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# Take a deep breath: The relief effect of spontaneous and instructed sighs

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ABSTRACT

Spontaneous sighing is related to subjective relief of negative emotional states. Whether this also applies to instructed sighing is not known. The present study aimed to investigate sEMG and respiratory variability (1) during recovery from mental stress with and without an instructed sigh; (2) before and after spontaneous sighs throughout the experiment. A spontaneous sigh was preceded by increasing sEMG and increasing random respiratory variability, and followed by decreasing sEMG and increased structured correlated respiratory variability. Following an instructed sigh, a smaller reduction in sEMG and an increase in random respiratory variability during recovery from mental stress were observed. Thus, a spontaneous sigh seemed to induce relief. An instructed sigh appeared to inhibit recovery from mental stress.


Spontaneous breathing in healthy persons is characterized by substantial variability [7,11,23,51,61], arising from various sources. Autonomic control processes, in response to perturbations, produce structured, time-dependent, deterministic, correlated, non-random breath-to-breath variations, returning respiration to its dynamic steady state in order to ensure system stability. Perturbations (e.g. through behavioral influences) elicit random variations in the respiratory system. Occasional random noise warrants system sensitivity; it trains the system in flexible and adaptive responding to perturbations so as to quickly return to a dynamic equilibrium [18,46]. As such, breathing shows considerable complexity and chaos resulting from neural control.

Respiratory centers in the brain stem include a rhythmogenic inspiratory network that generates a periodic rhythm consisting of specific spatiotemporal properties [13]. This rhythm-generating network, located in the pre-Bötzinger complex, functions as central rhythm and pattern generator defining amplitude and timing of respiratory bursts in the absence of feedback processes. This neural circuit is modulated both reflexively and behaviorally. Whereas brain stem structures control breathing through input of central and peripheral chemoreceptors and vagal afferents from pulmonary stretch receptors, contributing to ventilatory complexity [15,26,36,37,44], behavioral control modulates this regulation through input from cortical structures [34,39].

Although occasional perturbations, e.g. through behavioral influences, are essential for effective breathing regulation, persistent perturbations will dysregulate breathing and compromise breath-to-breath variability, either by inducing excessive random variability (endangering respiratory stability), or by reducing variability (compromising sensitivity). In line with the former, increased random respiratory variability is found during resistive loading above the perception threshold [6], during induction of mental stress [54] and in panic disorder [1,31,59,60,62]. In line with the latter, respiratory variability is reduced during attention tasks [54] and during imagery of anxious scripts and in healthy subjects scoring high on trait negative affectivity [53]. These findings suggest that respiratory regulation and spontaneous respiratory variability can be compromised by behavioral influences overriding autonomic control.

Based on the theory of stochastic resonance [50,57], we hypothesize that adding noise to the respiratory system enhances respiratory control and restores a healthy balanced ventilatory variability. One such noise element may be a sigh. Consistent evidence supports the hypothesis that sighs operate as general psychophysiological resetters and serve regulatory functions [56]. First, sighing reduces hypoxia and hypercapnia [3,9] and restores gas exchange [9]. Second, findings show that sighing prevents atelectasis [4,41] and restores lung compliance [8,10,14,21,33,35]. Third, sighs are abolished by vagotomy in cats [9,27], rats [3,21] and rabbits [19]. Moreover, through autonomic mechanisms a sigh increases bronchial and coronary blood flow and conductance [40]. Fourth, sighing resets parasympathetic control when sympathetic activity chronically dominates autonomic regulation [16]. Finally, sighing resets various fractions of respiratory variability to a healthy balance representing a sensitive, yet stable respiratory system: sighing resets respiratory short term memory and correlated respiratory variability [2,56].

The above considerations may help to understand psychological correlates of sighing. First, sighing is related to relief: relief of dyspnea and perceived restlessness [22], relief of negative affect and craving

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during smoking withdrawal [32], and relief of stress [48,55]. Sighing may temporarily relieve tension (both psychologically and physiologically e.g. muscle tension) built up during negative emotional states characterized by too random breathing or during sustained psychological states characterized by a reduction of respiratory variability [54]. Second, excessive sighing is found in panic disorder patients, which may account for respiratory malfunction in this group, such as highly irregular breathing, low respiratory short term memory and low baseline $pCO_2$ [1,31,45,58–60,62]. Although occasional sighs reset respiratory properties and are related to subjective relief, this temporary relief effect may negatively reinforce sighing as a coping response with negative emotions. It follows that the more intense the negative emotions, the higher the reinforcement value, and the more chronic the negative emotions, the more frequently sighs will be reinforced. Excessive sighing or intentional sighing when physiologically inappropriate may dysregulate breathing, as it can be considered as excessive noise that prohibits the system to return to its steady state.

The purpose of the current experiment is to further study respiratory variability as related to spontaneous sighing and to instructed sighing following a negative emotional state. Mental stress was induced as negative emotion by means of mental arithmetic. Muscle tension is added as physiological parameter in order to investigate tension and relief related to sighing. Consistent evidence shows that muscle tension increases during mental stress evoked by mental arithmetic [24,29,30,38].

We predict that in response to an instructed sigh following mental stress excessive random variability will occur and muscle tension will recover less. In contrast, muscle tension is predicted to progressively increase before a spontaneous sigh and gradually decrease after a spontaneous sigh. Finally, we aim to replicate the finding that towards spontaneous sighs respiratory variability becomes increasingly random, whereas structured correlated respiratory variability strongly increases following spontaneous sighs.

## 1. Method

### 1.1. Participants

Forty-three undergraduates participated in the study (21 men, age 18-22). The experiment was approved by the Ethics Committees of the Department of Psychology and of the Faculty of Medical Sciences.

### 1.2. Measures

Breathing data were continuously collected by means of respiratory inductive plethysmography (RIP), using the LifeShirt System® (Vivometrics Inc., Ventura, CA). Two RIP transducers at the level of the rib cage and the abdomen, sewn into a LifeShirt garment including three accelerometers, were connected to the LifeShirt recorder, a digital processing unit including a data storage card.

Surface electromyography (sEMG) of the M. Trapezius pars descendens (TD), pars transversus (TT) and pars ascendens (TA) was measured using pre-gelled Ag/AgCl contact electrodes (Nikomed, Denmark), attached according to European SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) recommendations and wired to a digital-analog converter unit (National Instruments, Austin, TX), sampled at 1000 Hz and digitised (24 bits) before stored on a personal computer.

### 1.3. Procedure

Participants were individually invited to an experiment studying physiological effects of mental arithmetics. Upon arrival, participants were informed on the course of the experiment and signed the informed consent. Then, the EMG electrodes were attached. Next, participants were instructed to perform three shoulder elevations separated by 1-min pauses to extract the maximal voluntary contraction (MVC) of the M. Trapezius pars descendens and reference voluntary contraction (RVC) of the M. Trapzius pars transversus and ascendens. Sitting on a low adjustable chair, participants performed the shoulder elevation for five seconds by lifting a handle with their hands on each side of the chair as high as possible with outstretched arms, without loading the low back muscles. Finally, they put on the LifeShirt garment and all sensors were connected to the LifeShirt recorder.

The experiment consisted of a 6-min baseline, followed by three task trials. Trials were presented in completely randomized order controlled by custom made stimulus presentation and data acquisition software Affect 4.0 [49]. Each trial contained a 6-min task phase followed by a 6-min recovery phase. The three different tasks consisted of one sustained attention task, one mental arithmetic task and one mental arithmetic task followed by an explicit instruction to sigh. The baseline and the recovery phases involved watching a documentary ('The March of the Penguins'). This documentary exposed participants to neutral visual stimuli reducing boredom during baseline and recovery. Participants were ensured that no questions about the documentary would be asked later on and they could relax and enjoy watching the movie. The mental arithmetic task consisted of continuous mental calculations of sums of five operations with a two- or three digit number, which had to be performed without any verbalization (e.g. 361 +7 *2 -4 /2 +13). Participants used the mouse cursor to indicate the correct answer choosing between three alternatives, after which feedback was given. Participants were informed that at the end of the study the five best performing participants would be rewarded with a movie ticket. The experimenter was seated next to the participant. This mental arithmetic task was considered to be stressful as task difficulty was high, feedback was given, evaluation and rewards were given related to performance within time constraints and an observer was present [5,17,25]. The sustained attention task consisted of indicating the largest number of three alternatives using the mouse cursor. This attention task required the same motor movement (indicating the correct answer with the cursor), but it was not stressful: in contrast to the mental arithmetic task, task difficulty was extremely low, no time constraints were applied and no task evaluation or reward for performance was given. The instruction to sigh implied to sigh within the following 20-sec time window. Participants were asked to practice an instructed sigh, so that the experimenter could check whether participants understood and succeeded in executing the instructions. When necessary, the experimenter illustrated a sigh and the participants were asked to mimic this.

Before the experiment started, they were explicitely instructed again not to speak, mumble of move the lips, to sit comfortably, not to change posture and not to move, except for their dominant hand using the mouse cursor.

## 2. Data analysis

Analysis of respiratory and EMG measures towards and in response to spontaneous and instructed sighs will be reported here as main results. Findings on respiration and respiratory variability during the various phases of the experiment have been described extensively elsewhere [54]. The effects of mental stress on these measures and sEMG will be summarized in the results section.

### 2.1. Parameter extraction

#### 2.1.1. Respiration

Editing of raw respiratory data was performed using Vivologic software (Vivometrics Inc., Ventura, CA). Two calibration procedures of the raw respiratory waveforms were carried out. First, the qualitative