). When men and women are considered separately, whether for cortisol, alpha-amylase, or testosterone, all of the correlations between first and second performance values are statistically significant with r values ranging from 0.46 to 0.85, and p-values ranging from 0.05 to < 0.001.

4.4. Cortisol/testosterone coupling predicts testosterone reactivity to recital stress

In variety of settings cortisol and testosterone are positively "coupled.'' That is, whether considered diurnally [23–26] or over an extended period of several weeks [12], within-person fluctuations of cortisol and testosterone levels occur in parallel: i.e., increases and decreases in one hormone are associated with corresponding increases and decreases in the other (Ref. [12] for a review). Participants in this study gave seven saliva samples over periods ranging from about 3 to 6 weeks. For each participant we calculated within-person Pearson zero-order correlations between cortisol and testosterone, cortisol and alpha-amylase, and testosterone and alpha amylase. Fourteen of 39 participants (9 women and 5 men) showed a statistically significant ($p \leq .05$) association between cortisol and testosterone, with r-values ranging from 0.75 to 0.97 (mean: r (12) = 0.82). For purposes of further analysis, we considered cortisol and testosterone levels for these individuals to be "coupled;" for the remaining individuals we considered cortisol and testosterone levels to be "uncoupled." Statistically significant correlations between cortisol and alpha-amylase and testosterone and alpha-amylase occurred less frequently (6 and 8 instances respectively, equally apportioned between men and women).

Whether for men or women, neutral-day (baseline) hormone values were not significantly related to cortisol/testosterone coupling. For women, testosterone reactivity (but not cortisol reactivity) for testosterone/cortisol coupled participants was significantly higher than for uncoupled participants for both the 1st and 2nd recitals (first recital: t (22) = 3.03, p = .006. Cohen's $d = 1.22$; second recital: t (22) = 2.29, p = .032), Cohen's $d = 1.00$) (Fig. 6). For men, whether for the first or second recital, cortisol and testosterone reactivity means for the coupled and uncoupled individuals were not significantly different (First recital cortisol, 137.0% vs 191.0%; Second recital 156.2% vs 194.5%; First recital testosterone, 21.0% vs 24.8%; Second recital testosterone, 19.4% vs 19.2%). For alpha-amylase reactivity, whether for women or men, means for coupled and uncoupled groups were not significantly different for either recital (Women, coupled vs uncoupled: 54% vs. 64% and 74% vs 114%, for 1st and second recitals, respectively; Men, coupled vs uncoupled: 49% vs. 53.% and 24% vs 52.1%, for first and second recitals, respectively).

5. Discussion

5.1. Cortisol

For men and women, cortisol levels rose relative to neutral-day baseline in association with both the first and second recitals. For women this increase was apparent in the pre-performance samples for the first and second performances, suggesting that anticipating a coming performance can increase cortisol levels (see also, [27]. This is in keeping with reports of "anticipatory" cortisol reactivity in sport as well as psychologically stressful non-sporting performance events [28] for a review). Cortisol also increased in association with the performance part of both the first and second recitals and remained significantly elevated relative to neutral-day baseline for at least 30 min after the end of the performance. In one study [27], for musicians with moderate to high performance anxiety, cortisol levels can remain elevated for as long as 24 h after a concert performance. The results of the present study, taken together with other reports (e.g. Refs. [27,5]), make it clear that music recitals and perhaps other music-related stage performances (e.g., Ref. [29]) belong on the list of performance settings associated with an increase in cortisol. Performance anxiety is common, even for the most experienced musicians. The cortisol/music performance connection is not limited to student-level solo music performers – the stress of a concert performance can lead to an increase salivary cortisol in a substantial number of elite-level orchestra musicians [6].

In the present study, although none of the performances was formally judged, they were an obligatory part of a college course in

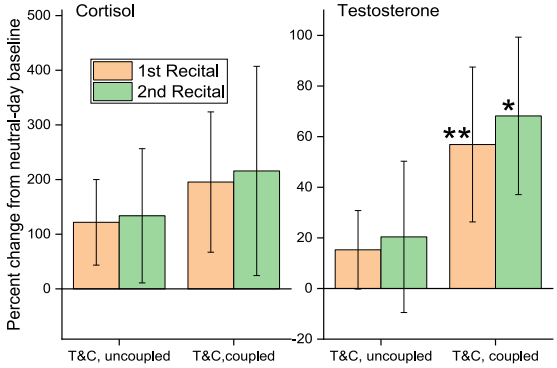

Fig. 6. Cortisol (C) and testosterone (T) reactivity for women participants expressed as percent change in hormone level from neutral day baseline according to whether T and C levels were coupled (N = 9) or uncoupled (N = 15). Error bars show 95% confidence intervals for the means. *p = .032; **p = .006.

which each participant was enrolled, and it was understood that the instructor would provide constructive feedback to each participant about each of his/her performances. These performances carry the possibility of being negatively judged by the course instructor as well as the other members of the audience and have that quality in common with other performance tasks known to provoke a rise in cortisol levels [7]. Apparently, even a subtle implication of evaluation can lead to an increase in cortisol during both the anticipation and performance phases of the recital.

5.2. Alpha-amylase

For women, pre-performance alpha-amylase levels for the first and second recitals were significantly higher than for neutral-day baseline (Fig. 3), presumably reflecting the psychological stress associated with the anticipation of the performance to follow. Levels remained elevated during the performance part of the recital through the 10-min interval after its end, but fell quickly after that. A similar pattern was seen for men but none of the statistical comparisons with neutral-day baseline were statistically significant. These results, at least for women, are in accordance with results of another study of music performance [5] and with the idea [13,14,20] that levels of alpha-amylase, like levels of salivary cortisol, track psychological stress. In men and women, TSST-related increases and subsequent decreases in salivary alpha-amylase are closely paralleled by changes in plasma norepinephrine, suggesting the use of this enzyme as an index for activation of the sympathetic nervous system [13]. It seems likely that the psychological stress of a solo music performance activates the sympathetic nervous system. Indeed, many of the symptoms of music performance anxiety (e.g., Ref. [2]) are probably caused by an increase in sympathetic activation. For many years beta blockers (e.g., propranolol) have been effectively used to alleviate performance anxiety in individuals whose symptoms are primarily somatic e.g., palpitations, hyperventilation, tremor, sweating palms [30] and betablockade prevents the stress-induced increase of salivary alpha-amylase levels in experimental settings [15].

5.3. Testosterone

For women, pre-performance levels of testosterone were not significantly different from neutral-day baseline, and we find no clear evidence that would suggest an increase in this hormone in anticipation of the performance to come. In contrast, levels of testosterone at 10-min post-performance were significantly elevated relative to neutral day baseline for both recitals. Performance-related increases in testosterone seen here for the women participants are reminiscent of those reported for other kinds of stressors including the TSST [11] and athletic competition (For reviews: [28,31]). While the general pattern of hormone change for men was similar to that for women (Fig. 4), differences between baseline and pre- and post-performance testosterone levels for men were not statistically significant.

5.4. Comparison of changes in the three products for each phase

Dickerson and Kemeny [7] propose that in most individuals there is a strong motive to preserve the social self against social-evaluative threats that include the possibility of "failure or poor performance" (p.358). In their view, a strong cortisol response to social-evaluative threat – a solo musical performance surely qualifies as such a threat – occurs in the service of this motive. The significant phase-specific changes in alpha-amylase and testosterone shown by the women in this study suggest that these products too can, in ways yet to be elaborated, act in support of the social self.

There were important similarities as well as differences for the three phases (anticipation, performance, recovery) for the three products. For women, there was a clear anticipatory increase in cortisol and alpha amylase, but not in testosterone. Cortisol and testosterone (but not alpha-amylase) increased in association with the performance phase of the recital. In response to psychosocial stress, peak increases in alpha-amylase typically precede peak levels of cortisol [14,16], with alpha-amylase appearing to, in the present study increase no further after the anticipation phase. Patterns were generally similar for men, although statistical significance was not reached for most analyses.

5.5. Individual differences and hormone coupling

Whether for cortisol, alpha-amylase, or testosterone, individual differences in baseline values for one hormone were not related to individual differences in either one of the others. This was true when participants were analyzed with men and women combined into a single group or when men and women were analyzed in separate groups.

In general, levels of cortisol, alpha-amylase, and testosterone increased in association with a solo music recital and peaked either before or 10-min after the conclusion of the performance depending on the individual. But there were exceptions. Some individuals showed little or no recital-related reactivity. For others, recital levels of cortisol or testosterone decreased relative to neutral-day baseline (Fig. 5). Individual differences in this regard could reflect differences in the subjective perception of stress (e.g., [5]).

Whether for cortisol, alpha-amylase, or testosterone, when recital-related change in hormone level is figured as percent of neutral-day baseline, individual differences in reactivity are conserved from one recital to the next – the most reactive individuals for the first recital tend to be the most reactive for the second recital (Fig. 5). Writing about women athletes, Edwards and Kurlander [22] suggested that women may have a "signature" change in hormone level that is conserved for one competition to another. As the results of the present study show, this is also apparent in the context of music performances and appears to be true for women and men.

There were 14 participants (women, N = 9; men, N = 5) for whom the zero-order correlation between cortisol and testosterone levels was statistically significant and, by this criterion, cortisol and testosterone levels were considered "coupled." For women, mean testosterone reactivity was substantially higher than mean reactivity for non-coupled participants (Fig. 6). It is intuitively reasonable that individuals would differ with respect to their psychological management of stress. For women, the positive connection between cortisol/testosterone coupling and recital-related testosterone reactivity suggests a coordinated hormonal response to the psychological stress of a music performance recital – one that perhaps reflects individual differences in the psychological management of recital-related stress. A similar effect was not evident in men. But sample size for men was substantially smaller than that for women – a fact that should caution against concluding that women and men differ in this regard without additional supporting evidence. Differences between coupled and uncoupled individuals with respect to alpha-amylase reactivity were not significantly different. While alpha-amylase levels are clearly affected by the prospect of a music recital, the alpha-amylase response is probably not part of the cortisol/testosterone dynamic as it relates to a solo music recital. The extent to which cortisol/testosterone coupling is predictive of psychological coping style in this setting as well as hormone reactivity to other stressors remain to be determined.

5.6. Sources and mechanisms

Cortisol is produced exclusively in the adrenal cortex. In men, the testes are a major source of testosterone and testosterone precursors; in women circulating testosterone comes from direct secretion from the adrenal glands and ovaries and indirect extra-glandular conversation of precursors secreted by the adrenals and ovaries. While it is generally assumed that increases in cortisol in blood or saliva reflect an increase in the secretion of these hormones, Edwards and Casto [28] make the case

that the rapid appearance of these hormones in association with stress need not involve either the hypothalamic-pituitary-adrenal (HPA) or hypothalamic-pituitary-gonadal (HPG) axes. The present study was not designed to offer help in selecting from the various mechanisms ([28] for a review) by which music recital stress might increase levels of these two hormones. It should be noted, however, that performance-related peaks in salivary cortisol and testosterone were apparent in saliva samples obtained 10 min after the conclusion of a brief (3–5 min) music performance – a response sufficiently rapid to suggests the involvement of processes other than activation of the HPA or HPG axes. Indeed, the pre-performance release of norepinephrine and other catecholamines (suggested by the pre-performance increase in alpha-amylase) could stimulate the release of testosterone and testosterone precursors from the adrenal cortex [32] and in that way be involved in the rapid increase in recital-connected increases in salivary testosterone levels.

Being able to anticipate potential threats may allow an individual to prepare responses to deal with the threat [33–36]. Humans have greater capacity for abstract thought and symbolic representation compared to other species and are very good in anticipating potential dangers. That cortisol and alpha-amylase rose in apparent anticipation of the recitals to come suggests that systems regulating cortisol and alpha-amylase are responsive to cognitive appraisals of future challenges. Whether these changes benefit or compromise performance in probably depends on an interaction between "person" factors and context, and the ability to anticipate future challenges may have a cost if it chronically activates stress-responsive systems in the body, leading to long-term negative effects on health [36].

5.7. Limitations

The sample size – 24 women and 15 men – was relatively small. That said, results for women were repeatable for the two recitals and sufficiently robust, statistically speaking, to provide convincing evidence that for women salivary levels of cortisol, alpha-amylase, and testosterone increase in association with solo music recitals either during the anticipation phase or the performance phase, or both depending on product. Men showed similar patterns for each of these products but the failure to reach statistical significance in some instances calls for a more cautious conclusion about the physiological correlates of a solo music recital in men. This study was conducted with amateur musicians enrolled in a music performance for academic credit. While performance anxiety is common in elite level music performers, the extent to which the physiological effects of a solo music recital on levels of cortisol, alpha-amylase, and testosterone apply to elite-level music performers is not known (but see Ref. [6] for a consideration the effect of a concert performance on cortisol reactivity in elite-level orchestral musicians).

We made no attempt to assess the menstrual cycle phase of the women participants in this study because the relatively small sample size would have precluded meaningful analysis of cycle phase as related to the physiological correlates of a music recital. Recently demonstrated [37] menstrual cycle differences in cortisol and testosterone reactivity to brief physical and psychological stressors in a laboratory setting encourage the study of menstrual phase differences in cortisol and testosterone reactivity in music performance and other real-world settings. The physiological effects of solo music recitals robustly apparent in women are generally paralleled by similar effects in men. This is clearly the case for cortisol (Fig. 2). But absent convincing statistical support, perhaps owing to the smaller sample size, any conclusions about the effects of music performance on salivary levels of testosterone and alpha-amylase for men would be premature.

5.8. Conclusions, significance, future research

For women in this study, cortisol, alpha-amylase, and testosterone increased in association with a solo music performance recital, with patterns unique to each product. Relative to neutral-day baseline, an increase in cortisol was seen shortly before the beginning of the performance, an "anticipation" effect that was carried over and amplified during the performance phase of the recital. Highest levels of alpha-amylase relative to baseline were seen prior to the onset of the performance phase of the recital. Statistically significant increases in testosterone were seen only for samples obtained 10 min after the completion of the performance, presumably reflecting a change in hormone level generated in connection with the performance phase of the recital. Patterns of phase-related increases in cortisol and testosterone were similar to those described for women athletes for saliva samples obtained on a neutral day (baseline) and before and immediately after an intercollegiate competition (e.g., Refs. [21,22]) suggesting a foundational psychological process (e.g., Ref. [38]) common to recital participants and women athletes. Statistically significant coupling between cortisol and testosterone was seen in some participants. For women, testosterone reactivity to a solo music recital was substantially higher for coupled individuals than for individuals in which these two hormones were not coupled. This effect was seen only in women, suggesting the possibility of a sex difference that is surely worth exploration. The extent to which coupling would predict hormone reactivity in women and men in response to other stressors is not known. Dismukes et al. [25], argue that the interrelated elements of *stress* and *challenge* facilitate coupling and increases in cortisol and testosterone. We take as a given that hormone reactivity in response to stress is adaptive and ultimately beneficial. The present research provides additional foundation for, and should encourage studies of, the adaptive character of cortisol/testosterone coupling and hormone reactivity in performance settings.

Declaration of conflicting interest

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

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