The Psychophysiology of Breathing

Omer Van den Bergh

Research Group on Health Psychology
University of Leuven, Belgium

Content

• What is breathing?
• How to measure it?
• How to manipulate and study it?
• Respiratory psychophysiology: some examples
What is breathing?

RESPIRATORY PHYSIOLOGY

Breathing...

- Biggest oscillator in the body
- Double control system
  - Voluntarily
  - Autonomically
- Relatively little investigated in psychophysiology
  - No “pure” (unsuspect) psychophysiological measure
  - Difficult to measure without altering it
Breathing…

To keep blood gas levels within (pre-set) boundaries

**O2**
- Arterial O2 saturation (SpO2)
- 93 – 100 % Hb fully saturated by O2

**CO2**
- Alveolar PCO2 (PACO2)
- Arterial PCO2 (PaCO2)
- End-tidal PETCO2 (mmHg) or FETCO2 (%).
  - Normal PETCO2 ± 40 mmHg
  - Normal FETCO2 (%) = ± 4.8 à 5%

Gas exchange in alveoli

- 300 million alveoli (0.05 to 0.25 mm each)
- ±100 m² surface in contact with the outside air
- Inspired air = 21% O2 - 0 to 0.5% CO2
- Expired air = 16.5% O2 - ±5% CO2
Respiratory control

- Rhythmicity center of the medulla (brain-stem)
  - I neurons
  - E neurons
- Apneustic center (pons)
  - stimulate I neurons
- Pneumotaxic center
  - inhibits apneustic center
  - inhibits inspiration

Respiratory control

- Sensors in different places in the body monitor breathing behavior and gas exchange
- Mammals are most sensitive to CO2 levels
  - varies most in respiration in response to different metabolic and environmental conditions.
Important effects of respiration on other systems

Respiratory gating (Eckberg, 2003)
- More parasympathetic outflow during expiration than during inspiration
  - RSA: Respiratory sinus arrhythmia
    - HR increases during inhalation and decreases during exhalation
      - Also other cardiorespiratory interactions
    - Fierce debate on HRV: What it means and yes/no correction for respiratory variables?
  - Startle response modulation?
  - ??

Respiratory sensation
Bottom-up AND top-down processes

How to measure breathing?

MEASURES AND PARAMETERS

Time related

- Respiratory band (chest)
- Straps
- Termistors (nose)
- ...

- $T_i$ : inspiratory time (s) (1,5-2 s)
- $T_e$ : expiratory time (s)
- Pauses ($P_{inexp} - P_{expin}$)

- $f = \frac{60}{(T_i+T_e)}$ (10-12 br/min)
- $T_i/T_{TOT}$ : duty cycle time
  - Reflects activity of respiratory rhythmic controller
Volume related

Pneumotachograph

\[ V_T = \text{tidal volume} \]

500-600 ml

RIP: respiratory inductive plethysmography

Time x Volume

- \[ V_E = f \times V_T \] (minute ventilation, L/min; normal ±6 L/min)
- Inspiratory drive: \( V_T/Ti \)
- ...

Pressure parameters

- \( P_{100} \): inspiratory occlusion pressure 100 ms after the onset of an inspiratory effort against a closed airway
  - reflects the summed motor output of the central respiratory controller (or the "central respiratory drive")
Central respiratory drive

Breathing patterns

- Respiratory variability
- Sighs
**Gas exchange - capnography**

- CO₂
  - PetCO₂ (mmHg)
  - FetCO₂ (%)

- O₂
  - PO₂
  - SaO₂

Photosensitive plethysmography

**Clinical variables**

- Flow-volume loop
- FVC
- FEV1
- PEF
- ...

- Airway resistance
  - FOT : Forced oscillation technique
MANIPULATIONS IN THE LAB

Dyspneic Stimuli: CO₂-inhalation

CO₂-inhalation (5% - 7.5% - 10%)
- Chemoreceptors (pH/CO₂)
- Rise in ventilation, HR, BP
- Breathlessness - air hunger
- Dizziness, warmth

35% → Panic !!
Dyspneic Stimuli: respiratory load

Flow resistors (loads)
- Mechanoreceptors
- Breathing muscles work harder
- Breathlessness – effort
- Fatigue

Other
- Occlusions
- Breath holding

RESPIRATORY PSYCHO(PHYSIO)LOGY
Research Group on Health Psychology
- Leuven

Dyspnea perception => symptom perception
- Perceptual-cognitive processes
- Affective-motivational responses
- Clinical implications (asthma, COPD)

Emotion and breathing regulation
- Breathing during defensive response mobilization
- Why do you sigh?
- Feedforward-regulation of breathing
- Interoceptive fear conditioning to respiratory cues
- Breathing and relaxation
Research Group on Health Psychology
- Leuven

Dyspnea perception => symptom perception
• Perceptual-cognitive processes
• Affective-motivational responses
• Clinical implications (asthma, COPD)

Emotion and breathing regulation
• Breathing during defensive response mobilizationn
• Why do you sigh?
• Feedforward-regulation of breathing
• Interoceptive fear conditioning to respiratory cues
• Breathing and relaxation

THE PLASTICITY OF SELF-REPORTED SYMPTOMS
Dyspnea as a Multidimensional Experience

Dyspnea/breathlessness…

“… a subjective experience of breathing discomfort that consists of qualitatively distinct sensations and affective-motivational responses that vary in intensity

“… experience derives from interactions among multiple physiological, psychological, social, and environmental factors…”


Dyspnea - breathlessness

Distinct Sensations

• Air hunger – suffocation
  – Mismatch ventilatory drive – actual ventilation
• Effort - work of breathing
  – Respiratory muscles must work harder
• Chest tightness
  – Bronchoconstriction

Simon et al. (1990). American Review of Respiratory Disease, 142, 1009-1014
Banzett & Moosavi, APS Bulletin, 11, 2001
Large individual differences

Treating Dyspnea

Physiologic Mechanisms
- Mechanoreceptors
- Chemoreceptors
- Afferent mismatch

Psychologic Mechanisms
- Cognitive factors
- Learning processes
- Memory representations
- Emotional factors (fear)
- Social context

- 3rd major complaint in medicine
  after fatigue and pain
  (cardio)pulmonary disorders
  neuromuscular
  70% of terminal cancer patients

- % explained by either set varies
  - among persons
  - as a function of time/learning experiences within person

Inaccurate perception of asthma symptoms: A cognitive-affective framework and implications for asthma treatment

Thomas Janssens 1, Geert Verhelst 1, Steven De Praetere 1, Bar Van Den Bergh 1, Dorus Van den Bergh 1
1 Research Institute for Health Sciences, University of Leuven, Leuven, Belgium

20 to 36 %
Top-down processes

- Perceptual-cognitive factors
  - Attention
  - Interpretation ("catastrophizing")
  - Expectancies/learning
  - Memory
- Emotional factors
  - Fear
  - Controllability
- Social context...

Acquiring bodily symptoms

**Odor-CO\textsubscript{2} inhalation paradigm**

**CO\textsubscript{2} inhalation trials**
- fast breathing
- smothering sensations
- chest tightness
- feelings of choking
- pounding heart
- sweating
- hot flushes
- lump in throat
- headache
- tension, anxious feelings

**Predictive cues**
- odors
- mental images
Methods

Odor CSs

**ACQUISITION**

<table>
<thead>
<tr>
<th>CS+</th>
<th>Odor 1+</th>
<th>7.5% CO₂</th>
<th>Ventilation (f, V₁, V̇E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS-</td>
<td>Odor 2+</td>
<td>room air</td>
<td>FETCO₂, HR, Subjective symptoms</td>
</tr>
</tbody>
</table>

**TEST**

<table>
<thead>
<tr>
<th>CS+</th>
<th>Odor 1+</th>
<th>room air</th>
<th>Ventilation (f, V₁, V̇E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS-</td>
<td>Odor 2+</td>
<td>room air</td>
<td>FETCO₂, HR, Subjective symptoms</td>
</tr>
</tbody>
</table>
Acquired symptoms to harmless odors

- Symptom learning to unpleasant odor only!
- No difference in contingency awareness

Van den Bergh et al., 1995, 1997, 1999

More elevated in high NA and in clinical MUS patients

Van den Bergh et al., 1998, 1999
Respiratory learning paradigm

**ACQUISITION**

- CS+ Odor 1+ HypC HV
- CS- Odor 2+ NorC HV

10 s + 80 s

- Ventilation (f, VT, VE)
- FETCO₂
- TCD
- Lightheadedness

**TEST**

- CS+ Odor 1+ NorC HV
- CS- Odor 2+ NorC HV
- CS+ Odor 1+ Norm Br
- CS- Odor 2+ Norm Br

- Ventilation (f, VT, VE)
- FETCO₂
- TCD
- Lightheadedness

Transcranial Doppler Ultrasonography

- TCD
- Online LH rating scale
- Respiratory measures
- CO₂ added through inspiratory tube
Mid Cerebral Artery (MCA)

2.1 Transcranial Doppler imaging

End-tidal CO₂ (fractional concentration)
Cerebral Blood Flow (mean velocity in rMCA)
Lightheadedness (rating 0-100)

(a) FetCO₂ (b) Vm (c) LH during 3 phases in 1 subject
Learning phase

Mean within-s r = -0.64 ± 0.17

CBF – rMCA

Max Lightheadedness

Test phase

Mean within-s r = -0.04 ± 0.24

CBF – rMCA

Max LH

Bresseleers et al., Psych Med., in press
The rise and fall of the “hyperventilation syndrome”

Hyperventilation syndrome?
- Because there was no 1-1 relationship between a self-reported (anxiety/panic) symptom and reduced PetCO$_2$
  - HVS has been dropped, but also HV as a stress response
- Taboo, to the benefit of physiotherapists?

Anxiety
- Faster breathing
- Reduced “duty cycle time”
  - (Ti/Ttot: greater proportion of inspiratory time of total breathing cycle; Van Diest et al., 2009)

- When and why hypocapnic breathing?
- Important role for interoceptive fear conditioning?

Other implications

- Symptom perception in asthma
  - Effects on treatment adherence and asthma control

- COPD
  - Social comparison during group rehabilitation on symptoms..

- MUS
Body – symptom correspondence

- within-subject correlation between a specific subjective report and a specific physiological response across a number of breathing trials

- Minute ventilation
- \( \text{PCO}_2 \)
- Faster/deeper breathing
- Breathlessness

Role of affective context

“Test of quality of air on subjective well-being”

High and low NA normals

**Negative frame**

**Unpleasant odor**
“breathing this air may make you feel tensed like when being *anxious* or expecting something *terrible* to occur”

**Positive frame**

**Pleasant odor**
“breathing this air may make you feel tensed like when *being in love* or looking out for *something really nice* to happen”
Role of context as memory cues

Correspondence

Symptom Level

Semantic cues

- within-subject correlation between a specific subjective report and a specific physiological response across a number of breathing trials

- Minute ventilation
- PCO₂
- Faster/deeper breathing
- Breathlessness

Van den Bergh et al., P&H, 2004
Semantic cues

- within-subject correlation between a specific subjective report and a specific physiological response across a number of breathing trials

- Minute ventilation
- PCO₂

- Faster/deeper breathing
- Breathlessness

Semantic cues:
Neutral vs Symptom rating

High and low symptom reporters (normals)

Bogaerts et al., JPR, 2008
Clinical MUS patients -

Bogaerts et al., 2010

Chronic Fatigue Patients

Brief induction of negative affective state
Imagery scripts (2 min)

Bogaerts et al., BRaT, 2007
Conclusions

• Relationship between peripheral physiology and interoceptive processes in the brain is quite “plastic”

• Basic learning mechanisms can shape interoceptive processes

• High trait NA more vulnerable to “somatovisceral illusions”
  – More fusing of affect with somatic information?
  – Relevance for somatization disorders, “functional syndromes”

• Role of deficient inhibitory control from right PFC in high NA/MUS?
FEAR (elevator)

You are alone in an elevator. It is very small and has no ventilation. You start feeling short of breath. It slowly becomes unbearable. You want to leave this place as soon as possible, but when the elevator stops the door is stuck. You are sweating and your heart pounds wildly. In despair, you start pushing all the buttons, but nothing helps. You perspire heavily and gasp for breath. It appears that there is almost no air available anymore in this little place. Your heart leaps into your mouth, while you pull on the door with all your strength. It remains jammed shut. Everything becomes black.

Emotional Imagery and FetCO₂

Figure 3. Mean FetCO₂ (per 20 s periods) for each imagery trial (first 20 s of baseline, 60 s script, 90 s silence, 60 s recovery).

Van Diest, et al., 2001
Imagining suffocation

Figure 1. Mean change in PETCO$_2$ in high- and low-trait anxious participants during imagery of the examination, the suffocation (su), and the entrapment-only (entrap-only) scripts. Vertical bars denote 0.05 confidence intervals.

*Psychosomatic Medicine 67:813–819 (2005)*

Imagining suffocation

Healthy

MUD

Imagining suffocation

- Mental imagery of stressful scenes (e.g., being blocked in elevator) triggers
  - Dyspnea
  - Hyperventilation (↓ PetCO₂)

- In anxious healthy persons (Van Diest et al., 2001; 2005)

- In patients with medically unexplained dyspnea (Han et al., 2008)
  - ↓ PetCO₂ does not explain all dyspnea
  - Mismatch between emotion-related drive and actual ventilation (?)
Differentiation sensory - affective aspect

- Sensory aspect
  - Sensorimotor cortices
  - Supplemental motor area
  - Insula

- Unpleasantness
  - Amygdala
  - Insula

14/09/2010

The Affective Dimension of Laboratory Dyspnea

Air Hunger Is More Unpleasant than Work/Effort

Robert B.anzett1,2, Sarah H. Pedersen1, Richard M. Schwartzstein1,2, and Robert W. Lansing1,2

Am J Respir Crit Care Med Vol 177, pp 1384-1390, 2008

von Leupoldt et al., 2008
Dyspnea and pain

Homeostatic emotions
- pain
- dyspnea, ‘air hunger’

shared network

- anterior/mid insula
- dACC
- amygdala
- medial thalamus

IAPS pictures - Loads

8 sec
Start at inspiratory onset

Onset inspiration

1500ms
500ms

Insp Load

Fear picture (8 s)
1500 ms startle probe

Startle EMG (T-score)

Light Load | Strong Load | No Stim | Picture

Pappens et al., 2010

7.5% CO₂

Startle EMG (raw) in µV

Habituation | b CO₂ b CO₂
20% CO₂

Startle EMG (raw) in μV

Habituation base CO₂ base CO₂

10% CO₂ - cold pressor pain (2°)

Startle EMG (T-score)

baseline challenge recovery

CO₂ 10%

Cold Pain
Dyspnea and startle potentiation

- No SP *during* dyspneic stimulation
  - Despite aversiveness (ratings, SCR)
  - Consistent for chemical and mechanical stimuli
  - Not related to inter-individual differences in subjective fear
  - Fear of suffocation, anxiety sensitivity, trait anxiety, state anxiety

  - SP found during (more aversive) cold pressor pain
    (What about visceral pain?)

- “Standard” SP found for *anticipation* of dyspneic stimuli
  - Voluntary hyperventilation  
    Melzig et al., 2008
  - Load-load interoceptive conditioning  
    Pappens et al., in prep

**WHY DO YOU SIGH?**
### Total variability

<table>
<thead>
<tr>
<th>Block</th>
<th>VOOR</th>
<th>NA</th>
<th>Nicht-zucht</th>
</tr>
</thead>
<tbody>
<tr>
<td>block1</td>
<td>16</td>
<td>14</td>
<td>Zucht</td>
</tr>
<tr>
<td>block2</td>
<td>18</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>block3</td>
<td>20</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>block4</td>
<td>22</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

**Respiratory variability preceding and following sighs: A resetter hypothesis**

Elke Vliegeninx, Bae Van Doors, Paul M. Lehrin, André E. Auberin, Omer Van den Bergin.

*Research Group on Health Psychology, Department of Psychology, University of Ghent, Belgium. E-mail: elke.vliegeninx@ugent.be*
Manipulation breathing

• Rate
  – 6 breaths/min ??
  – Psychological effects?

**Effect of rosary prayer and yoga mantras on autonomic cardiovascular rhythms: comparative study**

Luciano Bernardi, Peter Sleight, Gabriele Bandinelli, Simone Cescetti, Lamberto Fattorini, Johanna Włodarczyk-Szalek, Alfonso Lai

**Conclusion** Rhythm formulas that involve breathing at six breaths per minute induce favourable psychological and possibly physiological effects.

**Slow Breathing Increases Arterial Baroreflex Sensitivity in Patients With Chronic Heart Failure**

Luciano Bernardi, MD, Cesare Porta, MD, Lucia Spicuzza, MD, Jerry Belhers, MD, Giovanni Spadaccini, MD, Ansel F. Frey, MD, Louis Y.C. Yeung, MD, John E. Sunshine, MD, Roberto Pedotti, MD, Roberto Tomassoni, MD

**Conclusion**—These data suggest that slow breathing, in addition to improving oxygen saturation and exercise tolerance as has been previously shown, may be beneficial by increasing baroreflex sensitivity (Circulation, 2002;105:142-145).

**Slow Breathing Improves Arterial Baroreflex Sensitivity and Decreases Blood Pressure in Essential Hypertension**

Chucko N. Joseph, Cesare Porta, Gaia Cescacci, Nadia Cesurughi, Maria Maffei, Marco Rossi, Luciano Bernardi

Memory for dyspnea..

**HOW WAS YOUR DYSPNEA LATELY?**

Rebreathing test (Read, 1967)

- Switch to rebreathing bag
- Switch to room air

**Baseline** (60 sec)  **Rebreathing** (150 sec)  **Recovery** (150 sec)

- ↑ PCO₂
- ↑ ventilation
- ↑ breathlessness

Online dyspnea rating (every 10 sec)
**Rebreathing test** *(Read, 1967)*

Baseline (60 sec) → Rebreathing (150 sec) → Recovery (150 sec)

Switch to rebreathing bag

Switch to room air

Stop! You can take out the mouthpiece now

---

**Which physical discomfort was worse?**

A long trial

B short

Stop at peak

- Equally intense
- Shorter duration
- Stops abruptly
Which trial lasted longer?

![Bar chart showing comparison between Healthy and MUS trials.]

χ² = 0.09; n.s.

Which trial caused the greatest dyspnea at peak?

![Bar chart showing comparison between Healthy and MUS trials.]

χ² = 3.23
Which trial caused greatest discomfort?

\[ \chi^2 = 4.88 \]

Which trial would you prefer to repeat tomorrow?

\[ \chi^2 = 5.01 \]
Which physical discomfort was worse?

A long trial  

B short

Stop at peak

- Equally intense
- Shorter duration
- Stops abruptly

peak-end rule: A preferred to B
→ adding more aversive stimulation makes memory of it more positive

Peak-end rule

- Experience (emotional, somatic) is encoded
  - not as an integration of all elements with equal weight,
  - but in the form of transitions and singular critical moments
- Memory of the chain of sensations is determined by
  - Segment that felt most intense (peak)
  - Sensations in the final segment (end)
  - Relative duration neglect

Kahneman (2000)