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Stress in the collective: Psychophysiological reactivity to an orchestra concert as a collective naturalistic, real-life stressor of psychosocial nature

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ABSTRACT

Background & objectives: The investigation of collective stress experiences, including collective stressors and the psychophysiological reactivity of a collective to these stressors, has been widely neglected so far. Here, we examined public non-professional orchestra concerts as collective naturalistic, real-life stressors of psychosocial nature and the resulting psychophysiological reactivity in a collective of non-professional orchestra musicians.
Methods: The members of two non-professional music orchestras ($N = 54$) were accompanied during a public concert (stress condition) and a rehearsal (control condition). We repeatedly assessed heart rate, salivary cortisol, and excitement levels before, during, and after the concert/rehearsal in addition to the anticipatory cognitive stress appraisal.
Results: We observed greater physiological reactivity to the concert compared to the rehearsal (p's $\leq$.017), with higher increases in heart rate levels in anticipation of and in reaction to the concert and in cortisol levels in reaction to the concert compared to the rehearsal. Moreover, orchestra members reported greater psychological reactivity to the concert than to the rehearsal (p's $\leq$.024) in terms of higher cognitive stress appraisal in anticipation and increased excitement levels before and during the concert compared to the rehearsal.
Discussion: Our findings indicate that orchestra concerts by non-professional musicians constitute collective naturalistic, real-life stressors of psychosocial nature, resulting in significant psychophysiological stress responses with reactivity kinetics differing between the sympathetic-adrenal-medullary axis, the hypothalamic-pituitary-adrenal axis, and the psychological response. Potential implications and modulating factors need to be elucidated in future studies.

1. Introduction

As social beings, humans are frequently exposed to stress in a collective (Cornwell, 2011; Fiske and Fiske, 2007). Whereas *individual* stress experiences have been extensively studied, the investigation of *collective* stress experiences, including collective stressors and the resulting psychophysiological reactivity of a collective, has been widely neglected. Given the growing population numbers (Moreno-Monroy et al., 2021; United Nations, 2022) and the wide-ranging negative consequences of stress for individuals and collectives (Ganster and Rosen, 2013; LeBlanc, 2009; Steptoe and Kivimäki, 2012), a more comprehensive understanding of the reactivity to collective stress exposure is warranted.

Most of the few published studies on psychophysiological reactivity to collective stress exposure were conducted under laboratory conditions. The Trier-Social-Stress-Test-for-Groups (TSST-G; von Dawans et al., 2011) is the hitherto only collective laboratory stressor, notably of psychosocial nature, combining elements of social-evaluation and uncontrollability in two motivated group-performance tasks (Dickerson and Kemeny, 2004; von Dawans et al., 2011). In reaction to the TSST-G as compared to a specifically tailored placebo-control condition, robust and reliable psychophysiological responses have been reported (Häusser et al., 2012; von Dawans et al., 2011).

Despite the numerous advantages of laboratory research, questions regarding the ecological validity remain (Holleman et al., 2020). In contrast to laboratory stressors, the investigation of naturalistic, real-life stressors supposedly implies the highest ecological validity. Collective public music performances (PMPs), such as orchestra concerts, likely

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represent motivated group-performance situations that include social-evaluative and uncontrollable elements (Dickerson and Kemeny, 2004) and may therefore constitute potent acute collective naturalistic, real-life stressors of psychosocial nature.

To the best of our knowledge, there are hitherto only five studies that investigated psychophysiological parameters in the context of collective PMP, either in professional orchestra musicians (Biasutti et al., 2016; Campisi et al., 2023; Halleland et al., 2009; Pilger et al., 2014) or in professional choir singers (Fancourt et al., 2015). Two of the studies primarily assessed *diurnal psychophysiological activity* in orchestra musicians on a concert day as compared to a control day (final rehearsal (Pilger et al., 2014) or ordinary workdays (Halleland et al., 2009)). Assessing the diurnal secretion of the hypothalamic-pituitary-adrenal (HPA) axis end-product cortisol (including one sampling timepoint during the concert intermission), both studies reported increased salivary cortisol levels on the morning of the concert day (Pilger et al., 2014) and/or during the intermission of the concert (Halleland et al., 2009; Pilger et al., 2014) as compared to the respective control day samples. Moreover, musicians reported higher valence, arousal, and dominance on the concert day compared to the control day (Pilger et al., 2014). The third study examined the *anticipatory physiological response* to a concert compared to a rehearsal in orchestra musicians. Assessing the sympathetic-adrenal-medullary (SAM) axis parameters blood pressure (BP) and heart rate (HR) immediately before the performances, higher HR levels were observed in anticipation of the concert than of the rehearsal, notably without differences in BP levels (Campisi et al., 2023). The fourth study assessed the *anticipatory psychological response* to a concert compared to a rehearsal in orchestra musicians and found higher levels of anxiety in anticipation of the concert (Biasutti et al., 2016). To the best of our knowledge, the fifth study (Fancourt et al., 2015) is the hitherto only one that investigated *reactive psychophysiological responses,* i.e., reactivity, to collective PMP in terms of performance-induced changes from baseline levels to levels during or after the concert while controlling for potential secondary effects of setting and task by comparison with a rehearsal (Green et al., 2014; Nicolson, 2008; Shapiro et al., 1978). That study examined HPA axis and anxiety reactivity to a choir concert of 60 min duration compared to the final rehearsal assessed as changes from immediately before to immediately after concert/rehearsal (Fancourt et al., 2015). Interestingly, significant increases in cortisol levels were observed in reaction to the concert compared to the rehearsal. Further, the choir singers reported significantly higher anxiety levels in anticipation of the concert compared to the rehearsal, with subsequent decreases to comparable anxiety levels after the concert/rehearsal.

Taken together, these studies provide initial evidence that collective PMPs in terms of orchestra or choir concerts may constitute acute collective naturalistic, real-life stressors of psychosocial nature that induce basal, anticipatory, and/or reactive psychophysiological alterations in professional musicians. Nevertheless, many questions remain open.

First, given that playing an instrument and singing constitute different physical demands (Somayaji et al., 2022), it remains unclear whether the observed collective cortisol stress reactivity observed in choir singers (Fancourt et al., 2015) also extends to orchestra musicians. As outlined above, the hitherto published studies considering public orchestra performances are restricted to the assessment of diurnal HPA axis activity and anticipatory psychophysiological responses (Campisi et al., 2023; Halleland et al., 2009; Pilger et al., 2014). The reactive psychophysiological response of orchestra musicians to public orchestra performance has not been investigated yet.

Second, regarding the psychophysiological reactivity to PMPs, a more detailed characterization of the reactivity kinetics, including peak levels and recovery, is essential for a comprehensive understanding of collective stress experiences, including modulating factors, and potential implications (Geurts and Sonnentag, 2006; Lovallo, 2015). So far, only HPA axis reactivity to collective public choir performance has been investigated in choir singers by assessing cortisol changes from immediately before to immediately after a choir concert (Fancourt et al., 2015). Therefore, a more precise characterization of the cortisol reactivity, in terms of a higher-frequency assessment, is outstanding. Moreover, investigation of the SAM axis reactivity to collective PMP, either in a choir, or in an orchestra, is completely lacking so far.

Third, only a minor proportion of existing orchestras are professional orchestras, whereas most orchestras are leisure orchestras. Interestingly, differences in the perception and the experience of concerts and/or rehearsals between professional and non-professional musicians have been reported (Juniu et al., 1996; Spahn et al., 2021a, b). Hitherto, the investigation of psychophysiological parameters in the context of collective music performances has been restricted to professional musicians only.

Targeting these research gaps, we set out to investigate public orchestra performance as a collective psychosocial, naturalistic, real-life stressor and the resulting psychophysiological reactivity in a collective of non-professional orchestra musicians. We aimed to characterize the kinetics of the psychophysiological reactivity to an orchestra concert while controlling for potential secondary effects of playing music in a group. To this end, we accompanied the members of two non-professional music orchestras during two conditions: a public concert (stress condition) and a rehearsal (control condition). We investigated *physiological reactivity* in terms of repeated measurements of HR (SAM axis) and salivary cortisol (HPA axis) before, during, and after the concert/rehearsal. Examination of *psychological reactivity* comprised the repeated assessment of excitement levels before, during, and after the concert/rehearsal in addition to the anticipatory cognitive stress appraisal. We hypothesized higher psychophysiological reactivity (i.e., cortisol, HR, and excitement) in addition to higher anticipatory cognitive stress appraisal to the concert compared to the rehearsal.

2. Materials and methods

2.1. Participants and participant characteristics

For this study, we recruited the (adult) members, i.e., musicians and conductors, of two non-professional orchestras. Prerequisite for study inclusion was the participation in both conditions, i.e., the concert and the respective control rehearsal.

Data was collected between September 2022 and November 2022. The study was carried out in accordance with the Declaration of Helsinki principles and was formally approved by the Ethics Committee of the University of Konstanz, Germany. All participants provided written informed consent prior to participation and received a financial compensation of 20€/study day.

Our final sample comprised a total of 54 orchestra members (orchestra 1: $n = 37$; orchestra 2: $n = 17$) who participated in the concert and the control rehearsal condition. Table 1 depicts the demographic, anthropometric, and health-related characteristics of the participants in addition to the baseline levels of psychophysiological parameters.

2.2. Procedure

Participants were monitored during a public concert (stress condition) and a rehearsal (control condition). To minimize potential confounding effects of workload, training level, technical demands, etc., the final (orchestra 1) or second final (orchestra 2) rehearsal was chosen as control condition. The rehearsals started at 2 p.m. (orchestra 1) or 8 p.m. (orchestra 2), the concerts at 7.30 p.m. (orchestra 1) or 7 p.m. (orchestra 2). Rehearsals and concerts were structured as follows: first half (duration: 45–60 min), intermission (duration: 15–25 min), second half (duration: 35–50 min).

Participants were asked to arrive 45 min before the beginning of the rehearsal/concert to collect demographic (i.e., age, sex), anthropometric (i.e., body weight and height), and health-related (i.e., menstrual cycle, intake of hormonal contraceptives, smoking) data via self-report on

Table 1
Participant characteristics.

Demographic, anthropometric, and health-related characteristics (*N* = 54)			
Age [years]	34.20 ± 2.20 (19 – 78)		
Sex [♀ | ♂]	30 | 24		
Phase of menstrual cycle [hormonal contraceptives | follicle phase | luteal phase | (post-)menopause | n.a.]	8 |11| 4 | 4 | 3		-
Regular smoking [yes | no]	3 | 51		
Body mass index [kg/m²]	22.50 ± 0.44 (14.28 – 31.74)		
Psychophysiological baseline characteristics			
	Rehearsal	Concert	*p* (*p with parameter-specific covariates*)
Salivary cortisol [nmol/l], *n* = 52	4.12 ± 0.39 (0.35 – 15.04)	4.13 ± 0.59 (0.99 – 20.51)	.12 (*.56, n = 49*)
Heart rate [bpm], *n* = 51	91.67 ± 1.78 (61.04 – 120.91)	100.61 ± 2.25 (67.98 – 145.29)	**<.001** (***.012***)
Anticipatory cognitive stress appraisal, *n* = 46	-5.12 ± 0.61 (-13.50 – 3.00)	-2.82 ± 0.71 (-12.00 – 8.50)	**.007**
Excitement, *n* = 42	26.04 ± 3.49 (0 – 81)	39.78 ± 4.25 (0 – 100)	**.013**

Footnote. Values are mean ± SEM (range) for metric data and n for nominal data; N = number of total participants; n = deviating sample size for the respective parameter.

mobile devices and to prepare and conduct the baseline assessment of psychophysiological parameters. Psychological assessment comprising excitement levels and anticipatory cognitive stress appraisal was realized via mobile devices. Physiological assessment comprised continuous HR recording and repeated saliva sampling for cortisol measurements. The first saliva sample was obtained –20 min before the beginning of the rehearsal/concert, immediately followed by the assessment of excitement levels. At –10 min before the beginning of the rehearsal/concert, participants completed the assessment of the anticipatory cognitive stress appraisal of the rehearsal/concert. Further saliva samples were obtained at the beginning and at the end of the intermission, as well as +1, +15, and +30 min after the end of the rehearsal/concert, always followed by the assessment of excitement levels.

2.3. Physiological reactivity assessment

2.3.1. Salivary cortisol

Saliva samples for the determination of salivary cortisol levels were collected using Salivettes (Sarstedt, Rommelsdorf, Germany) with participants chewing on the synthetic swab for exactly 1 min. Salivettes were centrifugated at 2500 rpm at room temperature for 10 min (Megafuge 40 R, Heraeus, Thermo Fisher Scientific, Langenselbold, Germany), aliquoted, and frozen at –80°C until analysis. We used enzyme-linked immunosorbent assays (ELISAs) to measure salivary free cortisol levels (Cortisol Saliva ELISA, RE52611, IBL International GmbH, Hamburg, Germany). The detection limit was 0.003 μg/dl. Inter- and intra-assay CVs were 8.9 % and 4.0 % in our sample. Due to technical problems, cortisol data of two participants are missing. One additional participant did not provide the last sample of the rehearsal and respective data was substituted by the previous one.

2.3.2. Heart rate

To obtain information on physiological reactivity during the rehearsal/concert, HR was continuously recorded using chest belts and sensors (Polar H10, Polar Electro GmbH, Büttelbronn, Germany). For the analyses of HR data, we calculated mean HR for time intervals of three minutes duration (timepoint, previous and subsequent minute) for the following timepoints: –20, –15, –10, and –5 min *before the beginning* of the rehearsal/concert, +1, +5, +10, +20, +30 min after the beginning of the *first half* of the rehearsal/concert, +5 min after *beginning of the intermission*, −5 min before the *end of the intermission*, +1, +5, +10, +20, and +30 min after the beginning of the *second half* of the rehearsal/concert as well as +1, +5, +10, +20 min after the *end* of the rehearsal/concert. HR data are missing in three participants due to recording discontinuities.

2.4. Psychological reactivity assessment

2.4.1. Anticipatory cognitive stress appraisal

The cognitive stress appraisal in anticipation of the rehearsal and the concert was assessed by self-report using the Primary Appraisal Secondary Appraisal questionnaire (PASA; Gaab, 2009). Notably, we adapted the PASA to refer to the respective collective music performance situation, i.e., the concert or the rehearsal. The PASA is based on the Transactional Model of Stress proposed by Lazarus and Folkman (1984) and comprises 16 items that are rated on a six-point scale (ranging from 1 = *strongly disagree* to 6 = *strongly agree)*. As *primary appraisal*, the respective situation is evaluated regarding perceived *threat* (4 items) and *challenge* (4 items). As *secondary appraisal*, the extent of the perceived coping possibilities is rated in terms of *self-concept of own abilities* (4 items) and *control expectancy* (4 items). The *stress index* reflecting an integrated measure of subjective stress perception is obtained by the formula *primary appraisal – secondary appraisal*. Possible scores range from 4 to 24 for primary and secondary appraisal and from −20 to 20 for the stress index. Higher scores indicate higher stress appraisal. Internal consistency was found to be good in the validation study (Cronbach's α (*N* = 81): .74–.80; (Gaab et al., 2005) and in our sample (Cronbach's α (*N* = 46): .73–.78). Data is incomplete for eight participants.

2.4.2. Excitement

A visual analog scale (VAS) ranging from 0 (not at all) to 100 (very much) was employed to assess participants' current excitement levels. The validity and reliability of VAS to assess acute stress-related cognitive and emotional states has previously been demonstrated (Abend et al., 2014; Lesage et al., 2012). Participants were asked to rate their excitement levels immediately after each saliva sample, i.e., at a total of six measurement timepoints. As many participants overlooked to do so at the last measurement timepoint of the rehearsal and/or the concert, we calculated the mean excitement levels of the last two measurement timepoints, rendering a total of five measurement timepoints. Excitement data is incomplete in 12 participants.

2.5. Statistical analyses

Data were analyzed with SPSS (Version 29.0) for Macintosh (IBM SPSS Statistics, Chicago IL, USA) and are presented as mean ± standard error of the mean (SEM). All tests were two-tailed with the significance level set at α = .05. Effect size parameters *f* were calculated from partial eta square (η_p^2) using G*Power for Macintosh (Version 3.1.9.6; Heinrich Heine University Düsseldorf, Germany) and are reported where appropriate (effect size conventions *f*: .10 = small; .25 = medium; .40 = large (Cohen, 1988)).

We a-priori calculated power-analyses using the statistical software G*Power for Macintosh (Version 3.1.9.6; Heinrich Heine University Düsseldorf, Germany) based on previous literature on cortisol reactivity to individual music performances without and with audience (Aufegger and Wasley, 2018). To allow for the detection of conservatively expected small to medium effect sizes of $f = .20$ with a power of $(1 – \beta) = .85$ in repeated measures analysis of variance (rmANOVA) with two repeated within-factors (condition, time) given the presumed lowest average correlation of $r = 0.3$ for cortisol as well as non-sphericity corrections of $\varepsilon = 0.3$ the required total sample size is $N = 52$. In order to not lose power and increase Type II error, we decided to not adjust for multiple comparisons based on previous recommendations (Barnett et al., 2022; Nakagawa, 2004; Perneger, 1998; Rothman, 1990).

Prior to statistical analyses, all data were tested for normal distribution using Kolmogorov-Smirnov and for homogeneity of variance using Levene's tests. In case of violation of the normal distribution assumption, data were transformed using the natural logarithm. To account for violations of sphericity, we applied Huynh-Feld correction where appropriate. For all analyses, missing data were listwise excluded for the respective parameter.

To test for *baseline differences in psychophysiological parameters* (i.e., cortisol, HR, excitement, stress appraisal), one-factorial rmANOVAs with the repeated within-factor condition (rehearsal vs. concert) for the first measurement timepoint were calculated.

To test for *differences in psychophysiological reactivity between the concert as compared to the rehearsal with respect to parameters assessed repeatedly in each condition* (i.e., cortisol, HR, excitement), we calculated two-factorial rmANOVAs with the two repeated within-factors condition (rehearsal vs. concert) and time (cortisol: 6 measurement timepoints; HR: 20 measurement timepoints; excitement: 5 measurement timepoints). Post-hoc testing comprised (1) the examination of differences between conditions at every individual measurement timepoint in terms of one-factorial rmANOVAs with the repeated within-factor condition (rehearsal vs. concert) as well as (2) the characterization of the reactivity within each condition separately in terms of one-factorial rmANOVAs with all measurement timepoints.

To test for *condition differences in anticipatory cognitive stress appraisal*, we calculated a one-factorial rmANOVA with the repeated within-factor condition (rehearsal vs. concert).

In all analyses, we included orchestra affiliation (i.e. orchestra 1 or 2) as covariate to account for potential between-orchestra variations. In physiological reactivity analyses, we additionally controlled for parameter-specific covariates, i.e., smoking, age, and sex for HR (Ginty et al., 2014; Kudielka et al., 2004a) and BMI, smoking, age, and sex in addition to a variable coding menstrual cycle and intake of hormonal contraceptives for cortisol (al'Absi et al., 2003; Gervasio et al., 2022; Herhaus and Petrowski, 2018; Kudielka et al., 2004b). Body mass index (BMI) was calculated by the formula BMI $= \text{kg/m}^2$.

For graphical illustration of our findings, we used absolute changes from baseline of original data for reasons of clarity.

3. Results

3.1. Physiological reactivity

3.1.1. Cortisol

Participants exhibited higher cortisol reactivity to the concert as compared to the rehearsal (interaction effect condition-by-time: $F(3.43, 144.03) = 3.33, p = .017, \eta_p^2 = .074, f = .28$; see Fig. 1). Subsequent post-hoc analyses revealed differences in cortisol levels between conditions at individual measurement timepoints. Cortisol levels were higher during the intermission of the concert as compared to the rehearsal (beginning of intermission: $p = .010$; end of intermission: $p = .007$) but not before ($p = .56$) or after (p's $\geq .20$) the concert as compared to the rehearsal. Further post-hoc testing comprised reactivity analyses for each condition separately. While cortisol levels increased significantly during the concert ($F(3.10, 130.05) = 2.72, p = .046, \eta_p^2 = .061, f = .25$), there were no significant changes in cortisol levels during the rehearsal ($F(3.46, 145.47) = 0.64, p = .62$).

3.1.2. Heart rate

We observed significant differences in the HR reactivity between rehearsal and concert with higher HR reactivity to the concert as compared to the rehearsal (interaction effect condition-by-time: $F(8.32, 382.91) = 3.00, p = .002, \eta_p^2 = .061, f = .25$; see Fig. 2). Post-hoc testing revealed higher HR levels for the concert as compared to the rehearsal at all measurement timepoints (p's $\leq .038$) except for +5 ($p = .85$) and +20 min ($p = .48$) after the end of the rehearsal/concert. Moreover, further post-hoc testing showed that HR levels increased significantly in reaction to both conditions (main effect time rehearsal: $F(7.85, 361.16) = 2.45, p = .014, \eta_p^2 = .051, f = .23$; main effect time concert: $F(7.63, 350.91) = 2.53, p = .012, \eta_p^2 = .052, f = .23$).

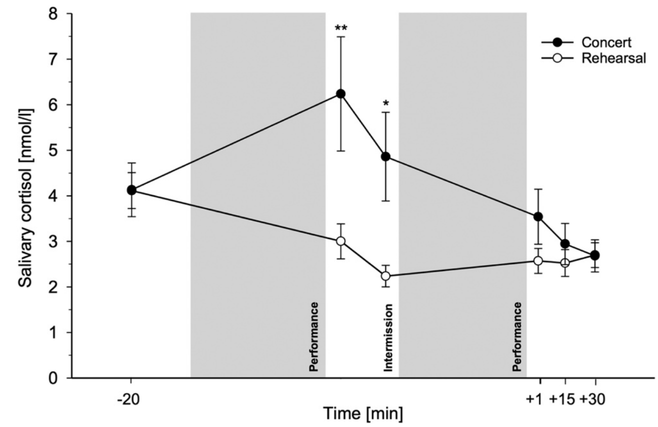

Fig. 1. Salivary cortisol reactivity (mean ± SEM) of non-professional individuals to an orchestra concert (black dots) and a rehearsal (white dots). Asterisks indicate significant differences between concert and rehearsal levels (* $p < .05$; ** $p < .01$).

3.2. Psychological reactivity

3.2.1. Anticipatory cognitive stress appraisal

Anticipatory cognitive stress appraisal differed significantly between the two conditions (main effect condition: $F(1.00, 44.00) = 8.02, p = .007, \eta_p^2 = .154, f = .43$) with participants reporting higher subjective stress in anticipation of the concert as compared to the rehearsal (see Table 1).

3.2.2. Excitement

Participants' excitement levels differed significantly between the rehearsal and the concert (interaction effect condition-by-time: $F(4.00, 40.00) = 2.89, p = .024, \eta_p^2 = .067, f = .27$; see Fig. 3). More precisely, post-hoc testing revealed that participants reported significantly higher

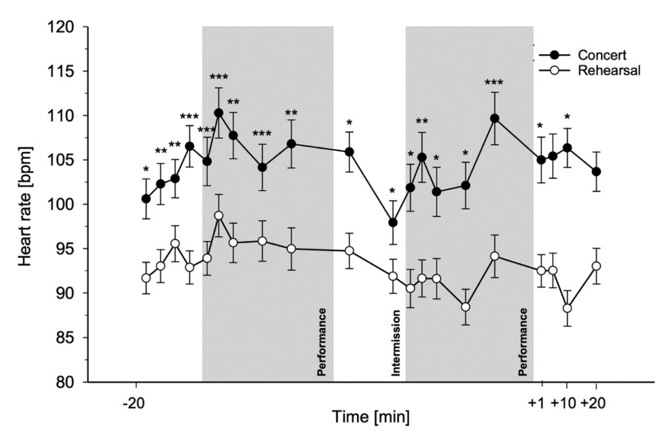

Fig. 2. Heart rate reactivity (mean ± SEM) of non-professional individuals to an orchestra concert (black dots) and a rehearsal (white dots). Asterisks indicate significant differences between concert and rehearsal levels (* $p < .05$; ** $p < .01$; *** $p < .001$).

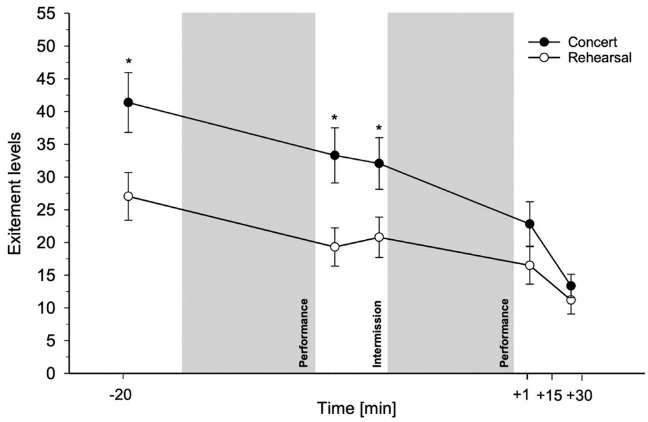

Fig. 3. Excitement levels (mean ± SEM) of non-professional individuals in reaction to an orchestra concert (black dots) and a rehearsal (white dots). Asterisks indicate significant differences between concert and rehearsal levels (* $p < .05$).

levels of excitement before ($p = .013$) and during (beginning of intermission: $p = .024$; end of intermission: $p = .017$) the concert as compared to the rehearsal while there were no differences in post-concert/post-rehearsal excitement levels (p's $\geq .42$). Further post-hoc testing showed that excitement levels decreased over the time in both conditions (main effect time rehearsal: $F(3.03, 121.38) = 6.50$, $p < .001$, $\eta_p^2 = .140$, $f = .40$; main effect time concert: $F(3.05, 122.17) = 15.86$, $p < .001$, $\eta_p^2 = .284$, $f = .63$).

4. Discussion

Here, we investigated for the first-time the public performance of non-professional orchestras as a collective naturalistic, real-life stressor of psychosocial nature and the resulting psychophysiological reactivity in a collective of non-professional orchestra musicians. To this end, we accompanied the members of two non-professional orchestras during a public concert and a rehearsal and repeatedly assessed HR (SAM axis), salivary cortisol (HPA axis), and excitement levels in addition to anticipatory cognitive stress appraisal, while controlling for potential secondary effects of playing music in a group and further potential confounding variables.

Regarding the *first main finding* of our study, orchestra members exhibited higher reactivity to the concert than to the rehearsal in all assessed physiological (i.e., HR and salivary cortisol) and psychological parameters (i.e., anticipatory cognitive stress appraisal and excitement) as expected. Notably, our within-subject study design controls for potential secondary effects of setting and task, i.e., playing music in a group. Therefore, we attribute the reactivity differences between the concert stress condition and the rehearsal control condition to the collective public performance situation characterized by uncontrollability (i.e., performance outcome cannot be controlled by one individual alone but depends on the group) and social-evaluative threat (i.e., presence of an evaluative audience) (Dickerson and Kemeny, 2004). Consequently, the observed activation of the SAM axis and the HPA axis, in addition to the psychological alterations in reaction to the concert (while controlling for potential secondary effects of the activity of playing music), indicates that a collective public non-professional orchestra concert constitutes a potent collective psychosocial naturalistic, real-life stressor (Dickerson and Kemeny, 2004).

The stress-inducing potential of collective public orchestra performances in non-professional musicians, on the one hand, corroborates with corresponding findings reported for professional musicians regarding diurnal psychophysiological activity and the anticipatory psychophysiological responses to collective public orchestra performances (Biasutti et al., 2016; Campisi et al., 2023; Halleland et al., 2009; Pilger et al., 2014) as well as for professional choir singers regarding the reactive psychophysiological response to a choir concert (Fancourt et al., 2015). On the other hand, it is in line with the reported psychosocial stress-inducing potential of individual PMPs in non-professional individuals regarding basal physiological activity (Gomez et al., 2018) or the anticipatory and reactive psychophysiological responses (Abel and Larkin, 1990; Aufegger and Wasley, 2018; Brotons, 1994; Craske and Craig, 1984; Fredrikson and Gunnarsson, 1992; Turan et al., 2022).

Our *second main finding* relates to the characterization of the hitherto unknown kinetics of the psychophysiological reactivity to collective psychosocial naturalistic real-life stressors in terms of collective public orchestra performance. Interestingly, regarding *physiological reactivity*, differential kinetics were observed for SAM axis (i.e., HR) and HPA axis (i.e., salivary cortisol) reactivity. Concerning the SAM axis, we observed significant HR increases in reaction to both the concert and the rehearsal, yet with higher increases to the concert and, overall, significantly elevated levels for all measurement time points before and during the concert compared to the rehearsal. Aside from the general SAM activation of playing music in a collective, these findings, thus, point to profound SAM axis activating effects of collective PMP in anticipation and in reaction of the public performance with sustained activation afterward. The observed anticipatory effects on SAM axis activity align with the only hitherto existing study examining SAM axis activation in anticipation of collective PMP, notably in professional orchestra musicians (Campisi et al., 2023). Moreover, similar SAM axis reactivity kinetics as in our study on collective public orchestra performance have been reported for individual PMPs (Brotons, 1994; Craske and Craig, 1984; Fredrikson and Gunnarsson, 1992) although not unequivocally (Aufegger and Wasley, 2018). SAM axis reactivity kinetics to collective PMP has not been investigated before to the best of our knowledge. Concerning the HPA axis, cortisol levels increased in reaction to the concert while there were no changes in reaction to the rehearsal. The highest cortisol levels and, at the same time, the only significant differences between the two conditions were observed during the intermission but not before or after the concert or rehearsal. In contrast to the SAM axis, collective PMP, thus, seems to only elicit a reactive response of the HPA axis, but not an anticipatory response or a sustained activation afterwards. The observed reactivity kinetics for cortisol corroborate the findings of previous studies in the context of collective PMPs that investigated diurnal cortisol secretion on concert days compared to rehearsal days in professional orchestra musicians (Halleland et al., 2009; Pilger et al., 2014) or concert-reactive cortisol responses in professional choir singers (Fancourt et al., 2015). More precisely, the two orchestra studies both reported significantly higher cortisol levels during the concert intermission compared to the respective sampling timepoint on the control days (Halleland et al., 2009; Pilger et al., 2014). Moreover, the significant cortisol increases from before to immediately after a 60 min choir concert and respective decreases during a rehearsal (Fancourt et al., 2015) align with our findings. Notably, the timing of the sampling immediately after the choir concert in that study (Fancourt et al., 2015) approximately coincides with the timing of the first sampling time point during the intermission in our study where we similarly observed increased levels as compared to baseline assessment and as compared to the rehearsal. As compared to the physiological reactivity observed in reaction to a collective laboratory stressor of psychosocial nature in terms of the TSST-G, the reactivity observed in our study in response to a collective naturalistic, real-life stressor was considerably lower (Maier et al., 2022; Schweda et al., 2019; Stephens et al., 2016; von Dawans et al., 2011). This divergence may relate to the characteristics of the two stressors. Both stressors include social-evaluative and uncontrollable elements. Nevertheless, while public concerts as an integral component of being in an orchestra are predictable and recurring and usually include sufficient preparation in terms of rehearsals, the TSST-G is a rather unexpected and new situation. Furthermore, unlike the individuals participating in the TSST-G, the members of an orchestra are not strangers to each other. This familiarity may constitute a stress buffering resource in terms of social support (Ditzen and Heinrichs, 2014). Consequently, the discrepancy between the perceived demands of the collective stress exposure and the individual and/or collective resources may, therefore, be minor for the public orchestra concert than for the TSST-G, resulting in mild to moderate psychophysiological stress reactions (Gaab et al., 2005; Lazarus and Folkman, 1984). It is conceivable that stress contagion effects (Auer et al., 2024) may add to the psychophysiological reactivity to both collective laboratory and naturalistic, real-life stress exposure. Furthermore, our results suggest that the kinetics of the psychophysiological reactivity to acute collective psychosocial stress under naturalistic, real-life conditions and under laboratory conditions are not equivalent. A discrepancy in the kinetics of the physiological reactivity to psychosocial naturalistic, real-life as compared to laboratory stress has been similarly reported for individual psychosocial stress (Wolfram et al., 2013).

Regarding *psychological reactivity*, we explicitly examined in this context for the first time anticipatory cognitive stress appraisal in addition to the repeated assessment of excitement levels, extending the previous assessment of stress-related psychological states that was restricted to anxiety (Biasutti et al., 2016; Fancourt et al., 2015) or valence, arousal, and dominance (Pilger et al., 2014). In line with the higher levels of stress-related psychological states in anticipation of a concert compared to a rehearsal reported in these studies (Biasutti et al., 2016; Fancourt et al., 2015; Pilger et al., 2014), the non-professional orchestra members in our study reported higher levels of cognitive stress appraisal and excitement in anticipation of the concert compared to the rehearsal. Moreover, our repeated assessment of excitement levels before, during, and after the concert/rehearsal allows to speculate about the kinetics of the psychological response to collective PMP. Considering the increased excitement levels in particular before the concert compared to the rehearsal and the findings regarding the higher anticipatory cognitive stress appraisal, non-professional musicians seem to react on the psychological level particularly in anticipation of a collective PMP. This assumed kinetic corroborates the increased levels of anxiety and other stress-related psychological states in professional musicians or choir singers in anticipation of collective PMPs (Biasutti et al., 2016; Fancourt et al., 2015; Pilger et al., 2014) and in non-professional individuals in anticipation of individual PMPs (Abel and Larkin, 1990; Aufegger and Wasley, 2018; Craske and Craig, 1984; Fredrikson and Gunnarsson, 1992; Gomez et al., 2018).

Our findings may have multiple *potential implications*. Regarding *practical implications*, mild to moderate physiological activation as observed in reaction to the orchestra concert has been shown to have enhancing effects on cognitive and behavioral levels, including selective attention towards and processing of goal-relevant stimuli (Qi and Gao, 2020; Qi et al., 2018) and executive motor control and action (Shields et al., 2019, 2016). In light of this, the physiological response to collective public orchestra performance may, on the one hand, relate to the coordination between orchestra members and, on the other hand, to the performance of the individuals. Regarding *implications for stress research* the outlined discrepancies between the psychophysiological reactivity to collective psychosocial naturalistic, real-life stressors as compared to collective psychosocial laboratory stressors emphasize the importance of complementing field studies in stress research in general. In particular, modulating factors and short- and long-term effects on the individual and the collective level regarding the psychophysiological reactivity to collective naturalistic, real-life stressors of psychosocial nature, including the relevance for long-term health and disease outcomes, warrant future elucidation (Kiecolt-Glaser et al., 2020; Turner et al., 2020).

Strengths of our study include, first, the investigation of collective stress experience in a non-artificial field setting entailing high ecological validity. Second, we controlled for a variety of confounders in our statistical analyses (e.g., age, sex, menstrual cycle, intake of oral contraceptives, and smoking) as well as for potential secondary effects of the setting and task of collective music playing by the inclusion of a rehearsal control day. Third, together with the control condition, our assessment period with baseline and reactivity assessment up to 30 min after concert/rehearsal cessation extends previous studies and allows for a more comprehensive understanding of the psychophysiological reactivity to collective public orchestra performances. Forth, our assessment was multidimensional as we considered reactivity of the major neuroendocrine stress systems in addition to the psychological reactivity. Naturally, there are also some limitations. First, the observed reactivity to a non-professional orchestra concert as a highly specific collective stressor may not generalize to other collective naturalistic, real-life stressors. Future studies are needed to identify and investigate other forms of collective stress experiences. Second, we cannot exclude a potential confounding from the choice of music pieces. However, given the within-subject study design with repeated assessment of different psychophysiological parameters and the control for orchestra affiliation as covariate, we consider the respective potentially confounding effects to be minor in our study.

5. Conclusions

Taken together, the present findings indicate that orchestra concerts by non-professional individuals constitute collective naturalistic, real-life stressors of psychosocial nature that induce significant psychophysiological stress responses. On the physiological level, stress systems appear to exhibit a reactivity kinetics characterized by anticipatory and reactive activation of the SAM axis and an exclusively reactive activation of the HPA axis. On the psychological level, the stress response seems to primarily occur in anticipation of the collective public orchestra performance. Future studies are needed to investigate modulating factors as well as short- and long-term effects on the individual and the collective level of the psychophysiological reactivity to collective public orchestra performance and other collective naturalistic, real-life stressors of psychosocial nature.

Statement of ethics

The project was approved by the Ethics Committee of the University of Konstanz and conducted in accordance with the Declaration of Helsinki principles. All participants provided written informed consent.

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CRediT authorship contribution statement

Lisa-Marie Walther: Writing – original draft, Visualization, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Petra H Wirtz:** Writing – original draft, Supervision, Resources, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Christine Sauter:** Writing – review & editing, Resources. **Alisa Auer:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of Competing Interest

None.

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