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Activation of respiratory muscles during respiratory muscle training

Stephan Walterspacher[a,b,*], Fabian Pietsch[c], David Johannes Walker[a,b], Kai Röcker[d,e],
Hans-Joachim Kabitz[a]

[a] Department of Pneumology, Cardiology and Intensive Care Medicine, Academic Teaching Hospital Konstanz, Luisenstr. 7, 78464 Konstanz, Germany
[b] Department of Pneumology and Internal Medicine, University Witten-Herdecke, Alfred-Herrhausen-Straße 50, 58448 Witten, Germany
[c] Department of Internal Medicine, Hospital Buchholz and Winsen, Steinbecker Str. 44, 21244 Buchholz, Germany
[d] Department of Rehabilitative and Sports Medicine, University Hospital Freiburg, Hugstetterstr. 55, 79106 Freiburg, Germany
[e] Department of Applied Public Health (AGW), Furtwangen University, Robert-Gerwig-Platz 1, 78120 Furtwangen, Germany

ABSTRACT

It is unknown which respiratory muscles are mainly activated by respiratory muscle training. This study evaluated Inspiratory Pressure Threshold Loading (IPTL), Inspiratory Flow Resistive Loading (IFRL) and Voluntary Isocapnic Hyperpnea (VIH) with regard to electromyographic (EMG) activation of the sternocleidomastoid muscle (SCM), parasternal muscles (PARA) and the diaphragm (DIA) in randomized order.

Surface EMG were analyzed at the end of each training session and normalized using the peak EMG recorded during maximum inspiratory maneuvers (Sniff nasal pressure: SnPna, maximal inspiratory mouth occlusion pressure: PImax).

41 healthy participants were included. Maximal activation was achieved for SCM by SnPna; the PImax activated predominantly PARA and DIA. Activations of SCM and PARA were higher in IPTL and VIH than for IFRL ($p < 0.05$). DIA was higher applying IPTL compared to IFRL or VIH ($p < 0.05$).

IPTL, IFRL and VIH differ in activation of inspiratory respiratory muscles. Whereas all methods mainly stimulate accessory respiratory muscles, diaphragm activation was predominant in IPTL.

1. Introduction

Respiratory muscle training (RMT) is a valued tool in sport medical, rehabilitative and intensive care medicine, aimed at increasing respiratory muscle strength and endurance, functional exercise capacity, dyspnea and quality of life in diseased participants and athletes (Geddes et al., 2008; Gosselink et al., 2011; Illi et al., 2012; Elkins and Dentice, 2015; Schellekens et al., 2016). Three main concepts of RMT have been established so far: (1) inspiratory flow resistive loading (IFRL), (2) inspiratory pressure threshold loading (IPTL) and (3) voluntary isocapnic hyperpnea (VIH) (McConnell and Romer, 2004; Nici et al., 2006). IFRL and IPTL mainly increase respiratory muscle strength, whereas VIH increases respiratory muscle endurance (McConnell and Romer, 2004). However, it remains unclear which specific respiratory muscle groups are being trained by each method of RMT. This is of special interest when specific muscles, e.g. the diaphragm, are affected by weakness such as in COPD (Kabitz et al., 2007), interstitial lung disease (Kabitz et al., 2006; Walterspacher et al., 2013) or neuromuscular diseases (Terzi et al., 2008). Previous studies have shown that respiratory muscle activation can be variable when IPTL is applied, with

predominant diaphragmatic activation in healthy subjects (de Andrade et al., 2005; Ramsook et al., 2016). Other forms of RMT have not been studied with regard to electromyographic activation so far.

This study aimed at examining the neuromuscular activation of the 3 methods of RMT on 3 exemplary respiratory muscles by surface electromyography (EMG) during exemplary bouts of RMT in healthy participants. The H_0 hypothesis was defined as that there is no difference in the activation pattern of the diaphragm between the three forms of RMT.

2. Materials and methods

2.1. Ethics

The study design has been approved by the ethical committee of the University Hospital Freiburg/Germany (vote number: 144/11). The study was registered at the German Clinical Trial Registry before inclusion of the first participant (DRKS00000815). Informed consent was obtained from all individual participants included in the study. The study was conducted in adherence to the Declaration of Helsinki (WMA, 2013).

Table 1
Demographic and baseline respiratory data.

Parameter	Male [n = 25]	Female [n = 19]	Significance
Age [y]	24.0* [24.0; 25.3]	24.0* [23.0; 25.0]	0.256
Height [cm]	182 (7.5)	170 (5.2)	< 0.001
Weight [kg]	74 (7.1)	58 (7.3)	< 0.001
BMI [kg/m²]	22 (1.6)	20 (2.1)	< 0.001
FVC [L]	5.7 (0.68)	3.8 (0.59)	< 0.001
FVC%pred [%]	100.1 (22.7)	93.7 (13.4)	0.330
FEV1 [L]	4.5 (0.53)	3.2 (0.38)	< 0.001
FEV1%pred [%]	100.0 (8.5)	90.8 (10.6)	0.008
FEV1/FVC [%]	79.5 (5.4)	87.4 (5.8)	< 0.001
PImax [kPa]	12.4 (3.1)	9.2 (1.8)	< 0.001
SnPna [kPa]	10.5 (2.9)	8.4 (2.7)	0.034
MVV [L]	185.2 (20.6)	126.7 (13.8)	< 0.001

All values are mean with standard deviation, values marked with * are not-normally distributed and presented as median with interquartile ranges. BMI: body mass index; FVC: forced vital capacity; FEV1: forced expiratory volume in 1 s; PImax: maximal static inspiratory mouth pressure; SnPna: sniff nasal pressure; TLC: breathing to total lung capacity; MVV: maximal voluntary ventilation.

2.2. Participants

Healthy participants naive to RMT were recruited for the study (see Table 1). Exclusion criteria included all acute and chronic diseases (defined by medical history and spirometry testing) as well as pregnancy.

2.3. Experimental trial setup

Following spirometric baseline measurements (normal values according to Matthys et al. (Matthys et al., 1995)) (ZAN500, nSpire Health GmbH, Oberthulba, Germany), all participants were positioned in a standardized seating position with unsuspended arms hanging loosely next to the body for electrode placement and recording. The investigator held all measurement and training devices in order to minimize postural activation of other related muscle groups. Primarily, maximal respiratory effort tests were performed to determine maximal respiratory muscle strength for RMT device setting and assessment of maximal electromyographic activation. These tests included measurement of sniff nasal pressure (SnPna), maximal static inspiratory mouth pressure (PImax), maximal voluntary ventilation (MVV) and breathing to total lung capacity (TLC) and were performed according to prior recommendations (ATS/ERS, 2002; Kabitz et al., 2014). Then, exemplary bouts of RMT were conducted with 5 min of rest in between (details see below and in Fig. 1). All RMT modes were randomized in order using a software-based algorithm (Saghaei, 2004).

2.4. Respiratory muscle training – device set up

2.4.1. Voluntary isocapnic hyperpnea

VIH was conducted using SpiroTiger M 1.4 (idiag AG, Fehraltorf, Switzerland). The set up was individualized according to the manufacturers recommendations: bag volume according to 50% of vital capacity; minute volume was set as 60% of MVV; target tidal volume was set as bag volume × 1.2; target breathing frequency was set as minute volume·target tidal volume^{-1}. Two exemplary bouts of VIH lasting 1 min with a 30 s break in between were applied.

2.4.2. Inspiratory flow resistive loading

IFRL was conducted using RespiFit in the endurance mode setting (Biegler, Mauerbach, Austria). The set up was individualized according to the manufacturers recommendations: tidal volume was assessed while breathing through the device with 14 breath/min for 30 s set at 80% of the individual PImax. Two exemplary bouts of IFRL lasting 1 min with a 30 s break in between were applied.

2.4.3. Inspiratory pressure threshold loading

IPTL was conducted using POWERbreathe (IPTL-PB) (Powerbreathe Classic, HaB International Ltd, Warwickshire, UK), set at 80% of the individual PImax based on recommendations for IPTL (Janssens et al., 2013). Furthermore, a variant of IPTL was conducted using RespiFit in strength mode with identical settings (IPTL-RF). Target pressure was assured with a separate pressure transducer (see below). Two bouts of each 5 inspiratory efforts with a 30 s break in between were applied with each device.

2.5. Pressure and flow assessment

Pressure and volume recordings during respiratory muscle testing and RMT were acquired by interposing a heated pneumotach (Model 3813, Hans Rudolph Inc., Shawnee, USA), combined with an automated magnetic shutter device (ZAN, nSpire Health GmbH, Oberthulba, Germany) and pressure transducer (AdInstruments Pty, Castle Hill, Australia). Flow and pressure tracings were connected to a 16 channel A/D converter (Powerlab, ADInstruments Pty, Castle Hill, Australia), recorded and examined simultaneously along with the EMG recordings (see below) (LabChart v.7.2, ADInstruments Pty, Castle Hill, Australia).

2.6. Electromyographic assessment

After localization of the anatomical landmarks for each muscle group the skin was prepared with alcoholic wipes and skin preparation gel (skinPure, NihonKoden, Tokyo, Japan) and was shaved in male participants. The pairs of bipolar silver gel-coated skin EMG electrodes (3 M RedDot ECG Electrodes, 3 M Deutschland, Neuss Germany) were placed bilaterally (inter-electrode distance of 2 cm) for the lower electrode 7 cm cranially of the incisura jugularis for the sternocleido-mastoid muscle (SCM) (Nava et al., 1993); for the parasternal muscles (PARA) at the 2nd intercostal space (Maarsingh et al., 2000). For the diaphragm (DIA) the electrode pairs were placed bilaterally at the lower costal margin, 16 cm laterally of the common electrode, placed 5 cm cranially of the xiphoid (Dionne et al., 2009).

All electrodes were connected to a 16 channel A/D converter (Powerlab, ADInstruments Pty, Castle Hill, Australia) and recorded simultaneously at a sampling rate of 10 kHz via a 16-channel bio-amplifier (gain x 1000; g.BSamp, g.tec medical engineering GmbH, Schiedlberg, Austria). Mouth pressure and respiratory flow traces were recorded at 400 Hz (Walterspacher et al., 2016).

The following signal filters were applied prior further calculations on all channels: mains filter at 50/60 Hz, high-pass filter at 0.5 Hz, low-pass filter at 1 kHz. Band pass filtering was applied in order to narrow the frequencies between 20 Hz and 1 kHz (Jolley et al., 2009). The signal was then processed to root-mean-square with a triangular averaging window of 200 ms (RMS; LabChart v.7.2, ADInstruments Pty, Castle Hill, Australia).

The RMS-EMG signals were analyzed during a manually selected 200 ms time frame at inspiration peak at specified time points (see Table 2) (Walterspacher et al., 2016). Electrocardiographic artifacts were avoided by visual inspection and the highest data of either side according to the signal-to-noise ratio are reported. The signal-to-noise ratio describes the proportion of baseline noise to the maximal innervation of the examined muscle. The individual body side with the lowest signal-to noise ratio for each muscle group was used for further examinations during each RMT mode.

For intra- and inter-individual comparison all EMG data of each RMT mode were calculated as% of the maximal innervation for each muscle group according to the maximal maneuvers performed at the beginning of each study session (%$_{max}$) (Jolley et al., 2009; Murphy et al., 2011).