Universidade do Porto

Faculdade de Desporto

# A função abdominal para a sincronização do controlo postural e da ventilação em indivíduos em risco de desenvolvimento da DPOC

Dissertação submetida com vista à obtenção do grau de Doutor no âmbito do Curso de Doutoramento em Fisioterapia pela Faculdade de Desporto da Universidade do Porto, nos termos do Decreto-lei n.º 74/2006 de 24 de março.

Orientador: Professor Doutor João Paulo Vilas-Boas

Faculdade de Desporto da Universidade do Porto (FADE-UP) e Laboratório de Biomecânica do Porto (LABIOMEP)

António Manuel Soares Mesquita Montes

Porto, 2017

Esta Tese teve o apoio da Faculdade de Desporto da Universidade do Porto (FADE-UP) e do Laboratório de Biomecânica do Porto (LABIOMEP), da Escola Superior de Saúde do Politécnico do Porto (ESS-P. Porto) e do Centro de Estudos do Movimento e Atividade Humana (CEMAH).

Referência:

Mesquita Montes, A. (2017). *A função abdominal para a sincronização do controlo postural e da ventilação em indivíduos em risco de desenvolvimento da DPOC.* Porto: A. Mesquita Montes. Dissertação de Doutoramento em Fisioterapia apresentada à Faculdade de Desporto da Universidade do Porto.

PALAVRAS-CHAVE: DOENÇA PULMONAR OBSTRUTIVA CRÓNICA; “ESTÁDIO 0”; RESPIRAÇÃO; POSTURA; MÚSCULOS ABDOMINAIS

*Eu sei que o meu trabalho é uma gota no oceano, mas sem ele o oceano seria menor.*

Madre Teresa de Calcutá

## Agradecimentos

Em primeiro lugar, ao Professor Doutor João Paulo Vilas-Boas expresso o meu profundo agradecimento pela orientação, pela pertinência das opiniões e críticas que elevaram, sem dúvida, os meus conhecimentos científicos, pela confiança e por todo o apoio.

À Professora Doutora Cristina Argel de Melo, pela amizade verdadeira, pela disponibilidade, pela compreensão e pela precisão científica dos seus comentários, que estimularam o meu desejo de querer saber e fazer melhor.

Ao Professor Doutor Paulo Carvalho pela amizade paternal e pela dedicação com que me transmitiu o seu saber.

À Mestre Rita Santos e ao Mestre Carlos Crasto pela amizade sincera e pelo apoio incondicional.

Ao Professor Doutor Rubim Santos pela colaboração e pela disponibilidade.

Ao Doutor Pedro Maciel Barbosa e ao Mestre Daniel Costa pela discussão ininterrupta.

Aos ex-estudantes da linha de investigação de "Biomecânica ventilatória e Controlo motor" da ESS-P.Porto: Ana Sofia Costa, Anabela Carvalho, Carolina Tam, Edgar Ribeiro, Ivo Esteves, Joana Maia, João Paulo Baptista, Liliana Bastos e Sara Gouveia, o meu obrigado pela ajuda inexcedível no recrutamento dos participantes e na recolha de dados.

A todos os colegas da Área Técnico-Científica da Fisioterapia da ESS-P.Porto pelo apoio incondicional e pela colaboração, em especial ao grupo de cardiorrespiratória.

Às inúmeras pessoas sem as quais esta Tese não teria sido possível.

Por último, dirijo um especial agradecimento aos meus pais, ao meu afilhado e à minha irmã, por acreditarem em mim, pelo apoio incondicional e encorajamento, pela paciência demonstrada e ajuda inexcedível na superação dos obstáculos que surgiram ao longo desta caminhada.

A presente Tese é baseada nos seguintes estudos originais, referenciados em numeração romana:

**Artigo I.** Mesquita Montes, A., Gouveia, S., Crasto, C., Argel de Melo, C., Carvalho, P., Santos, R., & Vilas-Boas, J. P. (2016). Abdominal muscle activity during breathing in different postural sets in healthy subjects. *Journal of Bodywork & Movement Therapies*. doi:10.1016/j.jbmt.2016.09.004 *(in Press)*

**Artigo II.** Mesquita Montes, A., Tam, C., Crasto, C., Argel de Melo, C., Carvalho, P., Santos, R., & Vilas-Boas, J. P. Respiratory activity and thoraco-abdominal movement in forward-leaning position with arm and head support in healthy subjects. Submetido para publicação.

**Artigo III.** Mesquita Montes, A., Baptista, J., Crasto, C., Argel de Melo, C., Santos, R., & Vilas-Boas, J. P. (2016). Abdominal muscle activity during breathing with and without inspiratory and expiratory loads in healthy subjects. *Journal of Electromyography and Kinesiology, 30*, 143-150. doi:10.1016/j.jelekin.2016.07.002

**Artigo IV.** Mesquita Montes, A., Esteves, I., Crasto, C., Argel de Melo, C., Santos, R., Santos, R., & Vilas-Boas, J. P. Centre of pressure displacement during breathing with and without inspiratory and expiratory loads in healthy subjects. Submetido para publicação.

**Artigo V.** Mesquita Montes, A., Maia, J., Crasto, C., Argel de Melo, C., Carvalho, P., Santos, R., Pereira, S., & Vilas-Boas, J. P. (2017). Abdominal muscle activity during breathing in different postures in COPD “Stage 0” and healthy subjects. *Respiratory Physiology & Neurobiolgy, 238*, 14-22. doi:10.1016/j.resp.2017.01.001

**Artigo VI.** Mesquita Montes, A., Crasto, C., Argel de Melo, C., Santos, R., Pereira, S., & Vilas-Boas, J. P. The effect of inspiratory and expiratory loads on the abdominal muscle activity during breathing in subjects “at risk” for the development of chronic obstructive pulmonary disease and healthy. Submetido para publicação.

**Artigo VII.** Mesquita Montes, A., Ribeiro, E., Crasto, C., Argel de Melo, C., Santos, R., Santos, R., Pereira, S., & Vilas-Boas, J. P. The effect of inspiratory and expiratory loads on the centre of pressure displacement during breathing in subjects “at risk” for the development of chronic obstructive pulmonary disease and healthy. Submetido para publicação.

# Índice Geral


Agradecimentos ..... v
Lista de Estudos Originais ..... vii
Índice Geral ..... ix
Índice de Figuras ..... xiii
Índice de Tabelas ..... xix
Índice de Apêndices ..... xxiii
Resumo ..... xxv
Abstract ..... xxvii
Lista de Abreviaturas e Símbolos ..... xxix
**Capítulo I. Introdução Geral** ..... 1
**Capítulo II. Revisão da Literatura** ..... 7
A função dos abdominais ..... 9
Doença pulmonar obstrutiva crónica (DPOC) ..... 13
**Capítulo III. Questões de Investigação e Objetivos** ..... 19
Questão de investigação 1 ..... 21
Questão de investigação 2 ..... 25
**Capítulo IV. Estudos originais** ..... 31
Artigo I ..... 33
- Abstract ..... 35
- Introduction ..... 36
- Methods ..... 38
- Results ..... 45
- Discussion ..... 49
- Conclusion ..... 52
- Acknowledgements ..... 53
- Conflict of interest statement ..... 53
- References ..... 53

Artigo II ..... 59
- Abstract ..... 61
- Introduction ..... 62
- Methods ..... 63
- Results ..... 70

Discussion ........ 76
Conclusion ........ 79
Acknowledgements ........ 79
Conflict of interest statement ........ 80
References ........ 80
Artigo III ........ 85
Abstract ........ 87
Introduction ........ 88
Methods ........ 89
Results ........ 97
Discussion ........ 100
Conclusion ........ 103
Acknowledgements ........ 104
Conflict of interest statement ........ 104
References ........ 104
Artigo IV ........ 109
Abstract ........ 111
Introduction ........ 112
Methods ........ 113
Results ........ 117
Discussion ........ 119
Conclusion ........ 122
Acknowledgements ........ 123
Conflict of interest statement ........ 123
References ........ 123
Artigo V ........ 127
Abstract ........ 129
Introduction ........ 130
Methods ........ 132
Results ........ 141
Discussion ........ 145
Conclusion ........ 151
Acknowledgements ........ 151
Conflict of interest statement ........ 152

References ........ 152
Artigo VI ........ 159
Abstract ........ 161
Introduction ........ 162
Methods ........ 164
Results ........ 171
Discussion ........ 174
Conclusion ........ 178
Acknowledgements ........ 178
Conflict of interest statement ........ 178
References ........ 179
Artigo VII ........ 185
Abstract ........ 187
Introduction ........ 188
Methods ........ 189
Results ........ 195
Discussion ........ 199
Conclusion ........ 202
Acknowledgements ........ 203
Conflict of interest statement ........ 203
References ........ 203
*Highlights* ........ 209
**Capítulo V. Discussão Geral** ........ 213
Discussão integrada dos resultados ........ 215
Considerações metodológicas ........ 226
Implicações para a prática clínica e a investigação futura ........ 229
**Capítulo VI. Conclusões** ........ 233
**Capítulo VII. Referências Bibliográficas** ........ 237
Apêndices ........ xxxiii
Apêndice 1. Parecer da comissão de ética ........ xxxv
Apêndice 2. Consentimento informado ........ xxxix

# Índice de Figuras

**Capítulo III**

Figura 1. Diagrama representativo do racional da presente Tese........... 29

**Capítulo IV**

Artigo I

Figure 1. Activation intensity of erector *spinae* muscle (expressed as %) during breathing in supine, tripod position, 4-point kneeling and standing. Data are presented as mean and standard deviation. *p* values for significant differences between postural sets are also presented.................................. 46

Figure 2. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during inspiration in supine, tripod position, 4-point kneeling and standing. Data are presented as mean and standard deviation. *p* values for significant differences between postural sets are also presented .................................................... 48

Figure 3. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during expiration in supine, tripod position, 4-point kneeling and standing. Data are presented as mean and standard deviation. *p* values for significant differences between postural sets are also presented .................................................... 48

Artigo II

Figure 1. Activation intensity of *sternocleidomastoideus* and *scalenus* muscles (expressed as %) during inspiration in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented ......................................................................................................... 72

Figure 2. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during

inspiration in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented .................................................... 73

Figure 3. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during expiration in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented .................................................................. 74

Figure 4. Magnitude of thoraco-abdominal movements – anterior-posterior of the upper ribcage, medial-lateral of the lower ribcage and anterior-posterior of the abdomen – (expressed as millimetres) during breathing in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented ........................................................................................... 75

Artigo III

Figure 1. Identification of one respiratory cycle (inspiration and expiration phases) through the respiratory flow transducer signal, and corresponding surface electromyography (sEMG) signal analysis. ...................................... 95

Figure 2. Surface electromyography (sEMG) signal analysis of one maximal expiratory pressure manoeuvre. T0 is the initial of expiratory phase. ................................................................................................................. 96

Figure 3. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during

inspiration without respiratory load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented ............................................ 98
Figure 4. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during expiration without respiratory load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented ............................................ 99

Artigo IV
Figure 1. Mean amplitude of the centre of pressure (CoP) displacement (expressed as millimetres), in anterior-posterior and medial-lateral directions, during breathing without load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented ........................................... 118
Figure 2. Mean velocity of the centre of pressure (CoP) displacement (expressed as millimetres.seconds$^{-1}$), in anterior-posterior and medial-lateral directions, during breathing without load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented ........................... 118
Figure 3. Total mean velocity of the centre of pressure (CoP) displacement (expressed as millimetres.seconds$^{-1}$) during breathing without load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented ......................................................................................... 119

Artigo V
Figure 1. Schematic representation of the four postures adopted by the participants. A: standing; B: supine; C: tripod position (45º of trunk flexion to vertical); D: 4-point kneeling position. ........................................................ 139
Figure 2. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles (expressed as %)

during inspiration in supine, tripod position, 4-point kneeling (4-point) and standing in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented .......... 144
Figure 3. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles (expressed as %) during expiration in supine, tripod position, 4-point kneeling (4-point) and standing in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented .......... 144
Figure 4. Activation intensity of erector *spinae* muscle (expressed as %) during breathing in supine, tripod position, 4-point kneeling (4-point) and standing in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented .......... 145

Artigo VI
Figure 1. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles (expressed as %) during inspiration without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented .......... 173
Figure 2. Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles (expressed as %) during expiration without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented .......... 174

Artigo VII
Figure 1. Base of support measurements from the footprints: halluces distance (HD), inter-*malleolus* distance (IMD) and effective foot length (EFL). .......... 195

Figure 2. Mean amplitude of the centre of pressure (CoP) displacement (millimetres), in anterior-posterior and medial-lateral directions, during breathing without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison between groups and within subjects is also presented ........................................................................................... 197
Figure 3. Mean velocity of the centre of pressure (CoP) displacement (millimetres.seconds$^{-1}$), in anterior-posterior and medial-lateral directions, during breathing without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison between groups and within subjects is also presented ................................................................... 198
Figure 4. Total mean velocity of the centre of pressure (CoP) displacement (millimetres.seconds$^{-1}$) during breathing without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison between groups and within subjects is also presented ............ 199

# Índice de Tabelas

**Capítulo IV**

Artigo I

Table 1. Sample characterization: demographic and anthropometric data, with mean, standard deviation, minimum and maximum. .............................. 39

Table 2. Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (OE), *transversus abdominis*/internal oblique (TrA/IO) and erector *spinae* (ES) muscles. .................................................. 42

Artigo II

Table 1. Sample characterization: demographic, anthropometric and body composition data, with mean, standard deviation, minimum and maximum. ......................................................................................... 64

Table 2. Activation intensity of upper *trapezius* muscle (expressed as %) during inspiration in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented .................................................... 71

Artigo III

Table 1. Sample characterization: demographic and anthropometric data, with mean, standard deviation, minimum and maximum. .............................. 90

Table 2. Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/internal oblique (TrA/IO) muscles. ........................................................................ 93

Table 3. Partial eta squared, effect size and power test for the comparison of the percentage of activation intensity of *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/internal oblique muscles (TrA/IO) between the different evaluation tasks (without respiratory load and with inspiratory or expiratory loads), during inspiration and expiration. ....... 100

Artigo IV

Table 1. Sample characterization: demographic and anthropometric data, with mean, standard deviation, minimum and maximum. ............................ 114

Artigo V

Table 1. “At Risk” for COPD and Healthy groups’ characterization: sociodemographic, anthropometric and body composition data, with mean and standard deviation. *p* values for significant differences between groups are also presented ............................................................................. 134

Table 2. Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (OE), *transversus abdominis*/internal oblique (TrA/IO) and erector *spinae* (ES) muscles. .................................................. 138

Table 3. Pulmonary function data in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for significant differences between groups are also presented............................................................ 142

Artigo VI

Table 1. “At Risk” for COPD and Healthy groups’ characterization: sociodemographic, anthropometric and body composition data, with mean and standard deviation. *p* values for significant differences between groups are also presented ............................................................................. 165

Table 2. Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/internal oblique (TrA/IO) muscles. ....................................................................... 168

Table 3. Pulmonary function data in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for significant differences between groups are also presented............................................................ 172

Artigo VII

Table 1. “At Risk” for COPD and Healthy groups’ characterization: sociodemographic, anthropometric and body composition data, with mean and standard deviation. *p* values for significant differences between groups are also presented ........................................................................................ 191

Table 2. Pulmonary function data in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for significant differences between groups are also presented ............................................................. 196

*Highlights*

Tabela 1. *Highlights* dos resultados da presente Tese. ........................ 211

# Índice de Apêndices

Apêndice 1. Parecer da comissão de ética ............................................. xxvii
Apêndice 2. Consentimento informado .................................................... xxxi

# Resumo

**Introdução:** Embora existam estratégias para coordenar o controlo postural e a ventilação numa situação normal, a função muscular abdominal pode estar comprometida na doença pulmonar obstrutiva crónica (DPOC). Não obstante um défice na capacidade dos músculos do tronco para a dupla tarefa na DPOC, não existe evidência científica no estádio GOLD 0: *at risk*. **Objetivos:** Avaliar a função muscular abdominal para a sincronização da função postural e da mecânica da ventilação, em indivíduos saudáveis (1) e em risco de desenvolvimento da DPOC (2). **Metodologia:** Estudo de medidas repetidas, numa amostra constituída por: (1) adultos jovens saudáveis (idade entre os 18 e os 25 anos); e (2) indivíduos fumadores sintomáticos, com espirometria normal (idade superior a 40 anos). A atividade muscular abdominal (eletromiografia de superfície) durante a ventilação foi avaliada em diferentes conjuntos posturais ou com e sem resistências inspiratória e expiratória. O deslocamento do centro de pressão (plataforma de forças) foi avaliado durante a ventilação com e sem resistências ventilatórias. **Resultados:** Os Artigos I, II e III indicaram que o transverso abdominal/oblíquo interno parece ser o músculo mais relevante aquando de um aumento das exigências postural ou ventilatória, em indivíduos saudáveis. O padrão específico de recrutamento dos músculos abdominais parece afetar a contribuição do tronco para o controlo postural (Artigo IV). Os Artigos V e VI sugerem que, durante a ventilação, indivíduos em risco de desenvolvimento da DPOC possuem um recrutamento muscular do reto abdominal e do oblíquo externo, que se repercute num aumento do deslocamento médio-lateral do centro de pressão (Artigo VII). **Conclusão:** O padrão específico de recrutamento da camada miofascial superficial do abdómen durante a ventilação e, por sua vez, o seu impacto negativo no controlo postural, suportam um novo potencial clínico em indivíduos em risco de desenvolvimento da DPOC.

PALAVRAS-CHAVE: DOENÇA PULMONAR OBSTRUTIVA CRÓNICA; “ESTÁDIO 0”; RESPIRAÇÃO; POSTURA; MÚSCULOS ABDOMINAIS

# Abstract

**Introduction:** Although there are strategies for the synchronization of postural control and breathing in a normal situation, the abdominal muscle function may be compromised in chronic obstructive pulmonary disease (COPD). Nevertheless a deficit in the ability of trunk muscles' dual task in COPD, there is no scientific evidence in stage GOLD 0: at risk. **Aims:** To evaluate the abdominal muscle function for the synchronization of postural and respiratory functions, in healthy subjects (1) and in subjects "at risk" for the development of COPD (2). **Methods:** Repeated measures study, with a sample composed by: (1) healthy young adults (age between 18 and 25 years); and (2) symptomatic smokers, with a normal spirometry (over 40 years of age). Abdominal muscle activity (surface electromyography) was assessed during breathing in different postural sets or with and without inspiratory and expiratory loads. Centre of pressure displacement (forceplate) was assessed during breathing with and without respiratory loads. **Results:** Research papers I, II and III indicated that *transversus abdominis*/internal oblique seems to be the most relevant muscle when postural or respiratory demand increases. The specific recruitment pattern of abdominal muscles seems to affect the contribution of trunk for postural control (Research paper IV). Research papers V and VI suggested that, during breathing, subjects "at risk" for the development of COPD have a recruitment of *rectus abdominis* and external oblique muscles, which reflects in an increased medio-lateral displacement of the centre of pressure (Research paper VII). **Conclusions:** The specific recruitment pattern of superficial muscle layer of ventrolateral abdominal wall during breathing and, consequently, its negative impact on the postural control, support a potential new clinic entity in subjects "at risk" for the development of COPD.

KEYWORDS: CHRONIC OBSTRUCTIVE PULMONARY DISEASE, "STAGE 0", RESPIRATION, POSTURE, ABDOMINAL MUSCLES

# Lista de Abreviaturas e Símbolos

| | |
|---|---|
| 4-point | 4-point kneeling |
| BMI | Body mass index |
| BoS | Base of support |
| CAT | COPD assessment test |
| CNS | Central nervous system |
| CoM | Centre of mass |
| CoP | Centre of pressure |
| COPD | Chronic obstructive pulmonary disease |
| DPOC | Doença Pulmonar Obstrutiva Crónica |
| EFL | Effective foot length |
| EL | Expiratory load |
| EO | External oblique |
| ES | Erector *spinae* |
| $FEF_{25\%}$ | Forced expiratory flow at 25 % of FVC |
| $FEF_{50\%}$ | Forced expiratory flow at 50 % of FVC |
| $FEF_{75\%}$ | Forced expiratory flow at 75 % of FVC |
| $FEF_{25\%-75\%}$ | Forced expiratory flow at 25 %-75 % of FVC |
| $FEV_1$ | Forced expiratory volume in one second |
| FVC | Forced vital capacity |
| GOLD | *Global Initiative for Cronic Obstructive Lung Disease* |

| | |
|---|---|
| HD | Halluces distance |
| IL | Inspiratory load |
| IMD | Inter-*malleolus* distance |
| IO | Internal oblique |
| MEP | Maximal expiratory pressure |
| MIP | Maximal inspiratory pressure |
| MIVC | Maximal isometric voluntary contraction |
| mMRC | Modified British Medical Council |
| *p* (*P*) | *p*-value |
| $\eta_p^2$ | Partial eta square |
| RA | *Rectus abdominis* |
| RMS | Root mean square |
| sEMG | Surface electromyography |
| SitAHS | Sitting with forward-leaning trunk and arm/head support |
| SitAS | Sitting with forward-leaning trunk and arm support |
| SNC | Sistema Nervoso Central |
| StandAS | Standing with forward-leaning trunk and arm support |
| TrA | *Transversus abdominis* |
| TrA/IO | *Transversus abdominis*/internal oblique |
| USit | Upright sitting |
| UStand | Upright standing |

| | |
|---|---|
| UT | Upper *trapezius* |
| WRL | Without respiratory load |

**Capítulo I**

# Introdução Geral

A doença pulmonar obstrutiva crónica (DPOC), uma patologia comum prevenível e tratável, é caracterizada por uma limitação persistente do fluxo expiratório, que é usualmente progressiva e associada a uma resposta crónica inflamatória nas vias aéreas e no pulmão, a partículas ou a gases nocivos (Global Initiative for Chronic Obstructive Lung Disease, 2016; Vestbo et al., 2013). Esta patologia é uma das principais causas de morbilidade e mortalidade em todo o mundo, que resulta numa elevada responsabilidade social e económica (Lozano et al., 2012). De acordo com a estimativa da World Health Organization (2004), a DPOC afeta cerca de 63,6 milhões de pessoas em todo o mundo, sendo que em Portugal a prevalência estimada é de 14,2% da população (região de Lisboa) (Barbara et al., 2013). A World Health Organization (2008) prevê que em 2030 a DPOC seja a terceira causa de morte no mundo.

O estádio *Global Initiative for Chronic Obstructive Lung Disease* (GOLD) 0: *at risk*, subcategoria de indivíduos em risco de desenvolvimento da DPOC, foi descartado das atualizações da *Global strategy for diagnosis, management, and prevention of chronic obstructive pulmonary disease* por não existir evidência científica de que estes indivíduos estivessem mais propensos ao desenvolvimento da DPOC (Fabbri, Pauwels, Hurd, & GOLD Scientific Committee, 2004). Contudo, ao expandir os sintomas presentes na GOLD 0: *at risk* (tosse crónica e produção de expetoração), para outros sintomas respiratórios crónicos, como a dispneia, a pieira, a limitação da atividade física e as exacerbações relacionadas com a DPOC (que necessitam de cuidados em saúde), os fumadores sintomáticos, mas com uma espirometria normal possuem maior risco de morbilidade e mortalidade (de Marco et al., 2007; de Oca et al., 2012; Mannino, Doherty, & Buist, 2006; Stavem, Sandvik, & Erikssen, 2006). A investigação direcionada ao subconjunto de indivíduos em risco de desenvolvimento da DPOC pode suportar um novo potencial clínico e permitir a compreensão da história natural da DPOC (Rodriguez-Roisin et al., 2016).

A função coordenada entre o suporte postural antigravítico (controlo postural) e o controlo do movimento da coluna vertebral e da pélvis (ventilação) é alcançada através da co-ativação sinérgica dos músculos abdominais (Key, 2013). O equilíbrio entre os níveis de atividade das camadas miofasciais profunda (transverso abdominal) e superficial (reto abdominal e oblíquos interno e externo) da parede ventrolateral do abdómen é importante para criar um nível de pressão intra-abdominal apropriado à exigência da dupla tarefa (Hodges & Gandevia, 2000a, 2000b; Kolar et al., 2010). Embora existam estratégias para proporcionar um suporte adaptativo para a modulação integrada destes mecanismos de controlo do *core* abdominal, a função muscular abdominal pode estar comprometida na DPOC, em que subsiste um maior desafio ventilatório.

A sobrecarga mecânica intrínseca sobre o diafragma, em indivíduos com limitação do fluxo expiratório, inclusive durante a ventilação em repouso (De Troyer, Leeper, McKenzie, & Gandevia, 1997; Gorini et al., 1990), resulta num aumento da *drive* neural para os músculos acessórios da inspiração (Gandevia, Leeper, McKenzie, & De Troyer, 1996) e da expiração (Ninane, Rypens, Yernault, & De Troyer, 1992), com consequente alteração do padrão de mobilização das cavidades torácica e abdominal (Martinez, Couser, & Celli, 1990). Não obstante a patofisiologia primária subjacente à DPOC ser caracterizada por um defeito ventilatório obstrutivo, consequências não respiratórias, incluindo a redução na performance muscular periférica, na mobilidade funcional e na capacidade de exercício, contribuem para os sintomas e a incapacidade (Maltais, LeBlanc, Jobin, & Casaburi, 2000). A evidência científica recente sugere que indivíduos com DPOC exibem também défices significativos ao nível do controlo postural (Beauchamp, Brooks, & Goldstein, 2010; Roig, Eng, Road, & Reid, 2009). É, portanto, razoável admitir a hipótese de que a capacidade dos músculos do tronco para a sincronização do controlo postural e da mecânica da ventilação pode estar comprometida em indivíduos em risco de desenvolvimento da DPOC (Smith, Chang, Seale, Walsh, & Hodges, 2010).

De modo a dar resposta às questões de investigação e aos respetivos objetivos, esta Tese encontra-se organizada em 7 capítulos. O **Capítulo I** compreende uma visão global da pertinência desta investigação. A revisão da literatura sobre o tema de investigação: a função dos abdominais para a sincronização do controlo postural e da mecânica da ventilação em indivíduos saudáveis e em risco de desenvolvimento da DPOC, encontra-se no **Capítulo II**. O **Capítulo III** explora as duas questões de investigação e os respetivos objetivos. O **Capítulo IV** é composto por sete estudos originais desenvolvidos no âmbito desta investigação. Ainda, neste capítulo, estão descritos os *highlights* dos estudos originais da presente Tese. A discussão integrada dos resultados, as considerações metodológicas e as implicações para a prática clínica e a investigação futura encontram-se no **Capítulo V**. O **Capítulo VI** descreve as principais conclusões desta Tese. As referências bibliográficas da presente Tese encontram-se no **Capítulo VII**. Contudo, as referências bibliográficas dos estudos originais estão apresentadas no final de cada um, para manter a estrutura original destes.

**Capítulo II**

# Revisão da Literatura

A alteração constante das forças internas e externas que atuam sobre o corpo humano determinam que o sistema nervoso central (SNC) organize um sistema de controlo e coordenação, complexo e diferenciado, para mover e manter a estabilidade da coluna vertebral e da pélvis (Horak, Henry, & Shumway-Cook, 1997). O SNC interpreta continuamente o estado de estabilidade, recebendo e integrando os *inputs* aferentes dos mecanorrecetores e de outros sistemas sensoriais, para criar uma resposta coordenada dos músculos do tronco (Balasubramaniam & Wing, 2002; Lackner & DiZio, 2005).

Os músculos diafragma, da parede anterior e lateral do abdómen e do pavimento pélvico delimitam uma estrutura cilindriforme que rodeia a coluna vertebral – o *core* abdominal (Hodges, 2004). Uma relação postural e funcional equilibrada entre o tórax e a pélvis proporciona as dimensões internas ideais do *core* abdominal, promovendo uma função otimizada entre o suporte postural antigravítico – o controlo postural – e o controlo do movimento da coluna vertebral e da pélvis – a ventilação (Key, 2013).

A ação coordenada entre o controlo postural e a ventilação é alcançada pela co-ativação sinérgica dos músculos do tronco, para proporcionar um suporte adaptativo na modulação destes mecanismos de controlo do *core* abdominal. Especificamente, o diafragma e o transverso abdominal possuem um papel crucial nos mecanismos de alteração da pressão interna do *core* abdominal – a pressão intra-abdominal (Hodges & Gandevia, 2000a, 2000b; Hodges, Gandevia, & Richardson, 1997). De realçar que a capacidade destes músculos para modelar apropriadamente o volume e a pressão do *core* abdominal não é apenas subjacente ao controlo postural e à ventilação, mas também a uma variedade de outras funções homeostáticas (Hodges, 1999).

## A função dos abdominais

Os músculos abdominais – o transverso abdominal, os oblíquos interno e externo e o reto abdominal – constituem um conjunto de camadas miofasciais que formam a parede anterior e lateral do abdómen (Drake, Vogl, & Mitchell, 2014). Estes músculos possuem um papel crucial num controlo complexo das sinergias que contribuem para o controlo postural e para a ventilação.

*Controlo postural*

Os músculos abdominais preservam o equilíbrio postural e a estabilidade da coluna vertebral multisegmentar, através da sua contribuição para a modulação da pressão intra-abdominal (Cholewicki, Juluru, & McGill, 1999). Este mecanismo de controlo e suporte postural é uma resposta antecipatória ou automática, apropriadamente adequada à tarefa, que promove um efeito de estabilização interna sobre a coluna lombar (Cresswell, Grundstrom, & Thorstensson, 1992).

A evidência científica sugere um controlo independente entre as camadas miofasciais profunda (transverso abdominal) e superficial (reto abdominal e oblíquos interno e externo) da parede ventrolateral do abdómen (Hodges & Richardson, 1999). A atividade tónica do transverso abdominal contribui para o controlo da estabilidade intervertebral (Crommert, Ekblom, & Thorstensson, 2011), através da modulação da pressão intra-abdominal (Cresswell et al., 1992) e/ou da transmissão de forças sobre a coluna lombar via fáscia toracolombar. Por sua vez, a ação fásica do reto abdominal e dos oblíquos interno e externo permite controlar os momentos de força impostos sobre a coluna vertebral, bem como a relação espacial entre o tórax, a coluna vertebral e a pélvis (McCook, Vicenzino, & Hodges, 2009; Saunders, Rath, & Hodges, 2004).

Deste modo, o equilíbrio entre os níveis de atividade muscular do diafragma, dos abdominais e do pavimento pélvico é importante para criar um nível de pressão intra-abdominal apropriado à exigência da tarefa, que possibilite o suporte postural e a confluência de padrões ventilatórios normais, durante as atividades funcionais (Hodges & Gandevia, 2000b; Kolar et al., 2010).

*Mecânica da ventilação*

A evidência científica enfatiza que a contribuição dos músculos abdominais para a ventilação, apesar da sua ação predominantemente expiratória, é também relevante para a inspiração (Macklem, 2014). De facto, a ventilação é alcançada pela modulação alternada do diafragma e do transverso abdominal, resultando em alterações cíclicas na configuração do *core* abdominal (Hodges & Gandevia, 2000b). Durante a inspiração, o aumento da pressão intra-abdominal criado pelo aplanamento das cúpulas diafragmáticas e consequente deslocamento das vísceras contra a parede abdominal deve ser combatido pela tensão dos músculos abdominais (De Troyer, Estenne, Ninane, Van Gansbeke, & Gorini, 1990). Sem uma *compliance* suficiente destes músculos, o tendão central do diafragma não pode ser efetivamente estabilizado, comprometendo, por sua vez, a expansão lateral da caixa torácica inferior (De Troyer & Estenne, 1988). Desta forma, os escalenos e os intercostais paraesternais aumentam a sua atividade tónica, deslocando o esterno e as costelas superiormente, alterando a configuração e os movimentos da caixa torácica (Macklem, 2014).

Por outro lado, aquando de um aumento da exigência ventilatória, o sistema respiratório tende a limitar a atividade muscular inspiratória, transferindo qualquer sobrecarga adicional aos músculos abdominais (Aliverti et al., 1997). O aumento da pressão intra-abdominal, criado pela contração dos músculos abdominais, durante uma expiração ativa pressiona cranialmente o diafragma e exerce um estiramento passivo sobre as suas fibras costais. Esta ação muscular expiratória otimiza a relação comprimento-tensão do diafragma, colocando-o numa posição de vantagem mecânica para a subsequente inspiração (De Troyer & Estenne, 1988).

*O desafio de coordenar múltiplas funções*

O controlo postural e a ventilação estão intrinsecamente ligados. Durante a ventilação a volume corrente, o controlo postural proporciona uma base de suporte espacialmente apropriada e estável da coluna vertebral inferior e da pélvis. Por sua vez, um tórax alinhado numa relação equilibrada com a pélvis possibilita a estabilização das fibras crurais do diafragma e a consecução das condições ótimas para a ação das fibras costais deste, permitindo uma descida eficaz do seu tendão central (Key, 2013). A criação de um nível de pressão intra-abdominal adequado, devido ao aplanamento das hemicúpulas diafragmáticas, é transmitida à zona de aposição do diafragma, auxiliando as suas fibras costais na elevação e rotação externa das costelas inferiores e, consequentemente, na expansão lateral da caixa torácica (De Troyer & Estenne, 1988; Goldman & Mead, 1973). Um padrão postural e ventilatório "saudável" depende de níveis de co-ativação e coordenação equilibrados entre os músculos diafragma, abdominais (nomeadamente o transverso abdominal) e do pavimento pélvico. Estes músculos têm que ser capazes de modular os seus níveis de atividade tónica para suportar o equilíbrio postural e ao mesmo tempo de sobrepor a atividade fásica para preservar as exigências ventilatórias (Hodges & Gandevia, 2000a, 2000b; Kolar et al., 2010). Apesar da dependência do sistema miofascial profundo (diafragma, transverso abdominal e músculos do pavimento pélvico), a criação de uma pressão intra-abdominal apropriada é também dependente de um nível de atividade equilibrado do sistema miofascial superficial (reto abdominal e oblíquos interno e externo). Se tal não ocorrer, o alinhamento da coluna vertebral e da pélvis pode ser perdido, comprometendo a mecânica da ventilação e/ou a função reflexa postural do sistema profundo (Key, 2013).

O movimento do diafragma, da caixa torácica e dos órgãos internos, durante a ventilação a volume corrente, cria forças que deslocam o centro de massa de todo o corpo, promovendo um distúrbio postural ligeiro (Kuznetsov & Riley, 2012). Os potenciais efeitos de destabilização provocados pela ventilação são contrabalançados por um processo ativo que envolve um recrutamento muscular coordenado de múltiplos segmentos (Hodges, Gurfinkel, Brumagne, Smith, & Cordo, 2002). Contudo, o controlo postural é desafiado aquando de um aumento da exigência ventilatória, ou se esta requerer controlo voluntário (David, Laval, Terrien, & Petitjean, 2012). Hodges, Heijnen, & Gandevia (2001) sugerem que, para a manutenção da homeostasia, o SNC prioriza a ventilação em detrimento de outras funções dos músculos do tronco. De facto, o aumento da *drive* respiratória descendente atenua a atividade postural do diafragma e do transverso abdominal (Hodges et al., 2001). O comprometimento da contribuição do sistema miofascial profundo para a estabilidade postural está associado a um aumento da atividade muscular do reto abdominal e do oblíquo externo (Hodges & Gandevia, 2000b).

Embora estejam descritas estratégias para coordenar a função postural e a mecânica da ventilação numa situação normal, a função abdominal pode estar comprometida aquando de um aumento da exigência de uma das funções, como por exemplo numa patologia respiratória crónica, em que subsiste um maior desafio ventilatório.

**Doença pulmonar obstrutiva crónica (DPOC)**

A limitação crónica do fluxo expiratório na DPOC é causada quer por doença das pequenas vias aéreas (bronquite crónica), quer por destruição do parênquima pulmonar (enfisema), sendo variável a contribuição relativa de cada uma destas características. Se a inflamação crónica causa alterações estruturais e estreitamento das vias aéreas, a destruição do parênquima pulmonar, também por processos inflamatórios, promove a perda das conexões alveolares às pequenas vias aéreas (diminuição do recuo elástico pulmonar) e a consequente limitação do fluxo expiratório (Global Initiative for Chronic Obstructive Lung Disease, 2016; Vestbo et al., 2013).

*Mecânica da ventilação*

A expiração é um processo passivo e dependente das propriedades de recuo elástico dos pulmões e da caixa torácica (Kenyon et al., 1997). Contudo, em indivíduos com DPOC, as alterações nas pequenas vias aéreas diminuem a capacidade de as manter abertas durante a expiração, tornando-a ineficaz na remoção de uma quantidade adequada de ar do tórax. O aprisionamento de ar nos pulmões no final da expiração (aumento do volume de reserva expiratório) – *air-trapping* –, modifica a posição estática ou de repouso do tórax, afetando os volumes pulmonares e as capacidades ventilatórias mobilizáveis – hiperinsuflação (Macklem, 2014). De facto, a diminuição da elasticidade pulmonar afeta as componentes ósseas da caixa torácica, horizontalizando as costelas e aumentando o diâmetro ântero-posterior do tórax (Cassart, Gevenois, & Estenne, 1996). Por sua vez, o aplanamento das hemicúpulas diagramáticas (encurtamento das suas fibras) limitam a amplitude de movimento disponível para a contração, diminuindo a sua capacidade para criar pressão inspiratória. O ângulo de ação das fibras diafragmáticas encurtadas torna-se tão horizontal (diminuição da zona de aposição) que, durante a inspiração, a caixa torácica inferior é puxada para dentro do tórax, contra a insuflação do pulmão (De Troyer, 1997; Decramer, 1997).

A sobrecarga mecânica intrínseca sobre o diafragma na DPOC, durante a ventilação em repouso, resulta provavelmente num aumento da atividade muscular acessória da inspiração (Gandevia et al., 1996) e da expiração (Ninane et al., 1992), com consequente alteração do movimento toracoabdominal (Martinez et al., 1990). Apesar do aumento da *drive* neural para o diafragma (De Troyer et al., 1997; Gorini et al., 1990), os indivíduos com DPOC possuem uma capacidade limitada de expansão lateral da caixa torácica inferior (De Troyer, 1997; Decramer, 1997; Martinez et al., 1990). A maioria da inspiração é, deste modo, alcançada por outros músculos inspiratórios, que para além de não serem tão eficientes, promovem sobretudo movimento na caixa torácica superior. Se a configuração em barril e a elevação do tórax, devido à hiperinsuflação, colocam os esternocleidomastoideos numa posição de encurtamento, tornando-os menos eficientes, por outro lado, os paraesternais e os escalenos são capazes de criar uma força superior à medida que os pulmões se aproximam da capacidade pulmonar total (Decramer, 1997).

A contração expiratória dos músculos abdominais pode ser uma resposta "automática" ao aumento do trabalho da ventilação e da estimulação ventilatória, mesmo em repouso (Martinez et al., 1990; Ninane et al., 1992).

Aliverti et al. (1997) propõem que o aumento da atividade destes músculos é uma resposta apropriada para assistir os músculos inspiratórios, através da redução do volume pulmonar no final da expiração. Esta ação altera a configuração diafragmática, otimizando as suas características de comprimento-tensão ou permitindo a libertação de energia elástica no início da inspiração (De Troyer & Estenne, 1988). Não obstante, indivíduos com DPOC têm demonstrado uma atividade muscular abdominal variável aquando de um aumento da exigência ventilatória (Laveneziana, Webb, Wadell, Neder, & O'Donnell, 2014). Este padrão de recrutamento muscular pode alterar a mecânica, bem como o trabalho e o custo energético da ventilação (Aliverti & Macklem, 2008).

*Controlo postural*

Não obstante a patofisiologia primária subjacente à DPOC ser caracterizada por um defeito ventilatório obstrutivo, a evidência científica recente sugere que indivíduos com DPOC exibem também défices significativos ao nível do controlo postural (Beauchamp et al., 2010; Roig et al., 2009). Testes clínicos (Beauchamp, Hill, Goldstein, Janaudis-Ferreira, & Brooks, 2009; Beauchamp et al., 2012; Butcher, Meshke, & Sheppard, 2004) e laboratoriais (Janssens et al., 2013; Roig, Eng, Macintyre, Road, & Reid, 2011; Smith et al., 2010) têm identificado um controlo postural anormal em diferentes graus de severidade da DPOC. Muitas hipóteses têm sido propostas, incluindo diminuição dos níveis de atividade física (Butcher et al., 2004), suplementação de oxigénio (Beauchamp et al., 2009), fraqueza muscular periférica (Beauchamp et al., 2012) e défices somatossensoriais (Janssens et al., 2013). Contudo, é razoável admitir a hipótese de que a capacidade dos músculos do tronco para a sincronização do controlo postural e da mecânica da ventilação pode estar comprometida em indivíduos com DPOC (Smith, Chang, & Hodges, 2016). A ativação dos músculos do tronco, por um aumento do trabalho da ventilação, e a presença de hiperinsuflação (O'Donnell & Webb, 1993), podem influenciar a rigidez do tronco e, consequentemente, a contribuição deste para o controlo postural (Smith et al., 2016).

“Estádio 0”

O *Global Initiative for Cronic Obstructive Lung Disease Report* instituiu que um diagnóstico clínico da DPOC teria de ser confirmado através da avaliação espirométrica, tendo como referência o índice de *Tiffeneau* (Pauwels et al., 2001). Deste modo, este documento definiu, originalmente, 5 estádios de severidade da DPOC: 0 e 1 (média), 2 (moderada), 3 (severa) e 4 (muito severa) (Celli, MacNee, & Force, 2004). O estádio GOLD *0: at risk* foi definido pela presença de tosse crónica e produção de expetoração ou hipersecreção crónica de muco (mucosidade na maioria dos dias, pelo menos 3 meses por ano, nos últimos 2 anos), mas com preservação do índice de *Tiffeneau*. Deste modo, este estádio oferecia a oportunidade única de identificar os indivíduos em risco de desenvolvimento da DPOC, de forma a aumentar a consciencialização entre os prestadores de cuidados de saúde (Rodriguez-Roisin et al., 2016). Posteriormente, o estádio GOLD 0: *at risk* foi descartado das atualizações da *Global strategy for diagnosis, management, and prevention of chronic obstructive pulmonary disease*, por não existir evidência científica de que estes indivíduos estivessem mais propensos ao desenvolvimento da DPOC (Fabbri et al., 2004).

O recente American Thoracic Society/European Respiratory Society Statement indica que uma das questões de investigação da atualidade é a comparação de *outcomes* entre indivíduos sintomáticos com ou sem DPOC (Celli et al., 2015). O subconjunto GOLD 0: *at risk* indicia uma categoria de indivíduos fumadores sintomáticos, com espirometria normal e que possuem um risco aumentado de desenvolver DPOC (Pauwels et al., 2001). Além do mais, a evidência científica refere que o dilema permanece no que diz respeito à simples presença de uma "fase inicial" do que se tornará uma DPOC (no sentido tradicional), ou de uma condição relacionada ao tabagismo (em separado), que é crónica e permanece sintomática, sem progressão da DPOC (Rodriguez-Roisin et al., 2016). Apesar da possibilidade de ocorrência de ambos os padrões, os sintomas associados à doença pulmonar precoce em fumadores têm sido subestimados e ainda não se encontram reconhecidos (Fabbri, 2016). De facto, ao expandir os sintomas presentes na GOLD 0: *at risk*, para outros sintomas respiratórios crónicos, como a dispneia, a pieira, a limitação da atividade física e as exacerbações relacionadas com a DPOC (que necessitam de cuidados em saúde), os fumadores sintomáticos, mas com uma espirometria normal, possuem maior risco de morbilidade e mortalidade (de Marco et al., 2007; de Oca et al., 2012; Mannino et al., 2006; Stavem et al., 2006). Muitos destes indivíduos com sintomas respiratórios, mas sem limitação do fluxo expiratório, exibem anormalidades nas vias aéreas, experienciando as implicações da doença, com consequente aumento do recurso aos cuidados de saúde (Oelsner et al., 2014; Regan et al., 2015).

A evidência científica nestes indivíduos pode suportar um novo potencial clínico em indivíduos fumadores com sintomas respiratórios crónicos, mas com espirometria normal. A exploração clínica e laboratorial de sinais e sintomas, respiratórios e não-respiratórios, podem complementar a avaliação da influência da DPOC (Rodriguez-Roisin et al., 2016). Rodriguez-Roisin et al. (2016) referem que "Estudos de investigação dirigidos a esta condição, provavelmente distinta no contexto dos efeitos sistémicos de fumar por si só, devem lançar a luz sobre a compreensão atual da história natural da DPOC".

**Capítulo III**

# Questões e Objetivos de Investigação

As questões de investigação da presente Tese prenderam-se com o efeito do aumento das exigências postural (diferentes conjuntos posturais) ou ventilatória (resistências inspiratória e expiratória) na atividade muscular abdominal e no deslocamento do centro de pressão em equilíbrio ortostático bipodal, em indivíduos jovens adultos saudáveis (1) e em risco de desenvolvimento da DPOC (2).

**Questão de investigação 1**

A ação coordenada entre o controlo postural e a ventilação é alcançada pela co-ativação sinérgica dos músculos do tronco, para proporcionar um suporte adaptativo na modulação destes mecanismos de controlo do *core* abdominal. Os músculos abdominais possuem um papel crucial num controlo complexo das sinergias que contribuem para a sincronização de ambas as funções, em situações nas quais subsiste um maior desafio postural ou ventilatório (Hodges & Gandevia, 2000a, 2000b; Hodges et al., 1997).

A modificação da orientação corporal no espaço altera a configuração e o comprimento dos músculos do tronco e, consequentemente, a capacidade dos músculos respiratórios atuarem durante a ventilação (De Troyer, 1983). Tais alterações na eficiência mecânica podem ser devidas à ação da gravidade e da base de suporte sobre a atividade muscular do tronco para a manutenção de um conjunto postural (Meadows & Williams, 2009; Mihailoff & Haines, 2013). As modificações na atividade muscular afetam as *compliances* torácica e abdominal (Estenne, Yernault, & De Troyer, 1985), que induzem alterações na configuração e no movimento toracoabdominal (Lee, Chang, Coppieters, & Hodges, 2010; Romei et al., 2010). A evidência científica refere que a atividade muscular abdominal aumenta de decúbito dorsal para de pé (Abe, Kusuhara, Yoshimura, Tomita, & Easton, 1996; Barrett, Cerny, Hirsch, & Bishop, 1994; De Troyer, 1983); contudo, esta é escassa no que diz respeito ao recrutamento específico dos músculos abdominais em conjuntos posturais frequentemente assumidos para a diminuição da carga sobre o sistema respiratório, tal como a posição de *tripod* (Booth, Burkin, Moffat, &

Spathis, 2014). Apesar dos benefícios deste conjunto postural no alívio da dispneia (O'Neill & McCarthy, 1983), o impacto sobre a mecânica da ventilação (atividade muscular e movimento toracoabdominal) ainda não se encontra claro, sendo alvo de controvérsia (Santos, Ruas, Sande de Souza, & Volpe, 2012). É colocada a hipótese de que a carga postural e o *stretch* gravitacional dos diferentes conjuntos posturais são fatores que devem ser considerados no recrutamento específico dos músculos abdominais para a mecânica da ventilação. O recrutamento muscular do transverso abdominal/oblíquo interno, devido ao seu arranjo mecânico (De Troyer et al., 1990), deve ser o mais efetivo na modulação da pressão intra-abdominal para permitir o suporte postural antigravítico e o controlo do movimento da coluna vertebral e da pélvis. Ademais, a posição de quadrupedia, que facilita a co-contração dos músculos profundos do core abdominal (Hides, Richardson, & Hodges, 2004), pode implicar um recrutamento específico dos músculos abdominais semelhante ao da posição de *tripod*, com impacto positivo na mecânica da ventilação.

O aumento da *drive* respiratória, por exercício ou sobrecarga mecânica, pressupõe uma contribuição significativa dos músculos abdominais para a ventilação (Aliverti et al., 1997; De Troyer et al., 1990). De facto, a ação destes músculos acessórios da expiração, é também importante para minimizar a deformação da caixa torácica e a sobrecarga sobre o diafragma (Hodges & Gandevia, 2000b). É colocada a hipótese de que diferentes resistências ventilatórias possuem um impacto diferenciado na atividade muscular abdominal durante a inspiração e a expiração. Tal como referido anteriormente, o transverso abdominal deve ser o músculo mais relevante para a modulação da pressão intra-abdominal, suportando os movimentos da caixa torácica e abdómen, em situações nas quais subsiste uma maior exigência ventilatória.

Os movimentos ventilatórios da caixa torácica e do abdómen criam uma perturbação cíclica da estabilidade do tronco e do equilíbrio do corpo (Kuznetsov & Riley, 2012). Embora indivíduos saudáveis sejam capazes de compensar ativamente o distúrbio postural da ventilação, o controlo postural é desafiado aquando de um aumento da exigência ventilatória, ou se esta requerer controlo voluntário (Hodges et al., 2002). É colocada a hipótese de que a compensação pode não ser completa e o grau da perturbação postural pode ser dependente de diferentes resistências respiratórias. A alteração na repartição da massa do tronco, devido a um recrutamento específico dos músculos abdominais, pode promover um impacto diferente sobre o deslocamento do centro de pressão em equilíbrio ortostático bipodal.

*Objetivo geral*

Avaliar a função muscular abdominal para a sincronização do controlo postural e da mecânica da ventilação, em indivíduos saudáveis.

Objetivos específicos

1. Avaliar o efeito de diferentes conjuntos posturais na atividade muscular abdominal, em indivíduos saudáveis.

Análise da intensidade de ativação dos músculos reto abdominal, oblíquo externo e transverso abdominal/oblíquo interno, durante a inspiração e a expiração, em decúbito dorsal, na posição de *tripod*, em quadrupedia e em posição ortostática.

Artigo I

*Abdominal muscle activity during breathing in different postural sets in healthy subjects*

2. Avaliar o efeito da inclinação anterior do tronco com apoio dos membros superiores e da cabeça na atividade muscular respiratória e no movimento toracoabdominal, em indivíduos saudáveis.

Análise da intensidade de ativação dos músculos trapézio superior, esternocleidomastoideu e escaleno durante a inspiração e dos músculos reto abdominal, oblíquo externo e transverso abdominal/oblíquo interno durante ambas as fases da ventilação, em pé ereto, em pé com inclinação anterior do tronco e apoio de braços, em sentado ereto, em sentado com inclinação anterior do tronco e apoio de braços e em sentado com inclinação anterior do tronco e apoio de braços e cabeça.

Análise da magnitude do movimento toracoabdominal: ântero-posterior do tórax superior, médio-lateral do tórax inferior e ântero-posterior do abdómen, durante a ventilação, nos conjuntos posturais referidos.

Artigo II

*Respiratory activity and thoraco-abdominal movement in forward-leaning position with arm and head support in healthy subjects*

3. Avaliar o efeito de resistências inspiratórias e expiratórias na atividade muscular abdominal, em indivíduos saudáveis.

Análise da intensidade de ativação dos músculos reto abdominal, oblíquo externo e transverso abdominal/oblíquo interno, durante a inspiração e a expiração, sem resistência respiratória e com resistência inspiratória ou expiratória.

Artigo III

*Abdominal muscle activity during breathing with and without inspiratory and expiratory loads in healthy subjects*

4. Avaliar o efeito de resistências inspiratórias e expiratórias no deslocamento do centro de pressão em equilíbrio ortostático bipodal, em indivíduos saudáveis.

Análise da amplitude média e da velocidade média, nas direções ântero-posterior e médio-lateral, e da velocidade média total do deslocamento do centro de pressão durante a ventilação, sem resistência respiratória e com resistência inspiratória ou expiratória.

Artigo IV

*Centre of pressure displacement during breathing with and without inspiratory and expiratory loads in healthy subjects*

**Questão de Investigação 2**

Indivíduos saudáveis exibem estratégias para coordenar a função postural e a mecânica da ventilação. Contudo, na DPOC, em que subsiste um maior desafio ventilatório, a capacidade dos músculos do tronco para a sincronização de ambas as funções pode estar alterada (Smith et al., 2016). O padrão de recrutamento dos músculos abdominais aquando de um aumento das exigências postural ou ventilatória pode alterar a mecânica, bem como o trabalho e o custo energético da ventilação (Aliverti & Macklem, 2008). Por sua vez, a alteração do padrão de recrutamento destes músculos pode-se repercutir em diferentes estratégias de controlo postural para a manutenção do equilíbrio (Smith et al., 2016).

As alterações associadas à doença pulmonar precoce em fumadores sintomáticos têm sido subestimadas e ainda não se encontram totalmente reconhecidas (Fabbri, 2016). A conjugação dos sintomas destes indivíduos em estádio GOLD 0: *at risk*, com outros sintomas respiratórios crónicos, como a dispneia, a pieira, a limitação da atividade física e as exacerbações relacionadas com a DPOC (que necessitam de cuidados em saúde), promove maior risco de morbilidade e mortalidade (de Marco et al., 2007; de Oca et al., 2012; Mannino et al., 2006; Stavem et al., 2006). A exploração clínica e laboratorial de sinais e sintomas, respiratórios e não-respiratórios, em fumadores sintomáticos, mas sem limitação do fluxo expiratório, podem ser importantes para compreender a história natural da DPOC (Rodriguez-Roisin et al., 2016).

*Objetivo geral*

Avaliar a função muscular abdominal para a sincronização do controlo postural e da mecânica da ventilação, em indivíduos em risco de desenvolvimento da DPOC.

Objetivos específicos

1. Avaliar o efeito de diferentes conjuntos posturais na atividade muscular abdominal, em indivíduos em risco de desenvolvimento da DPOC e em saudáveis.

Análise da intensidade de ativação dos músculos reto abdominal, oblíquo externo e transverso abdominal/oblíquo interno, durante a inspiração e a expiração, em decúbito dorsal, na posição de *tripod*, em quadrupedia e em equilíbrio ortostático bipodal.

Artigo V

*Abdominal muscle activity during breathing in different postures in COPD "Stage 0" and healthy subjects*

2. Avaliar o efeito de resistências inspiratórias e expiratórias na atividade muscular abdominal, em indivíduos em risco de desenvolvimento da DPOC e em saudáveis.

Análise da intensidade de ativação dos músculos reto abdominal, oblíquo externo e transverso abdominal/oblíquo interno, durante a inspiração e a expiração, sem resistência respiratória e com resistência inspiratória ou expiratória.

Artigo VI

*The effect of inspiratory and expiratory loads on the abdominal muscle activity during breathing in subjects "at risk" for the development of chronic obstructive pulmonary disease and healthy*

3. Avaliar o efeito de resistências inspiratórias e expiratórias no deslocamento do centro de pressão em equilíbrio ortostático bipodal, em indivíduos em risco de desenvolvimento da DPOC e em saudáveis.

Análise da amplitude média e da velocidade média, nas direções ântero-posterior e médio-lateral, e da velocidade média total do deslocamento do centro de pressão durante a ventilação, sem resistência respiratória e com resistência inspiratória ou expiratória.

Artigo VII

*The effect of inspiratory and expiratory loads on the centre of pressure displacement during breathing in subjects "at risk" for the development of chronic obstructive pulmonary disease and healthy*

A Figura 1 ilustra o racional da presente Tese.

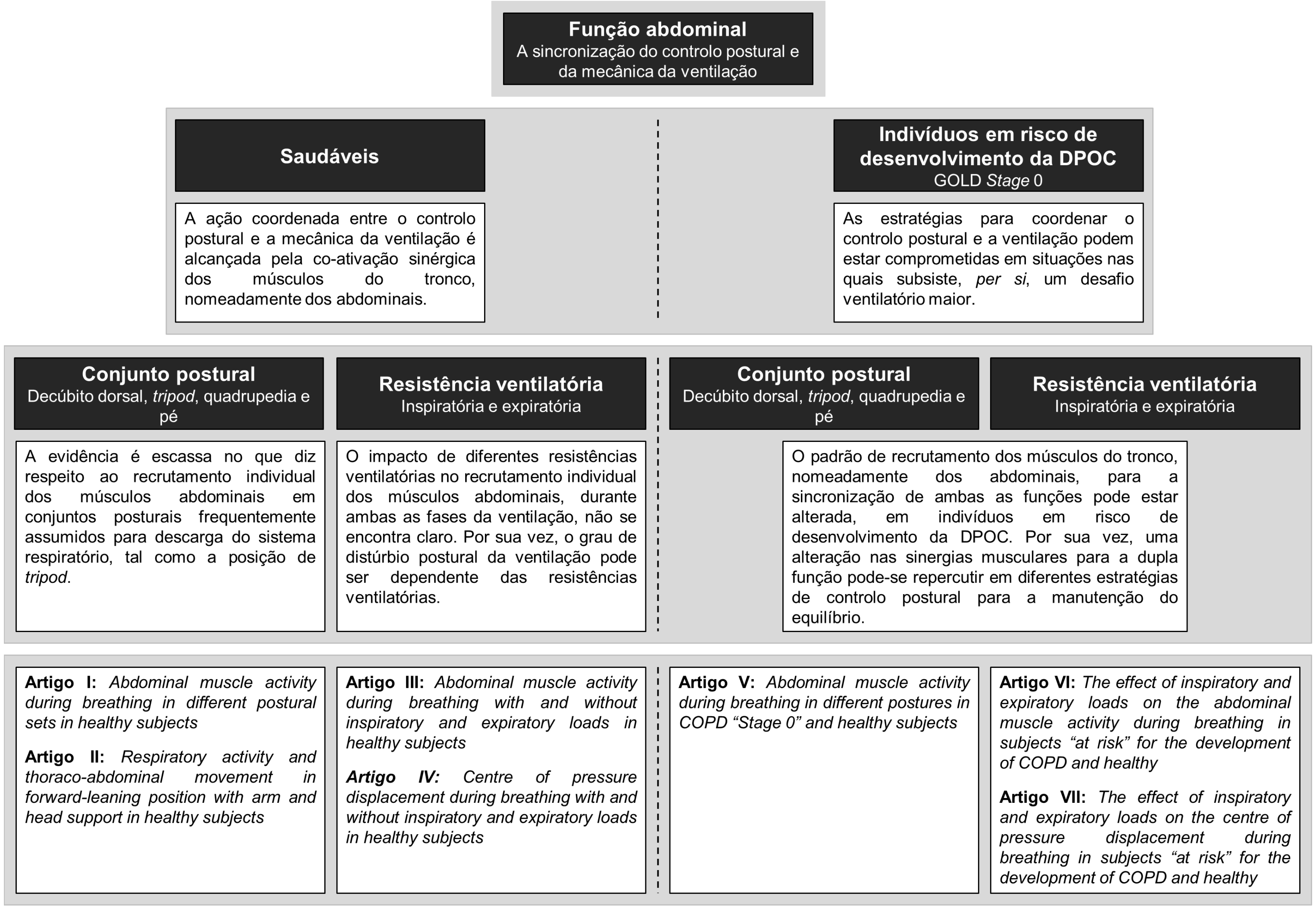


**Figura 1.** Diagrama representativo do racional da presente Tese.

**Capítulo IV**

# Estudos originais

# Abdominal muscle activity during breathing in different postural sets in healthy subjects

**António Mesquita Montes, MSc**[a,b], Sara Gouveia, PT[c], Carlos Crasto, MSc[a], Cristina Argel de Melo, PhD[a], Paulo Carvalho, PhD[a], Rita Santos, MSc[a], João Paulo Vilas-Boas, PhD[b]

[a] Department of Physiotherapy, and Activity and Human Movement Study Center (CEMAH), School of Allied Health Technologies, Polytechnic Institute of Porto, Rua Valente Perfeito 322, 4400-330 Vila Nova de Gaia, Portugal

[b] Faculty of Sport, CIFI2D, and Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Rua Dr. Plácido Costa 91, 4200-450 Porto, Portugal

[c] Physiotherapist, Private practice, Portugal

Mesquita Montes, A., et al. (2016). Abdominal muscle activity during breathing in different postural sets in healthy subjects. *Journal of Bodywork & Movement Therapies*. doi:10.1016/j.jbmt.2016.09.004

## Abstract

This study aims to evaluate the effect of different postural sets on abdominal muscle activity during breathing in healthy subjects. Twenty-nine higher education students (20.86±1.48 years; 9 males) breathed at the same rhythm (inspiration: 2 s; expiration: 4 s) in supine, standing, tripod and 4-point-kneeling positions. Surface electromyography was performed to assess the activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles during inspiration and expiration. During both breathing phases, the activation intensity of external oblique and *transversus abdominis*/internal oblique was significantly higher in standing when compared to supine ($p \leq 0.001$). No significant differences were found between tripod position and 4-point-kneeling positions. *Transversus abdominis*/internal oblique activation intensity in these positions was higher than in supine and lower than in standing. Postural load and gravitational stretch are factors that should be considered in relation to the specific recruitment of abdominal muscles for breathing mechanics.

## Keywords

Respiration; Postural control; Core abdominal; Body position; Surface electromyographic activity

## Introduction

Postural control is the ability to maintain the stability of the body and its segments in response to internal and external forces that threaten to disturb the body's equilibrium (Horak, Henry, & Shumway-Cook, 1997). The central nervous system (CNS) interprets and organizes sensory inputs from the vestibular, visual and proprioceptive systems and the information received from the receptors that are located in and around joints to provide postural control. As a result of this weighting, the CNS detects and predicts instability and responds with the appropriate output (Balasubramaniam & Wing, 2002; Lackner & DiZio, 2005), wherein the abdominal muscles preserve the postural equilibrium and spinal stability by modulating the intra-abdominal pressure (Cholewicki, Juluru, & McGill, 1999). This modulation occurs as a result of the coordination of the activity of the abdominal, pelvic floor and diaphragm muscles (Hodges, Butler, McKenzie, & Gandevia, 1997; Hodges & Gandevia, 2000a).

Nevertheless, the CNS modulates the motor activities of these trunk muscles during both postural and respiratory functions (Hodges, 1999) to concurrently regulate the intra-abdominal and intra-thoracic pressures (Hodges, Heijnen, & Gandevia, 2001). Although the activity of *rectus abdominis* (RA) and external oblique (EO) muscles is not respiration-related modulation, the tonic activity of diaphragm and *transversus abdominis* (TrA) muscles for postural control is modulated with the respiratory phasic activity (Hodges & Gandevia, 2000a, 2000b).

Despite their predominantly expiratory action, abdominal muscles contribute significantly to inspiration through their tonic activity, promoting a direct facilitation of diaphragm muscle contraction by preventing its excessive shortening during inspiration (Goldman, Lehr, Millar, & Silver, 1987). TrA muscle, due to its circumferential arrangement, has the most appropriate mechanical efficiency to perform this role (De Troyer, Estenne, Ninane, Van Gansbeke, & Gorini, 1990). Moreover, the increased intra-abdominal pressure generated through the abdominal muscle contraction during expiration prepares the respiratory system for the next inspiration by optimizing the length-tension relationship of diaphragm muscle fibres (De Troyer & Estenne, 1988).

Regarding the abdominal muscles' dual task, the change of body orientation in space alters the configuration and the length of abdominal muscles and, consequently, the ability of respiratory muscles to act during breathing (De Troyer, 1983). Such modifications in mechanical efficiency may be due to the action of gravity on the abdominal content and wall, which affects the abdominal compliance and induces a change in the length of diaphragm muscle fibres (Estenne, Yernault, & De Troyer, 1985) and, consequently, in functional residual capacity (Dean, 1985). Nevertheless, the impact of different postural sets on abdominal muscle activity for the synchronization of postural and respiratory functions is not yet clear. Although the abdominal muscle activity increases from supine to standing (Abe, Kusuhara, Yoshimura, Tomita, & Easton, 1996; Barrett, Cerny, Hirsch, & Bishop, 1994; De Troyer, 1983), there is little evidence regarding the individual recruitment of abdominal muscles in postural sets often assumed for unloading of the respiratory system, such as in tripod position (Booth, Burkin, Moffat, & Spathis, 2014). Furthermore, the four-point kneeling position, which facilitates the co-contraction of deep abdominal muscles – TrA muscle and lower fibres of internal oblique (IO) muscle – and back muscles – deep fibres of lumbar *multifidus* – (Hides, Richardson, & Hodges, 2004) may be performed to improve the breathing mechanics. Thus, the aim of the present study was to evaluate the effect of different postural sets on abdominal muscle activity during breathing in healthy subjects. Specifically, the activation intensity of RA, EO and *transversus abdominis*/internal oblique (TrA/IO) muscles, during inspiration and expiration, were analysed in supine, tripod, four-point kneeling and standing positions.

## Methods

*Sample*

A repeated measures study design was conducted with a sample composed by twenty-nine healthy higher education students who volunteered to participate in this research (9 males). Demographic and anthropometric data regarding the sample are described in Table 1. Participants were aged between 18 and 24 years and had not participated in aerobic physical activities with a moderate intensity (a minimum of 30 min on five days a week) or/and in aerobic physical activities with a vigorous intensity (a minimum of 20 min on 3 days a week), for a period exceeding one year (Thompson, 2014). Exclusion criteria included body mass index higher than 25 $kg.m^{-2}$; chronic nonspecific lumbopelvic pain (recurrent episodes of lumbopelvic pain for a period longer than three months); scoliosis, length discrepancy of the lower limbs or other postural asymmetries; history of spinal, gynaecological or abdominal surgery in the previous year; neurological or inflammatory disorders; metabolic or cardio-respiratory diseases; pregnancy or post-delivery in the previous six months; smoking habits; long-term corticosteroid therapy; and any conditions that may interfere with the data collection (American Thoracic Society/European Respiratory Society, 2002; Beith, Synnott, & Newman, 2001; Chanthapetch, Kanlayanaphotporn, Gaogasigam, & Chiradejnant, 2009; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Mew, 2009; Reeve & Dilley, 2009). Each participant provided written informed consent, according to the Declaration of Helsinki. The anonymity of participants and the confidentiality of data were guaranteed. The Institutional Research Ethics Committee previously approved this study.

**Table 1.** Sample characterization: demographic and anthropometric data, with mean, standard deviation, minimum and maximum.

| | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Age (years) | 20.86 | 1.48 | 18 | 24 |
| Body mass (kg) | 59.38 | 10.79 | 44 | 85 |
| Height (m) | 1.66 | 0.11 | 1.52 | 1.89 |
| BMI ($kg.m^{-2}$) | 21.34 | 1.77 | 18.34 | 24.45 |

BMI body mass index

*Instruments*

Surface electromyography (sEMG) was performed to bilaterally assess the muscle activity of TrA/IO, EO, RA and erector *spinae* (ES). The muscle activity was collected using the BioPlux research device (Plux wireless biosignals S.A., Arruda dos Vinhos, Portugal) with analogue channels of 12 bits and a sampling frequency of 1000 Hz, using double differential electrode leads. Disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon Corporate, Scottsdale AZ, United States of America) were used for the sEMG. The electrode characteristics were 4x2.2 cm of adhesive area, 1 cm diameter of each circular conductive area and 2 cm of inter-electrode distance. These electrodes were connected to bipolar active sensors emgPLUX with a gain of 1000, an analogue filter at 25-500 Hz and a common-mode rejection ratio of 110 dB. The reference electrode used was a disposable self-adhesive Ag/AgCl snap electrode (Noraxon Corporate, Scottsdale AZ, United States of America) for the sEMG, with 3.8 cm diameter of circular adhesive area and 1 cm diameter of circular conductive area. The sensors were Bluetooth connected through the sEMG device to a laptop. MonitorPlux software, version 2.0, was used to display and acquire the sEMG signal. An electrode impedance checker was used to assess the impedance level of skin (Noraxon Corporate, Scottsdale AZ, United States of America).

A respiratory flow transducer TSD117 – Medium Flow Trans 300 $L.min^{-1}$ connected to an amplifier DA100C – General Purpose Transducer Amplifier Module, was used to detect both breathing phases. The respiratory flow was collected using the Biopac MP100WSW Data Acquisition System device (Biopac Systems Inc., Goleta CA, United States of America) with a sampling frequency of 100 Hz. A bacterial filter AFT1 – Disposable Bacterial Filter, 22 mm, a mouthpiece AFT2 – Disposable Mouthpiece, 22 mm and a nose clip AFT3 – Disposable Noseclip were also used. Acqknowledge software, version 4.1, (Biopac Systems Inc., Goleta CA, United States of America) was used to display and acquire the respiratory flow signal. Biopac MP100WSW Data Acquisition System was synchronized with the BioPlux research.

A respiratory pressure meter MicroRPM (CareFusion Corporation, San Diego CA, United States of America) was used to assess the maximal expiratory pressure (MEP). This quasi-static maximal manoeuvre was used to normalize the sEMG signal of abdominal muscles (maximal muscle activity of each muscle during breathing). A bacterial filter AFT1, mouthpiece AFT2 and nose clip AFT3 were also used.

*Procedures*

Sample selection and characterization

An electronic questionnaire was delivered to all participants to verify the selection criteria and to collect sociodemographic information. Anthropometric measures were assessed in participants who met the participation criteria. Height (m) and body mass (kg) – were measured using a seca 222 stadiometer, with a precision of 1 mm (technical data of enterprise), and a seca 760 scale, with a precision of 1 kg (technical data of enterprise), respectively. Then, body mass index was calculated. To assess postural asymmetries, the lower limb length (cm) was measured using a seca 201 tape, with a precision of 1 mm (technical data of enterprise) (seca – Medical Scales and Measuring Systems, Hamburg, Germany), and the postural assessment was performed. These evaluations were performed to select the final sample. Women who were in luteal phase were contacted later for data collection.

## Data collection protocol

The study procedures took place at a biomechanical laboratory and were performed in a controlled environment. To avoid inter-rater error, each researcher was responsible for only one task.

To perform the sEMG, the hair was shaved and an abrasive cream was used to remove the dead cells from the skin's surface. Skin was then cleaned with isopropyl alcohol (70 %), removing its oiliness and holding the dead cells. An electrode impedance checker was used to make sure that the impedance levels were below 5 KΩ, thus ensuring a good acquisition of sEMG signal (Hermens et al., 2000). The self-adhesive electrodes were placed with participants in standing position, 5 min after the skin preparation. These electrodes were placed parallel to the muscle fibre orientation, according to the references described in Table 2 (Criswell, 2011; Marshall & Murphy, 2003). The electrode placements were confirmed by palpation and muscle contraction. The reference electrode was placed in the anterior superior iliac spine of the contralateral hand dominant side. All electrodes were tested to control the cross-muscular signal (cross-talk), electrical noise and other interferences of sEMG signal (Hermens et al., 2000).

**Table 2.** Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (OE), *transversus abdominis*/internal oblique (TrA/IO) and erector *spinae* (ES) muscles.

| Muscle | Anatomical landmarks |
|---|---|
| RA | 2 cm lateral to umbilicus, over the muscle mass |
| EO | Lateral to the RA and directly above the anterior superior iliac, halfway between the crest and ribs at a slightly oblique angle |
| TrA/IO | 2 cm medially and below to the anterior superior iliac spine<br>In this local, TrA and inferior IO muscle fibres are mixed, so it is impossible to distinguish the surface electromyographic activity of both. |
| ES | 2 cm lateral to spine, at L3 vertebra, over the muscle mass |

MEP was performed with the participant in standing, using a mouthpiece firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip to prevent the nasal breathing. To assess this manoeuvre, a forceful and maximal expiration was performed – the Valsalva manoeuvre – at total lung capacity. Each manoeuvre was encouraged verbally. These manoeuvres were performed during a 6-s period, with a resting time of 3 min. To normalize the sEMG signal of abdominal muscles, three reproducible manoeuvres were selected, according to American Thoracic Society/European Respiratory Society (2002) standards.

In standing, the maximal isometric voluntary contraction (MIVC) of ES muscle was performed to normalize data. The participant performed a trunk extension against an inelastic band placed on the scapular region. Three MIVC were performed, each one for a 6-s period, with a resting time of 3 min.

Each participant breathed in supine, standing, 4-point kneeling and tripod positions, in a single data collection moment. The order of postural sets was randomized. In supine and standing, the participant had the upper limbs along the body, with feet shoulder-width apart and knees in loose pack position. In 4-point kneeling position, the participant was in triple flexion of lower limbs (hip and knee at 90º), with hands shoulder-width apart and elbows in loose pack position. In tripod position, the participant was sitting, with 45° of trunk flexion to vertical, 90° of hip flexion and upper limbs supported on a table. All joint amplitudes were confirmed using the Bubble® Inclinometer (trunk amplitude) and Baseline® Plastic Goniometer 360 Degree Head (hip and knee amplitudes), both with a precision of 1º (technical data of enterprise). The respiratory flow transducer was kept perpendicular to the participant during all tasks. A single repetition of each task was performed for ten consecutive respiratory cycles, with a resting time of 3 min. The respiratory rhythm (inspiratory time: 2 s; expiratory time: 4 s) was marked through a recorded voice. The participant experienced this respiratory rhythm prior to data collection.

After data collection, the electrodes were removed and a moisturizing cream was applied.

Data processing

A routine was developed in MatLab Student software (MathWorks, Pozuelo de Alarcon, Spain) to synchronize and process data. Firstly, the sEMG signal was converted into volts. A 2$^{nd}$ order digital filter Infinite Impulse Response – Butterworth, one of 20 Hz (high pass) and another of 500 Hz (low pass), was applied to the sEMG signal to remove the electrical noise and/or cable movement; and, finally, a 2$^{nd}$ order digital filter Infinite Impulse Response – Butterworth of 30 Hz (high pass) was applied to remove the cardiac signal. Root mean square (RMS) to 10 samples was then calculated.

Acqknowledge software, version 4.1, was used to analyse data. The abdominal muscle activity was analysed during inspiration and expiration, independently. Both breathing phases were determined through the respiratory flow transducer signal. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles of each muscle was analysed during each task, with a posterior analysis of its average.

The muscle activity collected during the MEP manoeuvre was used to normalize the data related to the abdominal muscles. The mean RMS of three central seconds of the expiratory phase of each muscle was analysed, and then the average of the mean RMS of three reproducible manoeuvres was calculated. The percentage of activation intensity of each muscle was determined according to the following equation:

$$Muscle\ activation\ intensity\ (\%) = \left(\frac{mean\ RMS\ of\ each\ task}{RMS\ of\ the\ MEP}\right) * 100$$

Breathing is a bilateral task. Accordingly, the global analysis of activation intensity of the RA, EO and TrA/IO muscles was considered during each breathing phase. For that, the average of the percentage of muscle activation intensity of the two hemi-trunks was calculated.

ES muscle activity was continuously analysed during breathing. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles was analysed during each task, with a posterior analysis of its average. The muscle activity collected during the MIVC manoeuvre was determined to normalize the data related to the ES muscle. The mean RMS of three central seconds was analysed, and then the average of the mean RMS of three repeated manoeuvres was calculated. The percentage of muscle activation intensity was determined according the following equation:

$$Muscle\ activation\ intensity\ (\%) = \left(\frac{mean\ RMS\ of\ each\ task}{RMS\ of\ the\ MIVC}\right) * 100$$

As described above, the global analysis of ES muscle activation intensity was considered during breathing. For that, the average of the percentage of muscle activation intensity of the two hemi-trunks was calculated.

*Statistical analysis*

IBM SPSS Statistics® software, version 20.0, (IBM Corporation, Armonk NY, United States of America) was used for the descriptive and inferential data analysis, with a significance level of 0.05. Shapiro-Wilk test was used to test the normality of the data. Central tendency (mean) and dispersion (standard deviation) measures were used for the descriptive statistics. Repeated Measures Analysis of Variance was used to compare the percentage of muscle activation intensity between the different evaluation tasks (four postural sets), during inspiration and expiration. Bonferroni correction was used for the post-hoc analysis (Marôco, 2014).

## Results

*ES muscle activation intensity*

ES muscle activation intensity was significantly greater in standing when compared to 4-point kneeling ($p$=0,006), tripod ($p$=0.019) and supine ($p$=0.023) positions (see Fig. 1).

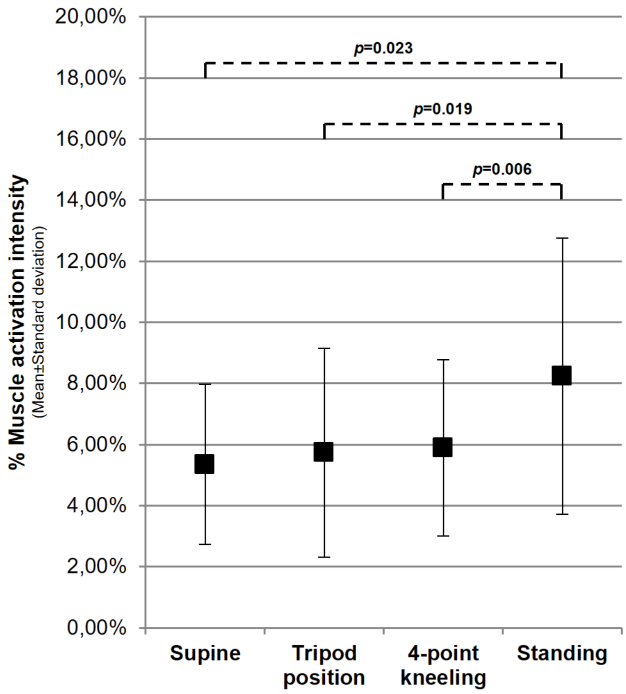


**Figure 1.** Activation intensity of erector *spinae* muscle (expressed as %) during breathing in supine, tripod position, 4-point kneeling and standing. Data are presented as mean and standard deviation. *p* values for significant differences between postural sets are also presented

*Abdominal muscle activation intensity*

Standing versus supine

During expiration, RA muscle activation intensity was significantly greater in standing when compared to supine ($p$=0.003) (see Fig. 3). The activation intensity of EO ($p$≤0.001) and TrA/IO ($p$<0.001) muscles was significantly greater in standing when compared to supine, during both inspiration and expiration (see Fig. 2 and Fig. 3).

Tripod position versus standing and supine

During expiration, RA muscle activation intensity was significantly lower in tripod position when compared to standing ($p$=0.042) (see Fig. 3). The activation intensity of EO (Inspiration: $p$=0.003; Expiration: $p$<0.001) and

TrA/IO ($p<0.001$) muscles was significantly lower in tripod position when compared to standing, during both inspiration and expiration (see Fig. 2 and Fig. 3).

During both breathing phases, TrA/IO muscle activation intensity was significantly greater in tripod position when compared to supine ($p \leq 0.001$) (see Fig. 2 and Fig. 3).

4-point kneeling versus standing and supine

During expiration, RA muscle activation intensity was significantly lower in 4-point kneeling position when compared to standing ($p=0.029$) (see Fig. 3). TrA/IO muscle activation intensity was significantly lower in 4-point kneeling position when compared to standing ($p<0.001$), during both inspiration and expiration (see Fig. 2 and Fig. 3).

During both breathing phases, the activation intensity of EO (Inspiration: $p=0.017$ and Expiration: $p=0.002$) and TrA/IO ($p<0.001$) muscles was significantly greater in 4-point kneeling position when compared to supine (see Fig. 2 and Fig. 3).

Tripod position versus 4-point kneeling

During both inspiration and expiration, no significant differences were found in the activation intensity of any of the abdominal muscles between 4-point kneeling and tripod positions (see Fig. 2 and Fig. 3).

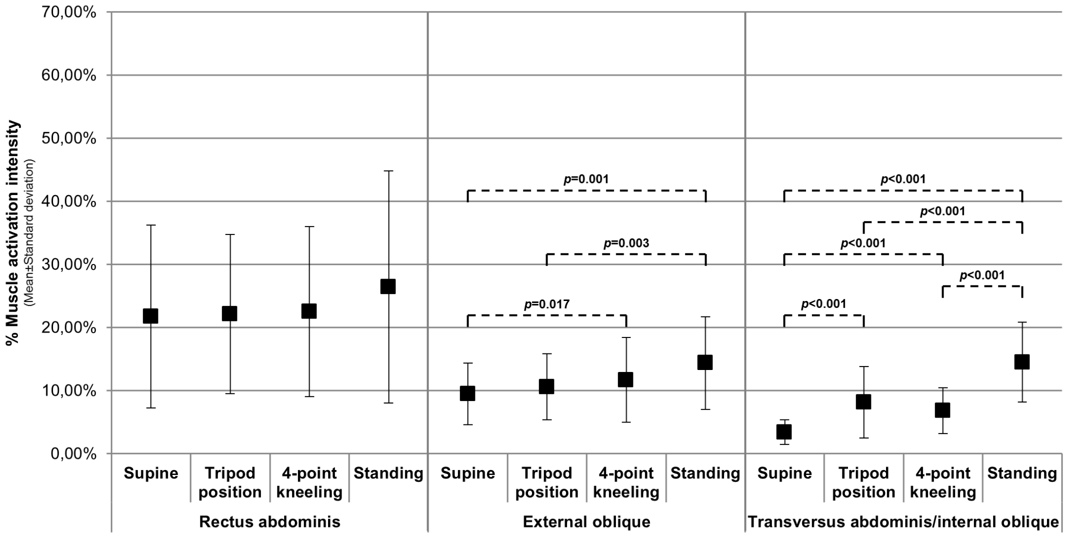


**Figure 2.** Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during inspiration in supine, tripod position, 4-point kneeling and standing. Data are presented as mean and standard deviation. *p* values for significant differences between postural sets are also presented

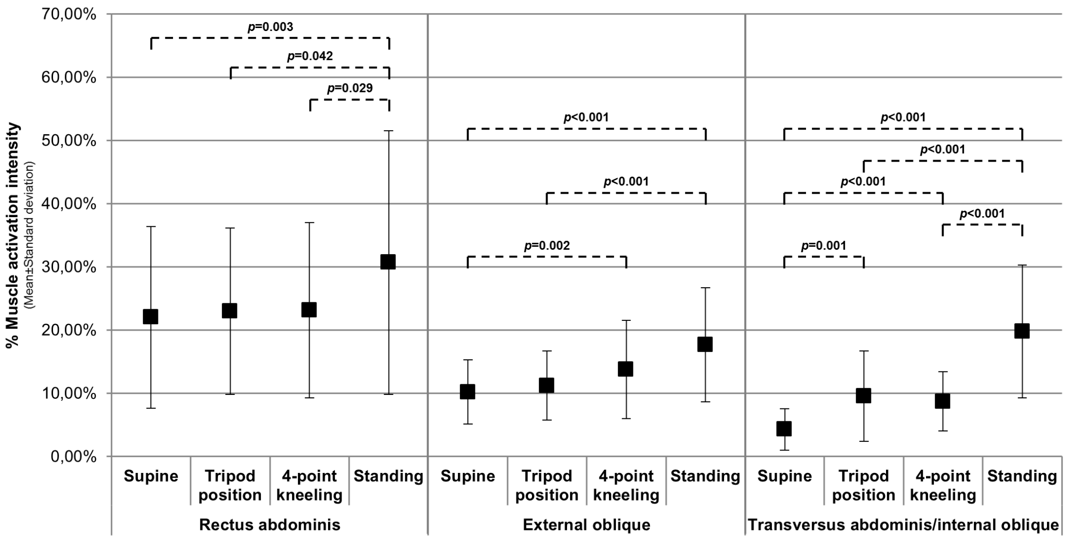


**Figure 3.** Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during expiration in supine, tripod position, 4-point kneeling and standing. Data are presented as mean and standard deviation. *p* values for significant differences between postural sets are also presented

## Discussion

The present study showed that the activation intensity of all abdominal muscles was higher in standing than in the other postural sets, during both inspiration and expiration. In tripod position and 4-point kneeling, TrA/IO muscle activation intensity was higher than in supine and lower than in standing, during both breathing phases. These data suggested that the abdominal muscles are important to the breathing mechanics, as well as postural control.

ES muscle activation intensity was measured. Different postural sets and functional goals (such as respiration) require that the CNS appropriately adjusts the postural muscle tone to gravity and changes in the base of support. The muscles which counteract the force of gravity, as ES muscle, should be more or less stiff or compliant to enable appropriate alignment for both stability and movement (Meadows & Williams, 2009; Mihailoff & Haines, 2013). The outcomes of this study indicated that the ES muscle activation intensity in standing was greater than in supine. In fact, the human skeletal motor system, due to the high position of the centre of mass regarding the small size of base of support, is poorly adapted to the preservation of a vertical position (standing) (Hodges, Gurfinkel, Brumagne, Smith, & Cordo, 2002). Unlike supine, the gravitational pull would be increased in standing, resulting in greater feedback from the stretch receptors of ES muscle, thus raising motor-neuron pool excitability and increasing muscle recruitment (Meadows & Williams, 2009; Mihailoff & Haines, 2013).

Postural sets, which require the maintenance of a static joint orientation of the spine, generally involve the coactivation of antigravity muscles and their antagonist muscles (abdominal muscles). In standing, the combination of a greater extensor moment (from ES muscle) and an opposing greater flexor moment (from abdominal muscles) tonically increases intra-abdominal pressure, and, consequently, unloads compressive forces on the spine (Cholewicki et al., 1999). Therefore, in the present study, a greater activation intensity of all abdominal muscles was observed in standing when compared to supine, which supports their primary postural function, increasing the postural tone when the challenge to stability is increased. Nevertheless, the worse breathing mechanics in supine may be explained by the lower recruitment of abdominal muscles. Although the elastic recoil for the lung is relatively unchanged due to the action of gravity, the chest wall mechanics, namely diaphragm muscle, is affected. In standing, the abdominal content is being pulled away from the diaphragm muscle. As opposed, in supine it is pushing inward against the relaxed diaphragm muscle, decreasing the overall outward recoil of the chest wall, and so the functional residual capacity (Levitzky, 2013). Thus, from standing to supine, the increased abdominal muscle compliance allows the resistance provided by the abdominal content to the diaphragm muscle descent is less effective in expanding the lower rib cage (Strohl et al., 1984). The results of the present study were consistent with earlier studies of Abe et al. (1996), Barrett et al. (1994) and De Troyer (1983). Mew (2009) also found a greater resting recruitment (thickness) of all abdominal muscles in standing when compared to supine, using ultrasound imaging. Nevertheless, Kera and Maruyama (2005) reported only a greater IO muscle activity in standing when compared to supine during spontaneous breathing. However, these authors did not normalize data to account for submaximal/maximal voluntary contraction.

The outcomes of this study indicated that the activation intensity of abdominal muscles in tripod position was lower than in standing and greater than in supine. The tripod position is often adopted as a result of breathlessness. Patients in respiratory distress lean forward with hands supporting them on their knees or forearms to stabilize and elevate the shoulder girdle (Bott et al., 2009). Consequently, this postural set improves the length-tension relationship of muscles that are attached between the ribs and upper limb or shoulder girdle, and so their capacity to act as accessory muscles of the breathing (Banzett, Topulos, Leith, & Nations, 1988). Moreover, this lean-forward position in sitting, with the passive fixing of shoulder girdle, reduces the postural load, resulting in lower ES muscle activation intensity in tripod position when compared to standing. In fact, as explained above, the gravitational pull would be reduced in tripod position, decreasing abdominal muscle recruitment. Furthermore, unlike supine, the downward and outward displacement of abdominal content in tripod position (Dean, 1985) may place the abdominal muscles in an improved position for contraction with some degree of lean forward. TrA muscle, due to its circumferential arrangement, has the most appropriate mechanical efficiency, which makes it easier to recruit into this postural set (De Troyer et al., 1990). Consequently, the tripod position may help to dome the diaphragm muscle, lengthening the muscle fibres, improving the length-tension relationship, and therefore its force and respiratory capacity (Barach, 1974). Thus, the improvement in breathing mechanics in this postural set may be explained by the higher TrA/IO muscle recruitment. There is little evidence regarding individual recruitment of abdominal muscles during breathing in forward lean positions. Nevertheless, Kera and Maruyama (2005) reported significantly higher muscle activity only for the EO muscle in sitting-with-elbow-on-the-knee when compared to supine. This recruitment may be explained by differences in setting between the sitting-with-elbow-on-the-knee and the tripod position, wherein in the last position there is a passive fixing of the shoulder girdle.

As in tripod position, a large base of support, which reduces the postural load, characterizes the 4-point kneeling position. Therefore, in this study, lower ES muscle activation intensity was observed in 4-point kneeling position when compared to standing, resulting in lower recruitment of abdominal muscles, as previously discussed. Moreover, the 4-point kneeling position, as well as the tripod position, allows the abdominal muscles to sag, facilitating a stretch (Norris, 1999). This postural set is likely to increase the feedback from the muscle stretch receptors, thus raising the motor-neuron pool excitability of the TrA/IO muscle (Beith et al., 2001). However, the gravitational stretch may be increased in 4-point kneeling position when compared to tripod position, which implies a more demanding TrA/IO muscle recruitment in isolation. This requirement is likely to increase the need for EO muscle recruitment to assist in postural and respiratory functions. Therefore, in the present study, the activation intensity of EO and TrA/IO muscles in 4-point-kneeling position was greater than in supine. EO and TrA/IO muscles share the same fibro-osseous attachments to the costal cartilages, the thoracolumbar fascia, the iliac crest and the pubis (Drake, Vogl, & Mitchell, 2014), whereby these muscles together flatten the abdomen in 4-point kneeling position.

The postural load and the gravitational stretch in both tripod and 4-point-kneeling positions allow forward movement of the abdominal content, out of the way of the diaphragm muscle. In this study, there were no significant differences in the activation intensity of all abdominal muscles between tripod position and 4-point kneeling. Thus, it is theorized that, in these postural sets, abdominal muscle recruitment, namely the TrA/IO muscle, may be important to thoracic-abdominal movement improvement. Accordingly, further investigation is needed in order to understand the impact of these postural sets or other abdominal muscle recruitment strategies, such as hollowing or bracing, on breathing mechanics and pattern.

None of the participants in the present study suffered from chronic respiratory pathologies. Chronic obstructive pulmonary disease may alter the patient's ability to recruit their abdominal muscles to the breathing mechanics. Therefore, the results of this study suggested that the tripod position often assumed by the breathless patients, as well as 4-point kneeling position, can have an impact on the enablement of abdominal muscle activation. However, further studies conducted among chronic obstructive pulmonary disease patients are needed.

## Conclusion

In healthy subjects, the change of body orientation promoted different impact on abdominal muscle activity during breathing. The highest activation intensity of abdominal muscles was observed in standing as opposed to supine. Postural load and gravitational stretch are factors that should be considered in relation to the specific recruitment of abdominal muscles for breathing mechanics. In tripod position and 4-point kneeling, TrA/IO muscle activation intensity may be a determining factor to improve the breathing mechanics. Thus, TrA/IO muscle recruitment seems to be important for the synchronization of postural and respiratory functions.

## Acknowledgments

A special thanks to Ivo Esteves, PT and João Baptista, PT for the assistance provided with participant recruitment and data collection.

## Conflict of interest statement

Nothing to declare.

## References

Abe, T., Kusuhara, N., Yoshimura, N., Tomita, T., & Easton, P. A. (1996). Differential respiratory activity of four abdominal muscles in humans. *Journal of Applied Physiology (1985), 80*(4), 1379-1389.

American Thoracic Society/European Respiratory Society. (2002). ATS/ERS Statement on respiratory muscle testing. *American Journal of Respiratory and Critical Care Medicine, 166*(4), 518-624.

Balasubramaniam, R., & Wing, A. M. (2002). *The dynamics of standing balance. Trends in Cognitive Sciences, 6*(12), 531-536.

Banzett, R. B., Topulos, G. P., Leith, D. E., & Nations, C. S. (1988). Bracing arms increases the capacity for sustained hyperpnea. *American Review of Respiratory Disease, 138*(1), 106-109.

Barach, A. L. (1974). Chronic obstructive lung disease: postural relief of dyspnea. *Archives of Physical Medicine and Rehabilitation, 55*(11), 494-504.

Barrett, J., Cerny, F., Hirsch, J. A., & Bishop, B. (1994). Control of breathing patterns and abdominal muscles during graded loads and tilt. *Journal of Applied Physiology (1985), 76*(6), 2473-2480.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82-87.

Booth, S., Burkin, J., Moffat, C., & Spathis, A. (2014). Positions to ease breathlessness. In S. Booth, J. Burkin, C. Moffat, & A. Spathis (Eds.), *Managing breathlessness in clinical practice* (pp. 49-65). London: Springer.

Bott, J., Blumenthal, S., Buxton, M., Ellum, S., Falconer, C., Garrod, R., . . . British Thoracic Society Physiotherapy Guideline Development, G. (2009). Guidelines for the physiotherapy management of the adult, medical, spontaneously breathing patient. *Thorax, 64*(Suppl 1), i1-51.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., & Chiradejnant, A. (2009). Abdominal muscle activity during abdominal hollowing in four starting positions. *Manual Therapy, 14*(6), 642-646.

Cholewicki, J., Juluru, K., & McGill, S. M. (1999). Intra-abdominal pressure mechanism for stabilizing the lumbar spine. *Journal of Biomechanics, 32*(1), 13-17.

Criswell, E. (2011). *Cram's introduction to surface electromyography* (2nd ed.). Sudbury, MA: Jones & Bartlett Publishers.

De Troyer, A. (1983). Mechanical role of the abdominal muscles in relation to posture. *Respiration Physiology, 53*(3), 341-353.

De Troyer, A., & Estenne, M. (1988). Functional anatomy of the respiratory muscles. *Clinics In Chest Medicine, 9*(2), 175-193.

De Troyer, A., Estenne, M., Ninane, V., Van Gansbeke, D., & Gorini, M. (1990). Transversus abdominis muscle function in humans. *Journal of Applied Physiology (1985), 68*(3), 1010-1016.

Dean, E. (1985). Effect of body position on pulmonary function. *Physical Therapy, 65*(5), 613-618.

Drake, R., Vogl, A. W., & Mitchell, A. W. M. (2014). Abdomen. In R. Drake, A. W. Vogl, & A. W. M. Mitchell (Eds.), *Gray's anatomy for students* (3rd ed., pp. 253-420). Philadelphia, PA: Churchill Livingstone/Elsevier.

Estenne, M., Yernault, J. C., & De Troyer, A. (1985). Rib cage and diaphragm-abdomen compliance in humans: effects of age and posture. *Journal of Applied Physiology (1985), 59*(6), 1842-1848.

Goldman, J. M., Lehr, R. P., Millar, A. B., & Silver, J. R. (1987). An electromyographic study of the abdominal muscles during postural and respiratory manoeuvres. *Journal of Neurology, Neurosurgery & Psychiatry, 50*(7), 866-869.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361-374.

Hides, J. A., Richardson, C. A., & Hodges, P. W. (2004). Local segmental control. In J. A. Hides, C. A. Richardson, & P. W. Hodges (Eds.), *Therapeutic Exercise for Lumbopelvic Stabilization* (2nd ed., pp. 185-219). Edinburgh: Churchill Livingstone.

Hodges, P. W. (1999). Is there a role for transversus abdominis in lumbo-pelvic stability? *Manual Therapy, 4*(2), 74-86.

Hodges, P. W., Butler, J. E., McKenzie, D. K., & Gandevia, S. C. (1997). Contraction of the human diaphragm during rapid postural adjustments. *The Journal of Physiology, 505*(Pt 2), 539-548.

Hodges, P. W., & Gandevia, S. C. (2000a). Activation of the human diaphragm during a repetitive postural task. *The Journal of Physiology, 522*(Pt 1), 165-175.

Hodges, P. W., & Gandevia, S. C. (2000b). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology (1985), 89*(3), 967-976.

Hodges, P. W., Gurfinkel, V. S., Brumagne, S., Smith, T. C., & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Experimental Brain Research, 144*(3), 293-302.

Hodges, P. W., Heijnen, I., & Gandevia, S. C. (2001). Postural activity of the diaphragm is reduced in humans when respiratory demand increases. *The Journal of Physiology, 537*(Pt 3), 999-1008.

Horak, F. B., Henry, S. M., & Shumway-Cook, A. (1997). Postural perturbations: new insights for treatment of balance disorders. *Physical Therapy, 77*(5), 517-533.

Kera, T., & Maruyama, H. (2005). The effect of posture on respiratory activity of the abdominal muscles. *Journal of Physiological Anthropology and Applied Human Science, 24*(4), 259-265.

Lackner, J. R., & DiZio, P. (2005). Vestibular, proprioceptive, and haptic contributions to spatial orientation. *Annual Review of Psychology, 56*, 115-147.

Levitzky, M. G. (2013). Mechanics of breathing. In M. G. Levitzky (Ed.), *Pulmonary physiology* (pp. 12-57). New York, NY: McGraw-Hill Education/Medical.

Marôco, J. (2014). *Análise estatística com o SPSS Statistics* (6th ed.). Pero Pinheiro: ReportNumber, Lda.

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology, 13*(5), 477-489.

Meadows, L., & Williams, J. (2009). An understanding of functional movement as a basis for clinical reasoning. In S. Raine, L. Meadows, & M. Lynch-Ellerington (Eds.), *Bobath concept: theory and clinical practice in neurological rehabilitation* (pp. 23-42). Oxford: Wiley-Blackwell.

Mew, R. (2009). Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. *Manual Therapy, 14*(6), 690-695.

Mihailoff, G. A., & Haines, D. E. (2013). Motor system I: peripheral sensory, brainstem, and spinal influence on anterior horn neurons. In D. E. Haines (Ed.), *Fundamental neuroscience for basic and clinical applications* (pp. 324-337). Philadelphia, PA: Elsevier/Saunders.

Norris, C. (1999). Functional load abdominal training: part 2. *Journal of Bodywork and Movement Therapies, 3*(4), 208-214.

Reeve, A., & Dilley, A. (2009). Effects of posture on the thickness of transversus abdominis in pain-free subjects. *Manual Therapy, 14*(6), 679-684.

Strohl, K. P., Mead, J., Banzett, R. B., Lehr, J., Loring, S. H., & O'Cain, C. F. (1984). Effect of posture on upper and lower rib cage motion and tidal volume during diaphragm pacing. *American Review of Respiratory Disease, 130*(2), 320-321.

Thompson, P. D. (2014). Health appraisal and risk assessment. In L. S. Pescatello, R. Arena, D. Riebe, & P. D. Thompson (Eds.), *ACSM's guidelines for exercise testing and prescription* (9th ed., pp. 1-18). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

# Respiratory activity and thoraco-abdominal movement in forward-leaning position with arm and head support in healthy subjects

**António Mesquita Montes, MSc**[a,b], Carolina Tam, PT[c], Carlos Crasto, MSc[a], Cristina Argel de Melo, PhD[a], Paulo Carvalho, PhD[a], Rita Santos, MSc[a], Rui Vilarinho, MSc[a], João Paulo Vilas-Boas, PhD[b]

[a] Department of Physiotherapy, and Activity and Human Movement Study Center (CEMAH), School of Allied Health Technologies, Polytechnic Institute of Porto, Rua Dr. António Bernardino de Almeida 400, 4200-072 Porto, Portugal

[b] Faculty of Sport, CIFI2D, and Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Rua Dr. Plácido Costa 91, 4200-450 Porto, Portugal

[c] Physiotherapist, Private practice, Portugal

Submetido para publicação

**Abstract**

Although the benefits of forward-leaning position on the relief of dyspnea are described, its impact on the mechanics of breathing is not yet clear. This study aims to evaluate the effect of forward-leaning position with arm/head support on the activity of respiratory accessory muscles and the thoraco-abdominal movement in healthy subjects. Thirty-three volunteers (18-29 years; 16 males) breathed at the same rhythm in upright standing and sitting, standing and sitting with forward-leaning trunk and arm support, and sitting with forward-leaning trunk and arm/head support. Surface electromyography was performed to assess the activity of inspiratory accessory (during inspiration) and abdominal (during both breathing phases) muscles. A motion capture system was used to assess the thoraco-abdominal movement. The upper trapezius activity in arm support positions was lower when compared to upright positions ($\eta_p^2$=0.470); however, it was observed a higher activity of *sternocleidomastoideus* ($\eta_p^2$=0.386) and *scalenus* ($\eta_p^2$=0.342) and anterior-posterior movement of upper ribcage ($\eta_p^2$=0.298). The abdominal activity in standing and sitting with forward-leaning trunk and arm support was lower when compared to upright positions ($\eta_p^2$=0.172–0.661); nevertheless, it was observed a higher anterior-posterior movement of abdomen ($\eta_p^2$=0.343). The medial-lateral movement of lower ribcage in sitting with forward-leaning trunk and arm/head support was lower when compared with other positions ($\eta_p^2$=0.184). In forward-leaning positions, the arm support increased recruitment of inspiratory accessory muscles, as well as it decreased abdominal muscle recruitment, namely *transversus abdominis*/internal oblique, improving the thoraco-abdominal movement. However, the head support seemed to have a negative impact on the movement of lower ribcage and abdomen.

**Keywords**

Respiration; Postural control; Tripod position; Surface electromyographic activity; Breathing movement

## Introduction

The forward-leaning position is often assumed by subjects with obstructive ventilatory defect, to improve respiratory muscle function, helping to unload the respiratory system and hence to relief the dyspnea (Bott et al., 2009; Gosselink, 2003). Literature has shown that the forward-leaning trunk improves the length-tension relationship or geometry of the respiratory muscles (namely diaphragm), increasing the output of them for breathing (Sharp, Drutz, Moisan, Foster, & Machnach, 1980). At the same time, the efficacy of contraction of the respiratory muscles in moving the chest wall might improve, enhancing lung volume changes (Delgado, Braun, Skatrud, Reddan, & Pegelow, 1982). Despite abdominal muscles may also be placed in an improved position for contraction by some degree of forward lean (Dean, 1985), there is little evidence regarding the individual recruitment of abdominal muscles in this postural set and its impact on thoraco-abdominal movement.

The forward-leaning position may be associated to the arm and head support (Booth, Burkin, Moffat, & Spathis, 2014); however, the effect of this strategy on the activity of inspiratory accessory muscles and the thoraco-abdominal movement is controversial. Sharp et al. (1980) indicated a decreasing contribution of upper ribcage muscles, as *sternocleidomastoideus* and *scalenus*, in forward-leaning position, reducing the energetic expenditure. Contrary, other authors showed that the arm support allows an optimizing recruitment of these muscles, contributing significantly to the ribcage elevation (Banzett, Topulos, Leith, & Nations, 1988; Kim et al., 2012).

Although the benefits of forward-leaning position on the relief of dyspnea are described (O'Neill & McCarthy, 1983), its impact on the mechanics of breathing is not yet clear (Santos, Ruas, Sande de Souza, & Volpe, 2012). Thus, the aim of the present study was to evaluate the effect of forward-leaning position with arm and head support on the activity of respiratory accessory muscles and thoraco-abdominal movement in healthy subjects. Specifically, the muscle activation intensity of upper *trapezius* (UT), *sternocleidomastoideus* and *scalenus* muscles during inspiration and the activation intensity of *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/internal oblique (TrA/IO) muscles during both breathing phases was analysed in upright standing (UStand); standing with forward-leaning trunk and arm support (StandAS); upright sitting (USit); sitting with forward-leaning trunk and arm support (SitAS); and sitting with forward-leaning trunk and arm/head support (SitAHS). Also, the magnitude of thoraco-abdominal movement (anterior-posterior of the upper ribcage, medial-lateral of the lower ribcage and anterior-posterior of the abdomen) during breathing was analysed in these postural sets.

## Methods

### *Sample*

A repeated measures study design was conducted with a sample composed by thirty-three healthy higher education students, who volunteered to participate in this research (16 males). Demographic and anthropometric data regarding the sample are described in Table 1. Participants had not participated in aerobic physical activities with a moderate intensity (a minimum of 30 min on five days a week) and/or aerobic physical activities with a vigorous intensity (a minimum of 20 min on 3 days a week), for a period exceeding one year (Thompson, 2014). Men and women had a waist/height ratio lower than 0.5 and a waist/hip ratio lower than 0.9 and 0.5, respectively (World Health Organization, 2011). Exclusion criteria included chronic nonspecific lumbopelvic pain (recurrent episodes of lumbopelvic pain for a period longer than three months); scoliosis, length discrepancy of the lower limbs or other postural asymmetries; history of spinal, gynaecological or abdominal surgery in the previous year; neurological or inflammatory disorders; metabolic or cardio-respiratory diseases; pregnancy or post-delivery in the previous six months; smoking habits; long-term corticosteroid therapy; and any conditions that may interfere with the data collection (American Thoracic Society/European Respiratory Society, 2002; Beith, Synnott, & Newman, 2001; Chanthapetch, Kanlayanaphotporn, Gaogasigam,

& Chiradejnant, 2009; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Mew, 2009; Reeve & Dilley, 2009). Each participant provided written informed consent, according to the Declaration of Helsinki. The anonymity of participants and the confidentiality of data were guaranteed. The Institutional Research Ethics Committee previously approved this study.

**Table 1.** Sample characterization: demographic, anthropometric and body composition data, with mean, standard deviation, minimum and maximum.

| | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Demographic and anthropometric data | | | | |
| Age (years) | 21.52 | 2.77 | 18 | 29 |
| Body mass (kg) | 62.26 | 9.31 | 48.40 | 84.20 |
| Height (m) | 1.68 | 0.08 | 1.53 | 1.84 |
| Body composition data | | | | |
| Waist/ height ratio | 0.43 | 0.03 | 0.38 | 0.50 |
| Waist/ hip ratio | 0.80 | 0.04 | 0.74 | 0.89 |

*Procedures*

Sample selection and characterization

An electronic questionnaire was delivered to all participants to verify the selection criteria and to collect sociodemographic information. Anthropometric and body composition measures were assessed in participants who met the participation criteria. Height (m) and body mass (kg) – were measured using a seca 222 stadiometer with an precision of 1 mm and a seca 760 scale with an precision of 1 kg, respectively (seca – Medical Scales and Measuring Systems, Hamburg, Germany). The waist circumference (cm) was measured around the obvious narrowing between the rib; and the iliac crest and hip perimeter (cm) was measured around the hips at the horizontal level of greatest gluteal protuberance (Eston, Hawes, Martin, & Reilly, 2009). The average of three measurements was calculated for each zone, and the waist/height and waist/hip ratios were determined. Also, the lower limb length (cm) was measured and a postural assessment was performed. These evaluations were performed to select the final sample. Women who were in luteal phase were contacted later for data collection.

## Data collection protocol

The study procedures took place at a biomechanical laboratory and were performed in a controlled environment. To avoid inter-rater error, each researcher was responsible for only one task.

Surface electromyography (sEMG) was performed to assess the muscle activity of UT, *sternocleidomastoideus*, *scalenus*, RA, EO, TrA/IO of the dominant hand side. The muscle activity was collected using the BioPlux research device (Plux wireless biosignals S.A., Arruda dos Vinhos, Portugal) with analogue channels of 12 bits and a sampling frequency of 1000 Hz, using double differential electrode leads. To perform the sEMG, the hair was shaved and an abrasive cream was used to remove the dead cells from the skin's surface. Skin was then cleaned with isopropyl alcohol (70 %), removing its oiliness and holding the dead cells. An electrode impedance checker (Noraxon Corporate, Scottsdale AZ, United States of America) was used to make sure that the impedance levels were below 5 KΩ, thus ensuring a good acquisition of sEMG signal (Hermens et al., 2000). Disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon Corporate, Scottsdale AZ, United States of America) were used for the sEMG. The electrode characteristics were 1 cm diameter of each circular conductive area and 2 cm of inter-electrode distance. These electrodes were connected to bipolar active sensors emgPLUX with a gain of 1000, an analogue filter at 25 to 500 Hz and a common-mode rejection ratio of 110 dB. The reference electrode used was a disposable self-adhesive Ag/AgCl snap electrode (Noraxon Corporate, Scottsdale AZ, United States of America) for the sEMG, with 1 cm diameter of circular conductive area. The self-adhesive electrodes were placed with participants in standing position, five minutes after the skin preparation. These electrodes were placed parallel to the muscle fibre orientation, according to the following references: UT, distance between the seventh cervical vertebrae and acromion; *sternocleidomastoideus*, distance between the mastoid process and the sternal notch, slightly posterior to the centre of the muscle belly; *scalenus*, slightly oblique angle just above the clavicle in the hollow triangle (that lies just posterior to the *sternocleidomastoideus*, just above the clavicle and anterior to the UT); RA, 2 cm lateral to the umbilicus, over the muscle mass; EO, Lateral to the RA and directly above the anterior superior iliac, halfway between the crest and ribs at a slightly oblique angle; TrA/IO, 2 cm medially and below to the anterior superior iliac spine (in this local, *transversus abdominis* and inferior internal oblique muscle fibers are mixed, so it is impossible to distinguish the surface electromyographic activity of both) (Criswell, 2011; Marshall & Murphy, 2003). The electrode placements were confirmed by palpation and muscle contraction. The reference electrode was placed in the anterior superior iliac spine of the contralateral hand dominant side. The sensors were Bluetooth connected through the sEMG device to a laptop. MonitorPlux software, version 2.0, was used to display and acquire the sEMG signal. All electrodes were tested to control the cross-muscular signal (cross-talk), electrical noise and other interferences of sEMG signal (Hermens et al., 2000).

A respiratory pressure meter MicroRPM (CareFusion Corporation, San Diego CA, United States of America) was used to assess the maximal inspiratory (MIP) and expiratory (MEP) pressures. These quasi-static maximal manoeuvres were used to normalize the sEMG signal of inspiratory and expiratory muscles (maximal muscle activity of each muscle during breathing), respectively. MIP and MEP were both performed with participants in standing position, using a mouthpiece firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip to prevent the nasal breathing. To assess MIP, a forceful and maximal inspiration was performed – the Muller manoeuvre – at residual volume; in turn, MEP was assessed through a forceful and maximal expiration – the Valsalva manoeuvre – at total lung capacity. Each manoeuvre was encouraged verbally. These manoeuvres were performed during a six-second period, with a resting time of three minutes. To normalize the sEMG signal of inspiratory and expiratory muscles, three reproducible manoeuvres were selected, according to American Thoracic Society/European Respiratory Society (2002) standards.

Qualisys Motion Capture System (Qualisys AB, Gothenburg, Sweden) was used to assess the magnitude of thoraco-abdominal movement: anterior-posterior of the upper ribcage, medial-lateral of the lower ribcage and anterior-posterior of the abdomen. Six reflectors markers were placed: above the xiphoid process, over the spinous process of seventh thoracic vertebra, on the ninth right and left ribs in the mid-axillary line bilaterally, over umbilicus and over the spinous process of third lumbar vertebra. The spatial position of reflector markers was collected using four infrared cameras Oqus 1, with a sampling frequency of 100 Hz, placed around the measurement volume. The wand calibration method was performed during thirty seconds, wherein the calibration results display a standard deviation of wand length lower than 0.75 mm. Qualisys Track Manager software was used to display and acquire the kinematic data. Qualisys Motion Capture System was synchronized with the BioPlux research.

Each participant breathed in UStand, StandAS, USit, SitAS and SitAHS, in a single data collection moment. The order of postural sets was randomized. The participants were barefoot, with feet shoulder-width apart and knees in loose pack position. In UStand, the participant was standing, with upper limbs along the body. In StandAS, the participant was standing, with 30º of trunk flexion to vertical and upper limbs supported on a table with 90º of shoulder flexion (in scapular plane). In USit, the participant was sitting, with 90° of hip flexion and upper limbs along the body. In SitAS, the participant was sitting, with 30º of trunk flexion to vertical, 90° of hip flexion and upper limbs supported on a table with 90º of shoulder flexion (in scapular plane). In SitAHS, the participant was in the same previously position, but with head resting on hands. All joint amplitudes were confirmed using the Bubble® Inclinometer (trunk amplitude) and Baseline® Plastic Goniometer 360 Degree Head (hip and knee amplitudes), both with a precision of 1º. A single repetition of each task was performed for ten consecutive respiratory cycles, with a resting time of three minutes. The respiratory rhythm (inspiratory time: two seconds; expiratory time: four seconds) was marked through a recorded voice. The participant experienced this respiratory rhythm prior to data collection. A mouthpiece and a noise clip were used during all tasks.

After data collection, the electrodes were removed and a moisturizing cream was applied.

## Data processing

A routine was developed in MatLab Student software (MathWorks, Pozuelo de Alarcon, Spain) to synchronize and process sEMG signal and kinematic data. Firstly, the sEMG signal was converted into volts. It was applied to the sEMG signal a $2^{nd}$ order digital filter Infinite Impulse Response – Butterworth, one of 20 Hz (high pass) and another of 500 Hz (low pass), to remove the electrical noise and/or cable movement; and, finally, a $2^{nd}$ order digital filter Infinite Impulse Response – Butterworth of 30 Hz (high pass), to remove the cardiac signal. Root mean square (RMS) to 10 samples was then calculated. For the kinematic data, the distances anterior-posterior of the upper ribcage (between the xiphoid process and seventh thoracic vertebra), medial-lateral of the lower ribcage (between the ninth right and left ribs) and anterior-posterior of the abdomen (between the umbilicus and third lumbar vertebra) are exported through the Qualisys Track Manager software. Finally, it was applied to the kinematic data a Mooving Average filter.

Acqknowledge software, version 4.1 (Biopac Systems Inc., Goleta CA, United States of America), was used to analyse data. The inspiratory muscle activity was analysed during inspiration, and the abdominal muscle activity was analysed during both inspiration and expiration, independently. The both inspiration and expiration phases were determined through the kinematic data. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles of each muscle was analysed in each task, with a posterior analysis of its average.

To normalize data of the inspiratory and abdominal muscles, the mean RMS of three central seconds of the MIP' inspiratory phase for inspiratory muscles and MEP' expiratory phase for abdominal muscles was analysed, respectively. Then, the average of the mean RMS of three reproducible MIP and MEP manoeuvres was calculated. The percentage of the activation intensity of each muscle was determined according to the following equation: Muscle activation intensity (%) = (mean RMS of each task / RMS of the MIP or MEP) *100.

The magnitude of thoraco-abdominal movements from the end expiration to end the inspiration was determined. For the ten respiratory cycles collected, the peak-to-peak amplitude of four central respiratory cycles was analysed each task, with a posterior analysis of its average.

*Statistical analysis*

IBM SPSS Statistics® software, version 20.0 (IBM Corporation, Armonk NY, United States of America), was used for the descriptive and inferential data analysis, with a significance level of 0.05. Shapiro-Wilk test was used to test the normality of the data. Central tendency (mean) and dispersion (standard deviation) measures were used for the descriptive statistics. Repeated Measures Analysis of Variance was used to compare the percentage of activation intensity of the inspiratory (during inspiration) and abdominal muscles (during both inspiration and expiration), as well as the magnitude of thoraco-abdominal movement (during breathing) between the different evaluation tasks (five postural sets). Bonferroni correction was used for the post-hoc analysis (Marôco, 2014). To quantify the effect size, the partial eta square ($\eta_p^2$) values will be calculated using cut-off provided by Cohen: $\eta_p^2$ =

0.01 – small effect, $\eta_p^2$ = 0.06 – medium effect, and $\eta_p^2$ = 0.14 – large effect (Cohen, 1988).

## Results

*Muscle activity*

Inspiratory accessory muscles

During inspiration, UT muscle activation intensity was significantly lower in SitAHS when compared to UStand, StandAS, USit and SitAS ($P$<0.001). Also, UT muscle activation intensity was significantly lower in StandAS and SitAS when compared to UStand ($P$=0.033 and $P$=0.022, respectively) and USit ($P$=0.003 and $P$=0.002, respectively) (Table 2).

**Table 2**. Activation intensity of upper *trapezius* muscle (expressed as %) during inspiration in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented

| | UStand | StandAS | USit | SitAS | SitAHS |
|---|---|---|---|---|---|
| Activation intensity (%) | 60.77 (29.84) | 40.60 (20.22) | 68.00 (29.27) | 38.59 (19.85) | 26.22 (12.90) |
| Between postural sets comparsion (*P* value) | | | UStand – StandAS: *P*=0.033<br>UStand – SitAS: *P*=0.022<br>UStand – SitAHS: *P*<0.001<br>StandAS – USit: *P*=0.003<br>StandAS – SitAHS: *P*<0.001<br>USit – SitAS: *P*=0.002<br>USit – SitAHS: *P*<0.001<br>SitAS – SitAHS: *P*<0.001 | | |
| Partial eta squared (effect size) | | | 0.470 (0.942) | | |

The activation intensity of *sternocleidomastoideus* and *scalenus* was significantly greater in StandAS, SitAS and SitAHS when compared to UStand (*sternocleidomastoideus*: *P*=0.006, *P*=0.009 and *P*=0.001, respectively; *scalenus*: *P*=0.005, *P*<0.001 and *P*=0.003, respectively) and Usit (*sternocleidomastoideus*: *P*=0.018, *P*=0.031 and *P*=0.002, respectively; *scalenus*: *P*=0.029, *P*=0.004 and *P*=0.009, respectively), during inspiration (Figure 1).

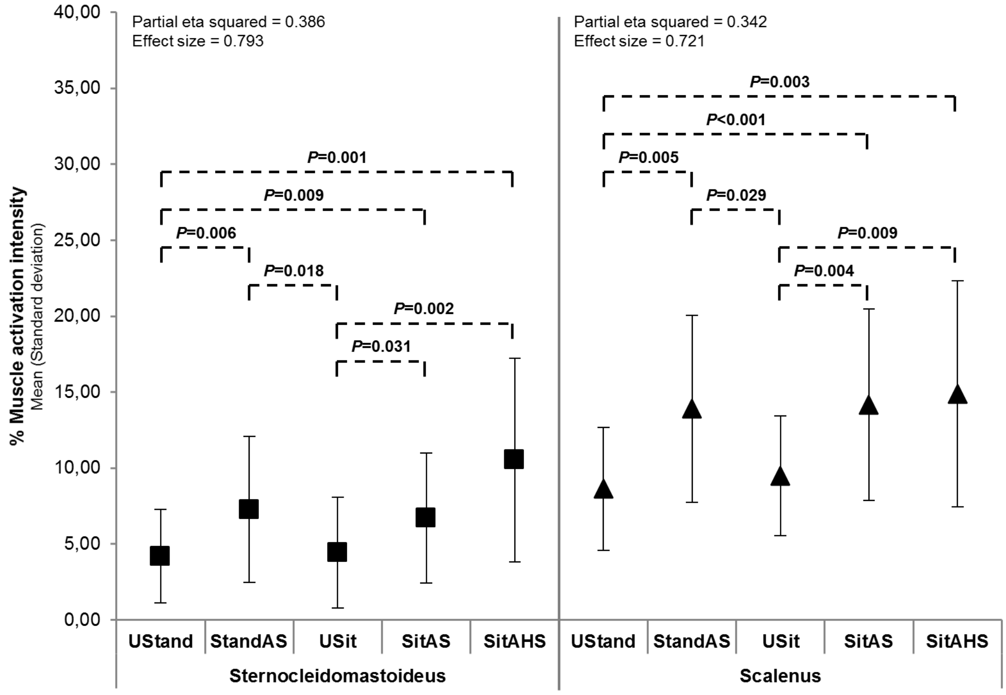


**Figure 1.** Activation intensity of sternocleidomastoideus and scalenus muscles (expressed as %) during inspiration in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented

Abdominal muscles

During both inspiration and expiration, the activation intensity of all abdominal muscles was significantly lower in SitAHS when compared to UStand (RA: *P*<0.050; EO and TrA/IO: *P*<0.001), StandAS (RA: *P*<0.050; EO and TrA/IO: *P*<0.001) and USit (RA: *P*<0.010; EO: *P*<0.001; TrA/IO: *P*<0.010). Also, the activation intensity of RA and EO muscles was significantly lower in SitAHS when compared to SitAS, during both breathing phases (RA and EO: *P*<0.010) (Figure 2 and 3).

During both inspiration and expiration, the activation intensity of EO and TrA/IO muscles was significantly lower in SitAS when compared to UStand

(EO and TrA/IO: *P*<0.001) and StandAS (EO and TrA/IO: *P*<0.001). Also, TrA/IO activation intensity was significantly lower in SitAS when compared to USit, during both breathing phases (*P*<0.050) (Figure 2 and 3).

During both inspiration and expiration, the activation intensity of EO and TrA/IO muscles was significantly lower in USit when compared to UStand (EO and TrA/IO: *P*<0.001) and StandAS (EO: *P*<0.010; TrA/IO: *P*<0.050) (Figure 2 and 3).

During both breathing phases, TrA/IO muscle activation intensity was significantly lower in StandAS when compared to UStand (*P*<0.001) (Figure 2 and 3).

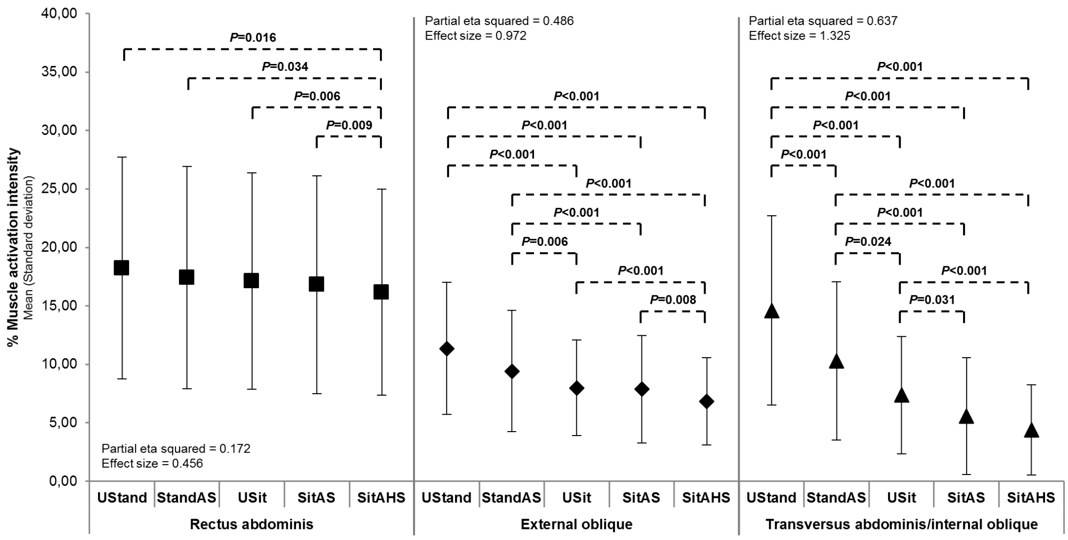


**Figure 2.** Activation intensity of rectus abdominis, external oblique and transversus abdominis/internal oblique muscles (expressed as %) during inspiration in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented

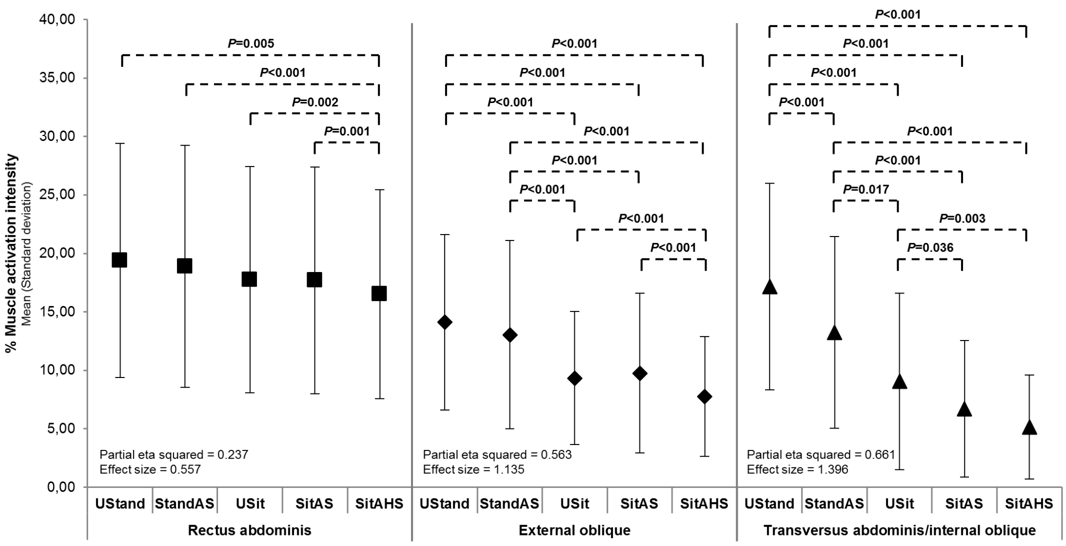


**Figure 3.** Activation intensity of rectus abdominis, external oblique and transversus abdominis/internal oblique muscles (expressed as %) during expiration in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented

*Thoraco-abdominal movement*

The magnitude of anterior-posterior movement of the upper ribcage was significantly greater in StandAS, SitAS and SitAHS when compared to UStand (*P*<0.001, *P*=0.029 and *P*=0.022, respectively) and USit (*P*<0.001, *P*=0.001 and *P*=0.002, respectively) (Figure 4).

The magnitude of medial-lateral movement of the lower ribcage was significantly lower in SitAHS when compared to UStand (*P*=0.001), StandAS (*P*=0.006), USit (*P*=0.003) and SitAS (*P*=0.015) (Figure 4).

The magnitude of anterior-posterior movement of the abdomen was significantly greater in SitAS when compared to UStand (*P*<0.001), USit (*P*=0.001) and SitAHS (*P*<0.001). Also, this movement was significantly greater in StandAS when compared to UStand ($P$<0.001) and USit ($P$=0.010) (Figure 4).

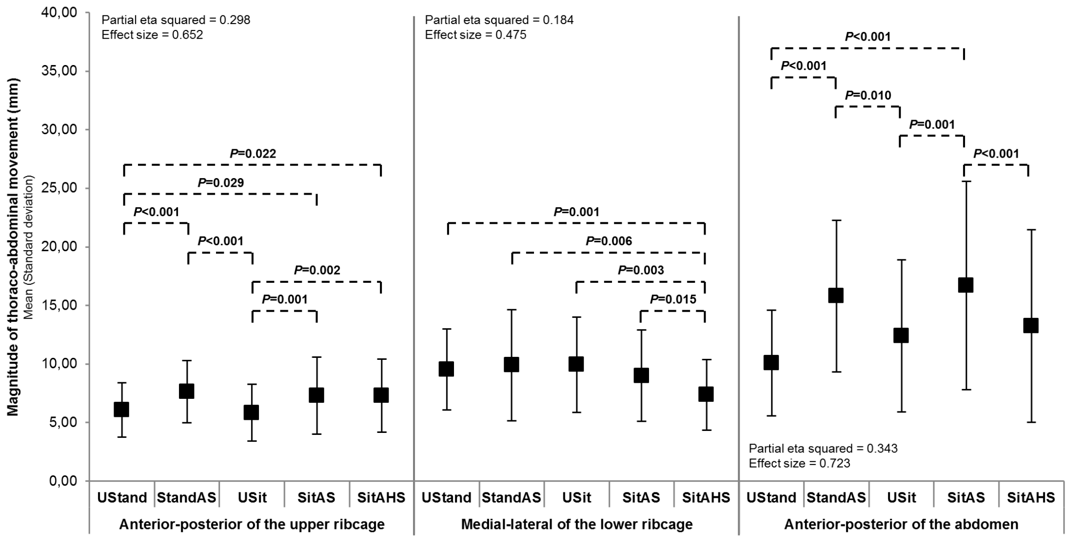


**Figure 4.** Magnitude of thoraco-abdominal movements – anterior-posterior of the upper ribcage, medial-lateral of the lower ribcage and anterior-posterior of the abdomen – (expressed as millimetres) during breathing in upright standing (UStand), standing with forward-leaning and arm support (StandAS), upright sitting (USit), sitting with forward-leaning and arm support (SitAS) and sitting with forward-leaning and arm support (SitAHS). Data are presented as mean and standard deviation. *P* values for significant differences, partial eta squared and effect size for the comparison between postural sets are also presented

*Effect size*

During inspiration, the comparison between the different postural sets showed a large effect in the activation intensity of inspiratory accessory ($\eta_p^2$=0.342–0.470) (Figure 1) and abdominal muscles ($\eta_p^2$=0.172–0.637) (Figure 2). During expiration, the comparison between the different postural sets showed a large effect in the activation intensity of all abdominal muscles ($\eta_p^2$=0.237–0.661) (Figure 3). Still, the comparison between the different postural sets showed a large effect in the magnitude of thoraco-abdominal movement ($\eta_p^2$=0.184–0.343) (Figure 4).

### Discussion

The present study showed that the forward-leaning positions with arm support (StandAS, SitAS and SitAHS) promoted a significantly lower UT muscle activation intensity in relation to upright positions (UStand and USit); however, it was observed a significantly higher activation intensity of *sternocleidomastoideus* and *scalenus* muscles and a significantly higher magnitude of anterior-posterior movement of the upper ribcage. Furthermore, the activation intensity of abdominal muscles was significantly lower in StandAS and SitAS when compared to upright positions; nevertheless, it was observed a higher magnitude of anterior-posterior movement of the abdomen. However, the head support (SitAHS) promoted lower magnitude of medial-lateral movement of the lower ribcage and anterior-posterior movement of the abdomen in relation to other forward-leaning positions.

UT muscle activation intensity was measured. Despite its accessory breathing action (stabilization of the head to help the respiratory action of cervical muscles, which are attached in ribcage) (Dalton, 2011), the UT muscle should be more or less stiff or compliant to enable the appropriate active support of arms and/or head (Starr & Dalton, 2011). The outcomes of the present study indicated that the UT muscle activation intensity was lower in StandAS, SitAS and SitAHS when compared to UStand and USit. In fact, the gravitational pull would be decreased in postural sets with passive support of arms (StandAS, SitAS and SitAHS), resulting in lower feedback from the stretch receptors of UT muscle, thus dropping motor-neuron pool excitability and decreasing muscle recruitment (Meadows & Williams, 2009; Mihailoff & Haines, 2013). In turn, the support of head on participant' hands, in SitAHS, further reduces the muscle loading, so that the UT muscle activation intensity was lower in this postural set when compared to other evaluated postural sets.

During inspiration, the activation intensity of *sternocleidomastoideus* and *scalenus* in StandAS, SitAS and SitAHS was greater when compared to UStand and USit. Normally, the trunk is stabilized and the accessory muscles of breathing move the vertebral column, arm, head or pelvis on the trunk (Starr & Dalton, 2011). When the shoulder girdle is fixed through the arm support, the ribcage becomes the mobile segment (Banzett et al., 1988; Kim et al., 2012). The effect of the muscle's pull is transferred to the ribcage and the *sternocleidomastoideus* and *scalenus* pull the sternum and the first two ribs, increasing the thoracic diameter by moving the ribcage upward and outward – pump-handle motion (Starr & Dalton, 2011). Therefore, in this study, a greater magnitude of anterior-posterior movement of upper ribcage was observed in StandAS, SitAS and SitAHS when compared to UStand and USit. The results of this study were consistent with earlier study of Kim et al. (2012). Although COPD subjects composed the study's sample, both collection protocols allow to evaluate the effect of gravity action on the mechanics of breathing.

Regarding the abdominal muscles' dual task (postural control and mechanics of breathing), the change of body orientation in space requires that the CNS appropriately adjusts the postural tone of them to gravity action and changes in the base of support (Meadows & Williams, 2009; Mihailoff & Haines, 2013). From standing (UStand and StandAS) to sitting (USit and SitAS) positions, it was observed a decreased activation intensity of EO and TrA/IO muscles, which supports the reduction of gravitational pull on muscle loading when the challenge to postural equilibrium and spinal stability is decreased (Cholewicki, Juluru, & McGill, 1999). Nevertheless, the forward-leaning trunk in standing (StandAS) or sitting (SitAS), with passive support of arms, also seemed to reduce the postural load, decreasing abdominal muscle recruitment, namely TrA/IO, when compared to respectively upright positions (UStand and USit). Due to its circumferential arrangement, TrA/IO muscle has the most appropriate mechanical efficiency to modulate the intra-abdominal pressure, supporting the ribcage and abdominal movements (Hodges & Gandevia, 2000a, 2000b). Thus, in this study, a greater magnitude of anterior-posterior movement of the abdomen in StandAS and SitAS when compared to UStand

and USit may be explained by the lower TrA/IO muscle recruitment. The reduced tonic contraction of this abdominal muscle in the forward-leaning positions raises the abdominal compliance, increasing the abdominal motion (Lee, Chang, Coppieters, & Hodges, 2010; Romei et al., 2010). A previous study reported that there was no effect of forward-leaning trunk in sitting on excursion toward the abdominal cavity (Kim et al., 2012). This different result may be explained by differences in setting between postural sets. In Kim et al. (2012) study, from neutral sitting position (as USit) to sitting-with-elbow-on-the-knee, the decreased angle between trunk and hips might increase the resistance of abdominal content to the downward movement of the diaphragm; however, in the present study, this angle was kept between USit and SitAS, minimizing the effect of forward-leaning trunk on inward movement of the abdominal content against the diaphragm muscle.

During both breathing phases, the activation intensity of abdominal muscles in SitAHS was lower than other postural sets. The head support, in sitting with forward-leaning trunk with arm support, increased the dropping of postural load and, consequently, abdominal muscle recruitment decreased. However, the head flexion might promote an upper trunk flexion that approximated the ribs to the pelvis, restricting the descent of central tendon of the diaphragm (anterior expansion of abdomen) and the elevation of lower ribs – bucket handle motion (lateral expansion of ribcage), during inspiration (De Troyer & Estenne, 1988). Therefore, in this study, a lower magnitude of medial-lateral movement of the lower ribcage and anterior-posterior movement of the abdomen was observed in SitAHS when compared to StandAS and SitAS. Therefore, these results in the magnitude of thoraco-abdominal movement also reflect passive influence on ribcage and abdominal compliance. The change of postural alignment affects the position, range of motion and coupling patterns of the spinal and rib articulations for breathing (Edmondston et al., 2007). Thus, the change in sagittal orientation of the vertebras, for example by head flexion, may have an impact on the position of ribs and rib axes and so on the three-dimensional shape of chest wall regions and their motion (Lee et al., 2010). Further investigation is needed to evaluate the change of postural alignment in these postural sets and to understand its effect on the mechanics and pattern of breathing.

None of the participants in the present study had chronic respiratory pathologies. Chronic obstructive pulmonary disease may alter the patient's ability to recruit their respiratory muscles to the mechanics of breathing and, consequently, to contribute for dyspnea sensation. Nevertheless, the results of this study suggested that the specific recruitment pattern of inspiratory accessory and abdominal muscles in forward-leaning positions with arm support might be important to the improvement of chest wall motion and hence to relief the dyspnea. Despite the head support might reduce the postural load in sitting with forward-leaning trunk with arm support, this postural set seemed to promote an impaired chest wall motion. Further studies conducted among chronic obstructive pulmonary disease patients are needed.

## Conclusion

The forward-leaning positions with arm support increased the recruitment of inspiratory accessory muscles, enhancing the anterior-posterior movement of the ribcage. These postural sets also decreased the recruitment of abdominal muscles, namely TrA/IO, increasing the anterior-posterior movement of the abdomen. However, the head support seemed to have a negative impact on movement of lower ribcage and abdomen.

## Acknowledgments

A special thanks to Anabela Carvalho, PT and Ana Sofia Costa, PT for the assistance provided with subject recruitment and data collection.

## Conflict of interest statement

None. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## References


American Thoracic Society/European Respiratory Society. (2002). ATS/ERS Statement on respiratory muscle testing. *American Journal of Respiratory and Critical Care Medicine, 166*(4), 518-624.

Banzett, R. B., Topulos, G. P., Leith, D. E., & Nations, C. S. (1988). Bracing arms increases the capacity for sustained hyperpnea. *American Review of Respiratory Disease, 138*(1), 106-109.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82-87.

Booth, S., Burkin, J., Moffat, C., & Spathis, A. (2014). Positions to ease breathlessness. In S. Booth, J. Burkin, C. Moffat, & A. Spathis (Eds.), *Managing breathlessness in clinical practice* (pp. 49-65). London: Springer.

Bott, J., Blumenthal, S., Buxton, M., Ellum, S., Falconer, C., Garrod, R., . . . British Thoracic Society Physiotherapy Guideline Development, G. (2009). Guidelines for the physiotherapy management of the adult, medical, spontaneously breathing patient. *Thorax, 64*(Suppl 1), i1-51.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., & Chiradejnant, A. (2009). Abdominal muscle activity during abdominal hollowing in four starting positions. *Manual Therapy, 14*(6), 642-646.

Cholewicki, J., Juluru, K., & McGill, S. M. (1999). Intra-abdominal pressure mechanism for stabilizing the lumbar spine. *Journal of Biomechanics, 32*(1), 13-17.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: L. Erlbaum Associates.

Criswell, E. (2011). *Cram's introduction to surface electromyography* (2nd ed.). Sudbury, MA: Jones & Bartlett Publishers.

Dalton, D. (2011). The vertebral column. In P. K. Levangie & C. C. Norkin (Eds.), *Joint structure and function: a comprehensive analysis* (5th ed., pp. 139-191). Philadelphia, PA: F. A. Davis Company.

De Troyer, A., & Estenne, M. (1988). Functional anatomy of the respiratory muscles. *Clinics In Chest Medicine, 9*(2), 175-193.

Dean, E. (1985). Effect of body position on pulmonary function. *Physical Therapy, 65*(5), 613-618.

Delgado, H. R., Braun, S. R., Skatrud, J. B., Reddan, W. G., & Pegelow, D. F. (1982). Chest wall and abdominal motion during exercise in patients with chronic obstructive pulmonary disease. *American Review of Respiratory Disease, 126*(2), 200-205.

Edmondston, S. J., Aggerholm, M., Elfving, S., Flores, N., Ng, C., Smith, R., & Netto, K. (2007). Influence of posture on the range of axial rotation and coupled lateral flexion of the thoracic spine. *Journal of Manipulative and Physiological Therapeutics, 30*(3), 193-199.

Eston, R., Hawes, M., Martin, A., & Reilly, T. (2009). Human body composition. In R. Eston & T. Reilly (Eds.), *Kinanthropometry and exercise physiology laboratory manual: tests, procedures and data - volume one: anthopometry* (pp. 5-53). London: Routledge.

Gosselink, R. (2003). Controlled breathing and dyspnea in patients with chronic obstructive pulmonary disease (COPD). *Journal of Rehabilitation Research & Development, 40*(5 Suppl 2), 25-33.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361-374.

Hodges, P. W., & Gandevia, S. C. (2000a). Activation of the human diaphragm during a repetitive postural task. *The Journal of Physiology, 522*(Pt 1), 165-175.

Hodges, P. W., & Gandevia, S. C. (2000b). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology (1985), 89*(3), 967-976.

Kim, K. S., Byun, M. K., Lee, W. H., Cynn, H. S., Kwon, O. Y., & Yi, C. H. (2012). Effects of breathing maneuver and sitting posture on muscle activity in inspiratory accessory muscles in patients with chronic obstructive pulmonary disease. *Multidisciplinary Respiratory Medicine, 7*(1), 9.

Lee, L. J., Chang, A. T., Coppieters, M. W., & Hodges, P. W. (2010). Changes in sitting posture induce multiplanar changes in chest wall shape and motion with breathing. *Respiratory Physiology & Neurobiology, 170*(3), 236-245.

Marôco, J. (2014). *Análise estatística com o SPSS Statistics* (6th ed.). Pero Pinheiro: ReportNumber, Lda.

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology, 13*(5), 477-489.

Meadows, L., & Williams, J. (2009). An understanding of Functional movement as a basis for clinical reasoning. In S. Raine, L. Meadows, & M. Lynch-Ellerington (Eds.), *Bobath concept: theory and clinical practice in neurological rehabilitation* (pp. 23-42). Oxford: Wiley-Blackwell.

Mew, R. (2009). Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. *Manual Therapy, 14*(6), 690-695.

Mihailoff, G. A., & Haines, D. E. (2013). Motor system I: peripheral sensory, brainstem, and spinal influence on anterior horn neurons. In D. E. Haines (Ed.), *Fundamental neuroscience for basic and clinical applications* (pp. 324-337). Philadelphia, PA: Elsevier/Saunders.

O'Neill, S., & McCarthy, D. S. (1983). Postural relief of dyspnoea in severe chronic airflow limitation: relationship to respiratory muscle strength. *Thorax, 38*(8), 595-600.

Reeve, A., & Dilley, A. (2009). Effects of posture on the thickness of transversus abdominis in pain-free subjects. *Manual Therapy, 14*(6), 679-684.

Romei, M., Mauro, A. L., D'Angelo, M. G., Turconi, A. C., Bresolin, N., Pedotti, A., & Aliverti, A. (2010). Effects of gender and posture on thoraco-abdominal kinematics during quiet breathing in healthy adults. *Respiratory Physiology & Neurobiology, 172*(3), 184-191.

Santos, T. V., Ruas, G., Sande de Souza, L. A., & Volpe, M. S. (2012). Influence of forward leaning and incentive spirometry on inspired volumes and inspiratory electromyographic activity during breathing exercises in healthy subjects. *Journal of Electromyography and Kinesiology, 22*(6), 961-967.

Sharp, J. T., Drutz, W. S., Moisan, T., Foster, J., & Machnach, W. (1980). Postural relief of dyspnea in severe chronic obstructive pulmonary disease. *American Review of Respiratory Disease, 122*(2), 201-211.

Starr, J., & Dalton, D. (2011). The torax and chest wall. In P. K. Levangie & C. C. Norkin (Eds.), *Joint structure and function: a comprehensive analysis* (5th ed., pp. 192-211). Philadelphia, PA: F. A. Davis Company.

Thompson, P. D. (2014). Health appraisal and risk assessment. In L. S. Pescatello, R. Arena, D. Riebe, & P. D. Thompson (Eds.), *ACSM's guidelines for exercise testing and prescription* (9th ed., pp. 1-18). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

World Health Organization. (2011). *Waist circumference and wais-hip ratio - Report of a WHO expert consultation.* Retrieved from http://www.who.int/nutrition/publications/obesity/WHO_report_waistcircumference_and_waisthip_ratio/en/

# Abdominal muscle activity during breathing with and without inspiratory and expiratory loads in healthy subjects

**António Mesquita Montes, MSc**[a,b], João Baptista, PT[c], Carlos Crasto, MSc[a], Cristina Argel de Melo, PhD[a], Rita Santos, MSc[a], João Paulo Vilas-Boas, PhD[b]

[a] Department of Physiotherapy, and Activity and Human Movement Study Center (CEMAH), School of Allied Health Technologies, Polytechnic Institute of Porto, Rua Valente Perfeito 322, 4400-330 Vila Nova de Gaia, Portugal

[b] Faculty of Sport, CIFI2D, and Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Rua Dr. Plácido Costa 91, 4200-450 Porto, Portugal

[c] Physiotherapist, Private practice, Portugal

Mesquita Montes, A., et al. (2016). Abdominal muscle activity during breathing with and without inspiratory and expiratory loads in healthy subjects. *Journal of Electromyography and Kinesiology, 30*, 143-150. doi:10.1016/j.jelekin.2016.07.002

**Abstract**

Central Nervous System modulates the motor activities of all trunk muscles to concurrently regulate the intra-abdominal and intra-thoracic pressures. The study aims to evaluate the effect of inspiratory and expiratory loads on abdominal muscle activity during breathing in healthy subjects. Twenty-three higher education students (21.09±1.56 years; 8 males) breathed at a same rhythm (inspiration: two seconds; expiration: four seconds) without load and with 10% of the maximal inspiratory or expiratory pressures, in standing. Surface electromyography was performed to assess the activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles, during inspiration and expiration. During inspiration, *transversus abdominis*/internal oblique activation intensity was significantly lower with inspiratory load when compared to without load (*p*=0.009) and expiratory load (*p*=0.002). During expiration, the activation intensity of all abdominal muscles was significantly higher with expiratory load when compared to without load (*p*<0.05). The activation intensity of external oblique (*p*=0.036) and *transversus abdominis*/internal oblique (*p*=0.022) was significantly higher with inspiratory load when compared to without load. *Transversus abdominis*/internal oblique activation intensity was significantly higher with expiratory load when compared to inspiratory load (*p*<0.001). *Transversus abdominis*/internal oblique seems to be the most relevant muscle to modulate the intra-abdominal pressure for the breathing mechanics.

**Keywords**

Respiration; Postural control; Core abdominal; Respiratory loads; Surface electromyographic activity

## Introduction

The constant change of internal and external forces acting on human body determines that the Central Nervous System (CNS) organizes a complex and differentiated control and coordination system, allowing movement without losing stability (Horak, Henry, & Shumway-Cook, 1997). CNS continuously interprets the stability status, receiving and integrating afferent input from the peripheral mechanoreceptors and other sensory systems, to generate a coordinated response of trunk muscles (Balasubramaniam & Wing, 2002; Lackner & DiZio, 2005). The global and core muscles provide stability to the multi segmental spine by modulating the intra-abdominal pressure (Cholewicki, Juluru, & McGill, 1999), which occurs through the coordination of abdominal, pelvic floor and diaphragm muscles activity (Hodges, Butler, McKenzie, & Gandevia, 1997; Hodges & Gandevia, 2000a).

Nevertheless, CNS modulates the motor activities of these trunk muscles during both postural and respiratory functions (Hodges, 1999) to concurrently regulate the intra-abdominal and intra-thoracic pressures (Hodges, Heijnen, & Gandevia, 2001). The postural control inputs from the supraspinal structures are integrated with the rhythmic drive to the inspiratory motoneurons of diaphragm muscle from the respiratory centres in the pons and medulla. Although *rectus abdominis* (RA) and external oblique (EO) muscles are a non respiration-related modulation, the *transversus abdominis* (TrA) muscle activity is modulated with the respiration and is out of phase with the diaphragm muscle activity. Then, the tonic activity of diaphragm and TrA muscles for the postural control is modulated with the respiratory phasic activity (Hodges & Gandevia, 2000a, 2000b).

During tidal breathing, the diaphragm muscle contraction causes a descent of its dome and, consequently, an increase in intra-abdominal pressure, which eventually prevents a further descent of the central tendon of diaphragm muscle (Goldman, Lehr, Millar, & Silver, 1987). This increased intra-abdominal pressure is countered by the tension in the abdominal muscles, namely TrA muscle (De Troyer, Estenne, Ninane, Van Gansbeke, & Gorini, 1990). Without sufficient compliance in abdominal muscles, the central tendon of diaphragm muscle cannot be effectively stabilized to promote lower ribs elevation and, consequently, lateral chest wall expansion (De Troyer & Estenne, 1988).

The breathing movements of rib cage and abdomen generate a cyclical disturbance to the trunk stability and the body equilibrium (Hodges, Gurfinkel, Brumagne, Smith, & Cordo, 2002). Despite healthy subjects are capable of actively compensate for the quiet breathing, postural control is compromised when the respiratory demand increases and requires voluntary control (David, Laval, Terrien, & Petitjean, 2012; Kuznetsov & Riley, 2012). This increased descending respiratory drive attenuates the postural activity of diaphragm and TrA muscles (Hodges et al., 2001). The impaired contribution of these core muscles to the spinal stability is associated with an increased activity of EO and RA muscles (Hodges & Gandevia, 2000b). Furthermore, the respiratory system tends to limit the inspiratory muscle activity, transferring any additional load to the expiratory muscles, placing the diaphragm muscle in improved mechanical advantage, to assist the subsequent inspiration (Aliverti et al., 1997). Nevertheless, the impact of different respiratory loads on abdominal muscle activity, during both breathing phases, for the synchronization of postural and respiratory functions is not yet clear. Thus, the aim of the present study was to evaluate the effect of inspiratory and expiratory loads on abdominal muscle activity during breathing, in healthy subjects. Specifically, it was analysed the activation intensity of RA, EO and *transversus abdominis*/internal oblique (TrA/IO) muscles, during inspiration and expiration, without respiratory load and with inspiratory or expiratory loads.

## Methods

### *Sample*

The study followed a repeated measures design with a sample composed by twenty-three healthy higher education students, who volunteered to participate in this research (8 males). Demographic and anthropometric data regarding the sample are described in Table 1. Participants were aged between 18 and 24 years and were not participated in moderate intensity, aerobic physical activity for a minimum of 30 min on five days a week or vigorous intensity, aerobic activity for a minimum of 20 min on 3 days a week, for a period exceeding one year (Thompson, 2014). It was defined as exclusion criteria the body mass index higher than 25 $kg.m^{-2}$; chronic nonspecific lumbopelvic pain (recurrent episodes of lumbopelvic pain for a period longer than three months); scoliosis, length discrepancy of the lower limbs or other postural asymmetries; history of spinal, gynaecological or abdominal surgery in the previous year; neurological or inflammatory disorders; metabolic or cardio-respiratory diseases; pregnancy or post-delivery in the previous six months; smoking habits; long-term corticosteroid therapy; and any conditions that may interfere with the data collection (American Thoracic Society/European Respiratory Society, 2002; Beith, Synnott, & Newman, 2001; Chanthapetch, Kanlayanaphotporn, Gaogasigam, & Chiradejnant, 2009; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Mew, 2009; Reeve & Dilley, 2009). Each participant provided a written informed consent form, according to the Declaration of Helsinki. The anonymity of participants and the confidentiality of data were guaranteed. The Institutional Research Ethics Committee previously approved this study.

**Table 1.** Sample characterization: demographic and anthropometric data, with mean, standard deviation, minimum and maximum.

| | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Age (years) | 21.09 | 1.56 | 18 | 24 |
| Body mass (kg) | 61.57 | 8.87 | 49 | 81 |
| Height (m) | 1.67 | 0.90 | 1.53 | 1.82 |
| BMI ($kg.m^{-2}$) | 21.96 | 1.51 | 19.02 | 24.45 |

BMI body mass index

*Procedures*

Sample selection and characterization

An electronic questionnaire was delivered to all participants to verify the selection criteria and to collect sociodemographic information. Anthropometric measures were assessed in participants who fulfil participation criteria. Height (m) and body mass (kg) – were measured using a seca 222 stadiometer with an accuracy of 1 mm and a seca 760 scale with an accuracy of 1 kg, respectively, and then used to calculate the body mass index. To assess postural asymmetries, the lower limb length (cm) was measured using a seca 201 tape with an accuracy of 1 mm (seca – Medical Scales and Measuring Systems, Hamburg, Germany) and the postural assessment was performed. These evaluations were performed to select the final sample. Women who were in luteal phase were contacted later for data collection.

Data collection protocol

The study procedures took place at a biomechanical laboratory and were performed in a controlled environment. To avoid inter-rater error, each researcher was responsible for an only task.

Surface electromyography (sEMG) was performed to bilaterally assess the muscle activity of TrA/IO, EO and RA. The muscle activity was collected using the BioPlux research device (Plux wireless biosignals S.A., Arruda dos Vinhos, Portugal), with analogue channels of 12 bits and a sampling frequency of 1000 Hz, using double differential electrode leads. To perform the sEMG, the hair was shaved and an abrasive cream was used to remove the dead cells from the skin's surface. Skin was then cleaned with isopropyl alcohol (70 %), removing its oiliness and holding the dead cells. An electrode impedance checker (Noraxon Corporate, Scottsdale AZ, United States of America) was used to make sure that the impedance levels were below 5 KΩ and thus ensure a good acquisition of sEMG signal (Hermens et al., 2000). Disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon Corporate, Scottsdale AZ, United States of America) were used for the sEMG. The electrode characteristics were 4x2.2 cm of adhesive area, 1 cm diameter of each circular conductive area and 2 cm of inter-electrode distance. These electrodes were connected to bipolar active sensors emgPLUX, with a gain of 1000, an analogue filter at 25 to 500 Hz and a common-mode rejection ratio of 110 dB. As the reference electrode, it was used a disposable self-adhesive Ag/AgCl snap electrode (Noraxon Corporate, Scottsdale AZ, United States of America) for the sEMG, with 3.8 cm diameter of circular adhesive area and 1 cm diameter of circular conductive area. The self-adhesive electrodes were placed in standing, five minutes after the skin preparation. These electrodes were placed parallel to the muscle fibers orientation, according to the references described in Table 2 (Criswell, 2011; Marshall & Murphy, 2003). The electrode placements were confirmed by palpation and muscle contraction. The reference electrode was placed in the anterior superior iliac spine of the contralateral dominant side. The sensors were Bluetooth connected through the sEMG device to a laptop. It was used the MonitorPlux software, version 2.0, to display and acquire the sEMG signal. All electrodes were tested to control the cross-muscular signal (cross-talk), electrical noise and other interferences of sEMG signal (Hermens et al., 2000). For this quality control, the baseline and power spectrum of sEMG signal were analysed. It is guaranteed that the baseline values were below 3.5 μV. Also, the power spectrum curves decreased and reached zero between 200 Hz and 250 Hz and atypical power peaks was not present.

**Table 2.** Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/internal oblique (TrA/IO) muscles.

| Muscle | Anatomical landmarks |
|---|---|
| RA | 2 cm lateral to umbilicus, over the muscle mass |
| EO | Lateral to the RA and directly above the anterior superior iliac, halfway between the crest and ribs at a slightly oblique angle |
| TrA/IO | 2 cm medially and below to anterior superior iliac spine<br>In this local, TrA and inferior IO muscle fibres are mixed, so it is impossible distinguish the surface electromyographic activity of both. |

A respiratory pressure meter MicroRPM (CareFusion Corporation, San Diego CA, United States of America) was used to assess the maximal inspiratory (MIP) and expiratory (MEP) pressures. The values obtained were used to determine the inspiratory and expiratory loads, respectively. MEP quasi-static maximal manoeuvre was used to normalize the sEMG signal of abdominal muscles (maximal muscle activity of each muscle during breathing). MIP and MEP were both performed with the participants in standing, using a bacterial filter AFT1 – Disposable Bacterial Filter, 22 mm and a mouthpiece AFT2 – Disposable Mouthpiece, 22 mm firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip AFT3 – Disposable Noseclip (Biopac Systems Inc., Goleta CA, United States of America) to prevent nasal breathing. To assess MIP, it was performed a forceful and maximal inspiration – Muller manoeuvre – at residual volume; in turn, MEP was assessed through a forceful and maximal expiration – Valsalva manoeuvre – at total lung capacity. Each manoeuvre was encouraged verbally. These manoeuvres were performed during six seconds, with a resting time of three minutes. To calculate the respiratory load, three reproducible manoeuvres were selected, according to the American Thoracic Society/European Respiratory Society (2002) standards. It was used 10 % of the best value of MIP and MEP for the inspiratory and expiratory loads, respectively.

All participants were submitted to three different tasks – breathing without respiratory load and with inspiratory or expiratory loads, in standing – in a single data collection moment. The data collection moment was started with breathing without respiratory load. The order of inspiratory or expiratory loads was randomized. A respiratory flow transducer TSD117 – Medium Flow Trans 300 $L.min^{-1}$, connected to an amplifier DA100C – General Purpose Transducer Amplifier Module, was used to detect the breathing phases. The respiratory flow was collected using the Biopac MP100WSW Data Acquisition System device (Biopac Systems Inc., Goleta CA, United States of America), with a sampling frequency of 100 Hz. A bacterial filter AFT1, a mouthpiece AFT2 and a nose clip AFT3 were also used. It was used the Acqknowledge software, version 4.1, in to display and acquire the respiratory flow signal. Biopac MP100WSW Data Acquisition System was synchronized with the BioPlux research. Thresholds IMT and PEP (Respironics Inc., Murrysville PA, United Stare of America) were used to apply the inspiratory and expiratory loads, respectively. These devices were adapted to the respiratory flow transducer.

The participants were barefoot and had the upper limbs along the body, with feet shoulder-width apart and knees in loose pack position. An A3 paper sheet was used to outline the base of support, keeping it for all tasks. The participants kept their gaze in a horizontal direction and the respiratory flow transducer was kept perpendicular to the participant during all tasks. A single repetition of each task was performed for ten consecutive respiratory cycles, with a resting time of three minutes. The respiratory rhythm (inspiratory time: two seconds; expiratory time: four seconds) was marked through a recorded voice. The participants experienced this respiratory rhythm prior to collect data.

After the data collection, the electrodes were removed and a moisturizing cream was applied on the electrode placements.

Data processing

A routine was developed in MatLab Student software (MathWorks, Pozuelo de Alarcon, Spain) to synchronize and process data. Firstly, the sEMG signal was converted into volts. It was applied to the sEMG signal a $2^{nd}$ order digital filter Infinite Impulse Response – Butterworth, one of 30 Hz (high pass) and another of 500 Hz (low pass), to remove the electrical noise and/or cable movement and to remove the cardiac signal. Root mean square (RMS) to 10 samples was then calculated.

Acqknowledge software, version 4.1, was used to analyse data. The abdominal muscle activity was analysed during inspiration and expiration, independently. These both breathing phases were identified through the respiratory flow transducer signal. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles of each muscle was analysed in each task, with a posterior analysis of its average (Fig. 1).

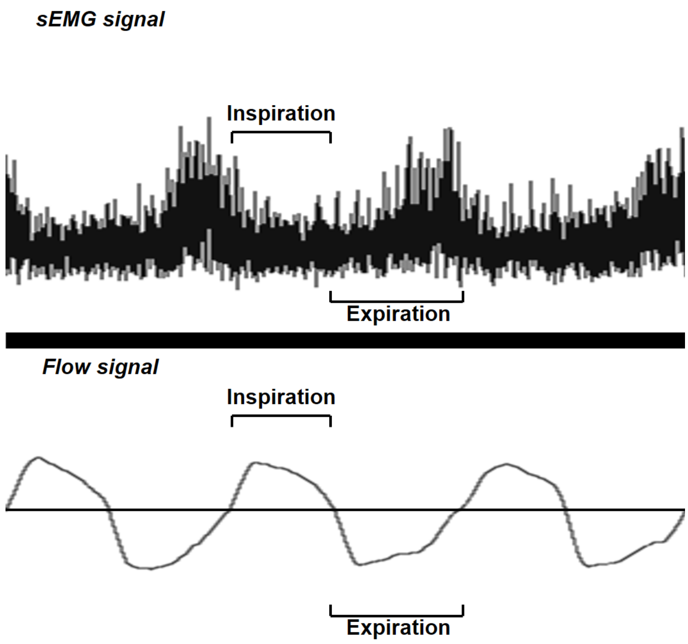


**Figure 1.** Identification of one respiratory cycle (inspiration and expiration phases) through the respiratory flow transducer signal, and corresponding surface electromyography (sEMG) signal analysis.

The muscle activity collected during the MEP manoeuvre was used to normalize data of the abdominal muscles. It was analysed the mean RMS of three central seconds of the expiratory phase of each muscle, and then the average of the mean RMS of three reproducible manoeuvres was calculated (Fig. 2). The percentage of the activation intensity of each muscle was determined according to the following equation:

$$Muscle\ activation\ intensity\ (\%) = \left(\frac{mean\ RMS\ of\ each\ task}{RMS\ of\ the\ MEP}\right) * 100$$

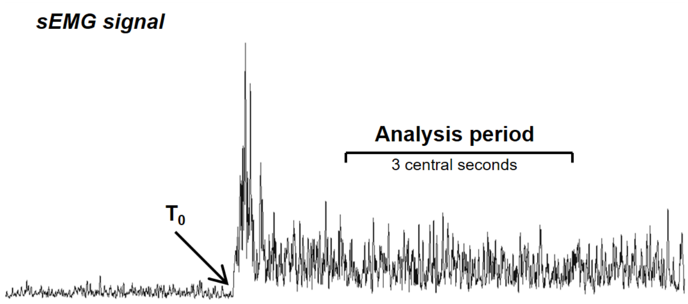


**Figure 2.** Surface electromyography (sEMG) signal analysis of one maximal expiratory pressure manoeuvre. $T_0$ is the initial of expiratory phase.

For the global analysis of activation intensity of the RA, EO and TrA/IO muscles during each breathing phase, the average of the percentage of muscle activation intensity of the two hemi-trunks was calculated.

*Statistical analysis*

IBM SPSS Statistics® software, version 20.0, (IBM Corporation, Armonk NY, United States of America) was used for the descriptive and inferential data analysis, with a significance level of 0.05. Shapiro-Wilk test was used to test the normality of the data. The central tendency (mean) and dispersion (standard deviation) measures were used for the descriptive statistics.

Repeated Measures Analysis of Variance was used to compare the percentage of muscle activation intensity between the different evaluation tasks (without respiratory load and with inspiratory or expiratory loads), during inspiration and expiration. Bonferroni correction was used for the post-hoc analysis (Marôco, 2014). To quantify the effect size, the partial eta square ($\eta_p^2$) values will be calculated using cut-off provided by Cohen: $\eta_p^2$ = 0.01 – small effect, $\eta_p^2$ = 0.06 – medium effect, and $\eta_p^2$ = 0.14 – large effect (Cohen, 1988).

## Results

*Inspiration*

During inspiration (Fig. 3), no significant differences were found in the activation intensity of RA an EO muscles between tasks. TrA/IO muscle activation intensity was significantly lower with inspiratory load when compared to without respiratory load (*p*=0.009) and expiratory load (*p*=0.002).

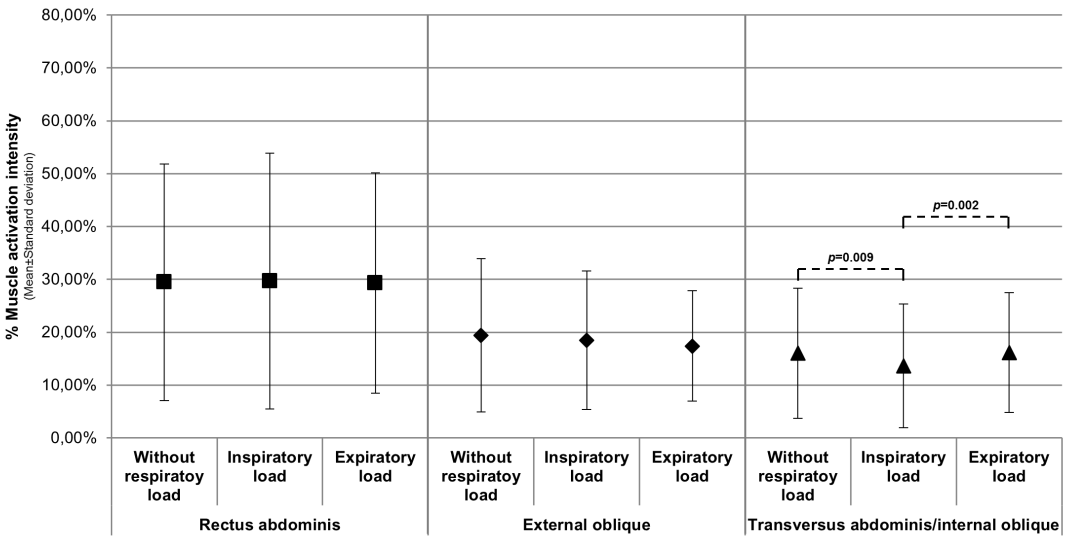


**Figure 3.** Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during inspiration without respiratory load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented

*Expiration*

During expiration (Fig. 4), the activation intensity of all abdominal muscles was significantly greater with expiratory load when compared to without respiratory load (RA: $p=0.005$; EO: $p=0.014$; TrA/IO: $p<0.001$). The activation intensity of EO ($p=0.036$) and TrA/IO ($p=0.022$) was significantly greater with inspiratory load when compared to without respiratory load. TrA/IO muscle activation intensity was significantly greater with expiratory load when compared to inspiratory load ($p<0.001$).

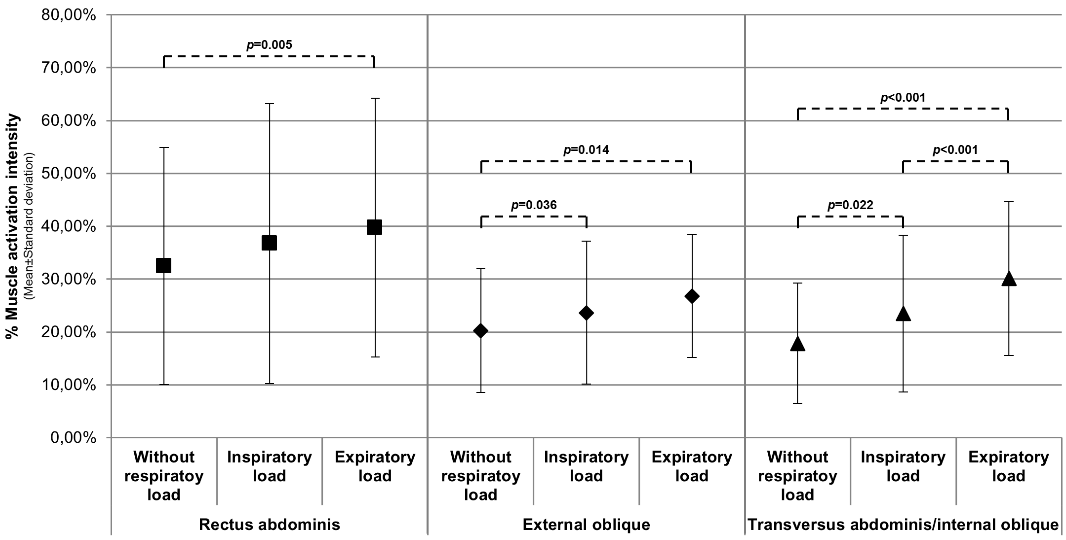


**Figure 4.** Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique muscles (expressed as %) during expiration without respiratory load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented

*Effect size*

Table 3 show the $\eta_p^2$, effect size and power test for the comparison of the percentage of activation intensity of RA, EO and TrA/IO muscles between the different tasks, during inspiration and expiration. During inspiration, the comparison between the different tasks showed a large effect in TrA/IO muscle activation intensity ($\eta_p^2$=0.248). Still, during expiration, the comparison between the different tasks showed a large effect in the activation intensity of all abdominal muscles (RA: $\eta_p^2$=0.167; EO: $\eta_p^2$=0.239; TrA/IO: $\eta_p^2$=0.545).

**Table 3.** Partial eta squared, effect size and power test for the comparison of the percentage of activation intensity of rectus abdominis (RA), external oblique (EO) and transversus abdominis/internal oblique muscles (TrA/IO) between the different evaluation tasks (without respiratory load and with inspiratory or expiratory loads), during inspiration and expiration.

| Breathing phase | Muscle | Partial eta squared | Effect size | Power test |
|---|---|---|---|---|
| Inspiration | RA | 0.002 | 0.045 | 0.070 |
| | EO | 0.061 | 0.255 | 0.738 |
| | TrA/IO | 0.248 | 0.574 | 1.000 |
| Expiration | RA | 0.167 | 0.448 | 0.997 |
| | EO | 0.239 | 0.560 | 1.000 |
| | TrA/IO | 0.545 | 1.094 | 1.000 |

## Discussion

The present study showed that, during inspiration, only TrA/IO muscle activation intensity was lower with inspiratory load when compared to without respiratory load and expiratory load. During expiration, the activation intensity of abdominal muscles was higher with both inspiratory and expiratory loads. Nevertheless, TrA/IO muscle activation intensity was higher with expiratory load when compared to inspiratory load. These data suggested that the abdominal muscles are important for the breathing mechanics.

All participants breathed at a same rhythm. The quiet expiration is a passive process, involving the use of elastic components recoil of the lungs and chest wall; no phasic activity of abdominal muscles is observed (Kenyon et al., 1997). However, in this study, the breathing with a mandatory rhythm increased the minute ventilation, implying a breathing below functional residual capacity and, consequently, a phasic respiratory activity of abdominal muscles. Moreover, the standardization of respiratory rhythm may have reduced a possible bias related to the respiratory load on minute ventilation.

The outcomes of the present study indicated that the TrA/IO muscle activation intensity was lower with inspiratory load when compared to without respiratory load and expiratory load, during inspiration, with a large effect. Previous research emphasized that the contribution of abdominal muscles for breathing, apart from their obvious expiratory action, may also be important during inspiration (Macklem, 2014) when the respiratory drive increases, e.g., exercise or mechanical load (Aliverti et al., 1997; De Troyer et al., 1990). For that, breathing is achieved by an alternate modulation of activity of the diaphragm and TrA muscles, resulting on cyclic changes in the shape of pressurized abdominal cavity. During inspiration, the lower TrA/IO muscle recruitment seemed to minimize the increased intra-abdominal pressure, as a result of the greater diaphragm muscle recruitment in response to the inspiratory load. Thus, in the present study, the results suggested that although the activity of RA and EO muscles were a non inspiration-related modulation, only the TrA/IO muscle activity was modulated during inspiration to support ribcage and abdominal movements, without losing trunk stability (Hodges & Gandevia, 2000b).

Nevertheless, in this study, the activation intensity of EO and TrA/IO muscles with inspiratory load was greater than without respiratory load, during expiration, with a large effect. In fact, the abdominal muscle contraction during expiration contributes to the next inspiration, maintaining the diaphragm muscle closer to its optimal length for tension generation (contractility) (De Troyer & Estenne, 1988). The gradual relaxation of TrA/IO muscle observed during inspiration observed in the present study minimizes the rib cage distortion and unloads the diaphragm muscle, allowing it to act as a flow generator rather than as a pressure generator (Macklem, 2014). The results of this study were consistent with earlier studies of De Troyer et al. (1990). Aliverti et al. (1997) reported that all abdominal muscles are recruited at the onset of even minimal exercise and their contribution increases progressively as it increases the exercise power. However, Hodges, Gandevia, and Richardson (1997) reported that only phasic activity of the TrA and IO muscles is observed during expiration with inspiratory load. These authors used a narrow tube to apply the inspiratory load. So, the overload may not be equal between subjects. Still, in the present study, the inspiratory load magnitude was calculated in relation to the MIP value of each participant. Furthermore, during data collection, all participants of this study remained standing, with their knees in loose pack position contrasting to the position used by Hodges, Gandevia, et al. (1997). The increased EO muscle activity due to the greater postural load of non-relaxed position may be a mechanism to compensate the reduced contribution of TrA and diaphragm muscles to the trunk stability. In fact, Hodges et al. (2001) reported that when the respiratory function of diaphragm muscle is challenged, the postural function of this and of TrA muscle may also be challenged, resulting in a negative effect on postural control. Further studies are needed to evaluate the effect of a low inspiratory load on postural control. The specific recruitment of abdominal muscles observed in the present study may provide a mechanism for the CNS to coordinate the respiration and the spinal control during breathing with a low inspiratory load.

All abdominal muscles showed a greater activation intensity with expiratory load when compared to without respiratory load, during expiration, with a large effect. In fact, voluntary efforts, such as empty the lung or raise the intra-abdominal pressure, are achieved by the contraction in concert of the superficial (RA and EO muscles) and deep (TrA/IO muscle) muscle layers of ventrolateral abdominal wall (De Troyer et al., 1990). These findings are corroborated by Barrett, Cerny, Hirsch, and Bishop (1994), who found that the abdominal muscle recruitment increases in proportion to the expiratory threshold load. Kaneko, Sato, and Maruyama (2006) also reported an increased abdominal muscle recruitment (thickness), measured by ultrasonography. Nevertheless, De Troyer et al. (1990) and Goldman et al. (1987) found that the TrA muscle frequently contracts together with EO and RA muscles during expiration below functional residual capacity, voluntary cough, expulsive manoeuvres and speech. Furthermore, in the present study, the activation intensity of TrA/IO muscle was greater with expiratory load when compared with inspiratory load, during expiration. Despite the fact that all abdominal muscles tend to contract together during expiratory voluntary efforts, there seems to be a specific recruitment of TrA/IO muscle, regarding

RA and the EO muscles, during breathing with expiratory load. These findings are consistent with earlier studies of Kaneko et al. (2006), who reported that the expiratory threshold loading increases mainly the TrA muscle thickness. This specific recruitment of the TrA/IO muscle strengthens the knowledge that the effect of this muscle on abdominal pressure is important to the act of breathing.

All participants in this study did not suffer from chronic respiratory pathologies. Chronic obstructive pulmonary disease may alter the patient's ability to modulate their abdominal muscles recruitment to maintaining the dual task. Therefore, it is important to understand if the abdominal muscle synergy observed with a low inspiratory load, it would be present in this population, for allow breathing without loosing the trunk stability. Otherwise, the results of the present study suggested that only 10% of MEP can have a potential impact on the facilitation of abdominal muscle activation, namely TrA/IO muscle, and, consequently, improves the breathing mechanics, minimizing the rib cage distortion and unloading the diaphragm muscle. Furthermore, it is difficult to evaluate the energetic cost of the benefit of sharing the work of abdominal muscles for the breathing. However, the TrA/IO muscle expiratory contraction, due to its circumferential arrangement, should be more effective in increasing abdominal pressure and deflating the lung so as to take on portion the work of the inspiratory muscles (De Troyer et al., 1990). Further studies conducted among chronic obstructive pulmonary disease patients are needed to select the appropriate intervention strategies to optimize the abdominal muscle synergy for the postural and respiratory functions.

## Conclusion

In healthy subjects, the inspiratory and expiratory loads promoted a different impact on abdominal muscle activity during both phases of breathing. Despite all abdominal muscles are important for breathing mechanics, TrA/IO muscle recruitment seems to be the most relevant to modulate the intra-abdominal pressure in situations wherein the respiratory demand increases.

## Acknowledgments

A special thanks to Ivo Esteves, PT and Sara Gouveia, PT for the assistance provided with participant recruitment and data collection.


## Conflict of interest statement

Nothing to declare.

## References


Aliverti, A., Cala, S. J., Duranti, R., Ferrigno, G., Kenyon, C. M., Pedotti, A., . . . Yan, S. (1997). Human respiratory muscle actions and control during exercise. *Journal of Applied Physiology (1985), 83*(4), 1256-1269.

American Thoracic Society/European Respiratory Society. (2002). ATS/ERS Statement on respiratory muscle testing. *American Journal of Respiratory and Critical Care Medicine, 166*(4), 518-624.

Balasubramaniam, R., & Wing, A. M. (2002). The dynamics of standing balance. *Trends in Cognitive Sciences, 6*(12), 531-536.

Barrett, J., Cerny, F., Hirsch, J. A., & Bishop, B. (1994). Control of breathing patterns and abdominal muscles during graded loads and tilt. *Journal of Applied Physiology (1985), 76*(6), 2473-2480.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82-87.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., & Chiradejnant, A. (2009). Abdominal muscle activity during abdominal hollowing in four starting positions. *Manual Therapy, 14*(6), 642-646.

Cholewicki, J., Juluru, K., & McGill, S. M. (1999). Intra-abdominal pressure mechanism for stabilizing the lumbar spine. *Journal of Biomechanics, 32*(1), 13-17.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: L. Erlbaum Associates.

Criswell, E. (2011). *Cram's introduction to surface electromyography* (2nd ed.). Sudbury, MA: Jones & Bartlett Publishers.

David, P., Laval, D., Terrien, J., & Petitjean, M. (2012). Postural control and ventilatory drive during voluntary hyperventilation and carbon dioxide rebreathing. *European Journal of Applied Physiology, 112*(1), 145-154.

De Troyer, A., & Estenne, M. (1988). Functional anatomy of the respiratory muscles. *Clinics In Chest Medicine, 9*(2), 175-193.

De Troyer, A., Estenne, M., Ninane, V., Van Gansbeke, D., & Gorini, M. (1990). Transversus abdominis muscle function in humans. *Journal of Applied Physiology (1985), 68*(3), 1010-1016.

Goldman, J. M., Lehr, R. P., Millar, A. B., & Silver, J. R. (1987). An electromyographic study of the abdominal muscles during postural and respiratory manoeuvres. *Journal of Neurology, Neurosurgery & Psychiatry, 50*(7), 866-869.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361-374.

Hodges, P. W. (1999). Is there a role for transversus abdominis in lumbo-pelvic stability? *Manual Therapy, 4*(2), 74-86.

Hodges, P. W., Butler, J. E., McKenzie, D. K., & Gandevia, S. C. (1997). Contraction of the human diaphragm during rapid postural adjustments. *The Journal of Physiology, 505*(Pt 2), 539-548.

Hodges, P. W., & Gandevia, S. C. (2000a). Activation of the human diaphragm during a repetitive postural task. *The Journal of Physiology, 522*(Pt 1), 165-175.

Hodges, P. W., & Gandevia, S. C. (2000b). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology (1985), 89*(3), 967-976.

Hodges, P. W., Gandevia, S. C., & Richardson, C. A. (1997). Contractions of specific abdominal muscles in postural tasks are affected by respiratory maneuvers. *Journal of Applied Physiology (1985), 83*(3), 753-760.

Hodges, P. W., Gurfinkel, V. S., Brumagne, S., Smith, T. C., & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Experimental Brain Research, 144*(3), 293-302.

Hodges, P. W., Heijnen, I., & Gandevia, S. C. (2001). Postural activity of the diaphragm is reduced in humans when respiratory demand increases. *The Journal of Physiology, 537*(Pt 3), 999-1008.

Horak, F. B., Henry, S. M., & Shumway-Cook, A. (1997). Postural perturbations: new insights for treatment of balance disorders. *Physical Therapy, 77*(5), 517-533.

Kaneko, H., Sato, H., & Maruyama, H. (2006). Evaluation of lateral abdominal muscle activity during expiratory threshold loading by ultrasonography. *Journal of Physical Therapy Science, 18*(2), 187-191.

Kenyon, C. M., Cala, S. J., Yan, S., Aliverti, A., Scano, G., Duranti, R., . . . Macklem, P. T. (1997). Rib cage mechanics during quiet breathing and exercise in humans. *Journal of Applied Physiology (1985), 83*(4), 1242-1255.

Kuznetsov, N. A., & Riley, M. A. (2012). Effects of breathing on multijoint control of center of mass position during upright stance. *Journal of Motor Behavior, 44*(4), 241-253.

Lackner, J. R., & DiZio, P. (2005). Vestibular, proprioceptive, and haptic contributions to spatial orientation. *Annual Review of Psychology, 56*, 115-147.

Macklem, P. T. (2014). The act of breathing. In A. Aliverti & A. Pedotti (Eds.), *Mechanics of breathing: new insights from new technologies* (pp. 3-10). Milano: Springer Milan.

Marôco, J. (2014). *Análise estatística com o SPSS Statistics* (6th ed.). Pero Pinheiro: ReportNumber, Lda.

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology, 13*(5), 477-489.

Mew, R. (2009). Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. *Manual Therapy, 14*(6), 690-695.

Reeve, A., & Dilley, A. (2009). Effects of posture on the thickness of transversus abdominis in pain-free subjects. *Manual Therapy, 14*(6), 679-684.

Thompson, P. D. (2014). Health appraisal and risk assessment. In L. S. Pescatello, R. Arena, D. Riebe, & P. D. Thompson (Eds.), *ACSM's guidelines for exercise testing and prescription* (9th ed., pp. 1-18). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

# Centre of pressure displacement during breathing with and without inspiratory and expiratory loads in healthy subjects

**António Mesquita Montes, MSc**[a,b], Ivo Esteves, PT[c], Carlos Crasto, MSc[a], Cristina Argel de Melo, PhD[a], Rita Santos, MSc[a], Rubim Santos PhD[a], João Paulo Vilas-Boas, PhD[b]

[a] Department of Physiotherapy, and Activity and Human Movement Study Center (CEMAH), School of Allied Health Technologies, Polytechnic Institute of Porto, Rua Dr. António Bernardino de Almeida 400, 4200-072 Porto, Portugal

[b] Faculty of Sport, CIFI2D, and Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Rua Dr. Plácido Costa 91, 4200-450 Porto, Portugal

[c] Physiotherapist, Private practice, Portugal

Submetido para publicação

**Abstract**

Although the central nervous system counteracts the destabilizing effect of quiet breathing, the degree of postural perturbation may be dependent on different respiratory loads. This study aims to evaluate the effect of inspiratory and expiratory loads on the centre of pressure displacement during breathing in healthy subjects. Forty-three higher education students (21.12±1.55 years; 14 males) breathed at the same rhythm (inspiration: two seconds; expiration: four seconds) without load and with 10% of the maximal inspiratory or expiratory pressures, in standing. A forceplate was used to assess the mean amplitude and mean velocity, in anterior-posterior and medial-lateral directions, and total mean velocity of the centre of pressure displacement during breathing. In anterior-posterior direction, mean amplitude and mean velocity were significantly higher with inspiratory (respectively, $p=0.008$ and $p=0.002$) and expiratory (both, $p<0.001$) loads when compared to without load. Also, mean amplitude and mean velocity were significantly higher with expiratory load when compared to inspiratory load (respectively, $p=0.003$ and $p=0.009$). In medial-lateral direction, mean amplitude and mean velocity were significantly higher with inspiratory load when compared to without load (respectively, $p=0.001$ and $p=0.003$). Total mean velocity was significantly higher with inspiratory load when compared to without load (both, $p<0.001$). The inspiratory and expiratory loads promoted changes on mass repartition of the trunk, resulting in an increased centre of pressure displacement, mainly in anterior-posterior direction. Increased trunk muscle activity, due to loaded inspiration, may reduce the contribution of the trunk moments/movements to the postural control, increasing the centre of pressure displacement in medial-lateral direction.

**Keywords**

Respiration; Postural control; Core abdominal; Respiratory loads; Balance

## Introduction

The human upright stance is an intrinsically unstable position due to high position of the centre of mass (CoM) regarding the small size of base of support (BoS) (Hodges, Gurfinkel, Brumagne, Smith, & Cordo, 2002; Schmid, Conforto, Bibbo, & D'Alessio, 2004). Despite the skeletal motor system is poorly adapted to the preservation of this vertical position, the central nervous system (CNS) controls the maintenance of postural equilibrium, relying on both real-time and off-line information given by the vestibular, visual and somatosensory inputs (Balasubramaniam & Wing, 2002; Lackner & DiZio, 2005). As a result of this weighting, the CNS is able to react to a constant change of external (gravity) and internal (mostly due to cardiorespiratory function) forces acting on the human body (Conforto, Schmid, Camomilla, D'Alessio, & Cappozzo, 2001; Gurfinkel, Kots, & Paltsev, 1971).

Postural control and breathing are mechanically and neuromuscularly interdependent. The periodic movement of structures such as the abdominals organs, diaphragm muscle and rib cage, during quiet breathing, contributes to the CoM displacement (Kuznetsov & Riley, 2012). In an upright stance, these breathing perturbations to posture are counteracted by a coordinated muscle recruitment of multiple segments of the body – postural-respiratory synergy (Hodges et al., 2002). In fact, Bouisset and Duchene (1994) reported that the higher effect of breathing on the centre of pressure (CoP) in a seated posture suggests that the trunk and lower limbs mobility is important for an effective compensation of postural perturbation.

Although healthy subjects are able of compensating the periodic disturbance during quiet stance, postural control is challenged when the respiratory demand increases and requires voluntary control (David, Laval, Terrien, & Petitjean, 2012). The contribution of movements and moments of the trunk and lower limbs, which counterbalances the respiration-related perturbation to postural control, may be altered due to either mechanical factors related to changes on breathing pattern – frequency, volume and/or thoraco-abdominal movement – or organizational factors associated to the postural and respiratory commands (David et al., 2012; Hodges et al., 2002; Kuznetsov &

Riley, 2012). Hodges, Heijnen, and Gandevia (2001) suggested that to maintain homeostasis when respiratory demand is increased, the CNS prioritises the respiratory drive over other functions of the respiratory muscles. As postural activity of the trunk muscles is altered (Hodges et al., 2001), the ability of the trunk movements and moments to contribute to the maintenance of postural control may be compromised (Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998). Thus, the compensation may be not complete and the degree of postural perturbation may be dependent on different respiratory loads. The aim of the present study was to evaluate the effect of inspiratory and expiratory loads on CoP displacement during breathing, in healthy subjects. Specifically, the mean amplitude and mean velocity, in anterior-posterior and medial-lateral, directions, and total mean velocity of the CoP displacement were analysed during breathing without respiratory load and with inspiratory or expiratory loads.

## Methods

### *Sample*

A repeated measures design was conducted with a sample composed by forty-three healthy higher education students who volunteered to participate in this research (14 males). Demographic and anthropometric data regarding the sample are described in Table 1. Participants were aged between 19 and 26 years and had not participated in moderate intensity, aerobic physical activity for a minimum of 30 min on five days a week or vigorous intensity, aerobic activity for a minimum of 20 min on 3 days a week, for a period exceeding one year (Thompson, 2014). Exclusion criteria included body mass index higher than 25 $kg.m^{-2}$; chronic nonspecific lumbopelvic pain (recurrent episodes of lumbopelvic pain for a period longer than three months); scoliosis, length discrepancy of the lower limbs or other postural asymmetries; history of spinal, gynaecological or abdominal surgery in the previous year; neurological or inflammatory disorders; metabolic or cardio-respiratory diseases; pregnancy or post-delivery in the previous six months; smoking habits; long-term corticosteroid therapy; and any conditions that may interfere with the data collection (American Thoracic Society/European Respiratory Society, 2002; Beith, Synnott, & Newman, 2001; Chanthapetch, Kanlayanaphotporn, Gaogasigam, & Chiradejnant, 2009; Mew, 2009; Reeve & Dilley, 2009). Each participant provided written informed consent, according to the Declaration of Helsinki. The anonymity of participants and the confidentiality of data were guaranteed. The Institutional Research Ethics Committee previously approved this study.

**Table 1.** Sample characterization: demographic and anthropometric data, with mean, standard deviation, minimum and maximum.

| | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Age (years) | 21.12 | 1.55 | 19 | 26 |
| Body Mass (kg) | 61.23 | 10.58 | 44.58 | 84.41 |
| Height (m) | 1.66 | 0.10 | 1.50 | 1.89 |
| BMI (kg.m$^{-2}$) | 21.95 | 1.91 | 18.42 | 24.95 |

BMI body mass index

*Procedures*

Sample selection and characterization

An electronic questionnaire was delivered to all participants to verify the selection criteria and to collect sociodemographic information. Anthropometric measures were assessed in participants who met the participation criteria. Height (m) and body mass (kg) – were measured using a seca 222 stadiometer with a precision of 1 mm and a forceplate FP4060-08 (Bertec Corporation®, Columbus OH, United States of America), respectively. Then, body mass index was calculated. To assess postural asymmetries, the lower limb length (cm) was measured using a seca 201 tape with a precision of 1 mm (seca – Medical Scales and Measuring Systems, Hamburg, Germany) and the postural assessment was performed. These evaluations were performed to select the final sample. Women who were in luteal phase were contacted later for data collection.

Data collection protocol

The study procedures took place at a biomechanical laboratory and were performed in a controlled environment. To avoid inter-rater error, each researcher was responsible for an only one task.

A forceplate FP4060-08, connected to an amplifier AM6500, was used to assess CoP displacement and body mass (kilograms). The ground reaction forces and torques were collected using the Qualisys Motion Capture System (Qualisys AB, Gothenburg, Sweden) with a sampling frequency of 100 Hz. Qualisys Track Manager software was used to display and acquire the ground reaction forces and moments signal.

A respiratory pressure meter MicroRPM (CareFusion Corporation, San Diego CA, United States of America) was used to assess the maximal inspiratory (MIP) and expiratory (MEP) pressures. The values obtained were used to determine the inspiratory and expiratory loads, respectively. MIP and MEP were both performed with participants in standing position, using a bacterial filter AFT1 – Disposable Bacterial Filter, 22 mm and a mouthpiece AFT2 – Disposable Mouthpiece, 22 mm firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip AFT3 – Disposable Noseclip (Biopac Systems Inc., Goleta CA, United States of America) to prevent nasal breathing. To assess MIP, a forceful and maximal inspiration was performed – the Muller manoeuvre – at residual volume; in turn, MEP was assessed through a forceful and maximal expiration – the Valsalva manoeuvre – at total lung capacity. Each manoeuvre was encouraged verbally. These manoeuvres were performed during a six-second period, with a resting time of three minutes. To calculate the respiratory load, three reproducible manoeuvres were selected according to the American Thoracic

Society/European Respiratory Society (2002) standards. It was used 10 % of the best value of MIP and MEP for the inspiratory and expiratory loads, respectively. Thresholds IMT® and PEP® (Respironics Inc., Murrysville PA, United Stare of America) were used to apply the inspiratory and expiratory loads, respectively. A bacterial filter AFT1, a mouthpiece AFT2 and a nose clip AFT3 were also used.

All participants were subjected to three different tasks – breathing without respiratory load and with inspiratory and expiratory loads, in standing – in a single data collection moment. The data collection moment started with breathing without respiratory load. The order of inspiratory or expiratory loads was randomized. The participants were barefoot and had the upper limbs along the body, with feet shoulder-width apart and knees in loose pack position. An A3 paper sheet was used to outline the BoS, keeping it for all tasks. The participants kept their gaze in a horizontal direction and the mouthpiece, sustained by their teeth, was used during all tasks. Three repetitions of each task were performed for forty seconds, with a resting time of three minutes. The respiratory rhythm (inspiratory time: two seconds; expiratory time: four seconds) was marked through a recorded voice. The participants experienced this respiratory rhythm prior data collection.

### Data processing

A routine based on the Duarte and Freitas (2010) study was developed in MatLab Student software (MathWorks, Pozuelo de Alarcon, Spain) to process and analyse data. A 4th order digital filter Infinite Impulse Response – Butterworth of 10Hz (low pass) was applied to the ground reaction forces and torques. For the forty seconds collected, the CoP position in anterior-posterior and medial-lateral directions of the central thirty seconds was determined. The signal trend was then removed. The CoP displacement variables were calculated: mean amplitude and mean velocity in anterior-posterior and medial-lateral directions, as well as total mean velocity. Finally, for all CoP displacement variables the average of three repetitions of each task was calculated.

*Statistical analysis*

IBM SPSS Statistics® software, version 20.0, (IBM Corporation, Armonk NY, United States of America) was used for the descriptive and inferential data analysis, with a significance level of 0.05. Shapiro-Wilk test was used to test the normality of the data. Central tendency (mean) and dispersion (standard deviation) measures were used for the descriptive statistics. Repeated Measures Analysis of Variance was used to compare the CoP displacement variables between the different evaluation tasks (without respiratory load and with inspiratory or expiratory loads). Bonferroni correction was used for the post-hoc analysis (Marôco, 2014).

## Results

In anterior-posterior direction, the mean amplitude (Figure 2) and mean velocity (Figure 3) of CoP displacement were significantly greater during breathing with inspiratory (respectively, $p$=0,008 and $p$=0,002) and expiratory (both, $p$<0,001) loads when compared to without respiratory load. The mean amplitude (Figure 2) and mean velocity (Figure 3) of CoP displacement in anterior-posterior direction were significantly greater during breathing with expiratory load when compared to inspiratory load, in anterior-posterior direction (respectively, $p$=0,003 and $p$=0,009).

In medial-lateral direction, the mean amplitude (Figure 2) and mean velocity (Figure 3) of CoP displacement was significantly greater during breathing with inspiratory load when compared to without respiratory load (respectively, $p$=0,001 and $p$=0,003).

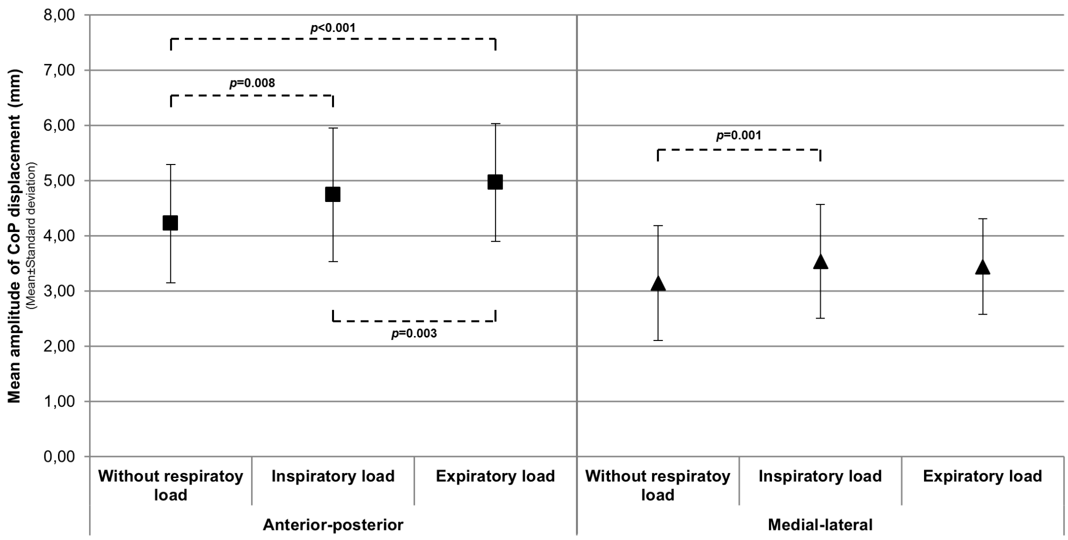


**Figure 1.** Mean amplitude of the centre of pressure (CoP) displacement (expressed as millimetres), in anterior-posterior and medial-lateral directions, during breathing without load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented

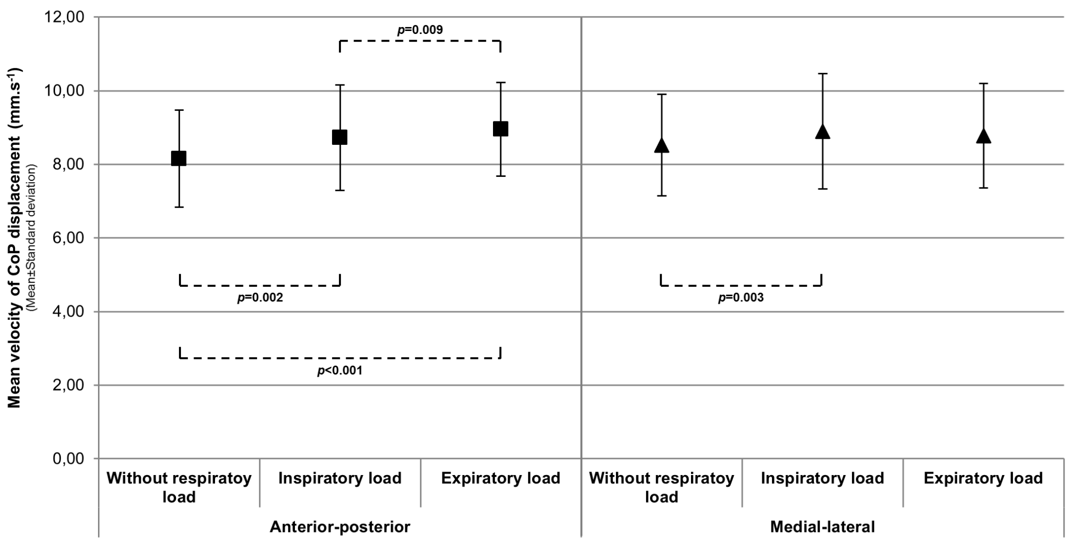


**Figure 2.** Mean velocity of the centre of pressure (CoP) displacement (expressed as millimetres.seconds$^{-1}$), in anterior-posterior and medial-lateral directions, during breathing without load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented

The total mean velocity of CoP displacement (Figure 4) was significantly greater during breathing with inspiratory and expiratory loads when compared to without respiratory load (both, $p<0,001$).

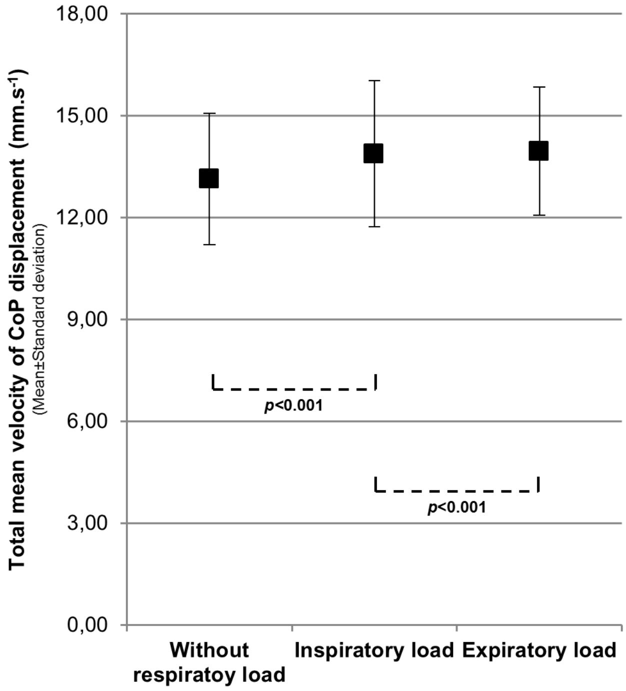


**Figure 3.** Total mean velocity of the centre of pressure (CoP) displacement (expressed as millimetres.seconds$^{-1}$) during breathing without load and with inspiratory or expiratory loads. Data are presented as mean and standard deviation. *p* values for significant differences between tasks are also presented

## Discussion

The results of the present study indicated that the inspiratory and expiratory loads promoted a significantly higher CoP displacement in relation to breathing without respiratory load. Loaded inspiration seemed to increase the CoP displacement in anterior-posterior and medial-lateral directions, whereas loaded expiration appeared to increase only in anterior-posterior direction. Although the inspiratory and expiratory loads increased the CoP displacement, the degree of task-dependent flexibility of the postural-respiratory synergy seemed to be different.

All participants breathed at a same rhythm. The respiratory frequency and volume may alter the ability of postural-respiratory synergy to counteract the breathing movements (David et al., 2012; Jeong, 1991; Kuznetsov & Riley, 2012). Nevertheless, the standardization of respiratory rhythm may have reduced the effect of respiratory load on minute ventilation.

The findings of this study indicated that the CoP displacement, mainly in anterior-posterior direction, was greater during breathing with inspiratory and expiratory loads when compared to without respiratory load. Breathing is achieved by an alternate modulation of activity of the diaphragm and *transversus abdominis* muscles, resulting on cyclic changes in the shape of pressurized thoracic and abdominal cavities (Hodges & Gandevia, 2000). During inspiration, the diaphragm muscle's shortening pushes down the abdominal contents while the *transversus abdominis* is lengthened, moving the abdomen outwards, to increase thoracic cavity diameter (De Troyer & Estenne, 1988; Hodges & Gandevia, 2000). The opposite pattern occurs during expiration. On a biomechanical perspective, it may be theorized that both respiratory loads increased the proportion of ribcage motion to the tidal volume; thus, changing the mass repartition of trunk (David et al., 2012) and disturbing the posture (Hamaoui, Gonneau, & Le Bozec, 2010). This could be related to an increased activity of accessory inspiratory and/or expiratory muscles in response to a minimal breathing effort (Ratnovsky, Zaretsky, Shiner, & Elad, 2003). Therefore, in the present study, it is reasonable to suppose that this potentially destabilizing effect of respiratory loads (inspiratory or expiratory loads) on the CoM position was not counteracted by a coordinated muscle recruitment of multiple segments (Kuznetsov & Riley, 2012) and it was detected on the CoP displacement. This inadequate control is most likely explained by a strategy that involves the angular motion in anterior-posterior direction at the ankle (Winter, Prince, Frank, Powell, & Zabjek, 1996), which was not able to effectively compensate for the respiratory-related challenge to the postural control, and to minimise the CoP displacement in anterior-posterior direction. Several studies reported a greater CoP displacement mostly in anterior-posterior direction when the respiratory demand increases, as during voluntary hyperventilation (David et al., 2012; Kuznetsov & Riley, 2012).

Nevertheless, in this study, the CoP displacement in anterior-posterior direction during breathing with expiratory load was greater than with inspiratory load. The specific mobilization of the rib cage during voluntary expiratory efforts implies a contraction in concert of the superficial and deep muscle layers of ventrolateral abdominal wall. This phasic activity of abdominal muscles during expiration pulls the abdominal wall inward of the thoracic cavity and the lower ribs caudally to deflate the ribcage (De Troyer, Estenne, Ninane, Van Gansbeke, & Gorini, 1990). The mobilization of the ribs could induce thoracic vertebrae displacements via the costovertebral joints, leading to larger disturbing movements. Hence, during breathing with expiratory load, the torque may have been higher and the disturbing effect more prominent at the thoracic level (Hamaoui et al., 2010).

The CoP displacement in medial-lateral direction seemed to be greater during breathing with inspiratory load. The main respiratory muscle groups are also involved in trunk stability, wherein the same motor unit pool is activated during both respiratory and postural functions (Hudson, Butler, Gandevia, & De Troyer, 2010). Previous studies suggested that the diaphragm muscle, as a major inspiratory muscle, is also important in maintaining an upright posture, and in stabilizing the spine under conditions of postural challenge and loading (Hodges, Gandevia, & Richardson, 1997). Diaphragm muscle contributes to the spinal stiffness via direct mechanical effect through the lumbar attachments of diaphragm muscle, as well as via its influence on intra-abdominal pressure (Hodges, Eriksson, Shirley, & Gandevia, 2005). The modulation of intra-abdominal pressure occurs together with abdominal, namely transversus abdominis, and pelvic floor muscles (Hodges et al., 1997). Thus, it may be theorized that an increased central respiratory drive, due to loaded inspiration, may have attenuated the postural commands reaching the motoneurons of diaphragm and transversus abdominis muscles, reducing the degree of compensation of the respiration-related perturbation to the postural control (Hodges et al., 2001). This impaired contribution of these core muscles is associated with an increased tonic activity of surface layer of the abdominal muscles (external oblique and rectus abdominis) (Hodges & Gandevia, 2000). Thus, the increased trunk stiffness may reduce the contribution of trunk movement and moments to the postural control, increasing CoP displacement, particularly in the medial-lateral direction. In fact, the balance control in medial-lateral direction is more dependent on the hip and trunk moments/movements, due to poor efficiency of the ankle muscles to control balance in this direction (Winter et al., 1996).

None of the participants in the present study had chronic respiratory pathologies. Although there are strategies to coordinate the conflicting postural and respiratory functions in healthy subjects, this may be not true when the respiratory demand is increased by disease. Chronic obstructive pulmonary disease may alter the patients' ability to modulate their trunk muscle recruitment to maintaining the dual task (Martinez, Couser, & Celli, 1990). Therefore, it is important to understand if the impact of low inspiratory load on the CoP displacement will be present in this population. Further studies conducted among chronic obstructive pulmonary disease patients are needed to select the appropriate intervention strategies to optimize the trunk muscle synergy for the postural and respiratory functions.

## Conclusion

In healthy subjects, the inspiratory and expiratory loads promoted changes on mass repartition of the trunk, resulting in an increased CoP displacement, mainly in anterior-posterior direction. The increased trunk muscle activity, due to loaded inspiration, may reduce the contribution of the trunk moments and movements to the postural control, increasing the CoP displacement in medial-lateral direction.

**Acknowledgments**

A special thanks to João Baptista, PT and Sara Gouveia, PT for the assistance provided with subject recruitment and data collection.

**Conflict of interest statement**

Nothing to declare.

**References**

American Thoracic Society/European Respiratory Society. (2002). ATS/ERS Statement on respiratory muscle testing. *American Journal of Respiratory and Critical Care Medicine, 166*(4), 518-624.

Balasubramaniam, R., & Wing, A. M. (2002). The dynamics of standing balance. *Trends in Cognitive Sciences, 6*(12), 531-536.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82-87.

Bouisset, S., & Duchene, J. L. (1994). Is body balance more perturbed by respiration in seating than in standing posture? *Neuroreport, 5*(8), 957-960.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., & Chiradejnant, A. (2009). Abdominal muscle activity during abdominal hollowing in four starting positions. *Manual Therapy, 14*(6), 642-646.

Conforto, S., Schmid, M., Camomilla, V., D'Alessio, T., & Cappozzo, A. (2001). Hemodynamics as a possible internal mechanical disturbance to balance. *Gait & Posture, 14*(1), 28-35.

David, P., Laval, D., Terrien, J., & Petitjean, M. (2012). Postural control and ventilatory drive during voluntary hyperventilation and carbon dioxide rebreathing. *European Journal of Applied Physiology, 112*(1), 145-154.

De Troyer, A., & Estenne, M. (1988). Functional anatomy of the respiratory muscles. *Clinics In Chest Medicine, 9*(2), 175-193.

De Troyer, A., Estenne, M., Ninane, V., Van Gansbeke, D., & Gorini, M. (1990). Transversus abdominis muscle function in humans. *Journal of Applied Physiology (1985), 68*(3), 1010-1016.

Duarte, M., & Freitas, S. M. (2010). Revision of posturography based on force plate for balance evaluation. *Revista Brasileira de Fisioterapia, 14*(3), 183-192.

Gurfinkel, V. S., Kots, Y. M., & Paltsev, E. I. (1971). The compensation of respiratory disturbances of the erect posture of man as an example of the organization of the interarticular interaction. In V. S. Gurfinkel, S. V. Fomin, & M. L. Tselin (Eds.), *Models of the structural functional organization of certain biological systems* (pp. 382-395). Cambridge: MIT Press.

Hamaoui, A., Gonneau, E., & Le Bozec, S. (2010). Respiratory disturbance to posture varies according to the respiratory mode. *Neuroscience Letters, 475*(3), 141-144.

Hodges, P. W., Eriksson, A. E., Shirley, D., & Gandevia, S. C. (2005). Intra-abdominal pressure increases stiffness of the lumbar spine. *Journal of Biomechanics, 38*(9), 1873-1880.

Hodges, P. W., & Gandevia, S. C. (2000). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology (1985), 89*(3), 967-976.

Hodges, P. W., Gandevia, S. C., & Richardson, C. A. (1997). Contractions of specific abdominal muscles in postural tasks are affected by respiratory maneuvers. *Journal of Applied Physiology (1985), 83*(3), 753-760.

Hodges, P. W., Gurfinkel, V. S., Brumagne, S., Smith, T. C., & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Experimental Brain Research, 144*(3), 293-302.

Hodges, P. W., Heijnen, I., & Gandevia, S. C. (2001). Postural activity of the diaphragm is reduced in humans when respiratory demand increases. *The Journal of Physiology, 537*(Pt 3), 999-1008.

Hudson, A. L., Butler, J. E., Gandevia, S. C., & De Troyer, A. (2010). Interplay between the inspiratory and postural functions of the human parasternal intercostal muscles. *Journal of Neurophysiology, 103*(3), 1622-1629.

Jeong, B. Y. (1991). Respiration effect on standing balance. *Archives of Physical Medicine and Rehabilitation, 72*(9), 642-645.

Kuznetsov, N. A., & Riley, M. A. (2012). Effects of breathing on multijoint control of center of mass position during upright stance. *Journal of Motor Behavior, 44*(4), 241-253.

Lackner, J. R., & DiZio, P. (2005). Vestibular, proprioceptive, and haptic contributions to spatial orientation. *Annual Review of Psychology, 56*, 115-147.

Marôco, J. (2014). *Análise estatística com o SPSS Statistics* (6th ed.). Pero Pinheiro: ReportNumber, Lda.

Martinez, F. J., Couser, J. I., & Celli, B. R. (1990). Factors influencing ventilatory muscle recruitment in patients with chronic airflow obstruction. *American Journal of Respiratory and Critical Care Medicine, 142*(2), 276-282.

Mew, R. (2009). Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. *Manual Therapy, 14*(6), 690-695.

Ratnovsky, A., Zaretsky, U., Shiner, R. J., & Elad, D. (2003). Integrated approach for in vivo evaluation of respiratory muscles mechanics. *Journal of Biomechanics, 36*(12), 1771-1784.

Reeve, A., & Dilley, A. (2009). Effects of posture on the thickness of transversus abdominis in pain-free subjects. *Manual Therapy, 14*(6), 679-684.

Schmid, M., Conforto, S., Bibbo, D., & D'Alessio, T. (2004). Respiration and postural sway: detection of phase synchronizations and interactions. *Human Movement Science, 23*(2), 105-119.

Thompson, P. D. (2014). Health appraisal and risk assessment. In L. S. Pescatello, R. Arena, D. Riebe, & P. D. Thompson (Eds.), *ACSM's guidelines for exercise testing and prescription* (9th ed., pp. 1-18). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

Winter, D. A., Patla, A. E., Prince, F., Ishac, M., & Gielo-Perczak, K. (1998). Stiffness control of balance in quiet standing. *Journal of Neurophysiology, 80*(3), 1211-1221.

Winter, D. A., Prince, F., Frank, J. S., Powell, C., & Zabjek, K. F. (1996). Unified theory regarding A/P and M/L balance in quiet stance. *Journal of Neurophysiology, 75*(6), 2334-2343.

# Abdominal muscle activity during breathing in different postures in COPD "Stage 0" and healthy subjects

**António Mesquita Montes, MSc**[a,b], Joana Maia, PT[c], Carlos Crasto, MSc[a], Cristina Argel de Melo, PhD[a], Paulo Carvalho, PhD[a], Rita Santos, MSc[a], Susana Pereira, BSc[c], João Paulo Vilas-Boas, PhD[b]

[a] Department of Physiotherapy, and Activity and Human Movement Study Center (CEMAH), School of Allied Health Technologies, Polytechnic Institute of Porto, Rua Dr. António Bernardino de Almeida 400, 4200-072 Porto, Portugal

[b] Faculty of Sport, CIFI2D, and Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Rua Dr. Plácido Costa 91, 4200-450 Porto, Portugal

[c] Physiotherapist, Private practice, Portugal

[d] Cardiovascular, Respiratory and Sleep Technician, Private practice, Portugal

Mesquita Montes, A., et al. (2017). Abdominal muscle activity during breathing in different postures in COPD "Stage 0" and healthy subjects. *Respiratory Physiology & Neurobiology, 238*, 14-22. doi:10.1016/j.resp.2017.01.001

## Abstract

This study aims to evaluate the effect of different postures on the abdominal muscle activity during breathing in subjects "at risk" for the development of chronic obstructive pulmonary disease (COPD) and healthy. Twenty-nine volunteers, divided in "At Risk" for COPD (n=16; 47.38±5.08 years) and Healthy (n=13; 47.54±6.65 years) groups, breathed at the same rhythm in supine, standing, tripod and 4-point-kneeling positions. Surface electromyography was performed to assess the activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles, during inspiration and expiration. From supine to standing, an increased activation of all abdominal muscles was observed in "At Risk" for COPD group; however, in Healthy group, TrA/IO muscle showed an increased activation. In both groups, the TrA/IO muscle activation in tripod and 4-point kneeling positions was higher than in supine and lower than in standing. Subjects "at risk" for the development of COPD seemed to have a specific recruitment of the superficial layer of ventrolateral abdominal wall for the synchronization of postural function and mechanics of breathing.



## Keywords

GOLD "Stage 0"; Respiration; Postural control; Core abdominal; Body position

## Introduction

Chronic Obstructive Pulmonary Disease (COPD) is described as the presence of persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways (Global Initiative for Chronic Obstructive Lung Disease, 2016; Vestbo et al., 2013). This obstructive ventilatory defect increases the volume of air in the lungs at the end of expiration, keeping the inspiratory muscles, especially diaphragm, in a mechanically disadvantaged position, which decreases their ability to generate inspiratory pressure (O'Donnell, 2001). This intrinsic mechanical loading of diaphragm muscle in COPD subjects (De Troyer, Leeper, McKenzie, & Gandevia, 1997; Gorini et al., 1990) presumably results in an increased activity of the accessory muscles of inspiration (Gandevia, Leeper, McKenzie, & De Troyer, 1996) and expiration (Ninane, Rypens, Yernault, & De Troyer, 1992) and a changed thoraco-abdominal movement (Martinez, Couser, & Celli, 1990). This increased activity of trunk muscles in COPD may imply a challenge for the synchronization of postural function and mechanics of breathing (Smith, Chang, Seale, Walsh, & Hodges, 2010).

The central nervous system (CNS) modulates the motor activities of trunk muscles during both postural control and respiratory functions to regulate the intra-abdominal and intra-thoracic pressures (Hodges, Heijnen, & Gandevia, 2001). This modulation occurs as a result of the coordination of the activity of abdominal, pelvic floor and diaphragm muscles (Hodges & Gandevia, 2000). Regarding trunk muscles' dual task, the change of body orientation in space alters their configuration and length and, consequently, the ability of respiratory muscles to act during breathing (De Troyer, Sampson, Sigrist, & Kelly, 1983). Such modifications in mechanical efficiency may be due to the action of gravity and the changes in the base of support on the activity of trunk muscles required for the maintenance of posture (Meadows & Williams, 2009; Mihailoff & Haines, 2013). This affects the compliance of ribcage and abdomen (Estenne, Yernault, & De Troyer, 1985), changing the thoraco-abdominal configuration and movement (Lee, Chang, Coppieters, & Hodges, 2010; Romei et al., 2010), and, consequently, the functional residual capacity and the degree of limitation on expiratory tidal flow (Dean, 1985).

The body position is one of the controlled-breathing techniques to enhancement of COPD' debilitating effects on the ventilatory pump, improving the respiratory muscle function and decreasing the dyspnea (Gosselink, 2003). For that, COPD subjects often adopt the tripod position (sitting with forward-leaning trunk and arm support) during episodes of dyspnea (Booth, Burkin, Moffat, & Spathis, 2014). Literature has shown that this forward-leaning position improves the length-tension relationship of diaphragm muscle and its function, as well as decreases the recruitment of *sternocleidomastoideus* and *scalenus* muscles (Sharp, Drutz, Moisan, Foster, & Machnach, 1980), improving thoraco-abdominal movement (Delgado, Braun, Skatrud, Reddan, & Pegelow, 1982) and decreasing dyspnea (O'Neill & McCarthy, 1983). Also, the arm support, in tripod position, allows other accessory muscles (*pectoralis* major and minor) significantly contribute to the ribcage elevation (Banzett, Topulos, Leith, & Nations, 1988). Nevertheless, there is little evidence regarding the individual recruitment of abdominal muscles in this posture. As tripod position, the four-point kneeling position, which facilitates the recruitment of deep abdominal muscles (Hides, Richardson, & Hodges, 2004), may be performed to improve the mechanics of breathing.

Although it is recognized that the primary underlying pathophysiology in COPD affects the respiratory muscle activity, the impact of different postures on abdominal muscle activity for the synchronization of postural function and mechanics of breathing is not yet clear in subjects “at risk” for the development of COPD (presence of chronic respiratory symptoms, in addiction to some evidence of impaired lung function) (Rodriguez-Roisin et al., 2016). When expanding symptomatic burden in COPD “Stage 0” to include other chronic respiratory symptoms, such as dyspnea, wheeze and limited physical activity, symptomatic smokers without airflow limitation experience significant morbidity and need health care resources, which represents a potential clinical entity (de Marco et al., 2007; de Oca et al., 2012; Mannino, Doherty, & Sonia Buist, 2006; Stavem, Sandvik, & Erikssen, 2006). The scientific evidence in these subjects may be important to understand the natural history of COPD. The aim of the present study was to evaluate the effect of different postures on the abdominal muscle activity during breathing in subjects “at risk” for the development of COPD and healthy. Specifically, the activation intensity of *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/internal oblique (TrA/IO) muscles, during inspiration and expiration, was analysed in supine, standing, tripod and 4-point-kneeling positions.

## Methods

*Sample*

A cross-sectional study design was conducted with a sample composed by twenty-nine volunteers: volunteers of an higher education institution: sixteen subjects “at risk” for the development of COPD – “At Rrisk” for COPD group; and thirteen healthy subjects – Healthy group. Sociodemographic, anthropometric and body composition data were similar between groups (Table 1). Participants had not participated in aerobic physical activities with a moderate intensity (a minimum of 30 min on five days a week) and/or aerobic physical activities with a vigorous intensity (a minimum of 20 min on 3 days a week), for a period exceeding one year (Thompson, 2014). As inclusion criteria for the “At Risk” for COPD group, participants had dyspnea, chronic cough and sputum production at least for three months in two consecutive years, as well as history of exposure to risk factors (e. g. smoking habits at least for fifteen years) (Rodriguez-Roisin et al., 2016). Moreover, these participants had to have Grade 1 or more in the Modified British Medical Research Council (mMRC) questionnaire and one point or more, out of five points, in the first four items of the COPD Assessment Test (CAT) (presence of cough, mucus, chest tightness and breathlessness) (Global Initiative for Chronic Obstructive Lung Disease, 2016). Exclusion criteria for both groups included chronic nonspecific lumbopelvic pain (recurrent episodes of lumbopelvic pain for a period longer than three months); scoliosis, length discrepancy of the lower limbs or other postural asymmetries; history of spinal, gynaecological or abdominal surgery in the previous year; neurological or inflammatory disorders; metabolic or chronic cardio-respiratory diseases; pregnancy or post-delivery in the previous six months; long-term corticosteroid therapy; and any conditions that may interfere with the data collection (American Thoracic Society/European Respiratory Society, 2002; Beith, Synnott, & Newman, 2001; Chanthapetch, Kanlayanaphotporn, Gaogasigam, & Chiradejnant, 2009; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Mew, 2009; Miller et al., 2005; Reeve & Dilley, 2009). Each participant provided written informed consent, according to the Declaration of Helsinki. The anonymity of participants and the confidentiality of data were guaranteed. The Institutional Research Ethics Committee approved this study.

**Table 1.** "At Risk" for COPD and Healthy groups' characterization: sociodemographic, anthropometric and body composition data, with mean and standard deviation. *p* values for significant differences between groups are also presented

| | "At Risk" for COPD group (n=16) | Healthy group (n=13) | Between groups comparison (*p* value) |
|---|---|---|---|
| Demographic and anthropometric data | | | |
| Gender (n male) | 5 | 6 | 0.466 |
| Age (years) | 47.4±5.1 | 47.5±6.7 | 0.941 |
| Body mass (kg) | 71.1±14.8 | 79.6±15.9 | 0.151 |
| Height (m) | 1.7±0.1 | 1.7±0.1 | 0.935 |
| Body composition data | | | |
| Body fat (%) | 29.3±9.4 | 32.0±8.9 | 0.446 |
| Total body water (%) | 48.9±5.8 | 48.6±4.7 | 0.890 |
| Muscle mass (kg) | 47.3±10.5 | 52.9±13.4 | 0.222 |
| Bone mineral mass (kg) | 2.5±0.5 | 2.8±0.6 | 0.209 |
| Visceral fat | 7.0±3.2 | 9.2±2.9 | 0.073 |

*Instruments*

Surface electromyography (sEMG) was performed to assess the muscle activity of RA, EO, TrA/IO and erector *spinae* (ES) of the dominant hand side. ES muscle activity was measured such as an indicator of the action of gravity and the changes in the base of support. The muscle activity was collected using the BioPlux research device (Plux wireless biosignals S.A., Arruda dos Vinhos, Portugal) with analogue channels of 12 bits and a sampling frequency of 1000 Hz, using double differential electrode leads. Disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon Corporate, Scottsdale AZ, United States of America) were used for the sEMG. The electrode characteristics were 4x2.2 cm of adhesive area, 1 cm diameter of each circular conductive area and 2 cm of inter-electrode distance. These electrodes were connected to bipolar active sensors emgPLUX with a gain of 1000, an analogue filter at 25-500 Hz and a common-mode rejection ratio of 110 dB. The reference electrode used was a disposable self-adhesive Ag/AgCl snap electrode (Noraxon Corporate, Scottsdale AZ, United States of America) for the sEMG, with 3.8 cm diameter of circular adhesive area and 1 cm diameter of circular conductive area. The sensors were Bluetooth connected through the sEMG device to a laptop. MonitorPlux software, version 2.0, was used to display and acquire the sEMG signal. An electrode impedance checker was used to assess the impedance level of skin (Noraxon Corporate, Scottsdale AZ, United States of America).

A respiratory flow transducer TSD117 – Medium Flow Trans 300 $L.min^{-1}$ connected to an amplifier DA100C – General Purpose Transducer Amplifier Module, was used to detect both breathing phases. The respiratory flow was collected using the Biopac MP100WSW Data Acquisition System device (Biopac Systems Inc., Goleta CA, United States of America) with a sampling frequency of 100 Hz. A bacterial filter AFT1 – Disposable Bacterial Filter, 22 mm, a mouthpiece AFT2 – Disposable Mouthpiece, 22 mm and a nose clip AFT3 – Disposable Noseclip were also used. Acqknowledge software, version 4.1, (Biopac Systems Inc., Goleta CA, United States of America) was used to display and acquire the respiratory flow signal. A digital trigger signal coming from BioPlux research to Biopac MP100WSW Data Acquisition System was used to synchronize the respiratory flow signal and the sEMG signal. Biopac MP100WSW Data Acquisition System was synchronized with the BioPlux research.

A respiratory pressure meter MicroRPM (CareFusion Corporation, San Diego CA, United States of America) was used to assess the maximal expiratory pressure (MEP). This quasi-static maximal manoeuvre was used to normalize the sEMG signal of abdominal muscles (maximal muscle activity of each muscle during breathing). A bacterial filter AFT1, mouthpiece AFT2 and nose clip AFT3 were also used.

*Procedures*

Sample selection and characterization

An electronic questionnaire was delivered to all participants to verify the selection criteria and to collect sociodemographic information. Also, the mMRC and CAT were included in this questionnaire. Anthropometric and body mass composition measures were assessed in participants who met the participation criteria. Height (m) was measured using a seca 222 stadiometer with a precision of 1 mm. Body mass (kg) and body mass composition – body fat (%), total body water (%), muscle mass (kg), bone mineral mass (kg) and visceral fat – were assessed using a Tanita Ironman Inner Scan BC-549 body composition monitor with a precision of 1 kg and 1 % (Tanita – Monitoring Your Health, Amsterdam, Netherlands). To assess postural asymmetries, the lower limb length (cm) was measured using a seca 201 tape with a precision of 1 mm (seca – Medical Scales and Measuring Systems, Hamburg, Germany) and the postural assessment was performed. These evaluations were performed to select the final sample. Women who were in luteal phase were contacted later for data collection.

A MasterScreen Body plethysmograph of volume-constant type (Jaeger – CareFusion Corporation, San Diego CA, United States of America) was used to record forced vital capacity and then to assess pulmonary function: forced expiratory volume in one second ($FEV_1$)/forced vital capacity (FVC); % predicted of $FEV_1$, FVC, peak expiratory flow, forced expiratory flow at 75 % ($FEF_{75\%}$)/50 % ($FEF_{50\%}$)/25 % ($FEF_{25\%}$) of FVC and $FEF_{25\text{-}75\%}$. FVC manoeuvre (closed circuit method) was recorded with participants in sitting position, using a mouthpiece firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip to prevent nasal breathing. To assess this manoeuvre, a completely and rapidly inhalation was performed with a pause of one second at total lung capacity, followed by a maximally exhalation until no more air can be expelled while maintaining the upright posture. Each manoeuvre was encouraged verbally. A minimum of three manoeuvres was performed. To test result selection, three reproducible manoeuvres were recorded, according to Miller et al. (2005) standards. An expert cardiovascular, respiratory and sleep technician was responsible for this assessment.

## Data collection protocol

The study procedures took place at a biomechanical laboratory and were performed in a controlled environment. To avoid inter-rater error, each researcher was responsible for only one task.

To perform the sEMG, the hair was shaved and an abrasive cream was used to remove the dead cells from the skin's surface. Skin was then cleaned with isopropyl alcohol (70 %), removing its oiliness and holding the dead cells. An electrode impedance checker was used to make sure that the impedance levels were below 5 KΩ, thus ensuring a good acquisition of sEMG signal (Hermens et al., 2000). The self-adhesive electrodes were placed with participants in standing position, five minutes after the skin preparation. These electrodes were placed parallel to the muscle fibre orientation, according to the references described in Table 2 (Criswell, 2011; Marshall & Murphy, 2003). The electrode placements were confirmed by palpation and muscle contraction. The reference electrode was placed in the anterior superior iliac spine of the contralateral hand dominant side. All electrodes were tested to control the cross-muscular signal (cross-talk), electrical noise and other interferences of sEMG signal (Hermens et al., 2000).

**Table 2.** Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (OE), *transversus abdominis*/internal oblique (TrA/IO) and erector *spinae* (ES) muscles.

| Muscle | Anatomical landmarks |
|---|---|
| RA | 2 cm lateral to the umbilicus, over the muscle mass |
| EO | Lateral to the RA and directly above the anterior superior iliac, halfway between the crest and ribs at a slightly oblique angle |
| TrA/IO | 2 cm medially and below to the anterior superior iliac spine<br>In this local, TrA and inferior IO muscle fibres are mixed, so it is impossible to distinguish the surface electromyographic activity of both. |
| ES | 2 cm lateral to spine, at L3 vertebra, over the muscle mass |

MEP was performed with the participant in standing, using a mouthpiece firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip to prevent the nasal breathing. To assess this manoeuvre, a forceful and maximal expiration was performed – the Valsalva manoeuvre – at total lung capacity. Each manoeuvre was encouraged verbally. These manoeuvres were performed during a six-second period, with a resting time of three minutes. To normalize the sEMG signal of abdominal muscles, three reproducible manoeuvres were selected, according to American Thoracic Society/European Respiratory Society (2002) standards.

In standing, the maximal isometric voluntary contraction (MIVC) of ES muscle was performed to normalize data. The participant performed a trunk extension against an inelastic band placed on the scapular region. Three MIVC were performed, each one for a six-second period, with a resting time of three minutes.

Each participant breathed in supine, standing, tripod and 4-point kneeling and tripod positions, in a single data collection moment. The order of postures postural sets was randomized. In supine and standing, the participant had the upper limbs along the body, with feet shoulder-width apart and knees in loose pack position. In 4-point kneeling position, the participant was in triple flexion of lower limbs (hip and knee at 90º), with hands shoulder-width apart and elbows in loose pack position. In tripod position, the participant was sitting, with 45° of trunk flexion to vertical, 90° of hip flexion and upper limbs supported on a table. All joint amplitudes were confirmed using the Bubble® Inclinometer (trunk amplitude) and Baseline® Plastic Goniometer 360º Head (hip and knee amplitudes), both with a precision of 1º (Figure 1). The respiratory flow transducer was kept perpendicular to the participant during all tasks. A single repetition of each task was performed for ten consecutive respiratory cycles, with a resting time of three minutes. The respiratory rhythm (inspiratory time: two seconds; expiratory time: four seconds) was marked through a recorded voice. This respiratory rhythm was previously defined in a pilot study. The participant experienced and get used to this externally paced respiratory rhythm prior to data collection. The standardization of respiratory rhythm may have reduced the effect of different postures on minute ventilation.

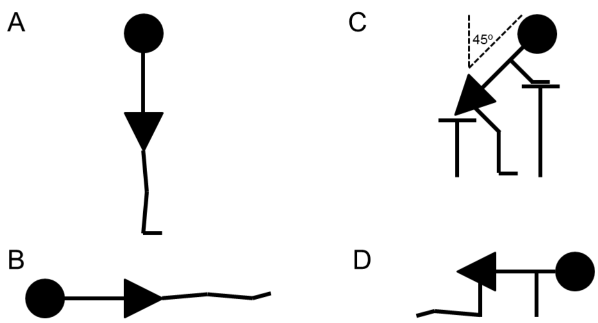


**Figure 1.** Schematic representation of the four postures adopted by the participants. A: standing; B: supine; C: tripod position (45º of trunk flexion to vertical); D: 4-point kneeling position.

After data collection, the electrodes were removed and a moisturizing cream was applied.

Data processing

A routine was developed in MatLab Student software (MathWorks, Pozuelo de Alarcon, Spain) to synchronize and process data. Firstly, the sEMG signal was converted into volts. It was applied to the sEMG signal a $2^{nd}$ order digital filter Infinite Impulse Response – Butterworth, one of 20 Hz (high pass) and another of 500 Hz (low pass), to remove the electrical noise and/or cable movement; and, finally, a $2^{nd}$ order digital filter Infinite Impulse Response – Butterworth of 30 Hz (high pass), to remove the cardiac signal. Root mean square (RMS) to 10 samples was then calculated.

Acqknowledge software, version 4.1, was used to analyse data. The abdominal muscle activity was analysed during inspiration and expiration, independently. These both breathing phases were determined through the respiratory flow transducer signal. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles of each muscle was analysed in each task, with a posterior analysis of its average.

The muscle activity collected during the MEP manoeuvre was used to normalize data of the abdominal muscles. The mean RMS of three central seconds of the expiratory phase of each muscle was analysed, and then the average of the mean RMS of three reproducible manoeuvres was calculated. The percentage of the activation intensity of each muscle was determined according to the following equation:

$$Muscle\ activation\ intensity\ (\%) = \left(\frac{mean\ RMS\ of\ each\ task}{RMS\ of\ the\ MEP}\right) * 100$$

ES muscle activity was analysed regardless the breathing phase. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles was analysed in each task, with a posterior analysis of its average. The muscle activity collected during the MIVC manoeuvre was determined to normalize data. The mean RMS of three central seconds was analysed, and then the average of the mean RMS of three repeated manoeuvres was calculated. The percentage of the activation intensity was determined according the following equation:

$$Muscle\ activation\ intensity\ (\%) = \left(\frac{mean\ RMS\ of\ each\ task}{RMS\ of\ the\ MIVC}\right) * 100$$

Statistical analysis

IBM SPSS Statistics® software, version 20.0, (IBM Corporation, Armonk NY, United States of America) was used for the descriptive and inferential data analysis, with a significance level of 0.05. Shapiro-Wilk test was used to test the normality of the data. Central tendency (mean) and dispersion (standard deviation) measures were used for the descriptive statistics. Chi-square was used to compare gender between groups ("At Risk" for COPD and Healthy). Student t-test was used to compare the age, anthropometric, body composition and pulmonary function data, as well as the percentage of muscle activation intensity, between groups. In each group, Repeated Measures Analysis of Variance was used to compare the percentage of muscle activation intensity between the different evaluation tasks (four postures postural sets), during inspiration and expiration. Bonferroni correction was used for the post-hoc analysis (Marôco, 2014).

## Results

### *Pulmonary function*

The forced expiratory volume in one second, peak expiratory flow and forced expiratory flow at 75% / 50% / 25% / 25-75% of FVC were significantly lower in "At Risk" for COPD group when compared to Healthy group ($p$<0.050). No significant differences were found in the FVC between groups (Table 3).

**Table 3.** Pulmonary function data in "At Risk" for COPD and Healthy groups, with mean and standard deviation. *p* values for significant differences between groups are also presented

| Pulmonary function | "At Risk" for COPD group (n=16) | Healthy group (n=13) | Between groups comparison (*p* value) |
|---|---|---|---|
| $FEV_1$/FVC | 74.3±6.5 | 82.8±1.5 | <0.001 |
| $FEV_1$ (% pred) | 94.9±15.3 | 116.8±13.6 | 0.001 |
| FVC (% pred) | 107.4±15.8 | 117.5±14.9 | 0.098 |
| PEF (% pred) | 103.2±17.3 | 120.6±14.5 | 0.009 |
| $FEF_{75}$ (% pred) | 92.8±27.2 | 126.9±17.2 | 0.001 |
| $FEF_{50}$ (% pred) | 64.00±17.2 | 112.4±17.6 | <0.001 |
| $FEF_{25}$ (% pred) | 50.2±13.5 | 85.2±15.2 | <0.001 |
| $FEF_{25-75}$ (% pred) | 60.9±15.1 | 104.7±16.1 | <0.001 |

$FEV_1$ forced expiratory volume in one second; FVC forced vital capacity; PEF peak expiratory flow; $FEF_{75}$/$FEF_{50}$/$FEF_{25}$/$FEF_{25-75}$ forced expiratory flow at 75% / 50% / 25% / 25-75% of FVC, respectively; % pred % predicted

*Abdominal muscle activity*

During both inspiration and expiration, no significant differences were found in the activation intensity of all abdominal muscles between groups (Figure 2 and 3).

"At Risk" for COPD group

In "At Risk" for COPD group, during both inspiration and expiration, the activation intensity of all abdominal muscles was significantly greater in standing when compared to supine (RA: $p<0.050$; EO: $p<0.050$; TrA/IO: $p<0.001$) and tripod positions (RA: $p\leq0.010$; EO: $p<0.010$; TrA/IO: $p=0.001$). Also, TrA/IO muscle activation intensity was greater in standing when compared to 4-point kneeling, during both breathing phases ($p<0.050$) (Figure 2 and Figure 3).

During both breathing phases, TrA/IO muscle activation was greater in 4-point-kneeling ($p<0.010$) and tripod ($p<0.050$) positions when compared to supine. Also, EO muscle activation intensity was greater in 4-point kneeling position when compared to supine, during both inspiration and expiration ($p<0.050$) (Figure 2 and Figure 3).

During both inspiration and expiration, only RA muscle activation intensity was greater in 4-point kneeling position when compared to tripod position ($p<0.050$) (Figure 2 and Figure 3).

Healthy group

In Healthy group, during both inspiration and expiration, no significant differences were found in activation intensity of RA and OE muscles between tasks (Figure 2 and Figure 3).

During both breathing phases, TrA/IO muscle activation intensity was significantly greater in standing when compared to supine ($p\leq0.001$), tripod ($p<0.010$) and 4-point kneeling ($p<0.050$) positions (Figure 2 and Figure 3).

During both inspiration and expiration, TrA/IO muscle activation intensity was significantly greater in 4-point kneeling ($p<0.050$) and tripod ($p<0.001$) positions when compared to supine (Figure 2 and Figure 3).

During both breathing phases, no significant differences were found in activation intensity of all abdominal muscles between tripod and 4-point kneeling positions (Figure 2 and Figure 3).

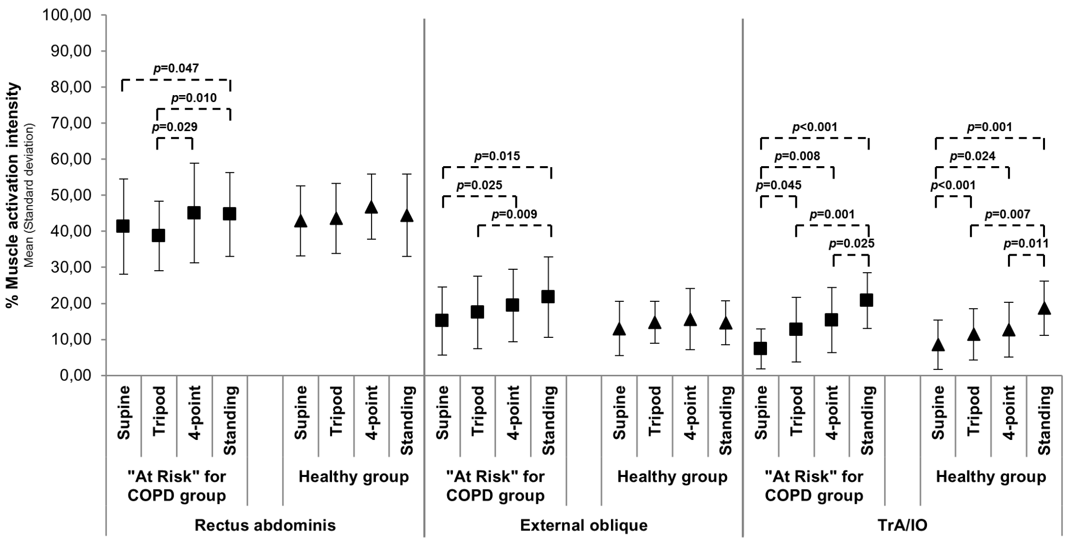


**Figure 2.** Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles (expressed as %) during inspiration in supine, tripod position, 4-point kneeling (4-point) and standing in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented

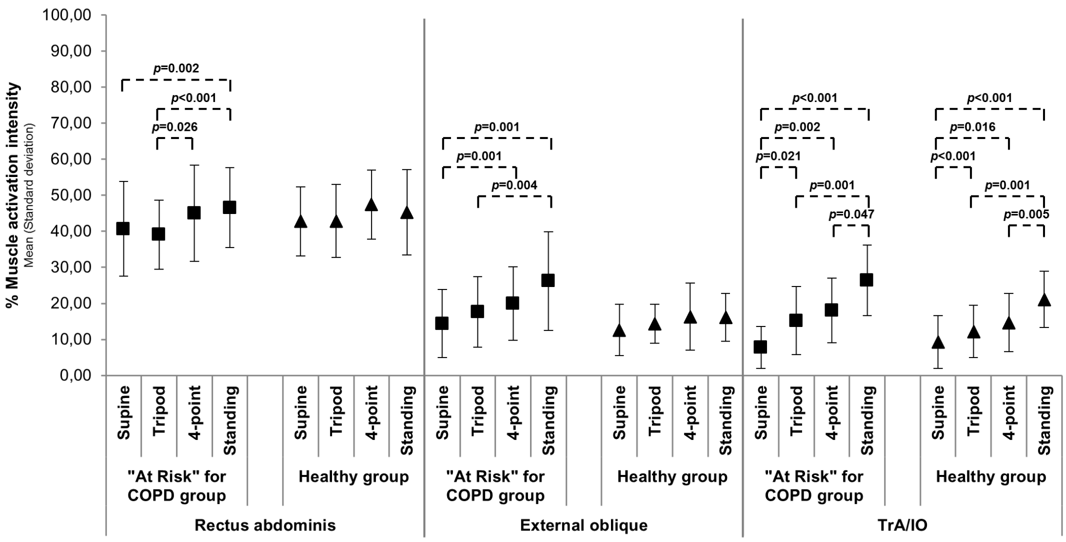


**Figure 3.** Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles (expressed as %) during expiration in supine, tripod position, 4-point kneeling (4-point) and standing in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented

*ES muscle activity*

During breathing, no significant differences were found between groups in ES muscle activation intensity (Figure 4).

In both "At Risk" for COPD and Healthy groups, ES muscle activation intensity was significantly greater in standing when compared to supine ($p$=0.001 and $p$=0.018, respectively), tripod ($p$=0.005 and $p$=0.027, respectively) and 4-point-kneeling ($p$=0.004 and $p$=0.032, respectively) (Figure 4).

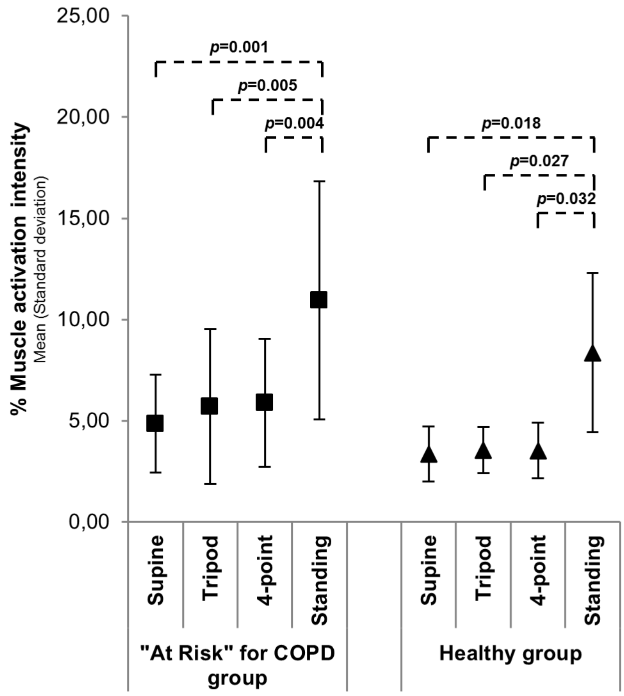


**Figure 4.** Activation intensity of erector *spinae* muscle (expressed as %) during breathing in supine, tripod position, 4-point kneeling (4-point) and standing in "At Risk" for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented

## Discussion

The present study showed that the different postures promoted a different impact on the abdominal muscle activity in each group. From supine to standing, an increased activation of all abdominal muscles (superficial and deep layers of ventrolateral abdominal wall) was observed in “At Risk” for COPD group. However, in Healthy group, TrA/IO muscle showed an increased activation intensity. These data suggested that subjects “at risk” for the development of COPD had a different recruitment pattern of abdominal muscles for the synchronization of postural function and mechanics of breathing.

The outcomes of the present study indicated that there were no significant differences between “At Risk” for COPD and Healthy groups in the activation intensity of all abdominal muscles in supine, during both inspiration and expiration. Neural drive to the diaphragm muscle (De Troyer et al., 1997; Gorini et al., 1990) and activity of parasternal intercostal and scalene muscles (Gandevia et al., 1996) are increased in COPD, during breathing at rest or when ventilation increases. Also, evidence has been described that the recruitment of abdominal muscles is frequent in subjects with COPD (Ninane et al., 1992; Ninane, Yernault, & de Troyer, 1993). Ninane et al. (1992) reported that, when breathing at rest in supine, this activation mainly concerns the *transversus abdominis* (TrA) muscle and its recruitment is related to the degree of airflow obstruction. In spite of existing a significant decrease in pulmonary function data, associated with airflow obstruction, it was not enough to reflect an obstructive ventilatory defect in “At Risk” for COPD group when compared to Healthy group (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). The Tiffeneau index, $FEV_1$ and $FEF_{25\text{-}75\%}$ values, in the study’ sample, were above the cut-off points that define the limit of normality (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). Thus, in supine, there was a decreased postural load that may not have been sufficiently challenging for the postural-respiratory synergy to change the recruitment pattern of abdominal muscles in these specific subjects.

From supine to standing, the recruitment pattern of abdominal muscles seemed to be different within each group. During both breathing phases, the activation intensity of all abdominal muscles was greater in standing when compared to supine, in “At Risk” for COPD group; however, in Healthy group, TrA/IO muscle activation intensity in standing was greater than in supine. Different postures and functional goals (such as respiration) require that the CNS appropriately adjusts the co-activation of trunk extensor and abdominal muscles to the action of gravity and the changes in the base of support (Meadows & Williams, 2009; Mihailoff & Haines, 2013). The human skeletal motor system, due to the high position of the centre of mass regarding the small size of the base of support, is poorly adapted to the preservation of a vertical position (standing) (Hodges, Gurfinkel, Brumagne, Smith, & Cordo, 2002). Unlike supine, the gravitational pull would be increased in standing, resulting in greater feedback from the stretch receptors of antigravity muscles (as ES muscle), thus raising motor-neuron pool excitability and increasing its muscle recruitment (Meadows & Williams, 2009; Mihailoff & Haines, 2013). Thus, in both groups, the activation intensity of abdominal muscles in standing was greater than in supine, which supports the primary postural function of abdominal muscles, increasing a postural tone when the challenge to stability is increased (Cholewicki, Juluru, & McGill, 1999). Nevertheless, the mechanics of ribcage and abdomen is affected due to the action of gravity. As opposed to supine, the abdominal content is being pulled away from the diaphragm muscle in standing, increasing the overall outward recoil of the chest wall, and so the functional residual capacity (Dean, 1985). Thus, from supine to standing, an increased activation intensity of abdominal muscles reduces the abdominal compliance. These changes allow the resistance provided by the abdominal content to the diaphragm muscle descent is more effective in expanding the lower rib cage (Strohl et al., 1984). The results of this study were consistent with earlier studies of Abe, Kusuhara, Yoshimura, Tomita, and Easton (1996), Barrett, Cerny, Hirsch, and Bishop (1994) and De Troyer (1983). The specific recruitment of abdominal muscles observed in each group may provide information relative to an impaired synchronization of postural function and mechanics of breathing in subjects who have dyspnea, chronic cough or sputum production, and a history of exposure to risk factors for the chronic obstructive pulmonary disease (as tobacco smoke), but did not exhibited an obstructive ventilatory defect (Rodriguez-Roisin et al., 2016). In Healthy group, the TrA/IO muscle activity may increase the transverse diameter of the lower rib cage (Key, 2013). Otherwise, the recruitment in concert of the superficial (RA and EO) muscles of ventrolateral abdominal wall, observed in “At Risk” for COPD group, helps to anchor the thorax caudally and their excessive activity may constrict the inferior thorax, interfering with diaphragm descent (Key, 2013). Further studies are needed to evaluate the effect of different postures on the thoraco-abominal movement in these subjects.

As supine, the lean-forward position in sitting with the passive fixing shoulder girdle, which characterizes the tripod position, reduces the postural load. Therefore, in both “At Risk” for COPD and Healthy groups, lower ES muscle activation intensity was observed in tripod position when compared to standing, resulting in lower recruitment of abdominal muscles, as previously discussed. Furthermore, in both groups, TrA/IO muscle activation intensity was greater in tripod position when compared to supine. Some degree of lean forward displaces downward and outward the abdominal content, lengthening the fibres of abdominal muscles (Dean, 1985), and may place them in an improved position for contraction. TrA muscle, due to its circumferential arrangement, has the most appropriate mechanical efficiency, which makes it easier to recruit into this posture (De Troyer, Estenne, Ninane, Van Gansbeke, & Gorini, 1990). This TrA/IO muscle recruitment, similar in both groups, may help to place the diaphragm muscle in a more favorable position on its length-tension curve, decreasing accessory muscle of inspiration’ recruitment and improving the thoraco-abdominal movement (Barach, 1974). Thus, it is reasonable to hypothesize that, in tripod position, the TrA/IO muscle recruitment for the synchronization of postural function and mechanics of breathing is beneficial to relief the dyspnea in subjects “at risk” for the development of COPD patients.

The findings of the present study indicated that, during both breathing phases, the TrA/IO muscle activation intensity was lower in 4-point kneeling position when compared to standing, as well the activation intensity of EO and TrA/IO muscles was greater in this position when compared to supine, in “At Risk” for COPD group; however, in Healthy group, TrA/IO muscle activation intensity in 4-point kneeling was lower than in standing and greater than in supine. In 4-

point kneeling position, the large base of support reduces the postural load, resulting in lower ES muscle activation intensity in this position when compared to standing, in “At Risk” for COPD and Healthy groups. In fact, as explained above, the gravitational pull would be reduced in 4-point kneeling position, decreasing recruitment of abdominal muscles. Moreover, this position, as well as the tripod position, allows the abdominal muscles to sag, facilitating their stretch (Norris, 1999). As observed in Healthy group, this posture is likely to increase the feedback from the muscle stretch receptors, thus raising the motor-neuron pool excitability of the TrA/IO muscle (Beith et al., 2001). However, in subjects “at risk” for the development COPD, breathing in 4-point kneeling position was more challenging for the synchronization of postural function and mechanics of breathing. An additional demanding recruitment of the superficial layer of ventrolateral abdominal wall, namely EO muscle, was required in these subjects (Mesquita Montes et al.).

In both groups, there were no significant differences in TrA/IO muscle activation intensity between 4-point kneeling and tripod positions. The postural load and gravitational stretch on the abdominal content and wall seemed to be similar in both postures. In 4-point kneeling and tripod positions, the TrA/IO muscle recruitment may be important to the improvement of the mechanics of breathing. However, in “At Risk” for COPD group, the RA muscle activation intensity was greater in 4-point kneeling position when compared to tripod position. As stated above, the challenge for postural-respiratory synergy may be increased during breathing in 4-point kneeling position. The RA muscle recruitment, observed in “At Risk” for COPD group, may be definitively harmful in an advanced pathological context. This specific recruitment of abdominal muscles in subjects with expiratory flow limitation may place the diaphragm under a mechanical disadvantage, impairing mechanics of breathing (Aliverti & Macklem, 2008; O'Donnell, 2001). Further studies conducted among several degrees of COPD are needed to evaluate the impact of tripod and 4-point kneeling position or other recruitment strategies of abdominal muscles on the breathing kinematics.

*Implications for future practice*

These data suggested that subjects “at risk” for the development of COPD represent a new clinical entity. The recruitment pattern of the superficial layer of ventrolateral abdominal wall during breathing may have a negative impact on its mechanics. Thus, strategies are needed to improve this recruitment pattern of abdominal muscles in these subjects. The specific recruitment of TrA/IO muscle in tripod position, observed in this study, may be of particular interest to the mechanics of breathing in subjects “at risk” for the development of COPD, as well as with expiratory flow limitation.

Furthermore, 4-point kneeling position is usually performed to dissociate muscle activity in the internal oblique (IO) and TrA from that of RA and EO (Hides et al., 2004). This dissociation, observed in Healthy group, may contribute to improve the mechanics of breathing. In subjects “at risk” for the development of COPD, the isolated recruitment of TrA/IO muscle becomes more difficult in 4-point kneeling position. Although the potential positive impact of TrA/IO muscle activity on the chest wall kinematics, the increased challenge for postural-respiratory synergy, in this posture, should be carefully controlled.

*Methodological considerations*

The results of the present study should be considered in light of a few limitations. First, the muscle activity of the deep layer of ventrolateral abdominal wall (namely TrA) was collected by the sEMG. For TrA/IO muscle, the bipolar electrodes were placed in parallel with the TrA muscle fibres. Nevertheless, the sEMG signal probably represents the muscle activity from both muscles. Similar to TrA muscle, the lower fibres of IO muscle have been proven to function as local muscle, contributing both muscles to the modulation of intra-abdominal pressure and to the support of abdominal content (Hodges, 2004; Marshall & Murphy, 2003). Furthermore, a crosstalk into the superficial and deep layers of ventrolateral abdominal wall might have occurred. A clinical test was performed for each abdominal muscle to test whether the bipolar electrodes have been placed properly (Hermens et al., 2000). Previous studies reported that the crosstalk between EO and TrA/IO muscles (at the electrode placement of EO muscle), as well as the crosstalk between RA and other abdominal muscles is minimal (Marshall & Murphy, 2003).

Second, the breathing pattern was not evaluated. Among the factors that may influence the respiratory system, sociodemographic, anthropometric and body composition variables can be highlighted (Kaneko & Horie, 2012; Romei et al., 2010). Although the variability between subjects may have been present, “At Risk” for COPD and Healthy groups were considered similar in those variables. So, the effect of natural variability between subjects upon the results was reduced.

## Conclusion

The change of body orientation promoted different impact on the abdominal muscle activity during breathing within each group. Subjects “at risk” for development of COPD seemed to have a specific recruitment of the superficial muscle layer of ventrolateral abdominal wall (RA and OE muscles) during breathing in situations wherein the postural load increases. Further studies are needed to evaluate the impact of this recruitment pattern on the mechanics, as well as the work and cost of breathing. Furthermore, TrA/IO muscle recruitment in tripod and 4-point kneeling positions should be taken into consideration for the improvement of the mechanics of breathing.

## Acknowledgments

A special thanks to Edgar Ribeiro, PT and Liliana Bastos, PT for the assistance provided with subject recruitment and data collection. We also thanks to Dr. Cristina Baeta and Dr. Sónia Magalhães from the Department of Cardiopneumology.

**Conflict of interest statement**

Nothing to declare.

**References**

Abe, T., Kusuhara, N., Yoshimura, N., Tomita, T., & Easton, P. A. (1996). Differential respiratory activity of four abdominal muscles in humans. *Journal of Applied Physiology (1985), 80*(4), 1379-1389.

Aliverti, A., & Macklem, P. T. (2008). The major limitation to exercise performance in COPD is inadequate energy supply to the respiratory and locomotor muscles. *Journal of Applied Physiology (1985), 105*(2), 749-751; discussion 755-747.

American Thoracic Society/European Respiratory Society. (2002). ATS/ERS Statement on respiratory muscle testing. *American Journal of Respiratory and Critical Care Medicine, 166*(4), 518-624.

Banzett, R. B., Topulos, G. P., Leith, D. E., & Nations, C. S. (1988). Bracing arms increases the capacity for sustained hyperpnea. *American Review of Respiratory Disease, 138*(1), 106-109.

Barach, A. L. (1974). Chronic obstructive lung disease: postural relief of dyspnea. *Archives of Physical Medicine and Rehabilitation, 55*(11), 494-504.

Barrett, J., Cerny, F., Hirsch, J. A., & Bishop, B. (1994). Control of breathing patterns and abdominal muscles during graded loads and tilt. *Journal of Applied Physiology (1985), 76*(6), 2473-2480.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82-87.

Booth, S., Burkin, J., Moffat, C., & Spathis, A. (2014). Positions to ease breathlessness. In S. Booth, J. Burkin, C. Moffat, & A. Spathis (Eds.), *Managing breathlessness in clinical practice* (pp. 49-65). London: Springer.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., & Chiradejnant, A. (2009). Abdominal muscle activity during abdominal hollowing in four starting positions. *Manual Therapy, 14*(6), 642-646.

Cholewicki, J., Juluru, K., & McGill, S. M. (1999). Intra-abdominal pressure mechanism for stabilizing the lumbar spine. *Journal of Biomechanics, 32*(1), 13-17.

Criswell, E. (2011). *Cram's introduction to surface electromyography* (2nd ed.). Sudbury, MA: Jones & Bartlett Publishers.

de Marco, R., Accordini, S., Cerveri, I., Corsico, A., Anto, J. M., Kunzli, N., . . . Burney, P. (2007). Incidence of chronic obstructive pulmonary disease in a cohort of young adults according to the presence of chronic cough and phlegm. *American Journal of Respiratory and Critical Care Medicine, 175*(1), 32-39.

de Oca, M. M., Halbert, R. J., Lopez, M. V., Perez-Padilla, R., Talamo, C., Moreno, D., . . . Menezes, A. M. (2012). The chronic bronchitis phenotype in subjects with and without COPD: the PLATINO study. *European Respiratory Journal, 40*(1), 28-36.

De Troyer, A. (1983). Mechanical role of the abdominal muscles in relation to posture. *Respiration Physiology, 53*(3), 341-353.

De Troyer, A., Estenne, M., Ninane, V., Van Gansbeke, D., & Gorini, M. (1990). Transversus abdominis muscle function in humans. *Journal of Applied Physiology (1985), 68*(3), 1010-1016.

De Troyer, A., Leeper, J. B., McKenzie, D. K., & Gandevia, S. C. (1997). Neural drive to the diaphragm in patients with severe COPD. *American Journal of Respiratory and Critical Care Medicine, 155*(4), 1335-1340.

De Troyer, A., Sampson, M., Sigrist, S., & Kelly, S. (1983). How the abdominal muscles act on the rib cage. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology, 54*(2), 465-469.

Dean, E. (1985). Effect of body position on pulmonary function. *Physical Therapy, 65*(5), 613-618.

Delgado, H. R., Braun, S. R., Skatrud, J. B., Reddan, W. G., & Pegelow, D. F. (1982). Chest wall and abdominal motion during exercise in patients with chronic obstructive pulmonary disease. *American Review of Respiratory Disease, 126*(2), 200-205.

Estenne, M., Yernault, J. C., & De Troyer, A. (1985). Rib cage and diaphragm-abdomen compliance in humans: effects of age and posture. *Journal of Applied Physiology (1985), 59*(6), 1842-1848.

Gandevia, S. C., Leeper, J. B., McKenzie, D. K., & De Troyer, A. (1996). Discharge frequencies of parasternal intercostal and scalene motor units during breathing in normal and COPD subjects. *American Journal of Respiratory and Critical Care Medicine, 153*(2), 622-628.

Global Initiative for Chronic Obstructive Lung Disease. (2016). Global strategy for diagnosis, management, and prevention of chronic obstructive pulmonary disease - Update 2016. Retrieved from http://goldcopd.org/global-strategy-diagnosis-management-prevention-copd-2016/

Gorini, M., Spinelli, A., Ginanni, R., Duranti, R., Gigliotti, F., & Scano, G. (1990). Neural respiratory drive and neuromuscular coupling in patients with chronic obstructive pulmonary disease (COPD). *Chest, 98*(5), 1179-1186.

Gosselink, R. (2003). Controlled breathing and dyspnea in patients with chronic obstructive pulmonary disease (COPD). *Journal of Rehabilitation Research & Development, 40*(5 Suppl 2), 25-33.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361-374.

Hides, J., Richardson, C., & Hodges, P. W. (2004). Local segmental control. In J. Hides, C. Richardson, & P. W. Hodges (Eds.), *Therapeutic Exercise for Lumbopelvic Stabilization* (2nd ed., pp. 185-219). Edinburgh: Churchill Livingstone.

Hodges, P. W. (2004). Abdominal mechanism and support of the lumbar spine and pelvis. In J. Hides, C. Richardson, & P. W. Hodges (Eds.), *Therapeutic Exercise for Lumbopelvic Stabilization* (2nd ed., pp. 31-58). Edinburgh: Churchill Livingstone.

Hodges, P. W., & Gandevia, S. C. (2000). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology (1985), 89*(3), 967-976.

Hodges, P. W., Gurfinkel, V. S., Brumagne, S., Smith, T. C., & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Experimental Brain Research, 144*(3), 293-302.

Hodges, P. W., Heijnen, I., & Gandevia, S. C. (2001). Postural activity of the diaphragm is reduced in humans when respiratory demand increases. *The Journal of Physiology, 537(Pt 3)*, 999-1008.

Kaneko, H., & Horie, J. (2012). Breathing movements of the chest and abdominal wall in healthy subjects. *Respiratory Care, 57*(9), 1442-1451.

Key, J. (2013). 'The core': understanding it, and retraining its dysfunction. *Journal of Bodywork and Movement Therapies, 17*(4), 541-559.

Lee, L. J., Chang, A. T., Coppieters, M. W., & Hodges, P. W. (2010). Changes in sitting posture induce multiplanar changes in chest wall shape and motion with breathing. *Respiratory Physiology & Neurobiology, 170*(3), 236-245.

Mannino, D. M., Doherty, D. E., & Sonia Buist, A. (2006). Global Initiative on Obstructive Lung Disease (GOLD) classification of lung disease and mortality: findings from the Atherosclerosis Risk in Communities (ARIC) study. *Respiratory Medicine, 100*(1), 115-122.

Marôco, J. (2014). *Análise estatística com o SPSS Statistics* (6th ed.). Pero Pinheiro: ReportNumber, Lda.

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology, 13*(5), 477-489.

Martinez, F. J., Couser, J. I., & Celli, B. R. (1990). Factors influencing ventilatory muscle recruitment in patients with chronic airflow obstruction. *American Review of Respiratory Disease, 142*(2), 276-282.

Meadows, L., & Williams, J. (2009). An understanding of Functional movement as a basis for clinical reasoning. In S. Raine, L. Meadows, & M. Lynch-Ellerington (Eds.), *Bobath concept: theory and clinical practice in neurological rehabilitation* (pp. 23-42). Oxford: Wiley-Blackwell.

Mesquita Montes, A., Gouveia, S., Crasto, C., de Melo, C. A., Carvalho, P., Santos, R., & Vilas-Boas, J. P. Abdominal muscle activity during breathing in different postural sets in healthy subjects. *Journal of Bodywork and Movement Therapies*.

Mew, R. (2009). Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. *Manual Therapy, 14*(6), 690-695.

Mihailoff, G. A., & Haines, D. E. (2013). Motor system I: peripheral sensory, brainstem, and spinal influence on anterior horn neurons. In D. E.

Haines (Ed.), *Fundamental neuroscience for basic and clinical applications* (pp. 324-337). Philadelphia, PA: Elsevier/Saunders.

Miller, M. R., Hankinson, J., Brusasco, V., Burgos, F., Casaburi, R., Coates, A., . . . Force, A. E. T. (2005). Standardisation of spirometry. *European Respiratory Journal, 26*(2), 319-338.

Ninane, V., Rypens, F., Yernault, J. C., & De Troyer, A. (1992). Abdominal muscle use during breathing in patients with chronic airflow obstruction. *American Review of Respiratory Disease, 146*(1), 16-21.

Ninane, V., Yernault, J. C., & de Troyer, A. (1993). Intrinsic PEEP in patients with chronic obstructive pulmonary disease. Role of expiratory muscles. *American Review of Respiratory Disease, 148*(4 Pt 1), 1037-1042.

Norris, C. (1999). Functional load abdominal training: part 2. *Journal of Bodywork and Movement Therapies, 3*(4), 208-214.

O'Donnell, D. E. (2001). Ventilatory limitations in chronic obstructive pulmonary disease. *Medicine & Science in Sports & Exercise, 33*(7 Suppl), S647-655.

O'Neill, S., & McCarthy, D. S. (1983). Postural relief of dyspnoea in severe chronic airflow limitation: relationship to respiratory muscle strength. *Thorax, 38*(8), 595-600.

Reeve, A., & Dilley, A. (2009). Effects of posture on the thickness of transversus abdominis in pain-free subjects. *Manual Therapy, 14*(6), 679-684.

Rodriguez-Roisin, R., Han, M. K., Vestbo, J., Wedzicha, J. A., Woodruff, P. G., & Martinez, F. J. (2016). Chronic Respiratory Symptoms with Normal Spirometry: A Reliable Clinical Entity? *American Journal of Respiratory and Critical Care Medicine*.

Romei, M., Mauro, A. L., D'Angelo, M. G., Turconi, A. C., Bresolin, N., Pedotti, A., & Aliverti, A. (2010). Effects of gender and posture on thoraco-abdominal kinematics during quiet breathing in healthy adults. *Respiratory Physiology & Neurobiology, 172*(3), 184-191.

Sharp, J. T., Drutz, W. S., Moisan, T., Foster, J., & Machnach, W. (1980). Postural relief of dyspnea in severe chronic obstructive pulmonary disease. *American Review of Respiratory Disease, 122*(2), 201-211.

Smith, M. D., Chang, A. T., Seale, H. E., Walsh, J. R., & Hodges, P. W. (2010). Balance is impaired in people with chronic obstructive pulmonary disease. *Gait & Posture, 31*(4), 456-460.

Stavem, K., Sandvik, L., & Erikssen, J. (2006). Can global initiative for Chronic Obstructive Lung Disease stage 0 provide prognostic information on long-term mortality in men? *Chest, 130*(2), 318-325.

Strohl, K. P., Mead, J., Banzett, R. B., Lehr, J., Loring, S. H., & O'Cain, C. F. (1984). Effect of posture on upper and lower rib cage motion and tidal volume during diaphragm pacing. *American Review of Respiratory Disease, 130*(2), 320-321.

Thompson, P. D. (2014). Health appraisal and risk assessment. In L. S. Pescatello, R. Arena, D. Riebe, & P. D. Thompson (Eds.), *ACSM's guidelines for exercise testing and prescription* (9th ed., pp. 1-18). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

Vestbo, J., Hurd, S. S., Agusti, A. G., Jones, P. W., Vogelmeier, C., Anzueto, A., . . . Rodriguez-Roisin, R. (2013). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. *American Journal of Respiratory and Critical Care Medicine, 187*(4), 347-365.

# The effect of inspiratory and expiratory loads on the abdominal muscle activity during breathing in subjects "at risk" for the development of chronic obstructive pulmonary disease and healthy

**António Mesquita Montes, MSc**[a,b], Carlos Crasto, MSc[a], Cristina Argel de Melo, PhD[a], Rita Santos, MSc[a], Susana Pereira, BSc[c], João Paulo Vilas-Boas, PhD[b]

[a] Department of Physiotherapy, and Activity and Human Movement Study Center (CEMAH), School of Allied Health Technologies, Polytechnic Institute of Porto, Rua Dr. António Bernardino de Almeida 400, 4200-072 Porto, Portugal

[b] Faculty of Sport, CIFI2D, and Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Rua Dr. Plácido Costa 91, 4200-450 Porto, Portugal

[c] Cardiovascular, Respiratory and Sleep Technician, Private practice, Portugal

Submetido para publicação

## Abstract

Subjects with chronic obstructive pulmonary disease (COPD) may exhibit important deficits in the ability of trunk muscles for the synchronization of postural function and mechanics of breathing. This study aims to evaluate the effect of inspiratory and expiratory loads on the abdominal muscle activity during breathing in subjects "at risk" for the development of COPD and healthy. Thirty-one volunteers, divided in "At Risk" for COPD (n=17; 47.71±5.11 years) and Healthy (n=14; 48.21±6.87 years) groups, breathed at the same rhythm without load and with 10% of the maximal inspiratory or expiratory pressures, in standing. Surface electromyography was performed to assess the activation intensity of *rectus abdominis* (RA), external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles, during inspiration and expiration. During inspiration, in "At Risk" for COPD group, RA muscle activation was higher with loaded expiration ($p$=0.016); however, in Healthy group it was observed a higher activation of external oblique and TrA/IO muscles ($p$<0.050). During expiration, while in "At Risk" for COPD group, RA muscle activation was higher with loaded inspiration ($p$=0.009), in Healthy group TrA/IO muscle showed a higher activation ($p$=0.025). Subjects "at risk" for the development of COPD seemed to have a specific recruitment of the superficial layer of ventrolateral abdominal wall for the mechanics of breathing.



## Keywords

GOLD "Stage 0"; Respiration; Postural control; Respiratory loads; Core abdominal

## Introduction

Chronic obstructive pulmonary disease (COPD) is described as the presence of persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways (Global Initiative for Chronic Obstructive Lung Disease, 2016; Vestbo et al., 2013). Although primary underlying pathophysiology in COPD is an obstructive ventilatory defect, emerging evidence suggests that subjects with COPD may also reveal an impaired postural control (Beauchamp, Brooks, & Goldstein, 2010; Roig, Eng, Road, & Reid, 2009), remaining yet unclear. Many hypotheses have been proposed, including decreased levels of physical activity (Butcher, Meshke, & Sheppard, 2004), oxygen supplementation (Beauchamp, Hill, Goldstein, Janaudis-Ferreira, & Brooks, 2009), peripheral muscle weakness (Beauchamp et al., 2012) and somatosensory deficits (Janssens et al., 2013; Roig, Eng, Macintyre, Road, & Reid, 2011). Nevertheless, it is reasonable to hypothesize that the ability of the trunk muscles for the synchronization of postural function and mechanics of breathing may be altered in COPD (Smith, Chang, Seale, Walsh, & Hodges, 2010).

The central nervous system modulates the motor activities of global and core muscles during both functions (Hodges, 1999) to concurrently regulate the intra-abdominal and intra-thoracic pressures (Hodges, Heijnen, & Gandevia, 2001). Although the activity of *rectus abdominis* (RA) and external oblique (EO) muscles are a non respiration-related modulation, the *transversus abdominis* (TrA) muscle activity is modulated with the respiration and is out of phase with the diaphragm muscle activity (Hodges & Gandevia, 2000a, 2000b). Despite healthy subjects are capable of actively compensate for the quiet breathing, the postural control is compromised when the respiratory demand increases and requires voluntary control (David, Laval, Terrien, & Petitjean, 2012; Kuznetsov & Riley, 2012). Analogously, in subjects with COPD, who have an increased work of breathing, the respiratory activation of trunk muscles (McKenzie, Butler, & Gandevia, 2009), and the presence of hyperinflation (O'Donnell, 2001), may influence trunk stiffness and, consequently, postural control (Smith, Chang, & Hodges, 2016). In fact, neural drive to the diaphragm muscle (De Troyer, Leeper, McKenzie, & Gandevia, 1997; Gorini et al., 1990) and activity of parasternal intercostal and scalene muscles (Gandevia, Leeper, McKenzie, & De Troyer, 1996) are increased in COPD, during breathing at rest or when ventilation increases. Furthermore, the expiratory contraction of abdominal muscles in subjects with COPD may be an “automatic” response to the increased work of breathing and ventilatory stimulation, even during resting breathing (Martinez, Couser, & Celli, 1990; Ninane, Rypens, Yernault, & De Troyer, 1992). It has been proposed that an increased abdominal muscle activity is an appropriated response to assist inspiratory muscles, reducing the end-expiratory lung volume (Aliverti et al., 1997). This action of abdominal muscles changes diaphragmatic configuration, optimizing its length-tension characteristics (De Troyer & Estenne, 1988), or it allows the release of stored elastic energy at the onset of inspiration (Aliverti et al., 1997). Nevertheless, the abdominal muscle activity has been shown to be variable in subjects with COPD when respiratory demand increases (Laveneziana, Webb, Wadell, Neder, & O'Donnell, 2014), and their recruitment pattern may change the mechanics, as well as the work and cost of breathing (Aliverti & Macklem, 2008). The impact of different respiratory loads on abdominal muscle activity, during both breathing phases, for the synchronization of postural function and mechanics of breathing is not yet clear in subjects “at risk” for the development of COPD (presence of chronic respiratory symptoms, in addiction to some evidence of impaired lung function) (Rodriguez-Roisin et al., 2016). The scientific evidence in these subjects may be important to understand the natural history of COPD. The aim of the present study was to evaluate the effect of inspiratory and expiratory loads on abdominal muscle activity during breathing in subjects “at risk” for the development of COPD and healthy. Specifically, it was analysed the activation intensity of RA, EO and *transversus abdominis*/internal oblique (TrA/IO) muscles, during inspiration and expiration, without respiratory load and with inspiratory or expiratory loads.

## Methods

*Sample*

The study followed a cross-sectional design with a sample composed by thirty-one volunteers of an higher education institution: seventeen subjects “at risk” for the development of COPD – “At Risk” for COPD group; and fourteen healthy subjects – Healthy group. Sociodemographic, anthropometric and body composition data were similar between groups (Table 1). Participants had not participated in aerobic physical activities with a moderate intensity (a minimum of 30 min on five days a week) and/or aerobic physical activities with a vigorous intensity (a minimum of 20 min on 3 days a week), for a period exceeding one year (Thompson, 2014). As inclusion criteria for the “At Risk” for COPD group, participants had dyspnea, chronic cough and sputum production at least for three months in two consecutive years, as well as history of exposure to risk factors (e. g. smoking habits at least for fifteen years) (Rodriguez-Roisin et al., 2016). Moreover, these participants had to have Grade 1 or more in the Modified British Medical Research Council (mMRC) questionnaire and one point or more, out of five points, in the first four items of the COPD Assessment Test (CAT) (presence of cough, mucus, chest tightness and breathlessness) (Global Initiative for Chronic Obstructive Lung Disease, 2016). Exclusion criteria for both groups included chronic nonspecific lumbopelvic pain (recurrent episodes of lumbopelvic pain for a period longer than three months); scoliosis, length discrepancy of the lower limbs or other postural asymmetries; history of spinal, gynaecological or abdominal surgery in the previous year; neurological or inflammatory disorders; metabolic or chronic cardio-respiratory diseases; pregnancy or post-delivery in the previous six months; long-term corticosteroid therapy; and any conditions that may interfere with the data collection (American Thoracic Society/European Respiratory Society, 2002; Beith, Synnott, & Newman, 2001; Chanthapetch, Kanlayanaphotporn, Gaogasigam, & Chiradejnant, 2009; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Mew, 2009; Miller et al., 2005; Reeve & Dilley, 2009). Each participant provided written informed consent, according to the Declaration of Helsinki. The anonymity of participants and the confidentiality of data were guaranteed. The Institutional Research Ethics Committee approved this study.

**Table 1.** "At Risk" for COPD and Healthy groups' characterization: sociodemographic, anthropometric and body composition data, with mean and standard deviation. *p* values for significant differences between groups are also presented

| | "At Risk" for COPD group (n=17) | Healthy group (n=14) | Between groups comparison (*p* value) |
|---|---|---|---|
| Sociodemographic and anthropometric data | | | |
| Gender (n male) | 5 | 6 | 0.477 |
| Age (years) | 47.71±5.11 | 48.21±6.87 | 0.815 |
| Body mass (kg) | 70.85±14.37 | 79.65±15.28 | 0.110 |
| Height (m) | 1.67±0.11 | 1.67±0.10 | 0.917 |
| Body composition data | | | |
| Body fat (%) | 28.85±9.29 | 32.66±8.91 | 0.256 |
| Total body water (%) | 49.19±5.73 | 48.13±4.93 | 0.588 |
| Muscle mass (kg) | 48.51±11.21 | 52.27±13.02 | 0.395 |
| Bone mineral mass (kg) | 2.57±0.56 | 2.76±0.63 | 0.374 |
| Visceral fat | 7.12±3.14 | 9.21±2.83 | 0.063 |

*Procedures*

Sample selection and characterization

An electronic questionnaire was delivered to all participants to verify the selection criteria and to collect sociodemographic information. Also, the mMRC and CAT were included in this questionnaire. Anthropometric and body mass composition measures were assessed in participants who met the participation criteria. Height (m) was measured using a seca 222 stadiometer with a precision of 1 mm. Body mass (kg) and body mass composition – body fat (%), total body water (%), muscle mass (kg), bone mineral mass (kg) and visceral fat – were assessed using a Tanita Ironman Inner Scan BC-549 body composition monitor with a precision of 1 kg and 1 % (Tanita – Monitoring Your Health, Amsterdam, Netherlands). To assess postural asymmetries, the lower limb length (cm) was measured using a seca 201 tape with a precision of 1 mm (seca – Medical Scales and Measuring Systems, Hamburg, Germany) and the postural assessment was performed. These evaluations were performed to select the final sample. Women who were in luteal phase were contacted later for data collection.

A MasterScreen Body plethysmograph of volume-constant type (Jaeger – CareFusion Corporation, San Diego CA, United States of America) was used to record forced vital capacity and then to assess pulmonary function: forced expiratory volume in one second ($FEV_1$)/forced vital capacity (FVC); % predicted of $FEV_1$, FVC, peak expiratory flow (PEF), forced expiratory flow at 75 % ($FEF_{75\%}$)/50 % ($FEF_{50\%}$)/25 % ($FEF_{25\%}$) of FVC and $FEF_{25\text{-}75\%}$. FVC manoeuvre (closed circuit method) was recorded with participants in sitting position, using a mouthpiece firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip to prevent nasal breathing. To assess this manoeuvre, a completely and rapidly inhalation was performed with a pause of one second at total lung capacity, followed by a maximally exhalation until no more air can be expelled while maintaining the upright posture. Each manoeuvre was encouraged verbally. A minimum of three manoeuvres was performed. To test result selection, three reproducible manoeuvres were recorded, according to Miller et al. (2005) standards. An expert cardiovascular, respiratory and sleep technician was responsible for this assessment.

Data collection protocol

The study procedures took place at a biomechanical laboratory and were performed in a controlled environment. To avoid inter-rater error, each researcher was responsible for an only one task.

Surface electromyography (sEMG) was performed to assess the muscle activity of RA, EO and TrA/IO of the dominant hand side. The muscle activity was collected using the BioPlux research device (Plux wireless biosignals S.A., Arruda dos Vinhos, Portugal) with analogue channels of 12 bits and a sampling frequency of 1000 Hz, using double differential electrode leads. To perform the sEMG, the hair was shaved and an abrasive cream was used to remove the dead cells from the skin's surface. Skin was then cleaned with isopropyl alcohol (70 %), removing its oiliness and holding the dead cells. An electrode impedance checker (Noraxon Corporate, Scottsdale AZ, United States of America) was used to make sure that the impedance levels were below 5 KΩ, thus ensuring a good acquisition of sEMG signal (Hermens et al., 2000). Disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon Corporate, Scottsdale AZ, United States of America) were used for the sEMG. The electrode characteristics were 4x2.2 cm of adhesive area, 1 cm diameter of each circular conductive area and 2 cm of inter-electrode distance. These electrodes were connected to bipolar active sensors emgPLUX with a gain of 1000, an analogue filter at 25 to 500 Hz and a common-mode rejection ratio of 110 dB. The reference electrode used was a disposable self-adhesive Ag/AgCl snap electrode (Noraxon Corporate, Scottsdale AZ, United States of America) for the sEMG, with 3.8 cm diameter of circular adhesive area and 1 cm diameter of circular conductive area. The self-adhesive electrodes were placed with participants in standing position, five minutes after the skin preparation. These electrodes were placed parallel to the muscle fibre orientation, according to the references described in Table 2 (Criswell, 2011; Marshall & Murphy, 2003). The electrode placements were confirmed by palpation and muscle contraction. The reference electrode was placed in the anterior superior iliac spine of the contralateral hand dominant side. The sensors were Bluetooth connected through the sEMG device to a laptop.

MonitorPlux software, version 2.0, was used to display and acquire the sEMG signal. All electrodes were tested to control the cross-muscular signal (cross-talk), electrical noise and other interferences of sEMG signal (Hermens et al., 2000).

**Table 2.** Recommendations for the electrode placements of *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/internal oblique (TrA/IO) muscles.

| Muscle | Anatomical landmarks |
|---|---|
| RA | 2 cm lateral to the umbilicus, over the muscle mass |
| EO | Lateral to the RA and directly above the anterior superior iliac, halfway between the crest and ribs at a slightly oblique angle |
| TrA/IO | 2 cm medially and below to anterior superior iliac spine<br>In this local, TrA and inferior IO muscle fibers are mixed, so it is impossible distinguish the surface electromyographic activity of both. |

A respiratory pressure meter MicroRPM (CareFusion Corporation, San Diego CA, United States of America) was used to assess the maximal inspiratory (MIP) and expiratory (MEP) pressures. The values obtained were used to determine the inspiratory and expiratory loads, respectively. MEP quasi-static maximal manoeuvre was used to normalize the sEMG signal of abdominal muscles (maximal muscle activity of each muscle during breathing). MIP and MEP were both performed with participants in standing position, using a bacterial filter AFT1 – Disposable Bacterial Filter, 22 mm and a mouthpiece AFT2 – Disposable Mouthpiece, 22 mm firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip AFT3 – Disposable Noseclip (Biopac Systems Inc., Goleta CA, United States of America) to prevent nasal breathing. To assess MIP, a forceful and maximal inspiration was performed – the Muller manoeuvre – at residual volume; in turn, MEP was assessed through a forceful and maximal expiration – the Valsalva manoeuvre – at total lung capacity. Each manoeuvre was encouraged verbally. These manoeuvres were performed during a six-second period, with a resting time of three minutes. To calculate the respiratory load, three reproducible manoeuvres were recorded according to the American Thoracic Society/European Respiratory Society (2002) standards. It was used 10 % of the best value of MIP and MEP for the inspiratory and expiratory loads, respectively.

All participants were subjected to three different tasks – breathing without respiratory load and with inspiratory and expiratory loads, in standing – in a single data collection moment. The data collection moment started with breathing without respiratory load. The order of inspiratory or expiratory loads was randomized. A respiratory flow transducer TSD117 – Medium Flow Trans 300 $L.min^{-1}$, connected to an amplifier DA100C – General Purpose Transducer Amplifier Module, was used to detect the breathing phases. The respiratory flow was collected using the Biopac MP100WSW Data Acquisition System device (Biopac Systems Inc., Goleta CA, United States of America), with a sampling frequency of 100 Hz. A bacterial filter AFT1, a mouthpiece AFT2 and a nose clip AFT3 were also used. Acqknowledge software, version 4.1, was used to display and acquire the respiratory flow signal. Biopac MP100WSW Data Acquisition System was synchronized with the BioPlux research. Thresholds IMT and PEP (Respironics Inc., Murrysville PA, United Stare of America) were used to apply the inspiratory and expiratory loads, respectively. These devices were adapted to the respiratory flow transducer.

The participants were barefoot and had the upper limbs along the body, with feet shoulder-width apart and knees in loose pack position. An A3 paper sheet was used to outline the base of support, keeping it for all tasks. The participants kept their gaze in a horizontal direction and the respiratory flow transducer was kept perpendicular to the participant during all tasks. A single repetition of each task was performed for ten consecutive respiratory cycles, with a resting time of three minutes. The respiratory rhythm (inspiratory time: two seconds; expiratory time: four seconds) was marked through a recorded voice. The participant experienced and get used to this externally paced respiratory rhythm prior to data collection.

After data collection, the electrodes were removed and a moisturizing cream was applied.

## Data processing

A routine was developed in MatLab Student software (MathWorks, Pozuelo de Alarcon, Spain) to synchronize and process data. Firstly, the sEMG signal was converted into volts. It was applied to the sEMG signal a 2nd order digital filter Infinite Impulse Response – Butterworth, one of 30 Hz (high pass) and another of 500 Hz (low pass), to remove the electrical noise and/or cable movement and to remove the cardiac signal. Root mean square (RMS) to 10 samples was then calculated.

Acqknowledge software, version 4.1, was used to analyse data. The abdominal muscle activity was analysed during inspiration and expiration, independently. These both breathing phases were identified through the respiratory flow transducer signal. For the ten respiratory cycles collected, the mean RMS of four central respiratory cycles of each muscle was analysed in each task, with a posterior analysis of its average.

The muscle activity collected during the MEP manoeuvre was used to normalize data of the abdominal muscles. The mean RMS of three central seconds of the expiratory phase of each muscle was analysed, and then the average of the mean RMS of three reproducible manoeuvres was calculated. The percentage of the activation intensity of each muscle was determined according to the following equation:

$$Muscle\ activation\ intensity\ (\%) = \left(\frac{mean\ RMS\ of\ each\ task}{RMS\ of\ the\ MEP}\right) * 100$$

*Statistical analysis*

IBM SPSS Statistics® software, version 20.0, (IBM Corporation, Armonk NY, United States of America) was used for the descriptive and inferential data analysis, with a significance level of 0.05. Shapiro-Wilk test was used to test the normality of the data. Central tendency (mean) and dispersion (standard deviation) measures were used for the descriptive statistics. Chi-square was used to compare gender between groups ("At Risk" for COPD and Healthy). Student t-test was used to compare the age, anthropometric, body composition and pulmonary function data, as well as the percentage of muscle activation intensity, between groups. In each group, Repeated Measures Analysis of Variance was used to compare the percentage of muscle activation intensity between the different evaluation tasks (without respiratory load and with inspiratory or expiratory loads), during inspiration and expiration. Bonferroni correction was used for the post-hoc analysis (Marôco, 2014).

## Results

*Pulmonary function*

The forced expiratory volume in one second, peak expiratory flow and forced expiratory flow at 75% / 50% / 25% / 25-75% of FVC were significantly lower in "At Risk" for COPD group when compared to Healthy group ($p$<0.050). No significant differences were found in the FVC between groups (Table 3).

**Table 3.** Pulmonary function data in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for significant differences between groups are also presented

| Pulmonary function | “At Risk” for COPD group (n=17) | Healthy group (n=14) | Between groups comparison (*p* value) |
|---|---|---|---|
| $FEV_1$/FVC | 74.30±6.25 | 82.75±1.67 | <0.001 |
| $FEV_1$ (% pred) | 95.23±14.87 | 117.30±13.04 | <0.001 |
| FVC (% pred) | 107.79±15,35 | 118.47±14.75 | 0.059 |
| PEF (% pred) | 102.64±16.87 | 117.85±16.41 | 0.017 |
| $FEF_{75}$ (% pred) | 93.09±26.37 | 123.97±18.13 | 0.001 |
| $FEF_{50}$ (% pred) | 63.91±16.64 | 110.08±17.23 | <0.001 |
| $FEF_{25}$ (% pred) | 49.40±13.48 | 84.44±14.83 | <0.001 |
| $FEF_{25-75}$ (% pred) | 60.18±14.96 | 102.56±15.86 | <0.001 |

$FEV_1$ forced expiratory volume in one second; FVC forced vital capacity; PEF peak expiratory flow; $FEF_{75}$/$FEF_{50}$/$FEF_{25}$/$FEF_{25-75}$ forced expiratory flow at 75% / 50% / 25% / 25-75% of FVC, respectively; % pred % predicted

*Muscle activity*

Inspiration

During inspiration, no significant differences were found in the activation intensity of all abdominal muscles between “At Risk” for COPD and Healthy groups during all tasks (Figure 1).

In “At Risk” for COPD group, RA muscle activation intensity was significantly greater during breathing with expiratory load when compared to without respiratory load (*p*=0.016) (Figure 1).

In Healthy group, the activation intensity of EO (*p*=0.008) and TrA/IO (*p*=0.039) muscles was significantly greater during breathing with expiratory load when compared to without respiratory load (Figure 1).

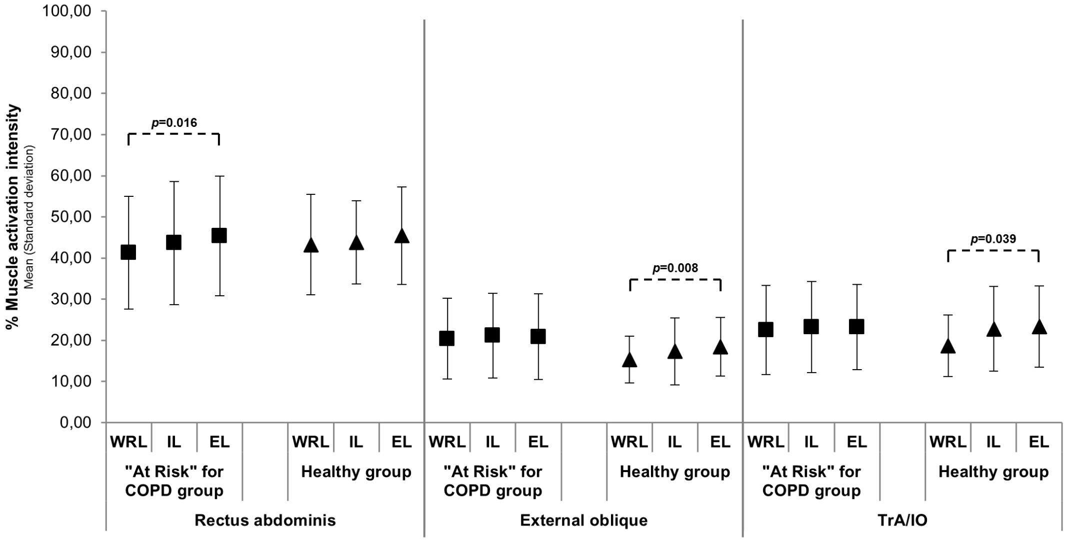


**Figure 1.** Activation intensity of *rectus abdominis*, external oblique and *transversus abdominis*/internal oblique (TrA/IO) muscles (expressed as %) during inspiration without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison within subjects is also presented

Expiration

During expiration, no significant differences were found in the activation intensity of all abdominal muscles between “At Risk” for COPD and Healthy groups during all tasks (Figure 2).

In “At Risk” for COPD group, the activation intensity of all abdominal muscles was significantly greater during breathing with expiratory load when compared to without respiratory load (RA: $p<0.001$; EO: $p=0.037$; TrA/IO: $p=0.014$). RA muscle activation intensity was significantly greater during breathing with inspiratory load when compared to without respiratory load ($p=0.009$) (Figure 2).

In Healthy group, the activation intensity of all abdominal muscles was significantly greater during breathing with expiratory load when compared to without respiratory load (RA: $p=0.008$; EO: $p=0.002$; TrA/IO: $p=0.007$). TrA/IO muscle activation intensity was significantly greater during breathing with inspiratory load when compared to without respiratory load ($p$=0.025). The activation intensity of all abdominal muscles was significantly greater during breathing with expiratory load when compared to inspiratory load (RA: $p$=0.035; EO: $p$=0.038; TrA/IO: $p$=0.007) (Figure 2).

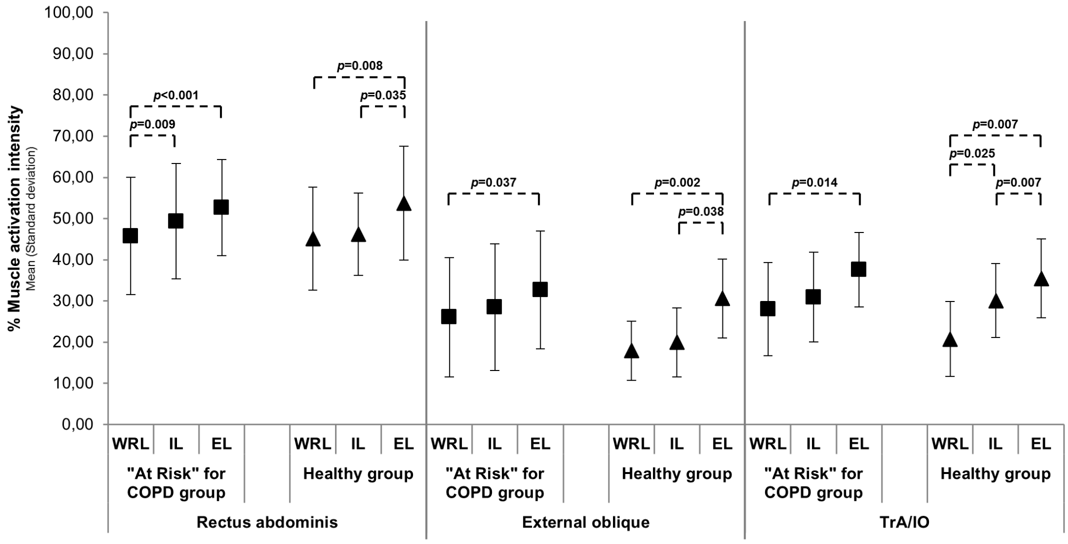


**Figure 2.** Activation intensity of rectus abdominis, external oblique and transversus abdominis/internal oblique (TrA/IO) muscles (expressed as %) during expiration without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. $p$ values for comparison within subjects is also presented

## Discussion

The present study showed that the inspiratory and expiratory loads promoted a different impact on abdominal muscle activity in each group. During inspiration, while in “At Risk” for COPD group the loaded expiration promoted higher RA muscle activation intensity, in Healthy group it was EO and TrA/IO muscles that showed higher activation intensity. During expiration, in “At Risk” for COPD group, the loaded inspiration promoted higher RA muscle activation intensity when compared to without respiratory load; however, in Healthy group it was observed higher TrA/IO muscle activation intensity. In both groups, the activation intensity of all abdominal muscles was higher with loaded expiration when compared to without respiratory load. These data suggested that subjects “at risk” for the development of COPD had a different recruitment pattern of abdominal muscles for the mechanics of breathing.

The quiet expiration is a passive process, involving the use of elastic components recoil of the lungs and chest wall; no phasic activity of abdominal muscles is observed (Kenyon et al., 1997). However, in this study, all participants breathed at a mandatory rhythm increased the minute ventilation, implying a breathing below functional residual capacity and, consequently, a phasic respiratory activity of abdominal muscles. Moreover, the standardization of respiratory rhythm may have reduced a possible bias related to the respiratory load on minute ventilation.

The findings of the present study indicated that there were no significant differences between “At Risk” for COPD and Healthy groups in activation intensity of all abdominal muscles during breathing without respiratory load. Evidence has been described that the abdominal muscle recruitment is frequent in COPD subjects (Ninane et al., 1992; Ninane, Yernault, & de Troyer, 1993). Ninane et al. (1992) reported that, when breathing at rest, the phasic expiratory activation mainly concerns the TrA muscle and its recruitment is related to the degree of airflow obstruction. Despite there was a decreased pulmonary function in “At Risk” for COPD group when compared to Healthy group, it seems that the differences do not reflect an obstructive ventilatory defect (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). The variables associated with airflow obstruction (Tiffeneau index, $FEV_1$ and $FEF_{25-75\%}$), in the study’ sample, were above the cut-off points that define the limit of normality (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). Thus, the breathing without respiratory load was not sufficiently challenging for postural-respiratory synergy in these specific subjects.

Due to inspiratory and expiratory loads, the respiratory demand increases and requires voluntary control, promoting a different recruitment pattern of abdominal muscles within the groups. During inspiration, in “At Risk” for

COPD group, the RA muscle activation intensity was greater during breathing with expiratory load when compared to without respiratory load; however, in Healthy group it was observed a greater activation intensity of EO and TrA/IO muscles, in the same comparison. Breathing is achieved by an alternate modulation of activity of the diaphragm and TrA muscles, resulting on cyclic changes in the shape of pressurized abdominal cavity, to support ribcage and abdominal movements (Hodges & Gandevia, 2000b). As a result of the tonic contraction of abdominal muscles during inspiration in both groups, the expiratory load seemed to reduce the compliance of abdominal wall, decreasing the contribution of abdominal movement to breathing. This abdominal muscle recruitment would prevent further descent of the central tendon of diaphragm muscle and its effectively stabilization promotes lateral chest wall expansion (De Troyer & Estenne, 1988). The results of this study were consistent with earlier study of Gothe and Cherniack (1980). The altered recruitment pattern of abdominal muscles within the groups, there may have different consequences. The TrA/IO muscle activity, observed in Healthy group, may increase the transverse diameter of the lower rib cage (Key, 2013). Otherwise, in “At Risk” for COPD group, the RA muscle recruitment helps to anchor the thorax caudally and their excessive activity may constrict the inferior thorax, interfering with diaphragm descent (Key, 2013). Further studies are needed to evaluate the effect of low expiratory load on the pattern of breathing in these subjects. The specific recruitment of abdominal muscles observed in each group may provide information relative to an impaired mechanics of breathing in subjects who have dyspnea, chronic cough or sputum production, and a history of exposure to risk factors for the chronic obstructive pulmonary disease (as tobacco smoke), but did not exhibited an obstructive ventilatory defect (Rodriguez-Roisin et al., 2016).

Nevertheless, in “At Risk” for COPD group, the RA muscle activation intensity during breathing with inspiratory load was greater when compared to without respiratory load, during expiration; however, it was observed a greater TrA/IO muscle activation intensity in Healthy group. Due to loaded inspiration, it was expected, in both groups, a greater abdominal muscle activity during expiration. The respiratory system tends to limit the inspiratory muscle activity, transferring any additional load to the expiratory muscles, optimizing the length-tension relationship of diaphragm muscle fibres, to assist the subsequent inspiration (Aliverti et al., 1997). In Healthy group, the TrA/IO muscle expiratory contraction, due to its circumferential arrangement, should be more effective in increasing abdominal pressure and deflating the lung so as to take on portion the work of the inspiratory muscles (De Troyer, Estenne, Ninane, Van Gansbeke, & Gorini, 1990). While TrA/IO muscle recruitment is beneficial in healthy subjects, the RA muscle expiratory contraction, observed in “At Risk” for COPD group, may be definitively harmful in an advanced pathological context. The inability of subjects with expiratory flow limitation to increase tidal expiratory flow rates and reduce end-expiratory lung volume below the resting value, or to induce the storage of elastic and gravitational energy in the diaphragm muscle and the abdomen (O'Donnell, 2001), by increasing expiratory activity of TrA/IO muscle, may place the diaphragm under a mechanical disadvantage. Furthermore, due to the work of breathing may be increased in RA muscle’ recruiters, an imbalance between energy supply and demand may result in competition between respiratory and other muscles for limited energy supplies (Aliverti & Macklem, 2008). In fact, Aliverti and Macklem (2008) reported that, as COPD progresses, subjects eventually learn to not recruit the abdominal muscles, minimizing the work and cost of breathing.

In both groups, all abdominal muscles showed a greater activation intensity with expiratory load when compared to without respiratory load, during expiration. Voluntary efforts, such as empty the lung or raise the intra-abdominal pressure, are achieved by the contraction in concert of the superficial (RA and EO muscles) and deep (TrA/IO muscle) muscle layers of ventrolateral abdominal wall (De Troyer et al., 1990). These findings are corroborated by Mesquita Montes et al. (2016).

As another point of view, this recruitment pattern of superficial abdominal muscles during breathing with respiratory loads, observed in subjects “At Risk” for the development of COPD, may impair the postural control. The excessive trunk muscle activity, namely abdominal muscles, in response to increased respiratory demand, can compromise the trunk moments/movements (Smith et al., 2016). Therefore, the reduced contribution of trunk movement to postural control may be the source to balance deficits that were reported in COPD subjects (Janssens et al., 2013; Smith et al., 2010). Accordingly, further investigation is needed in order to understand the impact of appropriate intervention strategies to optimize the abdominal muscle synergy for the postural function and mechanics of breathing.

## Conclusion

The inspiratory and expiratory loads promoted a different impact on abdominal muscle activity within of each group. Subjects "at risk" for development of COPD seemed to have a specific recruitment of the superficial muscle layer of ventrolateral abdominal wall in situations wherein the respiratory demand increases.

## Acknowledgments

A special thanks to Edgar Ribeiro, PT, Joana Maia, PT and Liliana Bastos, PT for the assistance provided with subject recruitment and data collection. We also thanks to Dr. Cristina Baeta and Dr. Sónia Magalhães from the Department of Cardiopneumology.

## Conflict of interest statement

Nothing to declare.

## References

Aliverti, A., Cala, S. J., Duranti, R., Ferrigno, G., Kenyon, C. M., Pedotti, A., . . . Yan, S. (1997). Human respiratory muscle actions and control during exercise. *Journal of Applied Physiology (1985), 83*(4), 1256-1269.

Aliverti, A., & Macklem, P. T. (2008). The major limitation to exercise performance in COPD is inadequate energy supply to the respiratory and locomotor muscles. *Journal of Applied Physiology (1985), 105*(2), 749-751; discussion 755-747.

American Thoracic Society/European Respiratory Society. (2002). ATS/ERS Statement on respiratory muscle testing. *American Journal of Respiratory and Critical Care Medicine, 166*(4), 518-624.

Beauchamp, M. K., Brooks, D., & Goldstein, R. S. (2010). Deficits in postural control in individuals with COPD - emerging evidence for an important secondary impairment. *Multidisciplinary Respiratory Medicine, 5*(6), 417-421.

Beauchamp, M. K., Hill, K., Goldstein, R. S., Janaudis-Ferreira, T., & Brooks, D. (2009). Impairments in balance discriminate fallers from non-fallers in COPD. *Respiratory Medicine, 103*(12), 1885-1891.

Beauchamp, M. K., Sibley, K. M., Lakhani, B., Romano, J., Mathur, S., Goldstein, R. S., & Brooks, D. (2012). Impairments in systems underlying control of balance in COPD. *Chest, 141*(6), 1496-1503.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82-87.

Butcher, S. J., Meshke, J. M., & Sheppard, M. S. (2004). Reductions in functional balance, coordination, and mobility measures among patients with stable chronic obstructive pulmonary disease. *Journal of Cardiopulmonary Rehabilitation and Prevention, 24*(4), 274-280.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., & Chiradejnant, A. (2009). Abdominal muscle activity during abdominal hollowing in four starting positions. *Manual Therapy, 14*(6), 642-646.

Criswell, E. (2011). *Cram's introduction to surface electromyography* (2nd ed.). Sudbury, MA: Jones & Bartlett Publishers.

David, P., Laval, D., Terrien, J., & Petitjean, M. (2012). Postural control and ventilatory drive during voluntary hyperventilation and carbon dioxide rebreathing. *European Journal of Applied Physiology, 112*(1), 145-154.

De Troyer, A., & Estenne, M. (1988). Functional anatomy of the respiratory muscles. *Clinics In Chest Medicine, 9*(2), 175-193.

De Troyer, A., Estenne, M., Ninane, V., Van Gansbeke, D., & Gorini, M. (1990). Transversus abdominis muscle function in humans. *Journal of Applied Physiology (1985), 68*(3), 1010-1016.

De Troyer, A., Leeper, J. B., McKenzie, D. K., & Gandevia, S. C. (1997). Neural drive to the diaphragm in patients with severe COPD. *American Journal of Respiratory and Critical Care Medicine, 155*(4), 1335-1340.

Gandevia, S. C., Leeper, J. B., McKenzie, D. K., & De Troyer, A. (1996). Discharge frequencies of parasternal intercostal and scalene motor units during breathing in normal and COPD subjects. *American Journal of Respiratory and Critical Care Medicine, 153*(2), 622-628.

Global Initiative for Chronic Obstructive Lung Disease. (2016). Global strategy for diagnosis, management, and prevention of chronic obstructive pulmonary disease - Update 2016. Retrieved from http://goldcopd.org/global-strategy-diagnosis-management-prevention-copd-2016/

Gorini, M., Spinelli, A., Ginanni, R., Duranti, R., Gigliotti, F., & Scano, G. (1990). Neural respiratory drive and neuromuscular coupling in patients with chronic obstructive pulmonary disease (COPD). *Chest, 98*(5), 1179-1186.

Gothe, B., & Cherniack, N. S. (1980). Effects of expiratory loading on respiration in humans. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology, 49*(4), 601-608.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361-374.

Hodges, P. W. (1999). Is there a role for transversus abdominis in lumbo-pelvic stability? *Manual Therapy, 4*(2), 74-86.

Hodges, P. W., & Gandevia, S. C. (2000a). Activation of the human diaphragm during a repetitive postural task. *The Journal of Physiology, 522*(Pt 1), 165-175.

Hodges, P. W., & Gandevia, S. C. (2000b). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology (1985), 89*(3), 967-976.

Hodges, P. W., Heijnen, I., & Gandevia, S. C. (2001). Postural activity of the diaphragm is reduced in humans when respiratory demand increases. *The Journal of Physiology, 537*(Pt 3), 999-1008.

Janssens, L., Brumagne, S., McConnell, A. K., Claeys, K., Pijnenburg, M., Burtin, C., . . . Troosters, T. (2013). Proprioceptive changes impair balance control in individuals with chronic obstructive pulmonary disease. *PLoS One, 8*(3), e57949.

Kenyon, C. M., Cala, S. J., Yan, S., Aliverti, A., Scano, G., Duranti, R., . . . Macklem, P. T. (1997). Rib cage mechanics during quiet breathing and exercise in humans. *Journal of Applied Physiology (1985), 83*(4), 1242-1255.

Key, J. (2013). 'The core': understanding it, and retraining its dysfunction. *Journal of Bodywork and Movement Therapies, 17*(4), 541-559.

Kuznetsov, N. A., & Riley, M. A. (2012). Effects of breathing on multijoint control of center of mass position during upright stance. *Journal of Motor Behavior, 44*(4), 241-253.

Laveneziana, P., Webb, K. A., Wadell, K., Neder, J. A., & O'Donnell, D. E. (2014). Does expiratory muscle activity influence dynamic hyperinflation and exertional dyspnea in COPD? *Respiratory Physiology & Neurobiology, 199*, 24-33.

Marôco, J. (2014). *Análise estatística com o SPSS Statistics* (6th ed.). Pero Pinheiro: ReportNumber, Lda.

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology, 13*(5), 477-489.

Martinez, F. J., Couser, J. I., & Celli, B. R. (1990). Factors influencing ventilatory muscle recruitment in patients with chronic airflow obstruction. *American Review of Respiratory Disease, 142*(2), 276-282.

McKenzie, D. K., Butler, J. E., & Gandevia, S. C. (2009). Respiratory muscle function and activation in chronic obstructive pulmonary disease. *Journal of Applied Physiology (1985), 107*(2), 621-629.

Mesquita Montes, A., Baptista, J., Crasto, C., de Melo, C. A., Santos, R., & Vilas-Boas, J. P. (2016). Abdominal muscle activity during breathing with and without inspiratory and expiratory loads in healthy subjects. *Journal of Electromyography and Kinesiology, 30*, 143-150.

Mew, R. (2009). Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. *Manual Therapy, 14*(6), 690-695.

Miller, M. R., Hankinson, J., Brusasco, V., Burgos, F., Casaburi, R., Coates, A., . . . Force, A. E. T. (2005). Standardisation of spirometry. *European Respiratory Journal, 26*(2), 319-338.

Ninane, V., Rypens, F., Yernault, J. C., & De Troyer, A. (1992). Abdominal muscle use during breathing in patients with chronic airflow obstruction. *American Review of Respiratory Disease, 146*(1), 16-21.

Ninane, V., Yernault, J. C., & de Troyer, A. (1993). Intrinsic PEEP in patients with chronic obstructive pulmonary disease. Role of expiratory muscles. *American Review of Respiratory Disease, 148*(4 Pt 1), 1037-1042.

O'Donnell, D. E. (2001). Ventilatory limitations in chronic obstructive pulmonary disease. *Medicine & Science in Sports & Exercise, 33*(Supple 7), S647-655.

Reeve, A., & Dilley, A. (2009). Effects of posture on the thickness of transversus abdominis in pain-free subjects. *Manual Therapy, 14*(6), 679-684.

Rodriguez-Roisin, R., Han, M. K., Vestbo, J., Wedzicha, J. A., Woodruff, P. G., & Martinez, F. J. (2016). Chronic Respiratory Symptoms with Normal Spirometry: A Reliable Clinical Entity? *American Journal of Respiratory and Critical Care Medicine*.

Roig, M., Eng, J. J., Macintyre, D. L., Road, J. D., & Reid, W. D. (2011). Postural Control Is Impaired in People with COPD: An Observational Study. *Physiotherapy Canada, 63*(4), 423-431.

Roig, M., Eng, J. J., Road, J. D., & Reid, W. D. (2009). Falls in patients with chronic obstructive pulmonary disease: a call for further research. *Respiratory Medicine, 103*(9), 1257-1269.

Smith, M. D., Chang, A. T., & Hodges, P. W. (2016). Balance recovery is compromised and trunk muscle activity is increased in chronic obstructive pulmonary disease. *Gait & Posture, 43*, 101-107.

Smith, M. D., Chang, A. T., Seale, H. E., Walsh, J. R., & Hodges, P. W. (2010). Balance is impaired in people with chronic obstructive pulmonary disease. *Gait & Posture, 31*(4), 456-460.

Thompson, P. D. (2014). Health appraisal and risk assessment. In L. S. Pescatello, R. Arena, D. Riebe, & P. D. Thompson (Eds.), *ACSM's guidelines for exercise testing and prescription* (9th ed., pp. 1-18). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

Vestbo, J., Hurd, S. S., Agusti, A. G., Jones, P. W., Vogelmeier, C., Anzueto, A., . . . Rodriguez-Roisin, R. (2013). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. *American Journal of Respiratory and Critical Care Medicine, 187*(4), 347-365.

# The effect of inspiratory and expiratory loads on the centre of pressure displacement during breathing in subjects "at risk" for the development of chronic obstructive pulmonary disease and healthy

**António Mesquita Montes, MSc**[a,b], Edgar Ribeiro, PT[c], Carlos Crasto, MSc[a], Cristina Argel de Melo, PhD[a], Paulo Carvalho, PhD[a], Rita Santos, MSc[a], Rubim Santos, PhD[a], Susana Pereira, BSc[c], João Paulo Vilas-Boas, PhD[b]

[a] Department of Physiotherapy, and Activity and Human Movement Study Center (CEMAH), School of Allied Health Technologies, Polytechnic Institute of Porto, Rua Dr. António Bernardino de Almeida 400, 4200-072 Porto, Portugal

[b] Faculty of Sport, CIFI2D, and Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Rua Dr. Plácido Costa 91, 4200-450 Porto, Portugal

[c] Physiotherapist, Private practice, Portugal

[d] Cardiovascular, Respiratory and Sleep Technician, Private practice, Portugal

Submetido para publicação

## Abstract

Emerging evidence suggests that subjects with chronic obstructive pulmonary disease (COPD) exhibit important deficits in balance, however the underlying mechanisms for reduced postural control remain unclear. This study aims to evaluate the effect of inspiratory and expiratory loads on the centre of pressure displacement during breathing in subjects “at risk” for the development of COPD and healthy. Thirty-one volunteers, divided in “At Risk” for COPD (n=17; 47.71±5.11 years) and Healthy (n=14; 48.21±6.87 years) groups, breathed at the same rhythm without load and with 10% of the maximal inspiratory or expiratory pressures, in standing. A forceplate was used to assess the mean amplitude and mean velocity, in anterior-posterior and medial-lateral directions, and total mean velocity of the centre of pressure displacement during breathing. During breathing without respiratory load and with expiratory load, no significant differences were found in the CoP displacement variables between groups. However, during breathing with inspiratory load, the mean velocity, in both directions ($p$<0.050), and total mean velocity ($p$=0.005) were higher in “At Risk” for COPD group when compared to Healthy group. Nevertheless, in “At Risk” for COPD group, the mean amplitude and mean velocity, in both directions, and total mean velocity were higher with inspiratory load when compared to without load ($p$<0.050) and expiratory load ($p$<0.050). The inability to use a multisegmental control strategy during breathing with low inspiratory load may have indicated an impaired contribution of respiratory muscles for postural control in these subjects “at risk” for the development of COPD.



## Keywords

GOLD Stage 0; Postural control; Respiratory loads; Core abdominal; Balance

## Introduction

Chronic Obstructive Pulmonary Disease (COPD) is characterized by persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways (Global Initiative for Chronic Obstructive Lung Disease, 2016; Vestbo et al., 2013). Although primary underlying pathophysiology in COPD is an obstructive ventilatory defect, non-respiratory consequences, including reduction in peripheral muscle performance, functional mobility and exercise capacity (Maltais, LeBlanc, Jobin, & Casaburi, 2000), contribute significantly to the symptoms and disability. Emerging evidence suggests that subjects with COPD also exhibit important deficits in balance (Beauchamp, Brooks, & Goldstein, 2010; Roig, Eng, Road, & Reid, 2009). Clinical (Beauchamp, Hill, Goldstein, Janaudis-Ferreira, & Brooks, 2009; Beauchamp et al., 2012; Butcher, Meshke, & Sheppard, 2004) and laboratory (Janssens et al., 2013; Roig, Eng, Macintyre, Road, & Reid, 2011; Smith, Chang, Seale, Walsh, & Hodges, 2010) measures have been identified an abnormal balance in subjects with varying degrees of COPD severity. Little is known regarding the disordered subcomponents underlying the postural control in subjects with COPD; however, the mechanic and neuromuscular interdependence between the postural control and breathing may be affected.

Healthy subjects are able of compensating the periodic disturbance during quiet stance (Kuznetsov & Riley, 2012) by a coordinated muscle recruitment of trunk and lower limbs – postural-respiratory synergy (Hodges, Gurfinkel, Brumagne, Smith, & Cordo, 2002). When the respiratory demand increases and requires voluntary control, the contribution of movements and moments of the trunk and lower limbs may be altered due to either mechanical factors related to changes on breathing pattern – frequency, volume and/or thoraco-abdominal movement – or organizational factors associated to the postural and respiratory commands (David, Laval, Terrien, & Petitjean, 2012; Hodges et al., 2002; Kuznetsov & Riley, 2012). As postural activity of the trunk muscles is altered when the descending respiratory drive is increased (Hodges, Heijnen, & Gandevia, 2001), the ability of the trunk movement and moments to contribute for the maintenance of postural control may be compromised (Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998). Thus, it is reasonable to hypothesize that the compensation may be not complete and the degree of postural perturbation may be dependent on different respiratory loads in subjects “at risk” for the development of COPD (presence of chronic respiratory symptoms, in addiction to some evidence of impaired lung function) (Rodriguez-Roisin et al., 2016). The scientific evidence in these subjects may be important to understand the natural history of COPD. The aim of the present study was to evaluate the effect of inspiratory and expiratory loads on the centre of pressure (CoP) displacement during breathing in subjects “at risk” for the development of COPD and healthy. Specifically, the mean amplitude and mean velocity, in anterior-posterior and medial-lateral directions, and total mean velocity of the CoP displacement were analysed during respiration without respiratory load and with inspiratory or expiratory loads.

## Methods

### *Sample*

A cross-sectional design was conducted with a sample composed by thirty-one volunteers of an higher education institution: seventeen subjects “at risk” for the development of COPD – “At risk” for COPD group; and fourteen healthy subjects – Healthy group. Sociodemographic, anthropometric and body composition data were similar between groups (Table 1). Participants had not participated in aerobic physical activities with a moderate intensity (a minimum of 30 min on five days a week) and/or aerobic physical activities with a vigorous intensity (a minimum of 20 min on 3 days a week), for a period exceeding one year (Thompson, 2014). As inclusion criteria for the “At Risk” for COPD group, participants had dyspnea, chronic cough and sputum production at least for three months in two consecutive years, as well as history of exposure to risk factors (e. g. smoking habits at least for fifteen years) (Rodriguez-Roisin et al., 2016). Moreover, these participants had to have Grade 1 or more in the Modified British Medical Research Council (mMRC) questionnaire and one point or more, out of five points, in the first four items of the COPD Assessment Test (CAT) (presence of cough, mucus, chest tightness and breathlessness) (Global Initiative for Chronic Obstructive Lung Disease, 2016). Exclusion criteria for both groups included chronic nonspecific lumbopelvic pain (recurrent episodes of lumbopelvic pain for a period longer than three months); scoliosis, length discrepancy of the lower limbs or other postural asymmetries; history of spinal, gynaecological or abdominal surgery in the previous year; neurological or inflammatory disorders; metabolic or chronic cardio-respiratory diseases; pregnancy or post-delivery in the previous six months; long-term corticosteroid therapy; and any conditions that may interfere with the data collection (American Thoracic Society/European Respiratory Society, 2002; Beith, Synnott, & Newman, 2001; Chanthapetch, Kanlayanaphotporn, Gaogasigam, & Chiradejnant, 2009; Mew, 2009; Miller et al., 2005; Reeve & Dilley, 2009). Each participant provided written informed consent, according to the Declaration of Helsinki. The anonymity of participants and the confidentiality of data were guaranteed. The Institutional Research Ethics Committee approved this study.

**Table 1.** "At Risk" for COPD and Healthy groups' characterization: sociodemographic, anthropometric and body composition data, with mean and standard deviation. *p* values for significant differences between groups are also presented

| | "At Risk" for COPD group (n=17) | Healthy group (n=14) | Between groups comparison (*p* value) |
|---|---|---|---|
| Sociodemographic and anthropometric data | | | |
| Gender (n male) | 5 | 6 | 0.477 |
| Age (years) | 47.71±5.11 | 48.21±6.87 | 0.815 |
| Body mass (kg) | 70.85±14.37 | 79.65±15.28 | 0.110 |
| Height (m) | 1.67±0.11 | 1.67±0.10 | 0.917 |
| Body composition data | | | |
| Body fat (%) | 28.85±9.29 | 32.66±8.91 | 0.256 |
| Total body water (%) | 49.19±5.73 | 48.13±4.93 | 0.588 |
| Muscle mass (kg) | 48.51±11.21 | 52.27±13.02 | 0.395 |
| Bone mineral mass (kg) | 2.57±0.56 | 2.76±0.63 | 0.374 |
| Visceral fat | 7.12±3.14 | 9.21±2.83 | 0.063 |

*Procedures*

Sample selection and characterization

An electronic questionnaire was delivered to all participants to verify the selection criteria and to collect sociodemographic information. Also, the mMRC and CAT were included in this questionnaire. Anthropometric and body mass composition measures were assessed in participants who met the participation criteria. Height (m) and body mass (kg) – were measured using a seca 222 stadiometer with a precision of 1 mm and a forceplate FP4060-08 (Bertec Corporation®, Columbus OH, United States of America), respectively. Body mass composition – body fat (%), total body water (%), muscle mass (kg), bone mineral mass (kg) and visceral fat – were assessed using a Tanita Ironman Inner Scan BC-549 body composition monitor with a precision of 1 kg and 1 % (Tanita – Monitoring Your Health, Amsterdam, Netherlands). To assess postural asymmetries, the lower limb length (cm) was measured using a seca 201 tape with a precision of 1 mm (seca – Medical Scales and Measuring Systems, Hamburg, Germany) and the postural assessment was performed. These evaluations were performed to select the final sample. Women who were in luteal phase were contacted later for data collection.

A MasterScreen Body plethysmograph of volume-constant type (Jaeger – CareFusion Corporation, San Diego CA, United States of America) was used to record forced vital capacity and then to assess pulmonary function: forced expiratory volume in one second ($FEV_1$)/forced vital capacity (FVC); % predicted of $FEV_1$, FVC, peak expiratory flow, forced expiratory flow at 75 % ($FEF_{75\%}$)/50 % ($FEF_{50\%}$)/25 % ($FEF_{25\%}$) of FVC and $FEF_{25\text{-}75\%}$. FVC manoeuvre (closed circuit method) was recorded with participants in sitting position, using a mouthpiece firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip to prevent nasal breathing. To assess this manoeuvre, a completely and rapidly inhalation was performed with a pause of one second at total lung capacity, followed by a maximally exhalation until no more air can be expelled while maintaining the upright posture. Each manoeuvre was encouraged verbally. A minimum of three manoeuvres was performed. To test result selection, three reproducible manoeuvres were recorded, according to Miller et al. (2005) standards. An expert cardiopulmonary technician was responsible for this assessment.

Data collection protocol

The study procedures took place at a biomechanical laboratory and were performed in a controlled environment. To avoid inter-rater error, each researcher was responsible for an only one task.

A forceplate FP4060-08, connected to an amplifier AM6500, was used to assess the CoP displacement and body mass (kilograms). The ground reaction forces and torques were collected using the Qualisys Motion Capture System (Qualisys AB, Gothenburg, Sweden) with a sampling frequency of

100 Hz. Qualisys Track Manager software was used to display and acquire the ground reaction forces and torques signal.

A respiratory pressure meter MicroRPM (CareFusion Corporation, San Diego CA, United States of America) was used to assess the maximal inspiratory (MIP) and expiratory (MEP) pressures. The values obtained were used to determine the inspiratory and expiratory loads, respectively. MIP and MEP were both performed with participants in standing position, using a bacterial filter AFT1 – Disposable Bacterial Filter, 22 mm and a mouthpiece AFT2 – Disposable Mouthpiece, 22 mm firmly held around the lips to prevent leakage and to support the cheeks, as well as a nasal clip AFT3 – Disposable Noseclip (Biopac Systems Inc., Goleta CA, United States of America) to prevent nasal breathing. To assess MIP, a forceful and maximal inspiration was performed – the Muller manoeuvre – at residual volume; in turn, MEP was assessed through a forceful and maximal expiration – the Valsalva manoeuvre – at total lung capacity. Each manoeuvre was encouraged verbally. These manoeuvres were performed during a six-second period, with a resting time of three minutes. To calculate the respiratory load, three reproducible manoeuvres were recorded according to the American Thoracic Society/European Respiratory Society (2002) standards. It was used 10 % of the best value of MIP and MEP for the inspiratory and expiratory loads, respectively. Thresholds IMT® and PEP® (Respironics Inc., Murrysville PA, United Stare of America) were used to apply the inspiratory and expiratory loads, respectively. A bacterial filter AFT1, a mouthpiece AFT2 and a nose clip AFT3 were also used.

All participants were subjected to three different tasks – breathing without respiratory load and with inspiratory and expiratory loads, in standing – in a single data collection moment. The data collection moment started with breathing without respiratory load. The order of inspiratory or expiratory loads was randomized. The participants were barefoot and had the upper limbs along the body, with feet shoulder-width apart and knees in loose pack position. An A3 paper sheet was used to outline the base of support (BoS), keeping it for all tasks. The participants kept their gaze in a horizontal direction and the mouthpiece, sustained by their teeth, was used during all tasks. Three repetitions of each task were performed for forty seconds, with a resting time of three minutes. The respiratory rhythm (inspiratory time: two seconds; expiratory time: four seconds) was marked through a recorded voice. The participant experienced and get used to this externally paced respiratory rhythm prior to data collection.

Data processing and analysing

A routine based on the Duarte and Freitas (2010) study was developed in MatLab Student software (MathWorks, Pozuelo de Alarcon, Spain) to process and analyse data. A $4^{th}$ order digital filter Infinite Impulse Response – Butterworth of 10Hz (low pass) was applied to the ground reaction forces and torques. For the forty seconds collected, the CoP position in anterior-posterior and medial-lateral directions of the central thirty seconds was determined. The signal trend was then removed. The CoP displacement variables were calculated: mean amplitude and mean velocity in anterior-posterior and medial-lateral directions, as well as total mean velocity. Finally, for all CoP displacement variables the average of three repetitions of each task was calculated.

The BoS area based on the Chiari, Rocchi, and Cappello (2002) study was determined using the footprints (Figure 1). The BoS area was calculated according to the following equation:

$$BoS = \left(\frac{HD + IMD}{2}\right) * EFL$$

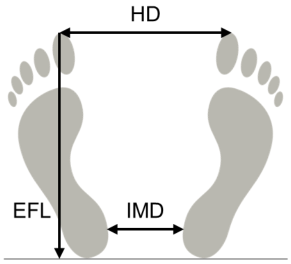


**Figure 1.** Base of support measurements from the footprints: halluces distance (HD), inter-*malleolus* distance (IMD) and effective foot length (EFL).

*Statistical analysis*

IBM SPSS Statistics® software, version 20.0, (IBM Corporation, Armonk NY, United States of America) was used for the descriptive and inferential data analysis, with a significance level of 0.05. Shapiro-Wilk test was used to test the normality of the data. Central tendency (mean) and dispersion (standard deviation) measures were used for the descriptive statistics. Chi-square was used to compare gender between groups ("At Risk" for COPD and Healthy). Student t-test was used to compare the age, anthropometric, body composition and pulmonary function data, as well as the CoP displacement between groups. In each group, Repeated Measures Analysis of Variance was used to compare the CoP displacement variables between the different evaluation tasks (without respiratory load and with inspiratory or expiratory loads). Bonferroni correction was used for the post-hoc analysis (Marôco, 2014).

## Results

*Pulmonary function*

The forced expiratory volume in one second, peak expiratory flow and forced expiratory flow at 75% / 50% / 25% / 25-75% of FVC were significantly lower in "At Risk" for COPD group when compared to Healthy group ($p$<0.050). No significant differences were found in the FVC between groups (Table 2).

**Table 2.** Pulmonary function data in "At Risk" for COPD and Healthy groups, with mean and standard deviation. *p* values for significant differences between groups are also presented

| Pulmonary function | "At Risk" for COPD group (n=17) | Healthy group (n=14) | Between groups comparison (*p* value) |
|---|---|---|---|
| $FEV_1$/FVC | 74.30±6.25 | 82.75±1.67 | <0.001 |
| $FEV_1$ (% pred) | 95.23±14.87 | 117.30±13.04 | <0.001 |
| FVC (% pred) | 107.79±15,35 | 118.47±14.75 | 0.059 |
| PEF (% pred) | 102.64±16.87 | 117.85±16.41 | 0.017 |
| $FEF_{75}$ (% pred) | 93.09±26.37 | 123.97±18.13 | 0.001 |
| $FEF_{50}$ (% pred) | 63.91±16.64 | 110.08±17.23 | <0.001 |
| $FEF_{25}$ (% pred) | 49.40±13.48 | 84.44±14.83 | <0.001 |
| $FEF_{25-75}$ (% pred) | 60.18±14.96 | 102.56±15.86 | <0.001 |

$FEV_1$ forced expiratory volume in one second; FVC forced vital capacity; PEF peak expiratory flow; $FEF_{75}$/$FEF_{50}$/$FEF_{25}$/$FEF_{25-75}$ forced expiratory flow at 75% / 50% / 25% / 25-75% of FVC, respectively; % pred % predicted

*BoS area*

No significant differences were found in BoS area between "At Risk" for COPD (409,39±104,07 $cm^2$) and Healthy (366,57±86,22 $cm^2$) groups.

*CoP displacement*

No significant differences were found in the CoP displacement variables between "At Risk" for COPD and Healthy groups during breathing without respiratory load and with expiratory load. However, during breathing with inspiratory load, the mean velocity, in both anterior-posterior (*p*=0.014) and medial-lateral (*p*=0.009) directions, and total mean velocity (*p*=0.005) of the

CoP displacement were significantly greater in “At Risk” for COPD group when compared to Healthy group (Figure 2, Figure 3 and Figure 4).

In “At Risk” for COPD group, the mean amplitude (Figure 2) and mean velocity (Figure 3), in both directions, and total mean velocity (Figure 4) of the CoP displacement were significantly greater during breathing with inspiratory load when compared to without respiratory load (mean amplitude: $p<0.010$; mean velocity: $p<0.050$; total mean velocity: $p=0.011$) and expiratory load (mean amplitude: $p<0.050$; mean velocity: $p<0.010$; total mean velocity: $p=0.007$). However, in healthy group, no significant differences were found between tasks.

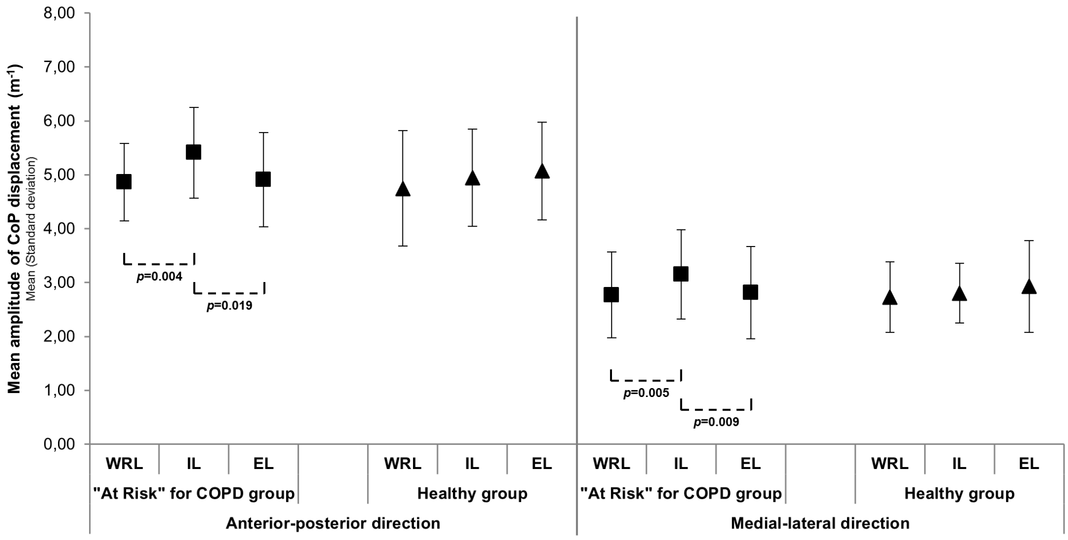


**Figure 2.** Mean amplitude of the centre of pressure (CoP) displacement (millimetres), in anterior-posterior and medial-lateral directions, during breathing without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison between groups and within subjects is also presented

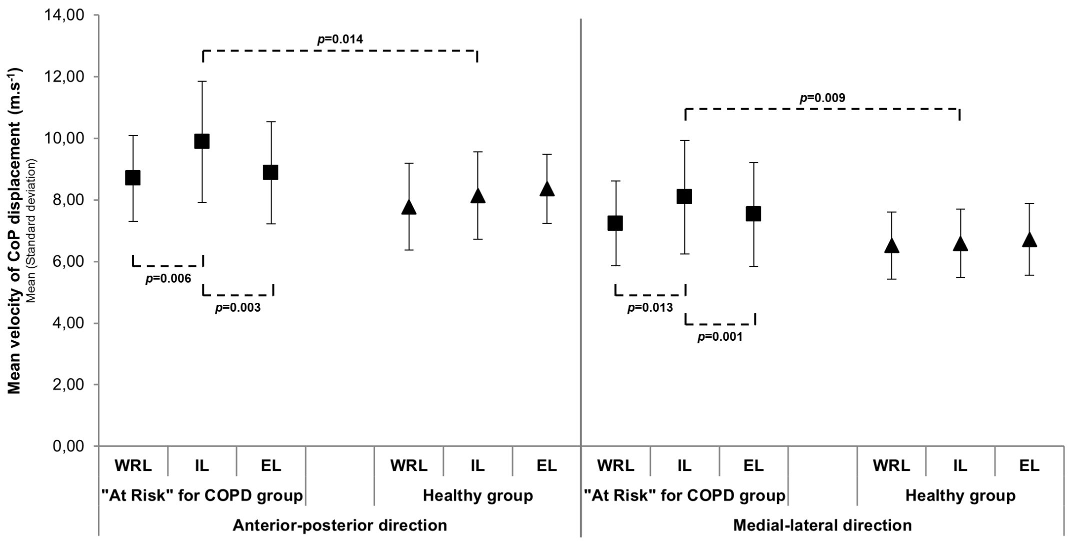


**Figure 3** Mean velocity of the centre of pressure (CoP) displacement (millimetres.seconds$^{-1}$), in anterior-posterior and medial-lateral directions, during breathing without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in "At Risk" for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison between groups and within subjects is also presented

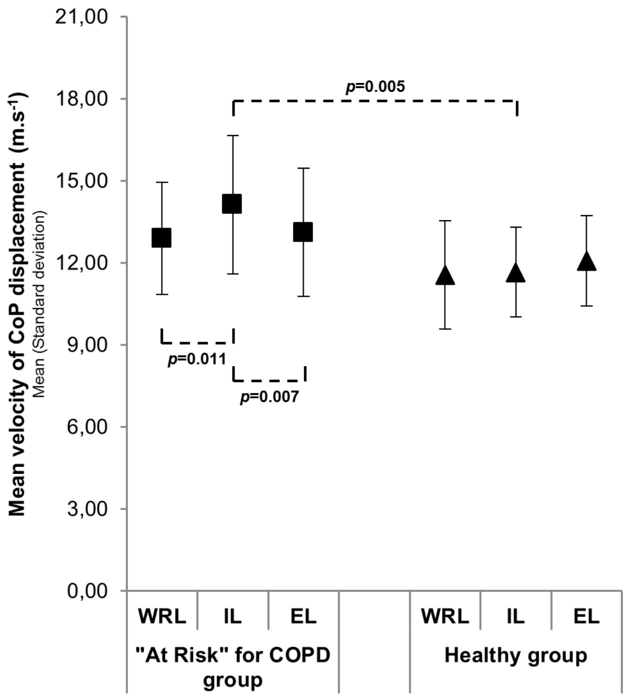


**Figure 4** Total mean velocity of the centre of pressure (CoP) displacement (millimetres.seconds$^{-1}$) during breathing without respiratory load (WRL) and with inspiratory (IL) or expiratory (EL) loads in “At Risk” for COPD and Healthy groups, with mean and standard deviation. *p* values for comparison between groups and within subjects is also presented

## Discussion

The results of the present study indicated that, during loaded inspiration, the mean velocity, in both directions, and total mean velocity of the CoP displacement were significantly higher in “At Risk” for COPD group in relation to Healthy group. Nevertheless, in “At Risk” for COPD group, the inspiratory load seemed to increase the CoP displacement, whereas no impact was found in Healthy group. These data suggested that subjects “at risk” for the development of COPD may have an impaired contribution of inspiratory muscles to postural control, when respiratory demand increases.

All participants breathed at a same rhythm. The respiratory frequency and volume may alter the ability of postural-respiratory synergy to counteract the breathing movements (David et al., 2012; Jeong, 1991; Kuznetsov & Riley, 2012). Nevertheless, the standardization of respiratory rhythm may have reduced the effect of respiratory load on minute ventilation.

The findings of this study indicated that there were no significant differences between “At Risk” for COPD and Healthy groups in the CoP displacement during breathing without respiratory load. In spite of existing a significant decrease in pulmonary function data associated with airflow obstruction in “At Risk” for COPD group, when compared to Healthy group, the differences do not reflect an obstructive ventilatory defect (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). The Tiffeneau index, FEV1 and FEF25-75 values, in the study’ sample, were above the cut-off points that define the limit of normality (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). The “At Risk” for COPD group, like the Healthy group, seemed to be able of compensating actively the breathing perturbations to posture during breathing without respiratory load. Thus, the periodic disturbance to the CoP during breathing without respiratory load was not sufficiently challenging for postural-respiratory synergy in these specific subjects.

Loaded inspiration changed the mass repartition of trunk and disturbs the posture, mainly in anterior-posterior direction (David et al., 2012). This could be related to an increased activity of accessory inspiratory and/or expiratory muscles in response to a minimal breathing effort (Ratnovsky, Zaretsky, Shiner, & Elad, 2003). Healthy subjects seemed to be able of compensating this potentially destabilizing effect of inspiratory load on the centre of mass position using a multisegmental control strategy (Hodges et al., 2002). However, in subjects “at risk” for the development of COPD, an inadequate ankle control strategy, which involves the angular motion in anterior-posterior direction (Winter, Prince, Frank, Powell, & Zabjek, 1996), was not able to effectively compensate for the respiratory-related challenge to the postural control, and to minimise the CoP displacement in anterior-posterior direction.

Nevertheless, the inability to use a multisegmental control strategy during breathing with a low inspiratory load, observed in “At Risk” for COPD group, could not be only related to the changes of the motor output of trunk muscles, but also by the contribution of central processing of the sensory inputs from them (Hall, Brauer, Horak, & Hodges, 2010). When the respiratory function of diaphragm and transversus abdominis muscles is challenged, e.g. during to loaded inspiration, its postural function may also be challenged, reducing the degree of compensation of the respiration-related perturbation to the postural control (Hodges et al., 2001). This impaired contribution of these core muscles is associated with an increased tonic activity of surface layer of the abdominal muscles (external oblique and rectus abdominis) (Hodges & Gandevia, 2000). Thus, in subjects "at risk" for the development of COPD, the increased trunk stiffness may reduce the contribution of trunk movement and moments to the postural control, increasing CoP displacement, particularly in the medial-lateral direction. In fact, the balance control in medial-lateral direction is more dependent on the hip and trunk moments/movements, due to poor efficiency of the ankle muscles to control balance in this direction (Winter et al., 1996). Therefore, in the present study, it is reasonable to suppose that the contribution of respiratory muscles for postural control may be impaired in "At Risk" for COPD group composed by subjects who have dyspnea, chronic cough or sputum production, and a history of exposure to risk factors for the chronic obstructive pulmonary disease (as tobacco smoke), but did not exhibited an obstructive ventilatory defect (Rodriguez-Roisin et al., 2016).

A maladaptive control strategy may be an underlying mechanism for impaired postural control contribution of the respiratory muscles to balance, in an advanced pathological context. Janssens et al. (2013) reported that moderate to severe COPD subjects, especially those with inspiratory muscle weakness, increased their reliance on ankle muscle proprioceptive signals and decreased their reliance on back muscle proprioceptive signals during balance, resulting in a decreased postural stability. Other authors found that severe COPD subjects had an increased trunk muscle activity during postural challenges, limiting the contribution of trunk movements to balance and its recover (Smith, Chang, & Hodges, 2016; Smith et al., 2010).

In “At Risk” for COPD group, there were no significant differences between breathing without respiratory load and with expiratory load in the CoP displacement. Such as what happened with loaded inspiration, it was expected that breathing with expiratory load challenged postural control. Voluntary expiratory efforts are achieved by the contraction in concert of the superficial and deep muscle layers of ventrolateral abdominal wall, which pulls the abdominal wall inward of the thoracic cavity and the lower ribs caudally to deflate the ribcage (De Troyer, Estenne, Ninane, Van Gansbeke, & Gorini, 1990). This change on the mass repartition of trunk seemed not to induce a posturographic disturbance in “At Risk” for COPD group. The signs and symptoms support the presence of a multifactorial obstruction of airways that may increase the mechanical load of breathing, resulting in a decreased capacity of inspiratory muscles (O'Donnell, 2001). Therefore, the phasic activity of abdominal muscles during expiration, in response to a low expiratory load, may have contributed to the next inspiration, maintaining the diaphragm muscle closer to its optimal length for tension generation (contractility) (De Troyer & Estenne, 1988). This recruitment may have unloaded the respiratory system (Aliverti et al., 1997), allowing trunk muscles to normally contribute for the postural control, and not promoting impact on the CoP displacement.

The different impact of respiratory (inspiratory and expiratory) loads on the CoP displacement in each group suggested that it is important to assess the altered postural control strategies to balance in subjects who have symptoms and risk factors of COPD, but do not exhibit an obstructive ventilatory defect. For that, an electromyographic activity record associated to a three-dimensional motion analysis of both trunk and lower limbs during different postural tasks and respiratory demands are needed.

## Conclusion

Subjects “at risk” for the development of COPD had an increased CoP displacement, in both directions, during loaded inspiration. The inability to use a multisegmental control strategy during breathing with low inspiratory load may have indicated an impaired contribution of respiratory muscles for postural control in these subjects.


## Acknowledgments

A special thanks to Joana Maia, PT and Liliana Bastos, PT for the assistance provided with subject recruitment and data collection. We also thanks to Dr. Cristina Baeta and Dr. Sónia Magalhães from the Department of Cardiopneumology.


## Conflict of interest statement

Nothing to declare.

## References


Aliverti, A., Cala, S. J., Duranti, R., Ferrigno, G., Kenyon, C. M., Pedotti, A., . . . Yan, S. (1997). Human respiratory muscle actions and control during exercise. *Journal of Applied Physiology (1985), 83*(4), 1256-1269.

American Thoracic Society/European Respiratory Society. (2002). ATS/ERS Statement on respiratory muscle testing. *American Journal of Respiratory and Critical Care Medicine, 166*(4), 518-624.

Beauchamp, M. K., Brooks, D., & Goldstein, R. S. (2010). Deficits in postural control in individuals with COPD - emerging evidence for an important secondary impairment. *Multidisciplinary Respiratory Medicine, 5*(6), 417-421.

Beauchamp, M. K., Hill, K., Goldstein, R. S., Janaudis-Ferreira, T., & Brooks, D. (2009). Impairments in balance discriminate fallers from non-fallers in COPD. *Respiratory Medicine, 103*(12), 1885-1891.

Beauchamp, M. K., Sibley, K. M., Lakhani, B., Romano, J., Mathur, S., Goldstein, R. S., & Brooks, D. (2012). Impairments in systems underlying control of balance in COPD. *Chest, 141*(6), 1496-1503.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82-87.

Butcher, S. J., Meshke, J. M., & Sheppard, M. S. (2004). Reductions in functional balance, coordination, and mobility measures among patients with stable chronic obstructive pulmonary disease. *Journal of Cardiopulmonary Rehabilitation and Prevention, 24*(4), 274-280.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., & Chiradejnant, A. (2009). Abdominal muscle activity during abdominal hollowing in four starting positions. *Manual Therapy, 14*(6), 642-646.

Chiari, L., Rocchi, L., & Cappello, A. (2002). Stabilometric parameters are affected by anthropometry and foot placement. *Clinical Biomechanics (Bristol, Avon), 17*(9-10), 666-677.

David, P., Laval, D., Terrien, J., & Petitjean, M. (2012). Postural control and ventilatory drive during voluntary hyperventilation and carbon dioxide rebreathing. *European Journal of Applied Physiology, 112*(1), 145-154.

De Troyer, A., & Estenne, M. (1988). Functional anatomy of the respiratory muscles. *Clinics In Chest Medicine, 9*(2), 175-193.

De Troyer, A., Estenne, M., Ninane, V., Van Gansbeke, D., & Gorini, M. (1990). Transversus abdominis muscle function in humans. *Journal of Applied Physiology (1985), 68*(3), 1010-1016.

Duarte, M., & Freitas, S. M. (2010). Revision of posturography based on force plate for balance evaluation. *Revista Brasileira de Fisioterapia, 14*(3), 183-192.

Global Initiative for Chronic Obstructive Lung Disease. (2016). Global strategy for diagnosis, management, and prevention of chronic obstructive pulmonary disease - Update 2016. Retrieved from http://goldcopd.org/global-strategy-diagnosis-management-prevention-copd-2016/

Hall, L. M., Brauer, S., Horak, F., & Hodges, P. W. (2010). Adaptive changes in anticipatory postural adjustments with novel and familiar postural supports. *Journal of Neurophysiology, 103*(2), 968-976.

Hodges, P. W., & Gandevia, S. C. (2000). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology (1985), 89*(3), 967-976.

Hodges, P. W., Gurfinkel, V. S., Brumagne, S., Smith, T. C., & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Experimental Brain Research, 144*(3), 293-302.

Hodges, P. W., Heijnen, I., & Gandevia, S. C. (2001). Postural activity of the diaphragm is reduced in humans when respiratory demand increases. *The Journal of Physiology, 537*(Pt 3), 999-1008.

Janssens, L., Brumagne, S., McConnell, A. K., Claeys, K., Pijnenburg, M., Burtin, C., . . . Troosters, T. (2013). Proprioceptive changes impair balance control in individuals with chronic obstructive pulmonary disease. *PLoS One, 8*(3), e57949.

Jeong, B. Y. (1991). Respiration effect on standing balance. *Archives of Physical Medicine and Rehabilitation, 72*(9), 642-645.

Kuznetsov, N. A., & Riley, M. A. (2012). Effects of breathing on multijoint control of center of mass position during upright stance. *Journal of Motor Behavior, 44*(4), 241-253.

Maltais, F., LeBlanc, P., Jobin, J., & Casaburi, R. (2000). Peripheral muscle dysfunction in chronic obstructive pulmonary disease. *Clinics In Chest Medicine, 21*(4), 665-677.

Marôco, J. (2014). *Análise estatística com o SPSS Statistics* (6th ed.). Pero Pinheiro: ReportNumber, Lda.

Mew, R. (2009). Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. *Manual Therapy, 14*(6), 690-695.

Miller, M. R., Hankinson, J., Brusasco, V., Burgos, F., Casaburi, R., Coates, A., . . . Force, A. E. T. (2005). Standardisation of spirometry. *European Respiratory Journal, 26*(2), 319-338.

O'Donnell, D. E. (2001). Ventilatory limitations in chronic obstructive pulmonary disease. *Medicine & Science in Sports & Exercise, 33*(Suppl 7), S647-655.

Ratnovsky, A., Zaretsky, U., Shiner, R. J., & Elad, D. (2003). Integrated approach for in vivo evaluation of respiratory muscles mechanics. *Journal of Biomechanics, 36*(12), 1771-1784.

Reeve, A., & Dilley, A. (2009). Effects of posture on the thickness of transversus abdominis in pain-free subjects. *Manual Therapy, 14*(6), 679-684.

Rodriguez-Roisin, R., Han, M. K., Vestbo, J., Wedzicha, J. A., Woodruff, P. G., & Martinez, F. J. (2016). Chronic Respiratory Symptoms with Normal Spirometry: A Reliable Clinical Entity? *American Journal of Respiratory and Critical Care Medicine*.

Roig, M., Eng, J. J., Macintyre, D. L., Road, J. D., & Reid, W. D. (2011). Postural Control Is Impaired in People with COPD: An Observational Study. *Physiotherapy Canada, 63*(4), 423-431.

Roig, M., Eng, J. J., Road, J. D., & Reid, W. D. (2009). Falls in patients with chronic obstructive pulmonary disease: a call for further research. *Respiratory Medicine, 103*(9), 1257-1269.

Smith, M. D., Chang, A. T., & Hodges, P. W. (2016). Balance recovery is compromised and trunk muscle activity is increased in chronic obstructive pulmonary disease. *Gait & Posture, 43*, 101-107.

Smith, M. D., Chang, A. T., Seale, H. E., Walsh, J. R., & Hodges, P. W. (2010). Balance is impaired in people with chronic obstructive pulmonary disease. *Gait & Posture, 31*(4), 456-460.

Thompson, P. D. (2014). Health appraisal and risk assessment. In L. S. Pescatello, R. Arena, D. Riebe, & P. D. Thompson (Eds.), *ACSM's guidelines for exercise testing and prescription* (9th ed., pp. 1-18). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

Vestbo, J., Hurd, S. S., Agusti, A. G., Jones, P. W., Vogelmeier, C., Anzueto, A., . . . Rodriguez-Roisin, R. (2013). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. *American Journal of Respiratory and Critical Care Medicine, 187*(4), 347-365.

Winter, D. A., Patla, A. E., Prince, F., Ishac, M., & Gielo-Perczak, K. (1998). Stiffness control of balance in quiet standing. *Journal of Neurophysiology, 80*(3), 1211-1221.

Winter, D. A., Prince, F., Frank, J. S., Powell, C., & Zabjek, K. F. (1996). Unified theory regarding A/P and M/L balance in quiet stance. *Journal of Neurophysiology, 75*(6), 2334-2343.

**Tabela 1.** *Highlights* dos resultados da presente Tese

| | Saudáveis | *"At Risk" for COPD* |
|---|---|---|
| **Conjunto postural** | **Artigo I:** ***Abdominal muscle activity during breathing in different postural sets in healthy subjects***<br>• A carga postural e o *stretch* gravitacional afetam o recrutamento dos músculos abdominais.<br>• De decúbito dorsal para de pé, a atividade muscular abdominal aumenta.<br>• Os conjuntos posturais de *tripod* e quadrupedia possuem um recrutamento dos músculos abdominais semelhante. A atividade muscular do transverso abdominal/oblíquo interno parece ser importante para a sincronização do controlo postural e da mecânica da ventilação. | **Artigo V:** ***Abdominal muscle activity during breathing in different postures in COPD "Stage 0" and healthy subjects***<br>• Em conjuntos posturais com maior carga postural, indivíduos em risco de desenvolvimento da DPOC possuem um recrutamento específico da camada miofascial superficial da parede ventrolateral do abdómen. Este padrão de recrutamento muscular pode afetar o movimento toracoabdominal.<br>• Tal como em indivíduos saudáveis, as posições de *tripod* e quadrupedia possuem um padrão de recrutamento dos músculos abominais, sobretudo do transverso abdominal/oblíquo interno, semelhante ao de indivíduos em risco de desenvolver DPOC. |
| | **Artigo II:** ***Respiratory activity and thoraco-abdominal movement in forward-leaning position with arm and head support in healthy subjects***<br>• O recrutamento específico dos músculos acessórios da inspiração e da expiração (nomeadamente do transverso abdominal/oblíquo interno) é relevante para a melhoria do movimento toracoabdominal em conjuntos posturais com inclinação anterior do tronco e suporte dos braços.<br>• Apesar do suporte da cabeça reduzir a carga postural, este conjunto postural parece ter um impacto negativo no movimento da caixa torácica inferior e abdómen. | |

| | Saudáveis | “At Risk” for COPD |
|---|---|---|
| **Resistência ventilatória** | **Artigo III**: ***Abdominal muscle activity during breathing with and without inspiratory and expiratory loads in healthy subjects***<br>• A atividade muscular do transverso abdominal/oblíquo interno é modulada durante a inspiração para suportar os movimentos da caixa torácica e do abdómen.<br>• A contração fásica expiratória dos músculos abominais, sobretudo do transverso abdominal/oblíquo interno, é importante para limitar o trabalho dos músculos inspiratórios. | **Artigo VI**: ***The effect of inspiratory and expiratory loads on the abdominal muscle activity during breathing in subjects “at risk” for the development of chronic obstructive pulmonary disease and healthy***<br>• Indivíduos em risco de desenvolvimento da DPOC possuem um recrutamento específico da camada miofascial superficial da parede ventrolateral do abdómen, em resposta às resistências inspiratória e expiratória. Este padrão de recrutamento muscular pode aumentar o trabalho e o custo energético da ventilação.<br>• O recrutamento muscular da camada miofascial superficial da parede ventrolateral do abdómen durante a ventilação pode comprometer a contribuição do tronco para o controlo postural. |
| | **Artigo IV**: ***Centre of pressure displacement during breathing with and without inspiratory and expiratory loads in healthy subjects***<br>• A repartição da massa do tronco, em resposta às resistências inspiratória ou expiratória, aumenta o deslocamento do centro de pressão na direção ântero-posterior.<br>• O aumento da atividade muscular do tronco, em resposta a uma resistência inspiratória, parece reduzir a contribuição do movimento do tronco para o controlo postural e, consequentemente, aumentar o deslocamento do centro de pressão na direção médio-lateral. | **Artigo VII**: ***The effect of inspiratory and expiratory loads on the centre of pressure displacement during breathing in subjects “at risk” for the development of chronic obstructive pulmonary disease and healthy***<br>• Indivíduos em risco de desenvolvimento da DPOC possuem um aumento do deslocamento do centro de pressão, em resposta a uma resistência inspiratória.<br>• A inabilidade para usar uma estratégia de controlo multisegmentar parece indicar um comprometimento da contribuição dos músculos ventilatórios para o controlo postural. |

Capítulo V

# Discussão Geral

O capítulo V encontra-se dividido em 3 partes: a discussão integrada dos resultados; as considerações metodológicas; e, por fim, a reflexão crítica das implicações clínicas e das perspetivas para futuras investigações.

## Discussão integrada dos resultados

A metodologia e os resultados de cada estudo foram discutidos individualmente no Capítulo IV. Neste capítulo está apresentada uma discussão integrada dos principais resultados (Tabela 1), orientada para as duas questões de investigação da presente Tese.

### *Função muscular abdominal em indivíduos saudáveis.*

A co-ativação sinérgica dos músculos abdominais proporcionam uma função otimizada entre o suporte postural antigravítico (controlo postural) e o controlo do movimento da coluna vertebral e da pélvis (ventilação) (Key, 2013). Apesar da dependência do sistema miofascial profundo (diafragma, transverso abdominal e músculos do pavimento pélvico), a criação de uma pressão intra-abdominal apropriada à exigência da dupla tarefa é também dependente de um nível de atividade equilibrado do sistema miofascial superficial (reto abdominal e oblíquos interno e externo) (Hodges & Gandevia, 2000a, 2000b; Kolar et al., 2010). Deste modo, os músculos abdominais proporcionam um suporte adaptativo para a modulação integrada destes mecanismos de controlo do core abdominal, em situações nas quais subsiste um maior desafio postural ou ventilatório (Hodges & Gandevia, 2000a, 2000b; Hodges et al., 1997).

Diferentes conjuntos posturais e objetivos funcionais requerem que o SNC ajuste apropriadamente o tónus postural à ação da gravidade e às alterações da base de suporte (Meadows & Williams, 2009; Mihailoff & Haines, 2013). A carga postural e o *stretch* gravitacional são fatores que devem ser considerados na compreensão do efeito da alteração da orientação do corpo no espaço sobre o recrutamento específico dos músculos abdominais, para a sincronização do controlo postural e da mecânica da ventilação. Posto isto, o Artigo I, da presente Tese, teve por objetivo avaliar a atividade muscular abdominal durante a ventilação em diferentes conjuntos posturais, em indivíduos saudáveis. A atividade das camadas miofasciais superficial (reto abdominal e oblíquo externo) e profunda (transverso abdominal/oblíquo interno) da parede ventrolateral do abdómen foi maior no conjunto postural de pé, comparativamente ao de decúbito dorsal. O sistema músculo-esquelético, devido à posição elevada do centro de massa em relação a uma base de suporte estreita, está pobremente adaptado à preservação da posição vertical (Hodges et al., 2002). Assim, o aumento do tónus postural do conjunto postural de decúbito dorsal para o de pé, no qual subsiste um maior desafio à estabilidade da coluna vertebral, suporta a função postural dos músculos abdominais (Cholewicki et al., 1999). Por sua vez, a menor eficiência da mecânica da ventilação em decúbito dorsal pode ser explicada por um menor recrutamento dos músculos abdominais. Embora o recuo elástico do tecido pulmonar não sofra alterações significativas, a mecânica da caixa torácica e do abdómen, nomeadamente do diafragma, é afetada pela ação da gravidade. Contrariamente ao conjunto postural de pé, em decúbito dorsal o conteúdo abdominal é empurrado contra o diafragma relaxado, diminuindo o recuo elástico da caixa torácica e, consequentemente, a capacidade residual funcional (Levitzky, 2013). Deste modo, no conjunto postural de decúbito dorsal, a resistência do conteúdo abdominal à descida do diafragma, devido a uma maior *compliance* muscular abdominal, pode ser menos efetiva na expansão lateral da caixa torácica inferior (Strohl et al., 1984). Estes resultados foram consistentes com os estudos anteriores de Abe et al. (1996), Barrett et al. (1994) e De Troyer (1983).

Não obstante o benefício do recrutamento das camadas miofasciais superficial e profunda da parede ventrolateral do abdómen na eficiência da mecânica da ventilação, a maior exigência postural em pé pode ter um impacto negativo no trabalho e no custo energético da ventilação. Outros conjuntos posturais, como o de *tripod*, são frequentemente assumidos para a diminuição da carga sobre o sistema respiratório durante episódios de sensação de dispneia (Bott et al., 2009). A inclinação anterior do tronco em sentado, com fixação passiva da cintura escapular, reduziu a carga postural, diminuindo a atividade muscular abdominal, comparativamente ao conjunto postural de pé. Além do mais, em oposição ao de decúbito dorsal, o deslocamento anterior e inferior do conteúdo abdominal no conjunto postural de *tripod* pode ter promovido um estímulo de *stretch* sobre a parede abdominal (Dean, 1985), aumentando a atividade muscular do transverso abdominal/oblíquo interno. O transverso abdominal, devido à sua configuração circunferencial, possui a eficiência mecânica mais apropriada para a sua contração neste conjunto postural (De Troyer et al., 1990). Assim, este recrutamento específico dos músculos abdominais no conjunto postural de *tripod* pode melhorar a relação comprimento-tensão do diafragma (alongamento das suas fibras musculares) e, consequentemente, a sua força e capacidade ventilatória (Barach, 1974). Deste modo, o impacto positivo no movimento toracoabdominal e no alívio da sensação de dispneia, reportado a este conjunto postural (O'Neill & McCarthy, 1983), pode ser explicado em parte por um maior recrutamento muscular do transverso abdominal/oblíquo interno. A evidência científica é escassa no que diz respeito ao recrutamento específico dos músculos abdominais nas posições de inclinação anterior do tronco. Kera & Maruyama (2005) reportaram que a atividade muscular do oblíquo externo foi maior em sentado com apoio dos cotovelos sobre os joelhos, comparativamente com o conjunto postural de decúbito dorsal. Este recrutamento específico dos músculos abdominais pode ser explicado pelas diferenças nas componentes de cada um dos conjuntos posturais. No conjunto postural de *tripod* a fixação passiva da cintura escapular contrasta com a maior exigência do conjunto postural avaliado por estes autores.

A carga postural e o *stretch* gravitacional nos conjuntos posturais de *tripod* e quadrupedia parecem ter tido o mesmo efeito sobre a atividade muscular abdominal. Ambos os conjuntos posturais são caracterizados por uma base de suporte alargada que diminui a carga postural; e por um deslocamento anterior do conteúdo abdominal que aumenta a excitabilidade da *pool* dos motoneurónios do transverso abdominal/oblíquo interno (Beith, Synnott, & Newman, 2001). Não obstante no conjunto postural de quadrupedia ter sido observado um maior *stretch* sobre a parede abdominal, é possível colocar a hipótese de que neste conjunto postural, tal como em *tripod*, o recrutamento dos músculos abdominais, nomeadamente do transverso abdominal/oblíquo interno, pode ser benéfico para a mecânica da ventilação.

A inclinação anterior do tronco em pé ou em sentado pode estar associada ao suporte dos braços e da cabeça (Booth et al., 2014). O impacto das diferentes componentes que podem constituir o conjunto postural de *tripod* na mecânica do tórax e do abdómen ainda não se encontra claro (Santos et al., 2012). Posto isto, o efeito da inclinação anterior do tronco com suporte dos braços e da cabeça na atividade muscular acessória da inspiração (esternocleidomastoideo e escaleno) e da expiração (abdominais) e no movimento toracoabdominal, em indivíduos saudáveis, foi avaliado no Artigo II. Nos conjuntos posturais com inclinação anterior do tronco e suporte dos braços (em pé e em sentado) foi observada uma maior atividade muscular acessória da inspiração. Quando a cintura escapular está fixa através do suporte dos braços, o segmento móvel é a caixa torácica (Banzett, Topulos, Leith, & Nations, 1988). Os músculos acessórios da inspiração com inserção na cervical, que possuem a função primordial de estabilizar/mobilizar a coluna vertebral (Starr & Dalton, 2011), transferem a sua ação para o tórax. Deste modo, nos conjuntos posturais com inclinação anterior do tronco e suporte dos braços, os esternocleidomastoideos e os escalenos deslocam o esterno e as duas primeiras costelas no sentido anterior e superior, aumentando o diâmetro ântero-posterior da caixa torácica superior (Kim et al., 2012). Kim et al. (2012) reportaram resultados consistentes com os da presente Tese.

A atividade muscular abdominal foi menor nos conjuntos posturais em pé (na posição ereta e com inclinação anterior do tronco), comparativamente aos conjuntos posturais em sentado (na posição ereta e com inclinação anterior do tronco e suporte de braços ou braços/cabeça). Como referenciado no Artigo I, o menor desafio ao equilíbrio postural e à estabilidade da coluna vertebral suporta a diminuição do tónus postural dos músculos abdominais (Cholewicki et al., 1999). Além do mais, nos conjuntos posturais com inclinação anterior do tronco e suporte dos braços observou-se uma menor atividade muscular do transverso abdominal/oblíquo interno, comparativamente aos respetivos conjuntos posturais na posição ereta. O transverso abdominal/oblíquo interno é o músculo mais relevante na modulação da pressão intra-abdominal para a preservação dos movimentos da caixa torácica e do abdómen durante a ventilação (Hodges & Gandevia, 2000a, 2000b). Assim, nos conjuntos posturais com inclinação anterior do tronco e suporte dos braços, o maior movimento ântero-posterior do abdómen pode ser explicado por um menor recrutamento muscular do transverso abdominal/oblíquo interno. A redução da contração tónica deste músculo diminui a resistência da parede abdominal ao seu conteúdo, aumentando o movimento abdominal (Lee et al., 2010; Romei et al., 2010). Um estudo anterior reportou que a inclinação anterior do tronco não teve efeito na excursão da cavidade abdominal (Kim et al., 2012). De sentado na posição ereta para sentado com apoio dos cotovelos sobre os joelhos, a diminuição do ângulo entre o tronco e os membros inferiores pode ter aumentado a resistência do conteúdo abdominal ao movimento inferior do diafragma (Kim et al., 2012). Contudo, na presente investigação, este ângulo foi mantido em ambos os conjuntos posturais em sentado, quer na posição ereta quer com inclinação anterior do tronco e suporte dos braços, minimizando o deslocamento do conteúdo abdominal contra o diafragma.

Não obstante a redução da carga postural, o suporte da cabeça parece ter tido um impacto negativo no movimento da caixa torácica inferior e do abdómen. A flexão da cabeça pode ter promovido uma flexão do tronco superior, que aproximou as costelas à pélvis, restringindo a descida do tendão central do diafragma (expansão anterior do abdómen) e a elevação das costelas inferiores (expansão lateral da caixa torácica). De facto, uma alteração do alinhamento postural da coluna vertebral no plano sagital pode afetar a posição das costelas e dos seus eixos articulares (Edmondston et al., 2007) e, por sua vez, a configuração tridimensional e o movimento da caixa torácica e do abdómen (Lee et al., 2010).

A evidência científica enfatiza que a contribuição dos músculos abdominais para a ventilação, apesar da sua ação predominantemente expiratória, é também relevante para a inspiração (Macklem, 2014) aquando de aumento da drive respiratória, durante a prática de exercício ou por imposição de uma resistência ventilatória mecânica (Aliverti et al., 1997; De Troyer et al., 1990). Posto isto, o Artigo III, da presente Tese, avaliou a atividade muscular abdominal durante a ventilação sem e com resistências ventilatórias, em indivíduos saudáveis. Durante a inspiração, um menor recrutamento muscular do transverso abdominal/oblíquo interno minimiza o aumento da pressão intra-abdominal, devido a uma maior atividade muscular do diafragma em resposta à resistência inspiratória. De facto, a modulação da atividade muscular do transverso abdominal/oblíquo interno durante a inspiração pode ser importante na minimização da distorção da caixa torácica e do abdómen (Hodges & Gandevia, 2000a, 2000b), bem como do trabalho do diafragma, permitindo a este atuar como um criador de fluxo, mais do que um criador de pressão (Macklem, 2014). Por sua vez, a atividade fásica expiratória dos músculos abdominais (oblíquo externo e transverso abdominal/oblíquo interno), observada na presente investigação durante a ventilação com resistência inspiratória, contribui para a próxima inspiração, mantendo o diafragma num comprimento ótimo para a criação de tensão (De Troyer & Estenne, 1988). Aliverti et al. (1997) reportaram que os músculos abdominais são recrutados ao mínimo aumento da exigência da ventilação e que a sua contribuição é progressivamente maior à medida que aumenta a intensidade de exercício. Contudo, no estudo de Hodges et al. (1997) foi observada uma atividade fásica expiratória do transverso abdominal/oblíquo interno durante a ventilação com resistência inspiratória. O recrutamento muscular do oblíquo externo, observado na presente investigação, pode ser explicado por um mecanismo de compensação à reduzida contribuição do transverso abdominal/oblíquo interno para a estabilidade do tronco, numa posição não-relaxada (em pé com os joelhos em *loose pack position*) (Hodges et al., 2001). O benefício de compartilhar o trabalho da ventilação com os músculos expiratórios é difícil de avaliar em termos de custo energético. Não obstante, a contração muscular expiratória do transverso abdominal/oblíquo interno, devido à sua configuração circunferencial, deve ser mais eficiente (que a do reto abdominal ou do oblíquo externo) no aumento da pressão intra-abdominal e na diminuição do volume pulmonar, com o objetivo de limitar o trabalho dos músculos inspiratórios (De Troyer et al., 1990).

O controlo postural é desafiado quando a exigência respiratória aumenta ou requer controlo voluntário (David et al., 2012). A contribuição do tronco e dos membros inferiores, que contrabalançam a perturbação da ventilação ao controlo postural (Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998), pode estar alterada quer por fatores mecânicos – o padrão da ventilação (frequência, volume e movimento toracoabdominal) –, quer por fatores organizacionais – os comandos centrais posturais e respiratórios para os músculos do tronco (David et al., 2012; Hodges et al., 2002; Kuznetsov & Riley, 2012). Posto isto, o efeito das resistências ventilatórias no deslocamento do centro de pressão, em indivíduos saudáveis, foi avaliado no Artigo IV. O deslocamento do centro de pressão na direção ântero-posterior foi maior durante a ventilação com resistências inspiratória e expiratória, comparativamente a sem resistência respiratória. De uma perspetiva biomecânica, um aumento da atividade muscular acessória da inspiração e/ou expiração, em resposta a um esforço mínimo ventilatório (Ratnovsky, Zaretsky, Shiner, & Elad, 2003), pode ter promovido uma alteração da repartição da massa do tronco (David et al., 2012) e, consequentemente, um distúrbio à postura (Hamaoui, Gonneau, & Le Bozec, 2010). O efeito potencialmente desestabilizador das resistências ventilatórias à postura não foi, deste modo, compensado por um recrutamento ativo dos múltiplos segmentos do corpo humano (tronco e membros inferiores) (Kuznetsov & Riley, 2012). Este controlo inadequado refletido no deslocamento do centro de pressão na direção ântero-posterior é, na sua maioria, explicado por uma estratégia ineficiente que envolve o movimento angular do tornozelo na direção ântero-posterior (Winter, Prince, Frank, Powell, & Zabjek, 1996). Diversos estudos reportaram uma maior oscilação do centro de pressão, sobretudo na direção ântero-posterior, durante a hiperventilação voluntária (David et al., 2012; Kuznetsov & Riley, 2012).

Os principais músculos ventilatórios estão também envolvidos na estabilidade do tronco, sendo que a mesma *pool* de motoneurónios é ativada durante ambas as funções, postural e ventilatória (Hudson, Butler, Gandevia, & De Troyer, 2010). Assim, um aumento da drive respiratória, devido à imposição de uma resistência inspiratória, pode ter atenuado os comandos centrais posturais para o diafragma e para o transverso abdominal/oblíquo interno, reduzindo o grau de compensação da perturbação da ventilação ao controlo postural (Hodges et al., 2001). O comprometimento da contribuição destes músculos para a estabilidade postural está associado a um aumento da atividade tónica da camada miofascial superficial da parede ventrolateral do abdómen (Hodges & Gandevia, 2000b). Deste modo, o aumento da rigidez do tronco pode ter reduzido a contribuição dos movimentos e dos momentos de força do tronco para o controlo postural, aumentando o deslocamento do centro de pressão na direção médio-lateral. O controlo do equilíbrio nesta direção é sobretudo dependente do tronco e da anca, devido à menor eficiência dos músculos do tornozelo (Winter et al., 1996).

*Função muscular abdominal em indivíduos em risco de desenvolvimento da DPOC*

Embora existam estratégias para coordenar a função postural e a mecânica da ventilação numa situação normal, a função abdominal pode estar comprometida aquando de um aumento da exigência de uma destas funções, como por exemplo na DPOC, em que subsiste um maior desafio ventilatório. A sobrecarga mecânica intrínseca sobre o diafragma, em indivíduos com limitação do fluxo expiratório (De Troyer, 1997; Gorini et al., 1990), pode comprometer a mecânica da ventilação. De facto, a maior exigência da ventilação na DPOC, inclusive em repouso, resulta num aumento da drive neural para os músculos acessórios da inspiração (Gandevia et al., 1996) e da expiração (Ninane et al., 1992), com consequente alteração do padrão de mobilização das cavidades torácica e abdominal (Martinez et al., 1990). Por sua vez, a alteração do padrão de recrutamento dos músculos do tronco, pode influenciar a rigidez do tronco e, consequentemente, afetar a contribuição deste para o controlo postural em indivíduos com DPOC (Smith et al., 2016). Não obstante a literatura recente sugerir um défice na capacidade dos músculos do tronco para a sincronização do controlo postural e da mecânica da ventilação na DPOC, não existe evidência científica em indivíduos em risco de desenvolvimento da DPOC. A investigação dirigida a fumadores sintomáticos, mas sem limitação do fluxo expiratório e sem as co-morbilidades associadas à doença pulmonar, podem ser importantes para compreender as alterações num contexto mais avançado da DPOC (Rodriguez-Roisin et al., 2016).

Os Artigos V e VI da presente Tese tiveram por objetivo avaliar a função muscular abdominal para a sincronização do controlo postural e da mecânica da ventilação, em indivíduos em risco de desenvolvimento da DPOC. Em ambos os estudos, não foram observadas diferenças entre os grupos *"At Risk" for COPD* e *Healthy*[1] na atividade muscular abdominal durante a ventilação, nas condições de base: decúbito dorsal (Artigo V) e sem resistência ventilatória (Artigo VI). A evidência científica tem descrito que, durante a ventilação em repouso, indivíduos com DPOC exibem uma atividade fásica expiratória dos músculos abdominais, sobretudo do transverso abdominal, e que este recrutamento muscular está relacionado com o grau de obstrução do fluxo expiratório (Ninane et al., 1992). Apesar de, na presente investigação, os dados da função pulmonar terem sugerido um maior grau de obstrução do fluxo expiratório no grupo *"At Risk" for COPD*, comparativamente ao grupo *Healthy*, estes não refletiram um defeito ventilatório obstrutivo (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). Os valores de Índice de *Tiffneau*, volume expiratório máximo no 1º segundo e fluxo expiratório forçado médio do grupo *"At Risk" for COPD* encontravam-se superiores aos *cut-off points* que definem o limite da normalidade (Global Initiative for Chronic Obstructive Lung Disease, 2016; Rodriguez-Roisin et al., 2016). Deste modo, ambas as condições de base parecem não ter sido suficientes para desafiar a sinergia

[1] Nesta secção foram consideradas as retroversões de grupos em risco de desenvolvimento da DPOC e saudável: *"At Risk" for COPD* e *Healthy*, respetivamente.

muscular abdominal que contribui para o controlo postural e para a ventilação.

O padrão de recrutamento dos músculos abdominais foi diferenciado em cada um dos grupos, nas situações em que subsistiu uma maior exigência postural (conjuntos posturais – Artigo V) ou ventilatória (resistências ventilatórias – Artigo VI). No grupo *Healthy* foi observado um padrão de recrutamento muscular do transverso abdominal/oblíquo interno. Por outro lado, o grupo *"At Risk" for COPD* exibiu um padrão de recrutamento da camada miofascial superficial da parede ventrolateral do abdómen. Esta alteração do padrão específico de recrutamento dos músculos abdominais pode providenciar informação relativa a uma incapacidade de sincronização do controlo postural e da mecânica da ventilação em indivíduos que possuem dispneia, tosse crónica ou produção de expetoração, bem como história de exposição a fatores de risco (fumo do tabaco) para a DPOC, mas que não exibem um defeito ventilatório obstrutivo (Rodriguez-Roisin et al., 2016).

Enquanto o recrutamento muscular do transverso abdominal/oblíquo interno é benéfico para a mecânica da ventilação em indivíduos saudáveis, o recrutamento muscular do reto abdominal e do oblíquo externo pode ser definitivamente prejudicial num contexto mais avançado da DPOC. No grupo *Healthy* o recrutamento muscular do transverso abdominal/oblíquo interno aumenta o diâmetro transversal da caixa torácica inferior; contudo, o excessivo recrutamento da camada miofascial superficial da parede ventrolateral do abdómen, observado no grupo *"At Risk" for COPD*, pode constringir o tórax inferior, interferindo com a descida do diafragma (Key, 2013). Por outro lado, a incapacidade de aumentar o fluxo expiratório e reduzir o volume pulmonar no final da expiração, ou de induzir um armazenamento de energia elástica e gravitacional no diafragma e no abdómen (O'Donnell, 2001), através da contração muscular do transverso abdominal/oblíquo interno, pode colocar o diafragma em desvantagem mecânica em indivíduos com limitação do fluxo expiratório. O recrutamento muscular do reto abdominal e do oblíquo externo pode, deste modo, aumentar o trabalho da ventilação, criando um desequilíbrio entre o suplemento de energia e a necessidade desta, que pode resultar numa competição entre os músculos respiratórios e outros músculos (Aliverti & Macklem, 2008). De facto, Aliverti & Macklem (2008) reportaram que, com o progresso da DPOC, os indivíduos eventualmente aprendem a não recrutar os músculos abdominais para minimizar o trabalho e o custo energético da ventilação.

O padrão específico de recrutamento dos músculos abdominais durante a ventilação com resistências ventilatórias, observado em indivíduos em risco de desenvolvimento da DPOC, pode ter um impacto negativo no controlo postural. Posto isto, o deslocamento do centro de pressão durante a ventilação sem e com resistências ventilatórias, em indivíduos em risco de desenvolvimento da DPOC, foi avaliado no Artigo VII. O grupo *Healthy* parece ter sido capaz de compensar o efeito potencialmente desestabilizador da resistência inspiratória sobre o centro de pressão, através de uma estratégia de controlo multisegmentar (Hodges et al., 2002). Contudo, o grupo *“At Risk” for COPD* não foi capaz de efetivamente compensar a perturbação da ventilação ao controlo postural e minimizar o impacto deste no deslocamento do centro de pressão. A incapacidade de usar uma estratégia de controlo multisegmentar, durante a ventilação com resistência inspiratória, pode não estar apenas relacionada com as alterações do *output* motor dos músculos do tronco, mas também com a contribuição do processamento central dos *inputs* destes músculos (Hall, Brauer, Horak, & Hodges, 2010). Quando a função respiratória do diafragma e do transverso abdominal é desafiada, como por exemplo por uma ventilação com resistência inspiratória, a função postural destes músculos pode ser também desafiada, reduzindo o grau de compensação da perturbação da ventilação ao controlo postural (Hodges et al., 2001). A alteração da contribuição do diafragma e do transverso abdominal está associada a um aumento da atividade tónica da camada miofascial superficial da parede ventrolateral do abdómen (Hodges & Gandevia, 2000b). Então, em indivíduos em risco de desenvolvimento da DPOC, um aumento da rigidez do tronco pode reduzir a contribuição do movimento e dos momentos de força deste para o controlo postural, aumentando o deslocamento do centro de pressão, particularmente na direção médio-lateral (Winter et al., 1996). Deste modo, na presente investigação, é razoável colocar a hipótese de que a contribuição dos músculos ventilatórios pode estar diminuída para o controlo postural.

Uma estratégia de controlo mal adaptada pode ser um mecanismo subjacente a uma diminuição da contribuição dos músculos respiratórios para o controlo postural num contexto patológico de limitação de fluxo expiratório. Janssens et al. (2013) reportaram que indivíduos com DPOC moderada a severa, especialmente os que possuem fraqueza muscular inspiratória, apresentaram um aumento dos *inputs* propriocetivos para os músculos do tornozelo e uma diminuição para os músculos do tronco, resultando numa diminuição da estabilidade postural. Outros autores observaram que indivíduos com DPOC severa revelam um aumento da atividade muscular do tronco durante desafios posturais, que limita a contribuição do tronco para a recuperação e manutenção do equilíbrio (Smith et al., 2016; Smith et al., 2010).

## Considerações metodológicas

### *Eletromiografia de superfície*

A eletromiografia de superfície foi, ao longo da presente investigação, o instrumento selecionado para a recolha da atividade da camada miofascial profunda da parede ventrolateral do abdómen, nomeadamente do transverso abdominal/oblíquo interno. Embora os elétrodos bipolares colocados sobre o transverso abdominal/oblíquo interno tenham sido alinhados paralelamente às fibras do transverso abdominal, o sinal electromiográfico provavelmente representou a atividade de ambos os músculos. As fibras mais inferiores do transverso abdominal curvam-se para baixo e medialmente, juntamente com as fibras da aponevrose do oblíquo interno, e inserem-se na crista púbica e na linha pectínea para formar o tendão conjunto (Hodges, 2004). Além do mais, as fibras inferiores de ambos os músculos contribuem mutuamente para a modulação da pressão-abdominal e para a contenção do conteúdo abdominal (Hodges, 2004; Marshall & Murphy, 2003). Marshall & Murphy

(2003) reportaram que o sinal electromiográfico representativo do transverso abdominal/oblíquo interno demonstra com precisão a atividade funcional destes músculos. Por outro lado, o *crosstalk* muscular, no qual os elétrodos bipolares captam o sinal electromiográfico dos músculos adjacentes inspiratórios ou expiratórios, pode ter ocorrido na presente investigação. Contudo, a colocação dos elétrodos bipolares, de acordo com as *guidelines*, e a respetiva verificação através da contração isolada de cada músculo, reduziu este fenómeno (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000).

A eletromiografia de superfície é, deste modo, uma alternativa mais simples, não-invasiva e com um custo-efetivo superior à eletromiografia de profundidade. Os resultados da presente Tese sugerem que este método pode ser interessante como aplicação clínica, na avaliação do transverso abdominal/oblíquo interno e dos restantes músculos abdominais na patologia respiratória.

*Ritmo ventilatório*

Todos os participantes ventilaram a um mesmo ritmo. O volume e a frequência da ventilação podem variar a atividade dos músculos ventilatórios e o distúrbio postural da ventilação (David et al., 2012; Jeong, 1991; Kuznetsov & Riley, 2012). Não obstante, a padronização de um ritmo ventilatório teve como objetivo reduzir o efeito dos conjuntos posturais ou das resistências inspiratória ou expiratória na ventilação minuto.

*Normalização dos dados electromiográficos*

A literatura sugere que o procedimento mais comum de normalização do sinal da eletromiografia de superfície é o da contração isométrica voluntária máxima de cada músculo (Burden, 2010). Contudo, na presente investigação, o sinal electromiográfico recolhido durante as manobras de medição das pressões inspiratória e expiratória máximas foram usadas para a normalização dos dados dos músculos inspiratórios e expiratórios, respetivamente. De facto, estas manobras são consideradas contrações quasi-estáticas máximas ventilatórias e, consequentemente, permitem uma análise do padrão específico de recrutamento dos músculos acessórios da inspiração e da expiração para a ventilação.

*Alteração dos conjuntos posturais*

A posição de *tripod* em sentado (com inclinação do tronco e suporte dos braços) diferiu nos Artigos I e II. No Artigo I, a inclinação do tronco foi de 45º em relação à vertical, enquanto no Artigo II foi de 30º. Embora a posição de *tripod*, correspondente à do Artigo I, seja a comummente referenciada na literatura, adaptações desta posição podem ser efetivadas para o alívio da dispneia, como é a posição de *tripod* em pé. Deste modo, um dos objetivos do Artigo II foi comparar a posição de *tripod* em pé e em sentado, pelo que foi necessário proceder a um estudo-piloto para seleção da amplitude de inclinação do tronco a usar em ambas as posições de *tripod*. Em prol do protocolo de recolha de dados, a avaliação da atividade dos músculos ventilatórios, em conjunto com o do movimento toracoabdominal só seria possível se a amplitude de inclinação do tronco fosse de 30º, em ambas as posições. Não obstante esta alteração, a posição de *tripod* em sentado com algum grau de inclinação anterior do tronco parece ser suficiente para promover um *stretch* gravitacional sobre os músculos abdominais, colocando-os numa posição mais favorável para a sua contração (Booth et al., 2014).

*Padrão ventilatório*

O padrão ventilatório (costal, abdominal ou misto) não foi avaliado na presente investigação. Diversos fatores, nomeadamente sociodemográficos, antropométricos e de composição corporal, podem afetar o movimento toracoabdominal em indivíduos saudáveis e, por sua vez, alterar o distúrbio postural da ventilação (Hamaoui et al., 2010; Kaneko & Horie, 2012; Romei et al., 2010). Apesar da variabilidade entre indivíduos, é de notar que, nos Artigos V, VI e VII, os grupos "*At Risk*" *for COPD* e *Healthy* foram considerados comparáveis, no que concerne aos fatores referidos. Deste modo, o efeito da variabilidade natural entre sujeitos sobre os resultados obtidos foi limitado.

**Implicações para a prática clínica e a investigação futura**

A partir dos resultados da presente Tese podem ser destacadas algumas implicações para a prática clínica e para a investigação futura.

*"Estádio 0" da DPOC*

A função abdominal para a sincronização do controlo postural e da mecânica da ventilação está alterada em indivíduos fumadores sintomáticos, mas com uma espirometria normal. O padrão de recrutamento da camada miofascial superficial da parede ventrolateral do abdómen durante a ventilação e, por sua vez, o seu impacto negativo no controlo postural, suportam um novo potencial clínico em indivíduos em risco de desenvolvimento da DPOC. Deste modo, torna-se pertinente compreender a evolução das repercussões no controlo postural e na mecânica da ventilação presentes no "estádio 0" da DPOC, num contexto patológico de limitação do fluxo expiratório.

*Conjuntos posturais*

O recrutamento muscular do transverso abdominal/oblíquo interno no conjunto postural de *tripod*, observado nos grupos *"At Risk" for COPD* e *Healthy*, pode ser benéfico para a sincronização do controlo postural e da mecânica da ventilação (Artigo V). Este padrão específico de recrutamento muscular pode melhorar a relação comprimento-tensão e a geometria dos músculos da ventilação, nomeadamente do diafragma, e, consequentemente, o output muscular para a ventilação. A carga postural e o *stretch* gravitacional sobre o conteúdo e a parede abdominal parecem ter sido semelhantes nos conjuntos posturais de *tripod* e quadrupedia. Não obstante ter sido observado no conjunto postural de quadrupedia um maior desafio para o controlo postural, a facilitação do recrutamento muscular do transverso abdominal/oblíquo interno pode ser benéfica para a mecânica da ventilação. É necessária investigação futura para compreender o impacto do conjunto postural de *tripod* e quadrupedia, ou de outras estratégias de recrutamento muscular do transverso abdominal/oblíquo interno, na mecânica e no padrão da ventilação em indivíduos em risco de desenvolvimento da DPOC, bem como com a presença de diversos graus de limitação do fluxo expiratório.

*Resistências*

A ventilação com resistência expiratória, no grupo *"At Risk" for COPD*, não induziu um distúrbio postural, com reflexo no deslocamento do centro de pressão, relativamente à ventilação sem resistência (Artigo VII). Contudo, tal como com a resistência inspiratória, era expectável que o aumento da atividade muscular abdominal durante a ventilação com a resistência expiratória tivesse aumentado o deslocamento do centro de pressão. Os sinais e os sintomas que caracterizam o grupo *"At Risk" for COPD* suportam a presença de uma obstrução multifatorial das vias aéreas. A obstrução multifactorial pode indiciar uma maior carga mecânica sobre a ventilação, resultando numa diminuição da capacidade dos músculos inspiratórios. A atividade fásica dos músculos abdominais durante a expiração, em resposta a uma resistência expiratória de baixa intensidade, pode ter contribuído para a próxima inspiração, mantendo o diafragma num comprimento ótimo para a criação de tensão. Esta contração expiratória pode ter diminuído a carga sobre o sistema respiratório, permitindo que os músculos do tronco contribuíssem normalmente para o controlo postural. Deste modo, torna-se pertinente avaliar a influência de um treino com resistências expiratórias de baixa intensidade, por diferentes mecanismos de pressão expiratória positiva, no controlo postural, em indivíduos em risco de desenvolvimento da DPOC, bem como com a presença de diversos graus de limitação do fluxo expiratório.

**Capítulo VI**

# Conclusões

A presente Tese contribui com evidência científica sobre a função muscular abdominal para a sincronização do controlo postural e da mecânica da ventilação, em indivíduos em risco de desenvolvimento da DPOC. Não obstante a importância das camadas miofasciais profunda e superficial da parede ventrolateral do abdómen, o transverso abdominal/oblíquo interno parece ser o músculo mais relevante em situações nas quais subsiste um maior desafio postural ou ventilatório, em indivíduos saudáveis. Contudo, o recrutamento muscular do reto abdominal e do oblíquo externo durante a ventilação, observado em indivíduos em risco de desenvolvimento da DPOC, pode não só afetar a mecânica, como o trabalho e o custo energético da ventilação. Por sua vez, este padrão específico de recrutamento dos músculos abdominais pode diminuir a contribuição dos movimentos e dos momentos de força do tronco para o controlo postural, com impacto negativo sobre o deslocamento do centro de pressão. Futura investigação deve compreender a evolução das repercussões no controlo postural e na mecânica da ventilação para suportar um novo potencial clínico em indivíduos fumadores sintomáticos, mas com uma espirometria normal. A intervenção terapêutica dirigida à função abdominal para a dupla tarefa poderá ser benéfica num contexto patológico de limitação do fluxo expiratório.

**Capítulo VII**

# Referências Bibliográficas

Abe, T., Kusuhara, N., Yoshimura, N., Tomita, T., & Easton, P. A. (1996). Differential respiratory activity of four abdominal muscles in humans. *Journal of Applied Physiology (1985), 80*(4), 1379-1389.

Aliverti, A., Cala, S. J., Duranti, R., Ferrigno, G., Kenyon, C. M., Pedotti, A., . . . Yan, S. (1997). Human respiratory muscle actions and control during exercise. *Journal of Applied Physiology (1985), 83*(4), 1256-1269.

Aliverti, A., & Macklem, P. T. (2008). The major limitation to exercise performance in COPD is inadequate energy supply to the respiratory and locomotor muscles. *Journal of Applied Physiology (1985), 105*(2), 749-751; discussion 755-747.

Balasubramaniam, R., & Wing, A. M. (2002). The dynamics of standing balance. *Trends in Cognitive Sciences, 6*(12), 531-536.

Banzett, R. B., Topulos, G. P., Leith, D. E., & Nations, C. S. (1988). Bracing arms increases the capacity for sustained hyperpnea. *American Review of Respiratory Disease, 138*(1), 106-109.

Barach, A. L. (1974). Chronic obstructive lung disease: postural relief of dyspnea. *Archives of Physical Medicine and Rehabilitation, 55*(11), 494-504.

Barbara, C., Rodrigues, F., Dias, H., Cardoso, J., Almeida, J., Matos, M. J., . . . Burney, P. (2013). Chronic obstructive pulmonary disease prevalence in Lisbon, Portugal: the burden of obstructive lung disease study. *Revista Portuguesa de Pneumologia, 19*(3), 96-105.

Barrett, J., Cerny, F., Hirsch, J. A., & Bishop, B. (1994). Control of breathing patterns and abdominal muscles during graded loads and tilt. *Journal of Applied Physiology (1985), 76*(6), 2473-2480.

Beauchamp, M. K., Brooks, D., & Goldstein, R. S. (2010). Deficits in postural control in individuals with COPD - emerging evidence for an important secondary impairment. *Multidisciplinary Respiratory Medicine, 5*(6), 417-421.

Beauchamp, M. K., Hill, K., Goldstein, R. S., Janaudis-Ferreira, T., & Brooks, D. (2009). Impairments in balance discriminate fallers from non-fallers in COPD. *Respiratory Medicine, 103*(12), 1885-1891.

Beauchamp, M. K., Sibley, K. M., Lakhani, B., Romano, J., Mathur, S., Goldstein, R. S., & Brooks, D. (2012). Impairments in systems underlying control of balance in COPD. *Chest, 141*(6), 1496-1503.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82-87.

Booth, S., Burkin, J., Moffat, C., & Spathis, A. (2014). Positions to ease breathlessness. In S. Booth, J. Burkin, C. Moffat, & A. Spathis (Eds.), *Managing breathlessness in clinical practice* (pp. 49-65). London: Springer.

Bott, J., Blumenthal, S., Buxton, M., Ellum, S., Falconer, C., Garrod, R., . . . British Thoracic Society Physiotherapy Guideline Development, G. (2009). Guidelines for the physiotherapy management of the adult, medical, spontaneously breathing patient. *Thorax, 64*(Suppl 1), i1-51.

Burden, A. (2010). How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. *Journal of Electromyography and Kinesiology, 20*(6), 1023-1035.

Butcher, S. J., Meshke, J. M., & Sheppard, M. S. (2004). Reductions in functional balance, coordination, and mobility measures among patients with stable chronic obstructive pulmonary disease. *Journal of Cardiopulmonary Rehabilitation, 24*(4), 274-280.

Cassart, M., Gevenois, P. A., & Estenne, M. (1996). Rib cage dimensions in hyperinflated patients with severe chronic obstructive pulmonary disease. *American Journal of Respiratory and Critical Care Medicine, 154*(3 Pt 1), 800-805.

Celli, B. R., Decramer, M., Wedzicha, J. A., Wilson, K. C., Agusti, A., Criner, G. J., . . . Research, A. E. T. F. f. C. (2015). An official American Thoracic Society/European Respiratory Society statement: research questions in COPD. *European Respiratory Journal, 45*(4), 879-905.

Celli, B. R., MacNee, W., & Force, A. E. T. (2004). Standards for the diagnosis and treatment of patients with COPD: a summary of the ATS/ERS position paper. *European Respiratory Journal, 23*(6), 932-946.

Cholewicki, J., Juluru, K., & McGill, S. M. (1999). Intra-abdominal pressure mechanism for stabilizing the lumbar spine. *Journal of Biomechanics, 32*(1), 13-17.

Cresswell, A. G., Grundstrom, H., & Thorstensson, A. (1992). Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. *Acta Physiologica Scandinavica, 144*(4), 409-418.

Crommert, M. E., Ekblom, M. M., & Thorstensson, A. (2011). Activation of transversus abdominis varies with postural demand in standing. *Gait & Posture, 33*(3), 473-477.

David, P., Laval, D., Terrien, J., & Petitjean, M. (2012). Postural control and ventilatory drive during voluntary hyperventilation and carbon dioxide rebreathing. *European Journal of Applied Physiology, 112*(1), 145-154.

de Marco, R., Accordini, S., Cerveri, I., Corsico, A., Anto, J. M., Kunzli, N., . . . Burney, P. (2007). Incidence of chronic obstructive pulmonary disease in a cohort of young adults according to the presence of chronic cough and phlegm. *American Journal of Respiratory and Critical Care Medicine, 175*(1), 32-39.

de Oca, M. M., Halbert, R. J., Lopez, M. V., Perez-Padilla, R., Talamo, C., Moreno, D., . . . Menezes, A. M. (2012). The chronic bronchitis phenotype in subjects with and without COPD: the PLATINO study. *European Respiratory Journal, 40*(1), 28-36.

De Troyer, A. (1983). Mechanical role of the abdominal muscles in relation to posture. *Respiration Physiology, 53*(3), 341-353.

De Troyer, A. (1997). Effect of hyperinflation on the diaphragm. *European Respiratory Journal, 10*(3), 708-713.

De Troyer, A., & Estenne, M. (1988). Functional anatomy of the respiratory muscles. *Clinics In Chest Medicine, 9*(2), 175-193.

De Troyer, A., Estenne, M., Ninane, V., Van Gansbeke, D., & Gorini, M. (1990). Transversus abdominis muscle function in humans. *Journal of Applied Physiology (1985), 68*(3), 1010-1016.

De Troyer, A., Leeper, J. B., McKenzie, D. K., & Gandevia, S. C. (1997). Neural drive to the diaphragm in patients with severe COPD. *American Journal of Respiratory and Critical Care Medicine, 155*(4), 1335-1340.

Dean, E. (1985). Effect of body position on pulmonary function. *Physical Therapy, 65*(5), 613-618.

Decramer, M. (1997). Hyperinflation and respiratory muscle interaction. *European Respiratory Journal, 10*(4), 934-941.

Drake, R., Vogl, A. W., & Mitchell, A. W. M. (2014). Abdomen. In R. Drake, A. W. Vogl, & A. W. M. Mitchell (Eds.), *Gray's anatomy for students* (3rd ed., pp. 253-420). Philadelphia, PA: Churchill Livingstone/Elsevier.

Edmondston, S. J., Aggerholm, M., Elfving, S., Flores, N., Ng, C., Smith, R., & Netto, K. (2007). Influence of posture on the range of axial rotation and coupled lateral flexion of the thoracic spine. *Journal of Manipulative and Physiological Therapeutics, 30*(3), 193-199.

Estenne, M., Yernault, J. C., & De Troyer, A. (1985). Rib cage and diaphragm-abdomen compliance in humans: effects of age and posture. *Journal of Applied Physiology (1985), 59*(6), 1842-1848.

Fabbri, L. M. (2016). Smoking, not COPD, as the disease. *The New England Journal of Medicine:, 374*(19), 1885-1886.

Fabbri, L. M., Pauwels, R. A., Hurd, S. S., & GOLD Scientific Committee. (2004). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary updated 2003. *COPD: Journal of Chronic Obstructive Pulmonary Disease, 1*(1), 105-141; discussion 103-104.

Gandevia, S. C., Leeper, J. B., McKenzie, D. K., & De Troyer, A. (1996). Discharge frequencies of parasternal intercostal and scalene motor units during breathing in normal and COPD subjects. *American Journal of Respiratory and Critical Care Medicine, 153*(2), 622-628.

Global Initiative for Chronic Obstructive Lung Disease. (2016). Global strategy for diagnosis, management, and prevention of chronic obstructive pulmonary disease - update 2016. Retrieved from http://goldcopd.org/global-strategy-diagnosis-management-prevention-copd-2016/

Goldman, M. D., & Mead, J. (1973). Mechanical interaction between the diaphragm and rib cage. *Journal of Applied Physiology (1985), 35*(2), 197-204.

Gorini, M., Spinelli, A., Ginanni, R., Duranti, R., Gigliotti, F., & Scano, G. (1990). Neural respiratory drive and neuromuscular coupling in patients with chronic obstructive pulmonary disease (COPD). *Chest, 98*(5), 1179-1186.

Hall, L. M., Brauer, S., Horak, F., & Hodges, P. W. (2010). Adaptive changes in anticipatory postural adjustments with novel and familiar postural supports. *Journal of Neurophysiology, 103*(2), 968-976.

Hamaoui, A., Gonneau, E., & Le Bozec, S. (2010). Respiratory disturbance to posture varies according to the respiratory mode. *Neuroscience Letters, 475*(3), 141-144.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361-374.

Hides, J. A., Richardson, C. A., & Hodges, P. W. (2004). Local segmental control. In J. A. Hides, C. A. Richardson, & P. W. Hodges (Eds.), *Therapeutic Exercise for Lumbopelvic Stabilization* (2nd ed., pp. 185-219). Edinburgh: Churchill Livingstone.

Hodges, P. W. (1999). Is there a role for transversus abdominis in lumbo-pelvic stability? *Manual Therapy, 4*(2), 74-86.

Hodges, P. W. (2004). Abdominal mechanism and support of the lumbar spine and pelvis. In J. A. Hides, C. A. Richardson, & P. W. Hodges (Eds.), *Therapeutic Exercise for Lumbopelvic Stabilization* (2nd ed., pp. 31-58). Edinburgh: Churchill Livingstone.

Hodges, P. W., & Gandevia, S. C. (2000a). Activation of the human diaphragm during a repetitive postural task. *The Journal of Physiology, 522*(Pt 1), 165-175.

Hodges, P. W., & Gandevia, S. C. (2000b). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology (1985), 89*(3), 967-976.

Hodges, P. W., Gandevia, S. C., & Richardson, C. A. (1997). Contractions of specific abdominal muscles in postural tasks are affected by respiratory maneuvers. *Journal of Applied Physiology (1985), 83*(3), 753-760.

Hodges, P. W., Gurfinkel, V. S., Brumagne, S., Smith, T. C., & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Experimental Brain Research, 144*(3), 293-302.

Hodges, P. W., Heijnen, I., & Gandevia, S. C. (2001). Postural activity of the diaphragm is reduced in humans when respiratory demand increases. *The Journal of Physiology, 537*(Pt 3), 999-1008.

Hodges, P. W., & Richardson, C. A. (1999). Transversus abdominis and the superficial abdominal muscles are controlled independently in a postural task. *Neuroscience Letters, 265*(2), 91-94.

Horak, F. B., Henry, S. M., & Shumway-Cook, A. (1997). Postural perturbations: new insights for treatment of balance disorders. *Physical Therapy, 77*(5), 517-533.

Hudson, A. L., Butler, J. E., Gandevia, S. C., & De Troyer, A. (2010). Interplay between the inspiratory and postural functions of the human parasternal intercostal muscles. *Journal of Neurophysiology, 103*(3), 1622-1629.

Janssens, L., Brumagne, S., McConnell, A. K., Claeys, K., Pijnenburg, M., Burtin, C., . . . Troosters, T. (2013). Proprioceptive changes impair balance control in individuals with chronic obstructive pulmonary disease. *PLoS One, 8*(3), e57949.

Jeong, B. Y. (1991). Respiration effect on standing balance. *Archives of Physical Medicine and Rehabilitation, 72*(9), 642-645.

Kaneko, H., & Horie, J. (2012). Breathing movements of the chest and abdominal wall in healthy subjects. *Respiratory Care, 57*(9), 1442-1451.

Kenyon, C. M., Cala, S. J., Yan, S., Aliverti, A., Scano, G., Duranti, R., . . . Macklem, P. T. (1997). Rib cage mechanics during quiet breathing and exercise in humans. *Journal of Applied Physiology (1985), 83*(4), 1242-1255.

Kera, T., & Maruyama, H. (2005). The effect of posture on respiratory activity of the abdominal muscles. *Journal of Physiological Anthropology and Applied Human Science, 24*(4), 259-265.

Key, J. (2013). 'The core': understanding it, and retraining its dysfunction. *Journal of Bodywork and Movement Therapies, 17*(4), 541-559.

Kim, K. S., Byun, M. K., Lee, W. H., Cynn, H. S., Kwon, O. Y., & Yi, C. H. (2012). Effects of breathing maneuver and sitting posture on muscle activity in inspiratory accessory muscles in patients with chronic obstructive pulmonary disease. *Multidisciplinary Respiratory Medicine, 7*(1), 9.

Kolar, P., Sulc, J., Kyncl, M., Sanda, J., Neuwirth, J., Bokarius, A. V., . . . Kobesova, A. (2010). Stabilizing function of the diaphragm: dynamic MRI and synchronized spirometric assessment. *Journal of Applied Physiology (1985), 109*(4), 1064-1071.

Kuznetsov, N. A., & Riley, M. A. (2012). Effects of breathing on multijoint control of center of mass position during upright stance. *Journal of Motor Behavior, 44*(4), 241-253.

Lackner, J. R., & DiZio, P. (2005). Vestibular, proprioceptive, and haptic contributions to spatial orientation. *Annual Review of Psychology, 56*, 115-147.

Laveneziana, P., Webb, K. A., Wadell, K., Neder, J. A., & O'Donnell, D. E. (2014). Does expiratory muscle activity influence dynamic hyperinflation and exertional dyspnea in COPD? *Respiratory Physiology & Neurobiology, 199*, 24-33.

Lee, L. J., Chang, A. T., Coppieters, M. W., & Hodges, P. W. (2010). Changes in sitting posture induce multiplanar changes in chest wall shape and motion with breathing. *Respiratory Physiology & Neurobiology, 170*(3), 236-245.

Levitzky, M. G. (2013). Mechanics of breathing. In M. G. Levitzky (Ed.), *Pulmonary physiology* (pp. 12-57). New York, NY: McGraw-Hill Education/Medical.

Lozano, R., Naghavi, M., Foreman, K., Lim, S., Shibuya, K., Aboyans, V., . . . Memish, Z. A. (2012). Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet, 380*(9859), 2095-2128.

Macklem, P. T. (2014). The act of breathing. In A. Aliverti & A. Pedotti (Eds.), *Mechanics of breathing: new insights from new technologies* (pp. 3-10). Milano: Springer Milan.

Maltais, F., LeBlanc, P., Jobin, J., & Casaburi, R. (2000). Peripheral muscle dysfunction in chronic obstructive pulmonary disease. *Clinics In Chest Medicine, 21*(4), 665-677.

Mannino, D. M., Doherty, D. E., & Buist, A. S. (2006). Global Initiative on Obstructive Lung Disease (GOLD) classification of lung disease and mortality: findings from the Atherosclerosis Risk in Communities (ARIC) study. *Respiratory Medicine, 100*(1), 115-122.

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology, 13*(5), 477-489.

Martinez, F. J., Couser, J. I., & Celli, B. R. (1990). Factors influencing ventilatory muscle recruitment in patients with chronic airflow obstruction. *American Review of Respiratory Disease, 142*(2), 276-282.

McCook, D. T., Vicenzino, B., & Hodges, P. W. (2009). Activity of deep abdominal muscles increases during submaximal flexion and extension efforts but antagonist co-contraction remains unchanged. *Journal of Electromyography and Kinesiology, 19*(5), 754-762.

Meadows, L., & Williams, J. (2009). An understanding of functional movement as a basis for clinical reasoning. In S. Raine, L. Meadows, & M. Lynch-Ellerington (Eds.), *Bobath concept: theory and clinical practice in neurological rehabilitation* (pp. 23-42). Oxford: Wiley-Blackwell.

Mihailoff, G. A., & Haines, D. E. (2013). Motor system I: peripheral sensory, brainstem, and spinal influence on anterior horn neurons. In D. E.

Haines (Ed.), *Fundamental neuroscience for basic and clinical applications* (pp. 324-337). Philadelphia, PA: Elsevier/Saunders.

Ninane, V., Rypens, F., Yernault, J. C., & De Troyer, A. (1992). Abdominal muscle use during breathing in patients with chronic airflow obstruction. *American Review of Respiratory Disease, 146*(1), 16-21.

O'Donnell, D. E. (2001). Ventilatory limitations in chronic obstructive pulmonary disease. *Medicine & Science in Sports & Exercise, 33*(7 Suppl), S647-655.

O'Donnell, D. E., & Webb, K. A. (1993). Exertional breathlessness in patients with chronic airflow limitation. The role of lung hyperinflation. *American Review of Respiratory Disease, 148*(5), 1351-1357.

O'Neill, S., & McCarthy, D. S. (1983). Postural relief of dyspnoea in severe chronic airflow limitation: relationship to respiratory muscle strength. *Thorax, 38*(8), 595-600.

Oelsner, E. C., Hoffman, E. A., Folsom, A. R., Carr, J. J., Enright, P. L., Kawut, S. M., . . . Barr, R. G. (2014). Association between emphysema-like lung on cardiac computed tomography and mortality in persons without airflow obstruction: a cohort study. *Annals of Internal Medicine, 161*(12), 863-873.

Pauwels, R. A., Buist, A. S., Ma, P., Jenkins, C. R., Hurd, S. S., & Committee, G. S. (2001). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: National Heart, Lung, and Blood Institute and World Health Organization Global Initiative for Chronic Obstructive Lung Disease (GOLD): executive summary. *Respiratory Care, 46*(8), 798-825.

Ratnovsky, A., Zaretsky, U., Shiner, R. J., & Elad, D. (2003). Integrated approach for in vivo evaluation of respiratory muscles mechanics. *Journal of Biomechanics, 36*(12), 1771-1784.

Regan, E. A., Lynch, D. A., Curran-Everett, D., Curtis, J. L., Austin, J. H., Grenier, P. A., . . . Genetic Epidemiology of, C. I. (2015). Clinical and Radiologic Disease in Smokers With Normal Spirometry. *JAMA Internal Medicine, 175*(9), 1539-1549.

Rodriguez-Roisin, R., Han, M. K., Vestbo, J., Wedzicha, J. A., Woodruff, P. G., & Martinez, F. J. (2016). Chronic respiratory symptoms with normal spirometry: a reliable clinical entity? *American Journal of Respiratory and Critical Care Medicine*.

Roig, M., Eng, J. J., Macintyre, D. L., Road, J. D., & Reid, W. D. (2011). Postural control is impaired in people with COPD: an observational study. *Physiotherapy Canada, 63*(4), 423-431.

Roig, M., Eng, J. J., Road, J. D., & Reid, W. D. (2009). Falls in patients with chronic obstructive pulmonary disease: a call for further research. *Respiratory Medicine, 103*(9), 1257-1269.

Romei, M., Mauro, A. L., D'Angelo, M. G., Turconi, A. C., Bresolin, N., Pedotti, A., & Aliverti, A. (2010). Effects of gender and posture on thoraco-abdominal kinematics during quiet breathing in healthy adults. *Respiratory Physiology & Neurobiology, 172*(3), 184-191.

Santos, T. V., Ruas, G., Sande de Souza, L. A., & Volpe, M. S. (2012). Influence of forward leaning and incentive spirometry on inspired volumes and inspiratory electromyographic activity during breathing exercises in healthy subjects. *Journal of Electromyography and Kinesiology, 22*(6), 961-967.

Saunders, S. W., Rath, D., & Hodges, P. W. (2004). Postural and respiratory activation of the trunk muscles changes with mode and speed of locomotion. *Gait & Posture, 20*(3), 280-290.

Smith, M. D., Chang, A. T., & Hodges, P. W. (2016). Balance recovery is compromised and trunk muscle activity is increased in chronic obstructive pulmonary disease. *Gait & Posture, 43*, 101-107.

Smith, M. D., Chang, A. T., Seale, H. E., Walsh, J. R., & Hodges, P. W. (2010). Balance is impaired in people with chronic obstructive pulmonary disease. *Gait & Posture, 31*(4), 456-460.

Starr, J., & Dalton, D. (2011). The torax and chest wall. In P. K. Levangie & C. C. Norkin (Eds.), *Joint structure and function: a comprehensive analysis* (5th ed., pp. 192-211). Philadelphia, PA: F. A. Davis Company.

Stavem, K., Sandvik, L., & Erikssen, J. (2006). Can global initiative for Chronic Obstructive Lung Disease stage 0 provide prognostic information on long-term mortality in men? *Chest, 130*(2), 318-325.

Strohl, K. P., Mead, J., Banzett, R. B., Lehr, J., Loring, S. H., & O'Cain, C. F. (1984). Effect of posture on upper and lower rib cage motion and tidal volume during diaphragm pacing. *American Review of Respiratory Disease, 130*(2), 320-321.

Vestbo, J., Hurd, S. S., Agusti, A. G., Jones, P. W., Vogelmeier, C., Anzueto, A., . . . Rodriguez-Roisin, R. (2013). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. *American Journal of Respiratory and Critical Care Medicine, 187*(4), 347-365.

Winter, D. A., Patla, A. E., Prince, F., Ishac, M., & Gielo-Perczak, K. (1998). Stiffness control of balance in quiet standing. *Journal of Neurophysiology, 80*(3), 1211-1221.

Winter, D. A., Prince, F., Frank, J. S., Powell, C., & Zabjek, K. F. (1996). Unified theory regarding A/P and M/L balance in quiet stance. *Journal of Neurophysiology, 75*(6), 2334-2343.

World Health Organization. (2004). The global burden of disease - update 2004. Retrieved from http://www.who.int/healthinfo/global_burden_disease/2004_report_update/en/

World Health Organization. (2008). World Health Statistics 2008. Retrieved from http://www.who.int/gho/publications/world_health_statistics/2008/en/

# Apêndices

# Apêndice 1. Parecer da comissão de ética

**De:** **Secretariado da Presidência** sec-presidencia@estsp.ipp.pt
**Assunto:** ESTSP - Comissão de Ética
**Data:** 19 de março de 2014, 14:21
**Para:** António Mesquita Montes antoniomesquitamontes@gmail.com

SD

Exmo. (a) Senhor (a)
António Mesquita Montes,

Para os efeitos convenientes, cumpre-me informar V. Exa. que por despacho do Senhor Presidente desta Escola, datado de 17 de março de 2014, e após parecer final da Comissão de Ética [em anexo], ***foi autorizada*** a realização do seu projeto de investigação intitulado,

*Influência de Resistências … Indivíduos Saudáveis"*

Com os melhores cumprimentos,

LUÍS CRISPIM
Secretariado da Presidência
Escola Superior de Tecnologia da Saúde
Instituto Politécnico do Porto

ESTSP | POLITÉCNICO DO PORTO

PARECER DA COMISSÃO DE ÉTICA

**Número de Registo da Comissão de Ética:** ____________4136/2013______________
**Data recepção do Documento:** _______________13/02/2014_______________
**Existência de entradas anteriores:** _________4136/2013 de 28/11/2013__________

**Título do Trabalho: Influência de resistências ventilatórias inspiratória e expiratória no controlo postural em indivíduos saudáveis**
**Investigador Responsável pela submissão à C.E.: António Manuel Soares Mesquita Montes**

**Data prevista para a realização do trabalho:** Início Março 2014 **Fim** Junho 2014

**RESUMO DO ESTUDO**

**Objectivos:** Nada a referir.
**Amostra:** Será seleccionada via email institucional. Tamanho da amostra previsto de 50.
**Formulário de dados a recolher:** O questionário de selecção da amostra foi rectificado, existindo agora apenas um campo para o nome.
**Material:** Nada a referir.
**Métodos:** As intervenções serão efectuadas pelo investigador responsável e, na ausência deste, pela restante equipa de investigação.
**Riscos:** Sim e é referido o procedimento a tomar caso este ocorra.
**Consentimento informado:** Presente.
**Autorização pelos responsáveis locais:** Presentes.
**Cronograma:** Conforme.

**Apreciação da Comissão de Ética:**
Todas as questões levantadas foram esclarecidas e/ou rectificadas.

**Parecer final da Comissão de Ética:**
De acordo com os dados analisados o parecer é favorável, ressaltando o facto de que o investigador deverá cumprir todas as directrizes submetidas a esta Comissão, com prejuízo de a decisão ser suspensa caso haja algum incumprimento grave.

**Data: 01/03/2014**
**Assinaturas:**

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DO PORTO
DATA [illegible]
N.º [illegible]
ENTRADA

ESTSP.011.CE.08.02

Todos os documentos submetidos à C.E. são objecto de total confidencialidade

ESTSP | POLITÉCNICO DO PORTO

## Declaração de consentimento informado

Conforme alei 67/98 de 26 de Outubro e a "Declaração de Helsínquia" da Associação Médica Mundial (Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996, Edimburgo 2000; Washington 2002, Tóquio 2004, Seul 2008)

**Designação do Estudo:** Influência de resistências ventilatórias inspiratória e expiratória no controlo postural em indivíduos em risco de desenvolvimento da DPOC e em saudáveis

Eu, abaixo-assinado ___________________________________________________:

Fui informado de que o Estudo de Investigação acima mencionado se destina a avaliar o efeito de uma resistência ventilatória inspiratória e expiratória e de diferentes conjuntos posturais, na atividade muscular do *core* abdominal, em indivíduos em risco de desenvolvimento da DPOC e em saudáveis.

Sei que neste estudo está prevista a realização de testes de função ventilatória tendo-me sido explicado em que consistem e quais os seus possíveis efeitos.

Foi-me garantido que todos os dados relativos à identificação dos participantes neste estudo são confidenciais e que será mantido o anonimato.

Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado.

Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Nome do Investigador e Contacto: António Mesquita Montes | 964941634.

Data ___/___/_____

Assinatura ______________________________________

ESTSP.011.CE.07.01