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Self-regulation and working memory in musical performers

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Abstract

Performing music in front of others can be stressful, even for experienced performers. The physiological effects of stress, namely, increases in cortisol and sympathetic nervous system activity, have been shown to have detrimental effects on cognition, particularly working memory. This study used an audition-like performance scenario to elicit a stress response in performers who differed in their degree of musical experience. We expected that participants with more musical experience would be better able to regulate their stress response, would report lower levels of anxiety, insecurity, and nervousness, and would show better working memory following the stressor, compared to participants with less musical experience. Although we did not find differences between more and less experienced performers in their sympathetic nervous system activity or their self-reported feelings of anxiety and nervousness, we did find some important differences: following the stressor, more experienced performers were less insecure, they showed better regulation of their cortisol response, and they demonstrated better working memory.

Keywords

cortisol; emotion; regulation; sympathetic nervous system; working memory

Performing music in front of an audience can often be stressful and produce feelings of nervousness, fear, and anxiety in the performer. These feelings of nervousness and fear may manifest themselves as music performance anxiety (MPA), a diagnosable social phobia of performing in front of an audience characterized by feelings of anxiety and/or by impairments in performance (Salmon, 1990). Even performers who do not suffer from MPA may experience some anxiety during the performance event, and this anxiety may be associated with a decrement in performance. In order to address impairments in performance, it is helpful to investigate cognitive systems that are both affected by stress and essential to musical performance. One cognitive system vital to musical performance is working memory (WM). As stated by Jonides, Lacey, and Nee (2005, p. 2): “Working memory is a system that can store a small amount of information briefly, keeping that information quickly accessible and available for transformation by rules and strategies, while updating it frequently.” Many studies have demonstrated that circulating glucocorticoids, such as the hormone cortisol, which is released in response to stressful stimuli, have adverse effects on WM (e.g., De Kloet, Oitzl, & Joels, 1999; Lupien, Gillin, & Hauger, 1999; Roozendaal, 2002; Wolf et al., 2001). The present study used a novel,

audition-like modification of an established stress-induction technique (the Trier Social Stress Task) called the Musical Performance Stress Task (MPST) to elicit a stress response in participants who had differing levels of musical experience. The goal of the present study was to determine whether individuals cope with a potentially stressful situation differently depending on their level of musical experience, and whether performance stress is associated with WM impairment.

In stressful situations, the hypothalamus activates the autonomic nervous system, specifically the sympathetic nervous system (SNS), and the endocrine system, specifically the hypothalamic-pituitary-adrenal (HPA) pathway. Activation of the SNS is comparatively fast, and involves the release of epinephrine and norepinephrine, which have immediate effects on heart rate, blood pressure, and respiration rate. Activation of the HPA pathway is comparatively slow and involves the release of cortisol, a corticosteroid hormone. Cortisol levels typically peak between 15 and 25 minutes following a stressor (Ramsay & Lewis, 2003).

Individuals vary in their reactivity to, and regulation after, a stressful event. Reactivity refers to an individual's initial endocrine and autonomic reaction to stimuli in the environment, and regulation, or response dampening, is defined as those processes that function to modulate reactivity via attentional and behavioral mechanisms (Braungart-Rieker & Stifter, 1996). Although regulation does not have to be consciously driven, it may be; some techniques to regulate the stress response include relaxation therapy (Manzoni, Pagnini, Castelnovo, & Molinari, 2008) and meditation (Wallace & Benson, 1972). Past studies have examined reactivity and regulation in adults through cortisol post-stressor measures (e.g., Earle, Linden & Weinberg, 1999; Jansen, Gispens-de Wied, & Kahn, 2000). On average, the reactivity phase, or the peak cortisol response to a stressor, is expected to occur approximately 20 minutes after the stressor (Ramsay & Lewis, 2003). Regulation, or response dampening, may be measured approximately 20 minutes after the peak response.

Adverse effects of cortisol and other glucocorticoids on WM have been repeatedly reported, using varied WM tasks and different techniques to manipulate cortisol levels – whether through pharmacological administration or stress induction (e.g., De Kloet, Oitzl, & Joels, 1999; Lupien et al., 1999; Roozendaal, 2002; Wolf et al., 2001). For instance, Lupien et al. (1999) pharmacologically manipulated participants' cortisol levels via intravenous administration of hydrocortisone. Forty-five minutes following hydrocortisone administration, participants completed two memory tasks, including an item-recognition WM task and a paired-associates declarative memory task. In the WM task, participants had to indicate whether a target letter matched a sample letter shown on that trial. The number of sample and target letters shown on any given trial varied in order to manipulate the number of comparisons (between sample and target stimuli) necessary to complete the trial. Compared to all other participants, those participants who received the highest dose of hydrocortisone were significantly slower to respond on target-absent trials as the number of required comparisons increased. Unlike WM, participants' declarative memory was not affected by cortisol levels.

To more deeply investigate the relation between stress-induced (rather than pharmacologically- manipulated) cortisol elevations and their effects on WM, Elizinga and Roelofs (2005) conducted a study that also incorporated measures of SNS activity. WM was assessed using forwards and backwards digit span tasks. SNS activity (heart rate and blood pressure), salivary cortisol, and WM were assessed at three time points: at baseline, at the end of the stress phase, and during the recovery period. To elicit a stress response, the stress phase consisted of the Trier Social Stress Task (TSST), a psychosocial stress task in which participants were given 5 minutes to prepare a 5-minute speech about why they were qualified for the position of a research assistant at their university. Results revealed that cortisol levels rose during the TSST in some participants (deemed responders), but not in others (deemed non-responders). Non-responders outperformed responders on the WM tasks during the stress phase, when both sympathetic measures and cortisol were high. During the recovery period, when cortisol remained elevated for the responders, but SNS measures had returned to baseline, there was no significant difference between the two groups in WM performance. These results suggested that despite elevated cortisol levels, WM was only impaired when SNS activity was also elevated.

Performers may use different types of WM depending on the characteristics of the music being performed. Musical performance utilizes tonal WM, and, in the case of lyrics, verbal WM, and greater WM capacity is associated with better musical performance (e.g., Meinz & Hambrick, 2010). Imaging studies have found that verbal and tonal WM rely on many of the same neural structures (Hickock, Buchsbaum, Humphries, & Muftuler, 2003; Koelsch et al., 2009; though see Schulze, Zysset, Mueller, Friederici, & Koelsch, 2010, for evidence of some differences between tonal and verbal WM in musicians). Past studies have found that very experienced musicians outperform individuals with little or no musical experience on different types of WM tasks: auditory WM tasks using tonal stimuli (Green & Samuel, 1986; Pallesen et al., 2010; Schulze et al., 2010), auditory WM tasks using verbal stimuli (Jakobson, Cuddy, & Kilgour, 2003; Jakobson, Lewycky, Kilgour, & Stoesz, 2008; Kilgour, Jakobson, & Cuddy, 2000), and visual WM tasks (Jakobson et al., 2008). All of these studies, however, were conducted to examine WM independent of the stressors that performers typically encounter. Additionally, with one exception (Jakobson et al., 2003), these studies compared participants who had considerable musical experience with participants who had little to no musical experience.

The present study sought to address these issues by testing performers who all had a moderate degree of musical experience and by developing a new audition-like modification of the TSST called the MPST to generate psychosocial stress in a musical context. Auditions are often stressful environments in which participants typically perform a well-practiced musical piece, scales, and sight-reading in front of judges for approximately 10 minutes. Sight-reading can be stressful, because performers are typically allowed little or no practice (Meinz & Hambrick, 2010). Auditions may be ambiguous and variable because performers are not told how long to play their prepared pieces, which scales to play, or how many octaves to play until the audition. Therefore the MPST emulated an audition while retaining many features of the TSST. In order to measure participants' experiences of nervousness, fear, and anxiety in reaction to the MPST, the present study used subjective rating scales and

physiological measures. The rating scales consisted of self-report measures of insecurity, anxiety, and nervousness. The physiological measures included SNS and HPA measures.

Three different WM measures were incorporated into the design of the study. It is well established that the two traditionally employed tests of WM that are contained in the Wechsler Adult Intelligence Scale (WAIS), Digit Span Forward (DSF) and Digit Span Backward (DSB), make different cognitive demands (Bireta et al., 2010; Reynolds, 1997). Recent fMRI research suggests that there are neuroanatomically distinct regions involved in the different sub-processes tapped by DSF and DSB (Tsukjura et al., 2011), specifically, maintenance and mental manipulation. By measuring the length of an individual's immediate span for remembering digits in the order they are heard, DSF primarily indexes an individual's capacity for registering and maintaining information in immediate memory. In DSB, a string of numbers is held in short-term memory store while reversing the sequence given, followed by the participant correctly reproducing the numbers in reverse order. DSB tests an individual's ability to mentally manipulate information, which implies updating or transforming information that is active in immediate memory. Mental manipulation processes are considered higher-order, executive functions which place greater cognitive demands on an individual than registering and maintaining information in WM. Given the importance of executive functions in WM, another WM subtest was added to the WAIS-IV, Digit Span Sequencing (DSS). In DSS, a string of numbers is presented out of order and the individual must repeat them in numerical order. The WM processing demands of DSB and DSS are similar, in that mental manipulation is involved in both WM subtests (Weiss, Saklofske, Coalson, & Raiford, 2010, p. 70). Thus, in the present study DSB and DSS were given to participants at the reactivity and recovery phases, respectively, to examine how neuroendocrine functioning and musical experience affect the executive function processes of WM. Using DSB and DSS at different phases therefore allowed for the assessment of similar WM processes while avoiding practice effects specific to each test.

Studies of the effects of cortisol on WM have typically tested college undergraduates, but expert performers comprise an informative sample for one to study the effects of stress on cognition. Expert musicians demonstrate control and execution in their domain that is easily distinguished from that of novices (Ericsson, Krampe, & Tesch-Romer, 1993). When exposed to chronic stress, like that which might occur with repeated performance opportunities, the HPA axis can show response habituation (Herman, Ostrander, Mueller, & Figueiredo, 2005). HPA axis habituation is highly dependent on both the intensity and predictability of the stressful stimulus (Pitman, Ottenweller, & Natelson, 1988). Therefore, if the stress associated with performing is regarded as intense and predictable for an individual, it is possible that the HPA axis can habituate to it. With repeated performance opportunities, perhaps experienced performers develop the ability to handle stress more efficiently than novice performers. This enhanced ability to handle stress may, in turn, affect WM in an advantageous manner.

The present study investigated the effects of a stressor on the stress response and WM in musical performers. Because judgments concerning which performers are experts at playing their instruments are likely to be highly idiosyncratic, the present study classified participants as either more experienced or less experienced performers. We predicted that

the SNS and HPA activity of more experienced performers would differ from that of less experienced performers through less initial reactivity to a stressful event, greater response dampening (termed “recovery”), or both. Additionally, we predicted that more experienced performers would report lower levels of insecurity, anxiety, and nervousness than less experienced performers. These differences would be revealed in negative correlations between musical experience and all cortisol, SNS, and subjective measures at both the reactivity and recovery phases.

Due to less reactivity of SNS and HPA activity, we expected that, compared to less experienced performers, more experienced performers would exhibit higher levels of WM performance immediately following the stressful event. In Elzinga and Roelofs’ (2005) study, cortisol levels remained elevated during the recovery period in cortisol responders, indicating a lack of cortisol regulation in these participants during the recovery period. Following this, we predicted that if differences between the more and less experienced performers in HPA regulation were found in the recovery phase, these differences might be further reflected in better WM performance during the recovery phase for more experienced, compared to less experienced, performers.

Method

Participants

Forty people with differing musical backgrounds participated in the study. Participants were recruited through the use of flyers, which were posted in the music building and the campus commons area, in-class announcements, and emails. Participants were given either class credit or \$20 for their participation. A total of 16 males and 24 females, aged 18–27 years ($M = 21.25$, $SD = 2.20$), participated. Participants were asked not to exercise, eat a heavy meal, drink caffeine, or smoke 1 hour prior to coming into the laboratory because these variables can have an influence on cortisol levels.

Participants were also asked to prepare a 2½-min solo they would like to play. Participants brought their own instruments to perform on, except pianists, for whom the experimenter provided an electric, full 88-weighted key Casio CDP-100 and a pedal; as such, a wide variety of instruments were represented. Because the MPST requires participants to be able to play the 12 major scales and be able to read standard musical notation, drummers and guitarists were not used. Vocal performers were excluded from the study to control for language processing during musical performance.

Procedure

A timeline for the experimental procedure is presented in Table 1. The study was conducted in the morning so that salivary cortisol could be collected during a time when HPA activity varies considerably between individuals (Rosmond, Dallman, & Bjöntorp, 1998). Participants arrived at the laboratory at either 9:00 a.m. or 10:45 a.m., after which participants were asked to sit and wait for 20 min. This ensured that any physical activity they may have engaged in prior to coming into the lab would not be captured in their baseline cortisol collection. During this time, participants were asked to relax while they

were oriented to the study. After this 20-min period, physiological measures, subjective measures, and WM were assessed to establish baselines.

Next, the experimenter explained to the participant that they would be playing in front of two judges. This was the first time participants heard that they would be judged on their performance. The experimenter exited the room to allow the participant to warm up (1 min) and to let the judges know that they may enter the room. The experimenter introduced the judges to the participant, and turned on a video camera in the presence of the participant. Participants stood 2 feet away from the judging table and the MPST (described below) was administered. The judges then left the room and the experimenter reentered the room to assess physiological measures, subjective measures, and WM. This was known as the reactivity phase.

During the recovery phase, participants were asked to complete a questionnaire and waited, as necessary, until 20 min elapsed. The experimenter again assessed physiological measures, subjective measures, and WM. Afterwards, participants were debriefed.

Tasks

Musical performance stress task—The MPST was created to make the TSST relevant to musical performance stress. The speech in the TSST was replaced with 2½ min of a prepared solo by the participant followed by 2½ min of scales, which were selected by the judge. This was then followed by 5 min of a preselected sight-reading piece consistent with the clef (treble, alto, or bass) the instrument played in. So as not to deviate too far procedurally from the TSST, the subsequent 5 min of the mental arithmetic task remained consistent with the TSST. All sightreading pieces were rated an intermediate level of difficulty by an online source (www.freescorers.com).

Participants were informed that they were being video recorded and judged throughout the task. The judges were two confederates, one male and one female, who had been instructed to maintain a serious demeanor. The judges were introduced as graduate students; one in psychology, who had been trained to monitor non-verbal behavior and cues of nervousness and anxiety, the second in music education, who would be assessing their performance on intonation, rhythm and style. The first judge administered the mental arithmetic task in which the participant was asked to serially subtract 13, beginning at 1587. The judge was instructed to respond to any subtraction mistakes by asking the participant to start from the beginning.

Working memory task—The WM was assessed with the Digit Span subtest of the Wechsler Adult Intelligence Scale IV (Wechsler, 2008). Approximately 20 min after the participant entered the laboratory, participants completed the forward digit span (DSF) test to establish baseline WM performance (T1). During the reactivity phase (T2), approximately 20 min after baseline and following the MPST, participants were given the backward digit span (DSB) task. During the recovery period (T3), approximately 20 min after the MPST, the experimenter administered the sequential digit span (DSS) task. For each assessment, the experimenter read a series of numbers of increasing length (the first series had two digits, the second series had three digits, and so forth up to the eighth series which contained nine

digits) at the rate of one digit per second. The participant was instructed to repeat the numbers of that trial either in the same order (forward), the reverse order (backward), or in ascending order (sequential). Each series contained two trials. If the participant was inaccurate on both trials of a series, the experimenter would stop conducting the digit span task. For scoring purposes, the number of digits was totaled for each correctly repeated trial. The total number of points possible was 88 for the forwards and sequencing digit span tasks, and 74 for the backwards digit span task.

Physiological assessments

All physiological and subjective measures were taken during the baseline (T1), reactivity (T2), and recovery (T3) phases of the experiment (approximately 20 min apart).

Salivary cortisol—Saliva samples were obtained using a dental cotton roll. Participants placed the roll in their mouth for approximately 1 minute to collect saliva. The rolls were then placed in salivettes, which were centrifuged and stored at -20°C until shipment to Salimetrics, Inc. for radioimmunoassay analysis. Each sample was assayed twice, and the intra-assay coefficient of variation was 3.0%. The cortisol values of the two assays were averaged and these scores were $\log_{10}$ -transformed for normality. Only the $\log_{10}$ -transformed scores were used in the final analysis.

Heart rate and oxygen level—Heart rate was recorded using Nellcor OxiMax N-65 Handheld Pulse Oximeter. The pulse oximeter also measured the participants' blood oxygen levels.

Blood pressure—Systolic and diastolic blood pressure was measured from the non-dominant arm with an Omron Premium blood pressure monitor.

Subjective measures

Participants answered questionnaires that subjectively measured feelings of anxiety, nervousness, and insecurity on a scale of 1–7, 1 being not very and 7 being very much.

Questionnaire

A questionnaire was given which included demographic questions and a number of questions about participants' musical experience. Female participants were asked additional questions regarding their menstrual cycle because menstrual phase may influence cortisol levels (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). The questionnaire appears in the Appendix.

Musical experience classification

Participants were categorized as either more experienced or less experienced performers following Ericsson et al.'s (1993) criteria for expertise. Participants were considered more experienced if they met two criteria: 1) they had more than 10 years of experience playing their current instrument, and 2) they practiced more than an hour a day, for more than 5 days out of the week, every week of the month for the past year. Participants who did not meet both criteria were considered less experienced.

Results

An alpha of 0.05 was used to determine statistical significance.

Two less-experienced participants were not included in further analysis due to outlying cortisol values (>3 SD above the mean change value), resulting in a final sample of 12 (M age = 21.67; 8 females) more experienced performers and 26 (M age = 21.12; 14 females) less experienced performers. Since the menstrual cycle can have a possible confounding influence on female cortisol levels (Kirschbaum et al., 1999), a Pearson R correlation was conducted to determine whether females in the two groups were matched in terms of menstrual cycle phase. While the more experienced music group consisted of a greater percentage of females compared to the less experienced group, musical experience group was not significantly correlated with menstrual cycle phase ($p > .05$). Menstrual cycle phase was therefore not included in further analysis.

Independent samples t tests revealed that more experienced performers had indeed played their instruments for more years (more experienced, $M = 13.25$, $SD = 4.07$; less experienced, $M = 7.98$, $SD = 3.25$; $t(36) = 4.28$, $p = .001$), and practiced more hours each day (more experienced, $M = 2.63$, $SD = 0.77$; less experienced, $M = 0.94$, $SD = 0.93$; $t(36) = 5.41$, $p = .001$), more days in a week (more experienced, $M = 5.58$, $SD = 1.16$; less experienced, $M = 3.08$, $SD = 1.83$; $t(36) = 4.35$, $p = .001$), and more weeks in a month (more experienced, $M = 4.00$, $SD = 0.00$; less experienced, $M = 3.00$, $SD = 1.39$; $t(36) = 2.48$, $p = .018$) compared to less experienced performers. While not used as a criterion to establish expertise by Ericsson et al., (1993), it should be noted that, in the month prior to testing, the average number of performances given in front of an audience by more experienced performers was significantly greater compared to less-experienced performers (more experienced, $M = 1.92$, $SD = 0.29$; less experienced, $M = 1.42$, $SD = 0.81$; $t(36) = 2.04$, $p = .048$).

Means and standard errors for the sympathetic nervous system measures and subjective assessments taken at the baseline, reactivity, and recovery phases are presented in Table 2 separately for participants in both musical experience groups. Average raw cortisol values for both groups are presented in Figure 1.

Musical experience and stress at baseline, reactivity, and recovery phases

Average cortisol values for each participant were $\log_{10}$ transformed for all analyses. To test the predictions that a high level of musical experience would be associated with: (a) less stress reactivity, and (b) greater stress recovery, Pearson R correlations were conducted between level of musical experience, and all physiological and subjective measures taken at all three phases. The results of these tests are presented in Table 3. As can be seen in the table, musical experience was not correlated with any of the physiological or subjective stress assessments at baseline. At the reactivity phase, the only significant correlation was between musical experience and less insecurity, $r(37) = -0.39$; $p = .016$. However, at the recovery phase, musical experience was associated with significantly lower cortisol values, $r(37) = -0.39$; $p = .016$. There were no other significant correlations between musical experience and any of the remaining sympathetic or subjective measures.

Working memory, cortisol reactivity, and cortisol regulation

Average WM values were computed for more and less experienced performers at the baseline, reactivity, and recovery phases. These are presented in Figure 2. Participants with more musical experience performed better than participants with less musical experience on the WM tasks at all three phases, but the only significant difference was at the recovery phase ($t(36) = 2.49, p = .018$). Greater musical experience was negatively correlated with lower cortisol values at all three assessments, but only significantly correlated at the recovery phase (see Table 3); furthermore, none of the sympathetic measures correlated significantly with musical experience. Thus, the only stress measure used to predict WM performance at each phase was cortisol response. To determine if musical experience contributed to WM performance above the contribution of neuroendocrine functioning, 2-step linear regression analyses were run at each phase to predict DSF, DSB, and DSS at the baseline, reactivity, and recovery phases, respectively.

At the baseline phase, in the first step, the baseline $\log_{10}$ cortisol was entered into the regression equation to predict DSF. This variable did not account for significant variance ($p > .05$). In a second step, the musical experience classification was entered into the equation, and these variables also did not account for significant variance ($p > .05$). At the reactivity phase, in the first step of the linear regression analysis DSB, cortisol response reactivity ($T2 \log_{10} \text{cortisol} - T1 \log_{10} \text{cortisol}$) was entered first, and the resulting equation was non-significant ($p > .05$). In a second step, musical experience classification was entered, and these variables likewise did not account for significant variance ($p > .05$). At the recovery phase, in the first step of the regression analysis predicting DSS, cortisol response dampening was entered first ($T3 \log_{10} \text{cortisol} - T2 \log_{10} \text{cortisol}$), yielding a non-significant F value ($p > .05$). However, when musical experience classification was entered in the second step, the model with two variables predicted significant variance in WM at this phase, $F(2, 35) = 3.38, p = .045$. Examining these variables separately within the hierarchical regression, only musical experience explained a significant amount of variance ($\beta = .40, p = .015$). Thus, despite the correlation between musical experience and cortisol levels during the recovery phase, only experience level predicted WM performance at that stage. Contrary to our predictions, cortisol response and musical experience did not predict WM performance during the initial stress reactivity period.

Discussion

This study examined the effects of an audition-like stressor on performers with differing levels of musical experience and is significant as the first to examine the role of HPA activity in relation to WM in musical performers. During the recovery phase, 50 minutes following the start of the MPST, the more experienced performers demonstrated significantly better WM than the less-experienced performers. These differences were not simply due to the more experienced performers having better WM abilities than the less-experienced performers, because baseline WM performance of the two experience groups was not significantly different. This finding is in contrast to that of other studies, which have found differences in WM between experienced musicians and individuals with little to no musical experience (Green & Samuel, 1986; Jakobson et al., 2003, 2008; Kilgour et al.,

2000; Pallesen et al., 2010; Schulze et al., 2010). The two groups of performers in the present study may not have differed in their baseline WM performance because the two comparison groups did not differ in their musical experience as greatly as those typically examined in other studies (for instance, rather than having little to no musical experience, the less experienced performers in the present study averaged nearly 8 years playing their current instrument).

The better WM performance of more experienced performers during the recovery phase did not appear to be due to SNS activity; contrary to our hypotheses, more experienced performers did not exhibit better SNS regulation than less experienced performers. Similarly, although having less musical experience was associated with more insecurity at the reactivity phase, subjective measures of nervousness and anxiety did not differ between experience groups. The experience groups did, however, differ in terms of their cortisol levels. Greater musical experience was associated with significantly lower levels of cortisol during the recovery phase. Thus, two of our primary hypotheses were confirmed: following the stressor, the more experienced performers demonstrated better cortisol regulation, and better performance on the WM task, than the less experienced performers. Although the present study did not demonstrate a direct link between cortisol regulation and improved WM performance, this lack of an effect may be due to the relatively small number of participants in this study.

The results of the present study are somewhat at odds with the results of Elzinga and Roelofs (2005), who found that WM was impaired when cortisol and SNS activity were elevated, but WM recovered when only cortisol was elevated. Contrary to their results, the present study found differences in WM performance as differences in cortisol levels increased, despite a return to baseline SNS activity. One potential explanation for these differing results is based on the different WM sub-processes required by the digit span tasks used by these two studies. A number of past studies have shown that WM is impaired when cortisol levels are elevated (e.g., Lupien et al., 1999; Wolf et al., 2001; Roozendaal, 2002), however, this impairment may depend on the WM sub-process being tested, which can include information encoding, information maintenance, and information manipulation. Past studies have found that moderately elevated cortisol levels are associated with enhanced information encoding (e.g., Al'Absi, Hugdahl, & Lovallo, 2002; Monk & Nelson, 2002; Schwabe & Wolf, 2010; Weerda, Muehlhan, Wolf, & Thiel, 2010). A recent study found that when examined separately, both information encoding and maintenance benefit from elevations in cortisol (Stauble, Thompson, & Morgan, 2013). Although Stauble et al.'s study did not explicitly examine information manipulation, this sub-process may be the source of cortisol's impairment on WM. The digit span tasks used to measure WM all require information encoding and maintenance, but only the backwards and sequential digit span tasks require information manipulation – and thus, perhaps only these two tasks would be negatively affected by increases in cortisol. Whereas the present study administered the digit span tasks separately during each phase, Elzinga and Roelofs (2005) administered all three tasks during each phase and represented WM by a composite score. This combination of tasks in which cortisol could have both helped and hindered performance makes direct comparisons between these two studies difficult.

A potential limitation of the present study is that different WM measures (DSF, DSB, and DSS) were used at each of the three phases, making comparisons between WM performance at each phase difficult. Additionally, it is possible that the difference in WM performance between more and less experienced performers during the recovery phase was not due to the influence of experience level, but was instead attributable to some other factor such as DSS ability. Although baseline DSS performance was not measured, we think this latter possibility is unlikely. Because the same WM sub-processes are required for DSS and DSB (Weiss et al., 2010), differences in performance on one task should be mirrored in differences in performance on the other. Since there was no significant difference in performance between musical experience groups on the DSB task, the difference in performance on the DSS task at the recovery phase does not appear to be due to differences between groups in the WM abilities required to complete these tasks.

A contribution of, as well as a limitation of, the present study is that the MPST is a new technique for eliciting psychosocial stress. It is difficult to determine if this performer-specific analog of the TSST indeed caused the desired acute-stress response. Given the seriousness of professional auditions, the MPST may have not provided the high degree of stress represented in a true audition or musical performance. Despite this question of degree of elicited stress, the present study did find experience-dependent differences in cortisol regulation following the MPST. Thus, the MPST may be a valuable tool in future studies of performance-related stress.

A career in music performance challenges the individual to demonstrate skills and techniques in front of an audience on numerous occasions. Stress reactivity and regulation may be an area of study to help performers on an individual level. Performers who understand how their bodies react to stress can improve their performances by manipulating behavioral, autonomic, and attentional mechanisms. Research on emotion regulation suggests that there are multiple points on the timeline of a potentially stressful experience at which individuals may employ different techniques to regulate their emotional response (John & Gross, 2009). For instance, individuals may strive to avoid altogether situations that they expect to be stressful. Once the potentially-stressful situation has begun, they may change aspects of the situation in order to decrease its negative emotional impact. During the situation, people may direct their attention to less stressful, or calming exogenous or endogenous stimuli, or they may actively change their thoughts about the event through cognitive reappraisal of the situation. Last, after the stress response has begun, individuals may attempt to temper this stress response. The present study found significant differences in cortisol between more and less-experienced performers only at this final stage, but the non-significantly lower cortisol levels of more experienced performers during the reactivity phase suggests that they may have attempted to alter their stress response during the MPST. It is not clear which strategy or strategies participants used during the study, and individuals differ in which strategy/ies they prefer (John & Gross, 2009). Future studies could directly examine the effectiveness of different emotion regulation strategies in performance situations.

Although replications and extensions are necessary to further the research on cognitive and physiological factors involved in musical performance, the present study sheds light on the

effects of stress on WM in performers. Since more experienced performers demonstrated better verbal WM in the present study, an interesting question is whether experienced performers demonstrate HPA regulation abilities in other stressful situations such as public speaking. In addition to verbal WM, future research could examine whether musical experience and/or cortisol regulation abilities affect tonal WM specifically. Additionally, future studies could examine the effectiveness of various stress reduction strategies in regulating HPA activity, or whether performance impairment in individuals with music performance anxiety is due to SNS activity, HPA activity, or a combination of both. In the meantime, the present study suggests that performers' ability to regulate HPA activity correlates with improved cognitive functioning under psychosocial performance stress.

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Appendix

Cortisol-Music Study Questionnaire

1. How old are you? _____
2. Check one: _____ male _____ female
3. What instrument(s) do you play (can include voice)? _____
4. How long have you played/sang? _____
5. Can you read music? ____ yes ____ no ____ a little
6. How often have you performed in front of an audience in the past week?
____ None ____ At least once ____ More than once
7. How often have you performed in front of an audience in the past month?
____ None ____ At least once ____ More than once
8. How often have you performed in front of an audience in the past year?
____ None ____ At least once ____ More than once
9. If you answered “at least once” or “more than once” for questions 5, 6, and 7, which of the following does the audience you perform in front of consist of (check all that apply)?
Close relatives ____ Peers ____ Professor/Tutor ____ Strangers ____
10. How often do you practice in a day (check one)?
____ Hardly ever ____ 10–30 minutes ____ 30–60 minutes ____ 1–3 hours ____ more than 3 hours
11. How often do you practice in a week (check one)?

___ Hardly ever ___ 1 day ___ 1–2 days ___ 2–3 days ___ 3–4 days ___ 4–5 days ___ 6–7 days

12. How often do you practice in a month (check one)?

___ Hardly ever ___ at least 1 week ___ 2 weeks ___ 3 weeks ___ every week of the month

13. Do you feel comfortable teaching others to play your instrument? _____

14. Have you tutored others to play your instrument? _____

If so about how many students have you taught approximately? _____

15. Can you sight read and if so how well do you feel you can sight read (check one)?

___ Not very well ___ Well ___ Very well

16. Have you ever played in a professional setting such as in a professional orchestra, symphony, ensemble, quartet, trio, etc.? ___ yes* ___ no

*If so, for how long have/were you in that professional setting?
_____

17. Have you ever been judged, critiqued, etc. on a solo performance?

___ yes ___ no

18. Have you ever served as a judged, critic, etc. for a solo or ensemble performance?

___ yes ___ no

19. What type of music have you played (check all that apply)?

___ Classical ___ Jazz ___ Contemporary ___ other *

*If other please specify _____

20. What type of music do you prefer to play?

___ Classical ___ Jazz ___ Contemporary ___ other *

*If other, please specify _____

21. How nervous would you say you feel performing in front of an audience (check one)?

___ Very nervous

___ I am somewhat nervous

___ Nervous at first, but once I start performing the nervousness goes away

___ Usually don't get nervous

___ Never nervous

22. Do you practice/perform any techniques to help cope with any anxiety/stress you may feel while performing in front of an audience?

If so, please list the techniques:

The following questions are for *female* participants only:

Past studies have shown that cortisol levels can vary according to hormonal contraceptive use and the phase in a woman's menstrual cycle.

1. Do you use any hormone-based contraceptives? ____ yes* ____ no

a. *Please list the type of contraceptive you use:

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b. How long have you been using this birth control method?

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2. When was the first day of your last menstrual period?

---

3. What is the average length of your menstrual cycle (in days)?

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4. How regular are your cycles (for example, every 28 days)?

Figure 1. Average raw cortisol values of more experienced, and less experienced performers at T1 (baseline), T2 (reactivity), and T3 (recovery). Bars represent standard errors.

Figure 2.

Average digit recall performance of more experienced, and less experienced performers. Bars represent standard errors. Participants completed the digit span forward task at T1, the digit span backward task at T2, and the digit span sequential task at T3.

Table 1

Experimental protocol indicating real time of phases and time relevant to the start of the stressor.

Procedure	Time (in min) from stressor	Phases
Participant arrives	-29	
Participant has been sitting/relaxing for 20 min	-9	
Sympathetic measures assessed (1 min):		Baseline
Heart rate	-8	
Blood pressure	-8	
Oxygen	-8	
Saliva sample for cortisol (3 min)	-7	
Forward digit span assessed (2 min)	-5	
Subjective measures assessed (1 min)	-3	
Participant warms up	-1	
Judges enter room, MPST begins:	0	
Solo	2.5	
Scales	5	
Sight-reading	10	
mental arithmetic	15	
Judges exit room, instruments put away	16	
Sympathetic measures assessed (1 min):		Reactivity
Heart rate	21	
Blood pressure	21	
Oxygen	21	
Saliva sample for cortisol (3 min)	22	
Backward digit span assessed (2 min)	25	
Subjective measures assessed (1 min)	27	
Participant is asked to relax (reads magazines) for 20 minutes	28	
Sympathetic measures assessed (1 min)		Recovery
Heart rate	48	
Blood pressure	48	
Oxygen	48	
Saliva sample for cortisol (3 min)	51	
Sequential digit span assessed (2 min)	53	
Subjective measures assessed (1 min)	54	
Participant is debriefed	56	
End of experiment	58	
Total time	≈1.5 hours	

Table 2

Means and standard deviations of cortisol levels, sympathetic nervous system activity, subjective measures, and working memory.

Measures:	More experienced performers (<i>n</i> = 12)			Less experienced performers (<i>n</i> = 26)		
	<i>M</i> (<i>SD</i>)			<i>M</i> (<i>SD</i>)		
	Baseline	Reactivity	Recovery	Baseline	Reactivity	Recovery
Log ₁₀ cortisol (µg/dL)	−0.73 (0.17)	−0.78 (0.21) [†]	−0.89 (0.13) [*]	−0.66 (0.20)	−0.65 (0.23)	−0.71 (0.22)
Systolic (mm Hg)	109 (14.74)	111 (21.36)	110 (13.91)	110 (13.67)	115 (11.91)	109 (12.99)
Diastolic (mm Hg)	73 (12.27)	77 (19.36)	74 (10.41)	72 (9.75)	76 (9.72)	75 (10.31)
Heart rate (bpm)	71 (16.15)	77 (12.65)	71 (10.98)	73 (10.31)	72 (9.88)	72 (8.59)
Oxygen (%)	98 (1.15)	98 (1.07)	98 (1.08)	98 (1.14)	97 (1.48)	98 (1.02)
Insecurity (1–7)	1.4 (0.90)	1.83 (1.11) [*]	1.33 (1.15)	1.84 (0.92)	3.15 (1.64)	2.15 (1.54)
Nervousness (1–7)	2.16 (1.52)	2.33 (1.96)	1.16 (0.57)	2.5 (1.27)	3.11 (1.55)	1.69 (0.97)
Anxiety (1–7)	1.91 (1.62)	2.5 (1.97)	1.33 (0.88)	2.10 (1.06)	3.25 (1.48)	2.03 (1.37)
Forwards WM (88)	53 (24.83)			43 (13.84)		
Backwards WM (74)		36 (17.82) [†]			27 (11.72)	
Sequential WM (88)			47 (13.84) [*]			36 (10.74)

Note. Comparisons are between more experienced and less experienced performers.[†] *p* < .10;^{*} *p* < .05.

Table 3

Pearson *R* correlations between musical experience level and cortisol levels, sympathetic nervous system activity, and subjective measures at baseline, reactivity, and recovery phases.

Measure	Baseline	Reactivity	Recovery
Log ₁₀ cortisol	−0.18	−0.29	−0.39*
Systolic (mm Hg)	−0.03	−0.14	0.03
Diastolic (mm Hg)	0.05	0.04	−0.06
Heart rate (bpm)	−0.06	0.24	−0.02
Oxygen (%)	0.09	0.17	−0.02
Insecurity	−0.22	−0.39*	−0.26
Nervousness	−0.12	−0.22	−0.28
Anxiety	−0.03	−0.19	−0.27

*
 $p < 0.05$.