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Hyperventilation in Anticipatory Music Performance Anxiety

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Abstract:	Objectives and Methods: Self-report studies have shown an association between music performance anxiety (MPA) and hyperventilation complaints. However, hyperventilation was never assessed physiologically in MPA. This study investigated (a) the self-reported affective experience, self-reported physiological symptoms, and cardio-respiratory variables including end-tidal pCO2 (PetCO2), which is an indicator for hyperventilation, in 67 university music students before a private and a public performance. The response coherence between these response domains was also investigated. Results: From the private to the public session, the intensity of all self-report variables increased (all ps<.001). As predicted, the higher the usual MPA level of the musician, the larger were these increases (all ps<.10). The main cardio-respiratory variables except PetCO2 also increased from the private to the public session (all ps<.05), but these increases were not modulated by the usual MPA level (all ps>.10). PetCO2 showed a unique response pattern as reflected by an interaction between usual MPA level and session (p<.01): it increased from the private to the public session for musicians with low MPA levels and decreased for musicians with high MPA levels. Self-reported physiological symptoms were related to the self-reported affective experience (all ps<.05) rather than to the physiological measures (all ps>.17). Conclusions: The present findings show for the first time how respiration is stimulated before a public performance in music students with different levels of MPA. The hypothesis of a hyperventilation tendency in high performance-anxious musicians is supported. The response coherence between physiological symptoms and physiological activation is weak.

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Hyperventilation in Anticipatory Music Performance Anxiety

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Abstract:

Objectives and Methods: Self-report studies have shown an association between music performance anxiety (MPA) and hyperventilation complaints. However, hyperventilation was never assessed physiologically in MPA. This study investigated (a) the self-reported affective experience, self-reported physiological symptoms, and cardio-respiratory variables including end-tidal pCO_2 ($P_{et}CO_2$), which is an indicator for hyperventilation, in 67 university music students *before* a private and a public performance. The response coherence between these response domains was also investigated.

Results: From the private to the public session, the intensity of all self-report variables increased (all *p*s<.001). As predicted, the higher the usual MPA level of the musician, the larger were these increases (all *ps*<.10). With the exception of PetCO2, the main cardio-respiratory variables also increased from the private to the public session (all *p*s<.05). These increases were not modulated by the usual MPA level (all *p*s>.10). $P_{et}CO_2$ showed a unique response pattern as reflected by an interaction between usual MPA level and session (*p*<.01): it increased from the private to the public session for musicians with low MPA levels and decreased for musicians with high MPA levels. Self-reported physiological symptoms were related to the self-reported affective experience (all *p*s<.05) rather than to the physiological measures (all *p*s>.17).

Conclusions: The present findings show for the first time how respiration is stimulated before a public performance in music students with different levels of MPA. The hypothesis of a hyperventilation tendency in high performance-anxious musicians is supported. The response coherence between physiological symptoms and physiological activation is weak.

Keywords: breathing; hyperventilation; musicians; performance anxiety; stage fright

Acronyms: ACC = accelerometer; ECG = electrocardiogram; HR = heart rate; HRV = heart rate variability; M = mean; MPA = music performance anxiety; $P_{et}CO_2$ = partial pressure of end-tidal CO_2; rmssd = root mean square of successive differences; SD = standard deviation; SE = standard error; STAI-S = state scale of the Spielberger State-Trait Anxiety Inventory; T_E = expiratory time; T_I = inspiratory time; T_I/T_{TOT} = duty cycle; T_{TOT} = total breath duration; TVV = tidal volume variability; V'_E = minute ventilation; V_I = inspiratory volume; V_T/T_I = mean inspiratory flow; %RC = percent of ribcage contribution to the inspiratory volume

1 Introduction

Almost all performers in areas ranging from public speaking and sports to artistic performance are familiar with performance anxiety. In a large survey of 2,212 professional orchestra musicians, 16% reported that stage fright (also known as music performance anxiety, MPA[1]) was a serious problem for them (3). Most recently, MPA has been defined as "the experience of marked and persistent anxious apprehension related to musical performance (…), which is manifested through combinations of affective, cognitive, somatic and behavioral symptoms" (p.433) (4). The present article concentrates on the negative affective component of MPA, the self-reported physiological symptoms, and the respiratory manifestations in order to investigate whether there is an underlying hyperventilation problem in MPA just prior to a public performance. The time before a performance was chosen because musicians' apprehensions were reported to be greatest prior to the performance rather than during the performance itself (5).

Questionnaire studies yielded evidence that the negative affective dimension of MPA is positively correlated with hyperventilation complaints before a performance (6). Despite the association between anxiety and hyperventilation (7), no study has yet analyzed in detail the breathing behavior that might be associated with MPA by measuring time, volume, and flow parameters, as well as end-tidal CO_2.

Hyperventilation is defined as breathing in excess of metabolic requirements (7). Thereby, more CO_2 is eliminated than produced (hypocapnia), which causes a rise of the pH level of the blood (respiratory alkalosis). The alkalosis leads to an immediate vasoconstriction and thereby, to a lack of oxygen supply to the tissues, especially to the brain. This mechanism is paralleled by a heightened affinity of the oxygen to the hemoglobin in alkaline conditions (Bohr effect), which further impairs the normal diffusion of oxygen into the tissues. These conditions are associated with a variety of physiological symptoms, such as trembling,

[1] But see Brodsky (1) and Studer et al. (2) for a discussion of the nomenclature.

tingling, palpitations, chest pain, and disturbances in breathing. These symptoms have a strong similarity with symptoms reported by performance-anxious musicians (8). However, these symptoms are not specific to hyperventilation. They were also shown to occur in other stressful situations without hypocapnia (7, 9). Therefore, the assessment of a physiological indicator for hyperventilation is needed.

Partial pressure of end-tidal CO_2 ($P_{et}CO_2$) measurement is the only deterministic indicator of hyperventilation (10) and the gold standard for the non-invasive assessment of hyperventilation. It is measured as the partial pressure of CO_2 at the end of each expiration. In healthy individuals, it closely approximates the partial pressure of CO_2 in the arterial blood, which is about 40 mmHg, as long as breathing is in equilibrium with the metabolism. $P_{et}CO_2$ levels at which symptoms can be expected are poorly documented (7). Values of approximately 30 mmHg are a commonly accepted threshold for possible symptom onset. At 20 mmHg, symptoms will appear in almost everyone (11). Importantly, hyperventilation is not an all-or-nothing phenomenon, but it occurs on a continuum of intensity, depending on the degree of hypocapnia and respiratory alkalosis.

Physiological reactions other than lowered $P_{et}CO_2$ have been associated with hyperventilation, i.e., heightened minute ventilation (V'_E) (7), increased thoracic breathing and sighing (12), and tachycardia (11). Furthermore, tidal volume variability (TVV) was shown to be higher in patients with panic disorder, a condition often associated with hyperventilation (13-14), and in driving phobics compared to healthy persons (15).

Up to now, hyperventilation was mostly assessed in the laboratory (9, 16-19). The present study fits in a line of psychophysiological research investigating longer lasting emotional responses in a more natural setting. The main goal of this study was to investigate whether there is an underlying hyperventilation problem in MPA before a performance. More specifically, the first goal was to determine the influence of the performance situation (private vs. public) and, in particular, the influence of MPA on the self-reported affective experience, the self-reported physiological symptoms, as well as on the actual cardio-respiratory activation that are known to co-occur during hyperventilation. Performing in front of an audience compared to playing alone was previously shown to cause increased physiological arousal in heart rate (HR) (20-21) and in neuroendocrine measures (21). We hypothesized that the physiological variables HR, V'_E, TVV, number of sighs and the percent of ribcage contribution to the inspiratory volume (%RC) increase, whereas $P_{et}CO_2$ decreases before a public performance compared to a private performance. Furthermore, we expected this increase (respectively decrease) to be greater in musicians with higher usual levels of MPA than in musicians with lower usual levels of MPA. Similarly, for the self-report variables, we predicted more anxiety, tension, and physiological symptoms prior to the public performance compared to the private performance. Again, these increases were expected to be greater with increasing levels of MPA.

The second goal was to investigate the response coherence between the self-reported affective experience, the self-reported physiological symptoms, and the actual physiological activation in MPA. Empirical evidence for response coherence in emotion, specifically in anxiety, is mixed (22). The few studies that investigated the response coherence between $P_{et}CO_2$ and the self-reported affective experience, and between $P_{et}CO_2$ and the self-reported physiological symptoms, also reported mixed results (13, 15, 23-24). There is only little knowledge on response coherence in MPA (20-21). We addressed this issue by testing an anxiety model that assumes that higher levels of anxiety always co-occur with increased levels of actual physiological responses and higher levels of self-reported physiological symptoms (25). We hypothesized that (a) self-reported anxiety is positively correlated with self-reported physiological symptoms; (b) self-reported anxiety is positively correlated with actual physiological activation (negatively with $P_{et}CO_2$); (c) HR is positively correlated with self-reported palpitations; and (d) $P_{et}CO_2$ is negatively correlated with tension and self-reported physiological symptoms.

Contrary to other physiological functions, respiration is situated at the intersection of automatic functioning and voluntary control. It is the only physiological reaction that can be consciously influenced and controlled. Therefore, it is a good target for therapeutic intervention to counteract exaggerated physiological arousal and to induce relaxation (26). Thus, a better understanding of its functioning is essential.

2 Methods

2.1 Participants

Sixty-seven students from six Swiss music universities participated in this study. Participants aged 16-30 years old (mean M=23.3; standard deviation SD=3.5) and were 60% female. Half of them (48%) took hormonal contraception. Their academic music education at university ranged between the first and eighth year. The sample was composed of 16% singers, 27% wind instrumentalists, 30% string players, 19% pianists, and 7% miscellaneous. None of the participants reported suffering from a cardiovascular, psychiatric, or metabolic disease. None took anxiolytic drugs before the performances of this study.

Data collection took place between November 2007 and July 2008. The study was approved by the local ethics committee.

2.2 Procedure

Participants underwent individual testing during three sessions (baseline, private, public), each separated by approximately one week. The measurements of the private and the public sessions were assessed during the 10 minutes before performing. All sessions took place in music schools and lasted 1- 1.5 hours.

Baseline session: This session served to familiarize the participants with the experimental setting, the experimenter, and the measurement devices, i.e., the LifeShirt®, a non-invasive ambulatory assessment device, and the capnometer. Furthermore, baseline values for all self-report variables and physiological parameters were collected.

After being given information on the study, the participants gave their consent. Then, they put on the LifeShirt® and did the respiratory volume calibration. Subsequently, the participants had 10 minutes to play their instrument and to get used to the measurement devices. After this period, the participants put on the nasal canula for the CO_2 assessment and answered a questionnaire on their usual MPA level. Afterwards, they were left alone for 10 minutes during which the physiological baseline measurements were made. The participants were asked to sit quietly, to breathe exclusively through the nose, and not to close their eyes to ensure a good measurement quality during an awake but relaxed state. They were allowed to read during this period. After this period, the participants rated their current affective experience and physiological symptoms.

Private session: The participants received a short introduction to the subsequent experimental procedure, put on the LifeShirt®, carried out the calibration, and were given 10 minutes to tune their instrument and warm up. Then, they put on the nasal canula, received the same instructions to sit quietly as in the baseline session, and were left alone for 10 minutes until the beginning of the performance. During this pre-performance phase, they were allowed to read. At the beginning and at the end of these 10 minutes, they rated their current affective experience and physiological symptoms. After the completion of the second self-ratings, the participants left for the performance without audience, which took approximately 10 minutes. After the performance, they were asked to indicate whether they had taken medication or illicit drugs prior to the performance and whether they had voluntarily controlled their respiration during the pre-performance phase.

Public session: The public session took place at approximately the same time of day as the private session. The experimental procedure of the public session was identical to the one described in the private session with the exception that the performance took place in front of an audience of approximately 10 persons. To make the situation more stressful, the participants were told that the audience was composed of music adepts and two experts, that the experts would evaluate the performance, and that the performance would be sound recorded. The participants performed in both sessions the same “moderately difficult” musical pieces, which they were free to choose. At the end of this session, the participants were asked to rate the similarity between the public performance of this study and a real public performance on a scale ranging from 1 “not at all similar” to 11 “extremely similar”.

2.3 Measurements

2.3.1 Assessment of the usual MPA level

MPA can be considered as state anxiety (occurring in specific situations, here performances) with trait character, since it is reasonable to assume that MPA remains stable for identical performance situations – at least over a certain time period. Therefore, we assessed the students’ usual MPA level with the state scale of Spielberger’s State Trait Anxiety Inventory (STAI-S) (27) by adapting the instructions to music performance situations (28). In order to determine the students’ usual MPA level, the instruction asked how they had felt before recent public solo performances they considered important. It consists of 20 items tapping apprehensive feelings of anxiety, each item rated on a 4-point Likert scale (1 “not at all” to 4 “very much so”). The total score can vary between 20, indicating no anxiety at all, to 80, indicating extreme anxiety. The use of the STAI-S allowed us to assess MPA, more precisely the negative affective dimension of MPA, as a continuous variable. The STAI-S was chosen for several reasons. Firstly, the affective dimension is the central component of the experience of MPA in many musicians (8). Secondly, almost all studies on MPA have used different ad hoc questionnaires, thus, there is no gold standard questionnaire to assess MPA. By contrast, the STAI-S – although somewhat unspecific – has been widely used in research on (performance) anxiety (1, 28).

2.3.2 Self-report measures

The items assessing the affective experience were “anxiety” and “tension”, whereas the items assessing the physiological symptoms were “vertigo”, “confusion/loss of contact with reality”, “shortness of breath”, “tingling in the fingers”, “difficulty in breathing deeply”, “palpitations”, “sweaty hands”, and “trembling in hands/legs”. These items are known to co-occur with hyperventilation problems. They were rated on an 11-point Likert scale ranging from 1 “not at all” to 11 “extremely”.

2.3.3 Physiological measures

The main physiological variables that were tested with respect to specific hypotheses are the following: $P_{et}CO_2$, HR, V'_E, %RC (a measure of thoraco-abdominal balance), TVV (measured as the root mean square of successive differences (rmssd) of expiratory volume), and number of sighs. Sighs were defined as tidal volumes exceeding two times the subject’s mean of the 10-min pre-performance phase (14).

To further the knowledge on the physiological activation in MPA and to better understand the changes in the main variables, we additionally assessed the following variables: inspiratory time (T_I), expiratory time (T_E), total breath duration (T_{TOT}), duty cycle (T_I/T_{TOT}, an index of inspiratory timing), inspiratory volume (V_I), mean inspiratory flow (V_T/T_I, an index of inspiratory drive), and heart rate variability (HRV; measured as the rmssd of R-R interbeat intervals). Finally, we assessed accelerometer (ACC) data for motion to control for the physical activity. Physiological parameters were sampled continuously.

The electrocardiogram (ECG), respiratory volume and time parameters, and ACC data were assessed with the LifeShirt® system (VivoMetrics Inc., Ventura, CA, USA; see Wilhelm, Pfaltz, and Grossman (29) for a detailed description), a non-invasive ambulatory assessment device acquiring and storing data continuously. The LifeShirt® is a snugly fitting T-shirt using respiratory inductive plethysmography, which is the gold standard for unobtrusive respiratory monitoring (30). Data were sampled at 200 Hz for the ECG and at 50 Hz for respiratory timing and volume parameters. An accelerometer was fixed on the sternum and connected to the LifeShirt® system. $P_{et}CO_2$ was recorded by means of a nasal canula connected to a non-dispersive infrared CO_2 monitor with a resolution of 1 mmHg, an accuracy of +/-2 mmHg, a sampling flow rate of 50 ml/min, and a sampling rate of 40 Hz (Microcap Handheld

Capnograph, Oridion Medical 1987 Ltd., Jerusalem). These are the standard properties of the $P_{et}CO_2$ assessment devices available on the market.

2.4 Data editing and response definition

For all physiological measures, data were averaged over the 10-min assessment period of each session (baseline, private, public). Detailed information on the calibration and editing of ECG and $P_{et}CO_2$ data are given in the Supplemental Digital Content 1.

2.5 Statistical analysis

All analyses were performed using Stata version 11.0 for Windows (Stata Statistical Software, StataCorp LP, Texas). Physiological variables, with the exception of the number of sighs, were treated as continuous, whereas all self-report variables and the number of sighs were treated as ordinal because the low number of response categories prevented a Gaussian approximation. To achieve approximate normality, right-skewed continuous variables were logarithmically transformed for the regression analyses.

In order to determine whether the physiological and the self-report variables were different in the baseline session depending on the MPA score, linear regression was carried out for the continuous variables, and ordered logistic regression for the ordinal variables. The MPA score was included in the analyses as the explanatory variable, additionally controlling for gender. The hypothesis testing was carried out in two steps. Firstly, to test the session (private vs. public) and the MPA's main effect on the dependent variables, mixed regression analyses were carried out for the continuous variables, and ordered logistic regression for the ordinal variables. These analyses included a random effect for each individual and were fitted by maximum likelihood. The session and the MPA score were included as the principal independent variables in the analyses. Gender, voluntary control of respiration, and ACC were additionally included because of their potential influence on the dependent variables[2]. When modeling $P_{et}CO_2$, we also included hormonal contraception as a potential confounder (23). For the self-report variables, the variations between the beginning and the end of the pre-performance phase of both the private and the public sessions were minimal (data not shown) and are therefore not analyzed separately. Instead, we used the responses measured at the beginning and the end of the pre-performance phase as repeated measurements. Secondly, the MPA x session interaction term was fitted additionally to test whether students with higher MPA scores reacted more strongly than those with lower MPA scores during the public session.

To test the response coherence between the different response domains, we calculated the change scores of all variables (public minus private session). We then calculated Pearson correlation coefficients between the change scores according to the hypotheses.

[2] Independent variables were coded as follows: session: private=0, public=1; gender: women=0, men=1; respiratory control: no=0, yes=1; ACC: continuous from 0=no movement to 50=extreme running; hormonal contraception: no=0, yes=1. All MPA scores were reduced by 20 points to have the minimal MPA score at 0 and the maximal MPA score at 60.

3 Results

3.1 Descriptive results and baseline analysis

The mean (SD) of the STAI-S was 46.6 (11.1). Scores ranged from 24 to 74. Therefore, almost the whole range of possible MPA scores was covered. In the baseline session, no dependent variable was associated with the MPA scores (all *p*s≥.10). Table 1 shows the descriptive results for all assessed variables for the baseline, the private, and the public sessions. The musicians rated the similarity between the public performance in the present study and a real concert as quite high (M=7.5, SD=1.6). This rating was independent of the MPA score ($r(67)$=-.08; p=.53). Finally, for more than 60% of the musicians, the ratings for tingling, confusion, and vertigo were at the lowest value and showed no variability. Therefore, no further analyses on these variables were performed.

During the pre-performance phase, eleven students reported having voluntarily controlled their respiration in the private session and 16 in the public session. Respiratory control was not correlated with the MPA score (private: $r(67)$=.10, p=.43; public: $r(67)$=-.01, p=.94).

3.2 Hypotheses testing

Session and MPA effects on the self-reported affective experience

The scores of anxiety and tension were significantly higher in the public session compared to the private one and increased significantly with increasing MPA scores (Table 2). The increase between the sessions was significantly larger in musicians with higher MPA levels compared to musicians with lower MPA levels (Table 3). The change scores of anxiety plotted against the MPA scores are shown in Figure 1.

Session and MPA effects on the self-reported physiological symptoms

Each self-reported symptom was higher in the public session than in the private session (Table 2). The scores for trembling, palpitations, sweaty hands, and marginally for shortness of breath significantly increased with increasing MPA scores (Table 2). The increases between the sessions were significantly greater in musicians with higher MPA levels compared to musicians with lower MPA levels for shortness of breath, difficulty in breathing deeply, sweaty hands, and marginally for palpitations (Table 3). The change scores of shortness of breath and sweaty hands plotted against the MPA scores are shown in Figure 1. Students who reported having voluntarily controlled their respiration had higher scores on palpitations, trembling, shortness of breath, and difficulty in breathing deeply than students not controlling their respiration (Table 2).

Session and MPA effects on the physiological activation

Regression analyses revealed that all physiological variables were significantly higher in the public session than in the private session, with the exceptions of $P_{et}CO_2$ for the main variables and T_E, T_{TOT}, T_I/T_{TOT}, and HRV for the exploratory variables (Table 2). The MPA score had no significant main effect on any of the physiological variables, except on V'_E and V_T/T_I. These two variables increased with increasing MPA scores. Men exhibited significantly higher values than women for $P_{et}CO_2$, V'_E, TVV, V_I, and V_T/T_I. However, after eliminating two male participants with very high minute ventilation during the pre-performance phase of either or both sessions (V'_E>14l/min), gender differences disappeared for these variables, except for $P_{et}CO_2$ and a marginal effect for TVV. $P_{et}CO_2$ was significantly lower in women taking hormonal contraception. Students who reported having voluntarily controlled their respiration showed significantly higher values for HR, TVV, number of sighs, T_I, T_E, T_{TOT}, and V_I, as well as a trend for lower $P_{et}CO_2$ values compared to students not controlling their respiration[3].

[3] In order to see whether wind-instrumentalists and non-wind-instrumentalists behaved differently during the period before the performances, the factor “instrument” was included in a supplementary regression analysis. This factor did not become significant for any of the physiological variables except for TI. TI was significantly higher in wind-instrumentalists than in non-wind-instrumentalists. Overall, these results show that wind-instrumentalists and non-wind-instrumentalists are comparable with respect to their physiological activation during the period before the performances. Therefore, these two groups were analyzed jointly.

The MPA x session interaction was significant only for $P_{et}CO_2$ (Table 3). Whereas, on average, $P_{et}CO_2$ values increased from the private to the public session in students with low MPA scores, these values decreased in students with high MPA scores (Figure 1). The regression analysis yielded a difference of 3 mmHg between the least and the most performance-anxious musician. The average $P_{et}CO_2$ level (min: 29 mmHg, max: 42 mmHg) was above the 30 mmHg threshold for the large majority of the musicians (97% and 95% in the private and public session, respectively). The change scores of two physiological variables without interaction effect (V'_E and HR) plotted against the MPA scores are depicted in Figure 1.

Response coherence between response domains based on change scores (public minus private)

Anxiety was positively correlated with tension ($r(66)$=.76, p<.001) and with each self-reported physiological symptom (vertigo $r(66)$=.57, confusion $r(66)$=.53, shortness of breath $r(66)$=.57, tingling $r(66)$=.35, difficulty breathing deeply $r(66)$=.57, palpitations $r(66)$=.49, sweaty hands $r(65)$=.28, and tremor $r(66)$=.29; all ps<.05). $P_{et}CO_2$ was not significantly correlated with anxiety, tension, or with any of the measures of self-reported physiological symptoms (all ps≥.17). HR and palpitations were not significantly correlated either ($r(66)$=.09; p=.49).

With respect to the actual physiological activation, anxiety was not significantly associated with any of the physiological variables, except marginally with %RC ($r(66)$=.21; p=.09). $P_{et}CO_2$ showed a significant negative correlation with TVV ($r(65)$=-.28; p<.05) and the number of sighs ($r(65)$=-.25; p<.05). There were no significant correlations between $P_{et}CO_2$

and the other primary variables of physiological activation (*p*s>.40)[4]. Also the correlation between $P_{et}CO_2$ and ACC was not significant (*r(65)*=-.10; *p*=.41).

[4] Analyzing students with a decrease and students with an increase in $P_{et}CO_2$ from the private to the public session separately with respect to the response coherence yielded largely identical results.

4 Discussion

This study focused on MPA in university music students and its association with hyperventilation. To our knowledge, this is the first study in the field of MPA investigating respiration beyond respiratory rate.

As hypothesized, all items assessing the self-reported affective experience and self-reported physiological symptoms were higher in the public session than in the private one. Given the increase in anxiety, we can reasonably assume that the stress manipulation was successful. Furthermore, the usual MPA level was closely related to the degree of the current self-reported anxiety and tension. This supports the validity of the retrospective assessment of the usual MPA level. The usual MPA level was also associated with most self-reported physiological symptoms. The most obvious explanation for this finding would be that higher scores of usual MPA causes higher current self-reported anxiety, which is associated with increased physiological activation and decreased $P_{et}CO_2$, and therefore, increased self-reported symptoms. However, given the absence of an association between the usual MPA level and the physiological activation and the low response coherence between the physiological activation and the self-reported physiological symptoms, this explanation does not hold. Other possible explanations for the association between the usual MPA level and the self-reported physiological symptoms are the following: Firstly, musicians declaring themselves as anxious may have a general tendency to report more symptoms of emotional and physiological distress (31). Secondly, anxious musicians may be more sensitive to bodily reactions and show a higher interoceptive accuracy (32). However, this view was not supported in other studies on anxiety (22). Thirdly, anxious musicians may focus more strongly on physiological reactions than less anxious musicians, and may report exaggerated physiological activation (22).

The increases in anxiety, tension, shortness of breath, difficulty breathing, and sweaty hands from the private to the public session were significantly greater with increasing MPA scores. This is in line with other findings from studies with flying phobics (33), driving phobics (15), and social phobics (22). Contrary to our hypothesis, the usual MPA level was not significantly associated with the reactivity reported for palpitations and trembling. This may be due to the occurrence of these symptoms in situations of both positive and negative arousal.

The actual physiological responses showed a significant shift towards a heightened activation from the private to the public session for all variables for which we hypothesized an increase. These findings show, for the first time, that the respiratory system is activated before a public music performance. The emerging breathing pattern is characterized by more irregular, slightly more thoracic, and increased ventilation with largely unchanged timing parameters. The latter finding is in line with a previous report of non-significant differences in the respiratory rate of musicians between an audience-free and a public performance (20). The results for the other physiological variables are consistent with previous findings reporting increases in physiological arousal from an audience-free to a public pre-performance phase in musicians for HR (20, 34) and blood pressure (34).

The absence of a significant association between the usual MPA level and most physiological variables shows that, on average, higher performance-anxious musicians and lower performance-anxious musicians do not differ in their actual cardio-respiratory activation. This is in accordance with previous studies showing significant session effects but no significant group effects between high- and low performance-anxious musicians with respect to HR and neuroendocrine measures (20-21). Studies on other forms of anxiety (social phobia, driving phobia, and flying phobia) also failed to yield group differences with respect to various physiological variables (15, 22, 33, 35). These results suggest that the activation of many physiological parameters before a stressful situation is associated with arousal in general rather than with anxiety *per se*.

$P_{et}CO_2$ was not comparable with the other physiological variables. Firstly, it did not show the expected overall decrease from the private to the public session. The absence of an overall session effect contrasts with reports showing a moderate (i.e., 1.4-3 mmHg) but significant decrease of $P_{et}CO_2$ between a relaxed and a stressful (emotional or cognitive) situation in clinical and non-clinical samples (15, 17-19). Secondly, it was the only physiological variable with a significant MPA x session interaction effect. However, the pattern of this interaction was surprising: Whereas, on average, $P_{et}CO_2$ increased from the private to the public session for musicians with low MPA scores, it decreased from the private to the public session for musicians with high MPA scores. Thus, whereas a tendency to hyperventilate in students with high MPA scores could be confirmed, students with low MPA scores rather seemed to hypoventilate, i.e., to breathe less than required by metabolic demands. A possible explanation for this finding is that hyperventilation seems to be the typical respiratory response during psychological challenges where very few, if any, active coping possibilities exist (36). Thus, highly anxious musicians who feel overwhelmed or out of control might react to the stressful performance situation by hyperventilating, whereas musicians who use active coping strategies do not. Increases in PetCO2 from the baseline to a stressful situation have been previously reported in some rare cases (18). These authors suggested that personality factors might contribute to the intensity and the direction of the PetCO2 response. A yet to be confirmed hypothesis is that hypoventilation might be associated with a strong control of the expression of emotion at the affective and physiological level. A respiratory biofeedback training that targets pCO2 levels directly has been shown to drastically reduce panic symptomatology including anxiety in panic patients (26).

In conclusion, these results show that both hyper- and hypoventilation should be addressed when studying respiration in arousing situations. The causes and possible (dis-)advantages of hypo- and hyperventilation in a stressful situation need to be addressed in future research. Unexpectedly, the significant MPA x session interaction effect on $P_{et}CO_2$ was not paralleled by a significant interaction effect on V'_E. Similarly, Alpers et al. (15) and Wilhelm et al. (13) observed lower $P_{et}CO_2$ levels in anxious subjects than in control subjects without significant differences in V'_E. Breathing patterns prone to enhance the CO_2 exchange such as elevated TVV and deep breaths, which disproportionally decrease $P_{et}CO_2$, may be at the foundation of this phenomenon (13). This view is supported by the positive correlations in this study between $P_{et}CO_2$ and both the number of sighs and TVV. Alternatively, a drop in $P_{et}CO_2$ without evidence in V'E change is likely to occur when subjects reduce their physical activity but continue breathing at an unaltered V'E level. However, this explanation is not supported by our data given that there was no significant MPA x session interaction for ACC, and $P_{et}CO_2$ did not correlate with ACC. Yet, since ACC was measured with one single accelerometer over the sternum, it probably does not capture well all types of physical activity and, thus, only imperfectly tracks overall metabolic changes. Finally, although participants were instructed to breathe exclusively through their nose, and $P_{et}CO_2$ was shown to be accurately measured even with very small amounts of air reaching at least one nostril (37), we cannot exclude the possibility of variations between nasal and mouth breathing to account for some of the inconsistency in the association between $P_{et}CO_2$ and V'E.

Students who reported having voluntarily controlled their respiration had significantly higher scores for shortness of breath, difficulty breathing, palpitations, and trembling, as well as higher HR, TVV, number of sighs, T_I, T_E, T_{TOT}, and V_I. $P_{et}CO_2$ was marginally lower in the students controlling their respiration. The experience of respiratory symptoms might push the students to control their respiration by breathing more slowly and deeply, accompanied by sighs. This breathing pattern widely used to induce relaxation can decrease $P_{et}CO_2$ and, in some cases, accentuate hypocapnia. However, the results do not allow us to conclude on cause effect relations. Therefore, a more detailed assessment of respiratory control would contribute to a more comprehensive understanding of the influence of respiratory control on breathing patterns.

Whereas the results showed a positive association between self-reported anxiety and self-reported physiological symptoms, there was no association between self-reported anxiety and physiological symptoms on the one hand and actual physiological activation on the other. This is in line with previous research showing that physiological symptom reporting is mainly related to psychological variables (e.g., state anxiety, trait anxiety) rather than to actual physiological activation (22, 24, 38). In accordance with this, Edelmann and Baker (39) reported a lack of accuracy in self-reports of actual physiological reactivity in social phobics, other clinically anxious individuals, and healthy individuals. In musicians, Fredrikson and Gunnarsson (21) reported that ratings of distress were uncorrelated with neuroendocrine measures and HR.

In line with previous findings showing only weak negative associations between $P_{et}CO_2$ and symptom perception (23-24), we found no significant coherence between $P_{et}CO_2$ and the self-reported affective experience, or between $P_{et}CO_2$ and the self-reported physiological symptoms. Therefore, and given the highly normal $P_{et}CO_2$ values, it is unlikely that symptom perception was due to hyperventilation. Furthermore, consistent with reports of low to moderate correlations between HR and perceived palpitations (22, 33, 40), the correlation between these variables was not significant. This might be due to the fact that some individuals perceived heart pounding rather than tachycardia, which is better related to stroke volume than to HR changes (41).

Although the response coherence between the physiological activation on the one hand and the affective experience and self-reported physiological symptoms on the other hand has often been reported to be low or inexistent, some recent studies on blood phobia found a strong response coherence between various physiological parameters on the one hand and self-reported anxiety, disgust, and symptoms on the other hand during and/or after the exposure to the feared stimulus (42-43). Importantly, these studies included exclusively patients with a DSM-diagnostic for specific phobia. Therefore, the anxiety intensity during the exposure period was particularly high in this group (42). Furthermore, the physiological activation was even higher during the recovery than during the exposure (42). Good response coherence seems to emerge in situations with particularly strong emotional and physiological reactions (44-45). Thus, weak or a total lack of response coherence, as observed in our study, may be a problem of limited intensity of the emotional and/or physiological reactions in a non-pathological group. However, alternative explications are possible. Firstly, there might be indeed only a loose association between actual physiological activation and both anxiety experience and self-reported physiological symptoms in MPA. Secondly, response coherence was assessed at the inter-individual level by comparing the intra-individual differences (public minus private session) between participants. This procedure implicitly assumes that two individuals with a comparable affective experience react similarly on the physiological level and, thus, disregards the possible existence of individual response coherence within the same person in different stressful situations over time. Thirdly, the low response coherence may be due to the influence of other emotions than anxiety. Whereas public performances are generally experienced as arousing, they can be ambivalent with respect to their valence and generate feelings as different as anxiety and pleasant anticipation. Finally, symptom perception might play a key role in emotional experience. This perception is assumed to depend on cognitive processes rather than on actual physiological responding (46). Thus, anxious participants may distort their own physiological responding in a stressful social situation, thereby decreasing the response coherence.

4.5 Limitations and outlook

There are some noteworthy limitations in the present study. Firstly, the study design was not randomized. This choice was made after discussions with musicians and researchers in the field, primarily to mirror real performance situations as best as possible, i.e., rehearsal before public concert. A randomized design is important to control for the effects of the novelty of the task on the first session and the effects of habituation for the following sessions. In the present study, all musicians participated in a baseline familiarization session one week before the private session. Thus, novelty was no issue in the private session. With respect to habituation, it can be reasonably assumed that all the participants - being professional music students – were already familiar with performance situations (private and public) prior to this study and, therefore, no significant habituation was to be expected during the study period. Even if there was a habituation effect, the randomization of the design would have actually amplified the reported session effects and would have given further evidence for our results. Secondly, the assessment of valence and arousal might have added valuable information to address debilitating and facilitating MPA separately, which would have allowed us to analyze the physiological activation in more detail. Thirdly, it should be kept in mind that the assessed measure of HRV, i.e. the rmssd of the interbeat intervals, is a limited one as it does not control for respiratory influences and as it is not the exact quantification synchronous with the respiratory cycle, such as high frequency HRV or peak valley. Finally, the assessment of sex hormones, which fluctuate across the menstrual cycle and can modulate $P_{et}CO_2$ (47), was not possible.

In conclusion, the present study has shown how the psychophysiological state, in particular the perception of somatic symptoms and the actual breathing pattern of music students with different levels of MPA change prior to a public performance. The findings suggest that the level of MPA modulates the balance between respiration and metabolic activity so that low-anxious musicians tend to hypoventilate, whereas high-anxious musicians tend to hyperventilate. For methodological reasons, the assessment of hyperventilation was restricted to the period before the performance. Future studies may extend our line of research by assessing hyperventilation during performance and by establishing the relationship between respiration and the quality of performance.

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Supplemental Digital Content 1.doc

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FIGURE CAPTION

Figure 1. Scatter plots and regression lines of the change scores (public minus private session) of selected self-report and physiological variables plotted against the MPA scores (STAI-S)

Figure 1 for publisher
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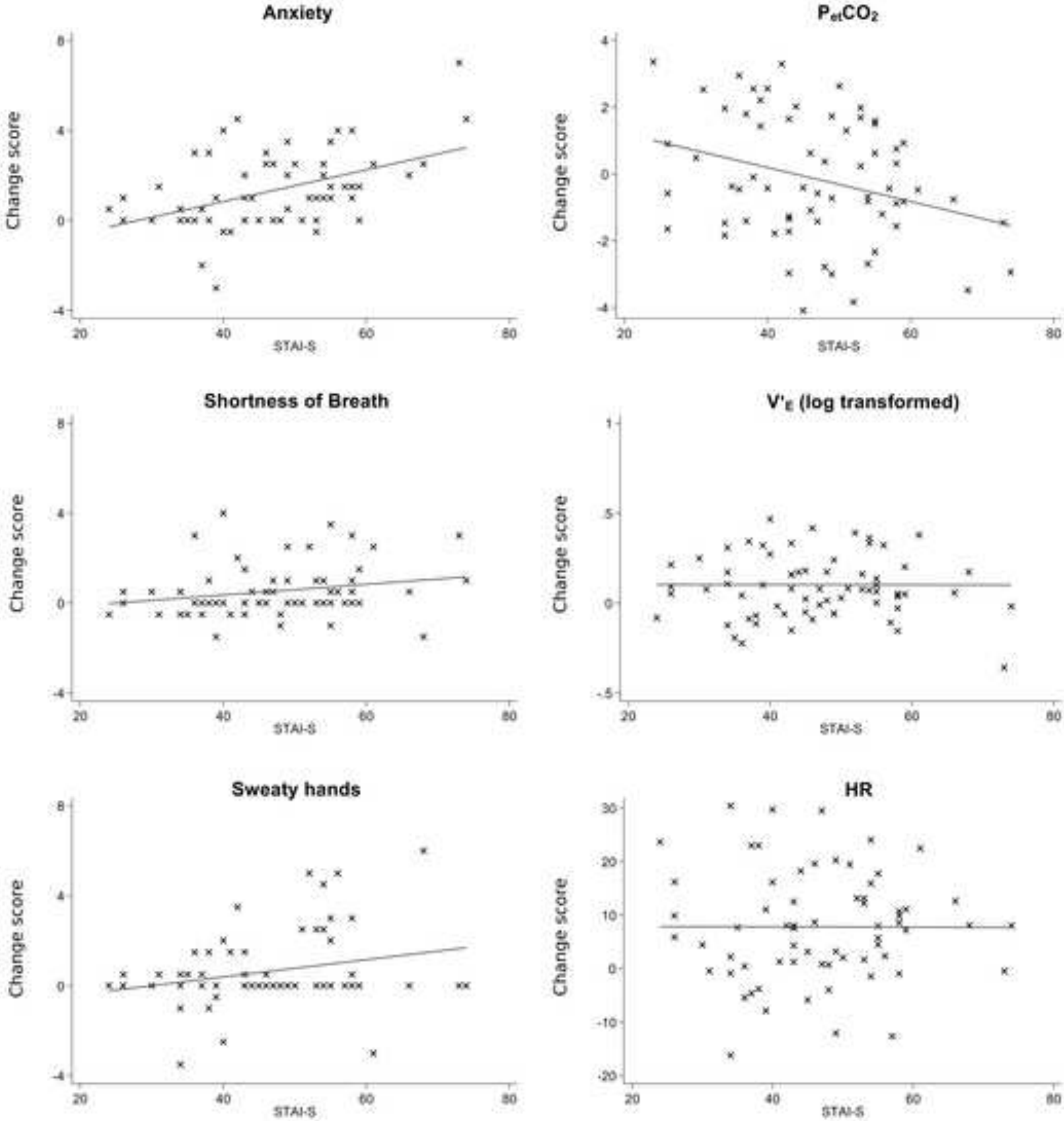

Supplemental Digital Content 1

Data editing and response definition

Calibration: Before starting the measurements in each session, every participant performed two volume calibrations while sitting and two while standing. For the present paper, only the sitting calibration was used. The calibration task consisted in breathing through the mouth successively ten times into an 800 ml plastic bag, emptying the bag completely with each inspiration and filling it completely with each expiration. Since there was considerable variation in the calibration quality between the different sessions, the calibration of the private session was chosen as the reference because the private session was the least stressful session compared to the baseline session (novelty of the calibration task) and the public session (stress due to the public performance). The better of the two sitting calibrations in the private session (highest number of suitable breaths, lowest variation between breaths) was applied to all three sessions. In each session, it was checked that each participant wore exactly the same garment in the same way and in the same position. The fixed volume bag calibration was preceded by a qualitative diagnostic calibration and applied to the raw signals of the thoracic and the abdominal bands of the LifeShirt®, which converted them into calibrated lung volumes.

$P_{et}CO_2$: $P_{et}CO_2$ was analyzed using the Matlab-based toolbox ANSLAB (Wilhelm & Peyk, 2006). This software program automatically detects plateaus in the CO_2 traces. In addition to the software's algorithm, $P_{et}CO_2$ traces were visually inspected in order to eliminate measurement artifacts and incomplete breaths. Breaths were included in the analysis if they (a) had a discrete shape (i.e., constantly increasing until reaching a distinct plateau and then constantly decreasing until reaching the minimum of the curve), and (b) did not drop suddenly by more than 4 mmHg in one single breath without obvious reason (Gardner, 1994; Ward & Yealy, 1998). Sighing was considered an obvious reason.