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Sustained maximal inspiration has similar effects compared to incentive spirometers

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A R T I C L E I N F O

Keywords:
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Incentive spirometer
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Optoelectronic plethysmography
Chest wall motion
Asynchrony

A B S T R A C T

Purpose: To compare the effects of flow incentive spirometer (FIS), volume incentive spirometer (VIS), and sustained maximal inspiration exercise (SMI) on breathing pattern, chest wall motion, and thoracoabdominal asynchrony.
Methods: Sixteen healthy adults aged 27.63 ± 5.26 years were evaluated by optoelectronic plethysmography in the supine position with trunk inclination of 45° during quiet breathing and during exercise performance.
Results: In the comparisons among exercises, VIS promoted a significantly higher inspiratory time and lower mean inspiratory flow compared with FIS. The rating of perceived exertion according to the Borg Scale was significantly higher after the performance of FIS compared with VIS. Regarding asynchrony, none of the exercises caused changes in thoracoabdominal synchrony between the rib cage and abdomen. However, both devices significantly reduced the asynchrony between the pulmonary and abdominal rib cage compared with quiet breathing.
Conclusion: SMI exercise was equivalent to incentive spirometers and may be an interesting alternative for clinical use in cases in which it is not possible to acquire the devices.

1. Introduction

Incentive spirometry was conceived by Bartlett et al. (1973) and has been primarily used with the aim of reversing the pathophysiological process of postoperative pulmonary complications, which mostly result in an abnormal ventilation pattern adopted by patients after a surgical process. Therefore, the aim of incentive spirometry is to maintain the inflation of the alveoli, simulating the mechanisms of sighing that occur in normal respiratory physiology (Bartlett et al., 1973; Tomich et al., 2007).

Flow incentive spirometers (FIS) do not have a volume displacement indicator, and flow generation occurs by an inspiratory effort that should be sufficient to raise the balls (Weindler and Kiefer, 2001). In contrast to FIS, volume incentive spirometers (VIS) have a marker indicating the volume to be reached, which may be previously established, as well as a flow quality indicator that allows the patient to control flow velocity during inspiration (Weindler and Kiefer, 2001). Previous studies in different populations have shown that the FIS presents disadvantages compared with the VIS, since it imposes greater work of breathing (Mang and Obermayer, 1989; Weindler and Kiefer, 2001; Tomich et al., 2007, 2010; Paisani et al., 2013; Lunardi et al., 2014), higher respiratory rate (Tomich et al., 2007, 2010), greater increase in inspiratory flow (Tomich et al., 2007), and less increase in inspiratory time (Tomich et al., 2007; Paisani et al., 2013; Lunardi et al., 2014).

The manoeuvre to perform the incentive spirometry consists of a deep and slow maximal inspiration, through the mouth, followed by a post-inspiratory pause and exhalation up to functional residual capacity (Bartlett et al., 1973; Armstrong, 2017). This manoeuvre also might be performed without devices by sustained maximal inspiration exercise (SMI). The SMI is an exercise that is simple to perform and does not require the use of a device. In addition, its effectiveness in promoting an increase in tidal volume and minute ventilation and a reduction in respiratory rate has been shown (Vieira et al., 2014). This exercise, VIS,

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and FIS shared the same aims and physiological principle, which is to increase transpulmonary pressure by decreasing pleural pressure (Bartlett et al., 1973).

Taking into account that the incentive spirometer is an instrument of individual use and its greater applicability occurs during the post-operative period (Tomich et al., 2010; Chang et al., 2010; Yamaguti et al., 2016; Restrepo et al., 2011; Santos et al., 2012; Paisani et al., 2013, Alaparthi2016), the use of this device can be onerous for both the institution and the patients and may not be accessible in many countries (Eltorai et al., 2017). Considering also the disadvantages of FIS compared with VIS, the SMI exercise might be an interesting alternative for use in clinical practice.

In this context, the aim of this study was to compare the effects of the FIS, VIS, and SMI exercise on breathing pattern, chest wall motion, and thoracoabdominal asynchrony of healthy individuals.

2. Methods

2.1. Design and sample

This was an observational study. Inclusion criteria were age between 20 and 44 years, body mass index between 18.5 and 29.99 kg/m^2 (WHO, 2014), normal lung function according to predicted values (Pereira et al., 2007), and self-reported absence of cardiac or neuromuscular diseases. The exclusion criteria were the inability to understand and/or perform any of the procedures from data collection. The study was approved by the Ethics Committee (CAAE 59190316.3.0000.5149), and all participants signed a written consent form.

2.2. Main measurement instrument

Optoelectronic plethysmography (BTS Bioenginneering, Milan, Italy) is a method capable of noninvasively evaluating breathing pattern and chest wall motion by means of indirect measurement of chest wall motion and its compartments: pulmonary rib cage (RCp), abdominal rib cage (RCa), and abdomen (Aliverti and Pedotti, 2003). This is a valid (Cala et al., 1996; Vogiatzis et al., 2005) and reliable (Vieira et al., 2013) method that can be used in different populations and experimental protocols (Parreira et al., 2012). The optoelectronic plethysmography system consists of special cameras that emit infrared light toward markers attached at specific anatomical points on the individual's chest wall. The infrared rays emitted are reflected by the markers and recaptured by the cameras, generating three-dimensional coordinates that allow calculation of chest wall volumes (Parreira et al., 2012). For data collection performed in the seated and standing position, 89 markers are used, and for data collection in the supine or inclined position (with 45° of trunk inclination), 52 markers are placed. Technical details including marker positions, data acquisition, and calibration process have previously been published (Parreira et al., 2012).

2.3. Procedures

Data were collected for 2 days, with a maximal interval of 1 week between them. On the first day, clinical and demographic data were registered. After blood pressure, respiratory rate, heart rate, and peripheral oxygen saturation (SpO_2) (Ohmeda TuffSat, Finland) monitoring, the participants underwent pulmonary function testing (Koko®, PFT type; nSpireHealth Inc., CO, USA). The test was performed according to the recommendations of the American Thoracic Society (Culver et al., 2017), and the values were compared with those predicted by Pereira et al. (2007). Next, the participants answered the Human Activity Profile (Souza et al., 2006) to register their physical activity level. The rating of perceived exertion to breath was recorded at the end of all exercises using the modified Borg 0–10 Scale (Borg, 1982). Both spirometry and the questionnaire were administered by trained assessors.

After that, participants were trained to perform FIS, VIS, and SMI exercise. For FIS performance, the device of the brand Respiron® (NCS, Brazil) was used. According to the manuals, it is necessary to generate flows corresponding to 600 mL/s to raise the first ball, 900 mL/s to raise the two balls, and 1200 mL/s to raise the three balls. The participant was asked to perform deep, slow, and continuous breathing, through the mouthpiece, raising three balls smoothly and uniformly until reaching the total lung capacity. Immediately after, a 3-second post-inspiratory pause, monitored by the assessor, was made followed by a normal expiration up to functional residual capacity (Restrepo et al., 2011). The regulator ring of the first chamber was kept at zero throughout the data collection so as not to add resistance to the exercise performance.

For VIS performance, the Spiro-Ball® (Leventon, Spain) was used. To execute this exercise, a deep inspiration was performed though the mouthpiece, keeping a constant and slow flow using visual feedback provided by the flow guide (smiling face) until total lung capacity was reached. Immediately after, a 3-second post-inspiratory pause, monitored by the assessor, was made followed by a normal expiration up to functional residual capacity (Restrepo et al., 2011). It was decided not to predetermine the volume to be reached during the exercise performance in order not to underestimate the performance of the individual regarding the other exercises analysed, in which there is no possibility of establishing a volume to be reached. Therefore, the volume reached was individually self-limited. The volume marker was kept at zero throughout the data collection.

During the performance of both spirometers, a nasal clip was used, and appropriate lip sealing around the mouthpiece was oriented to avoid air leakage. In addition, maintenance of the mouthpiece in the mouth was required throughout the exercise to avoid interfering with the chest wall volume acquisition by optoelectronic plethysmography, due to the movement of the arms to remove the mouthpiece. Thus, to exhale the air, the participants relaxed their lips and released the air through the sides of the mouth.

Finally, for SMI exercise performance, a slow and deep breath was performed, through the nostrils, until total lung capacity was reached, maintaining a 3-second post-inspiratory pause, monitored by the assessor, followed by a normal expiration through the mouth up to functional residual capacity (Vieira et al., 2014).

On the second day, vital signs were initially measured, then immediately, the 52 markers were placed on the participants' anterior and lateral chest wall using hypoallergenic bi-adhesive tape. Subsequently, the static and dynamic calibrations of the optoelectronic plethysmography were performed (Aliverti et al., 2001; Parreira et al., 2012).

In all situations, participants were evaluated in the supine position with a trunk inclination of 45°. The plinth was placed in the centre of the collection site, and for this study, eight optoelectronic plethysmography cameras arranged in parallel were used, four of them placed on the right side of the participant and four on the left side. Initially, 5 min of quiet breathing were recorded, which was defined by the spontaneous breathing pattern of the participant. Thereafter, 5 min of each breathing exercise were recorded as follows: two sessions of 2 min, with a 1-minute interval between them. The first 2-minute session was considered as an adaptation phase, while the second one was used for data analysis.

Participants received standard instructions during exercise performance. The instructions were given by the same assessor at the beginning and after 60 s of exercise. The order of the exercises was randomized by a computer program (https://random-number-generator.

com/pt/). A 10-minute interval among exercises was given for the participants, allowing heart rate, respiratory rate, and SpO_2 to return to baseline values. In addition, at the end of each exercise, the participants were asked to rate their perceived exertion to breath using a modified Borg 0–10 Scale.

2.4. Variables analysed

For breathing pattern analysis, the following variables were used: chest wall tidal volume (V_{cw}), minute ventilation, inspiratory time (Ti), respiratory rate, and mean inspiratory flow (V_{cw}/Ti). For chest wall motion, pulmonary rib cage percentage contribution ($V_{RCp\%}$), abdominal rib cage percentage contribution ($V_{RCa\%}$), and abdomen percentage contribution ($V_{AB\%}$) were measured. For thoracoabdominal asynchrony, phase angle (PhAng) and inspiratory phase ratio (PhRIB) between the rib cage and abdomen and between the pulmonary and abdominal rib cage were evaluated. A detailed description about the variables has been previously published (Parreira et al., 2012).

2.5. Data reduction

To determine the variables associated with breathing pattern, chest wall motion, and thoracoabdominal asynchrony, the middle 100 s from the 5 min registered for the quiet breathing and the middle 100 s of the second series of the breathing exercises were used.

2.6. Statistical analysis

Sample size calculation was based on the data of the 10 first participants of the study. Taking into account the differences between spirometers already reported in the literature, respiratory rate, Ti, and V_{cw}/Ti were considered in the analysis. The effect size index was calculated (*f*) using the sum of squares of the analysis of variance (ANOVA) summary table obtained by the software Statistical Package for Social Sciences (SPSS, Chicago, IL, USA), version 15.0. Thereafter, considering a significance level of 5%, a power of 80%, and the *f* obtained for each variable, the estimated sample size ranged between 8 and 10 individuals (Portney and Watkins, 2008).

Data were presented as measures of central tendency and dispersion, and the normality was verified by the Shapiro-Wilk test. The comparisons between exercises and the rest period prior to them were performed by Student *t* test for dependent samples and Wilcoxon test according to variable distribution. The comparisons among exercises were performed by the differences between the exercises and the quiet breathing period immediately prior to them (delta analysis). Normally distributed data were analysed using ANOVA for repeated measures with one factor (breathing exercises). Nonnormally distributed data were analysed using the analogous nonparametric test, the Friedman test. Post hoc analyses were performed by Bonferroni and Wilcoxon tests, respectively. The level of significance was set at 5%, and the SPSS version 15.0 was used for these analyses.

3. Results

Of the 22 initially recruited participants, six were excluded (three presented an abnormal pulmonary function test, and the other three did not attend on the second day of protocol collection). Therefore, 16 participants completed the study.

Participants' demographic, anthropometric, and spirometric data as well as physical activity level are presented in Table 1. All participants were classified as physically active by the Human Activity Profile questionnaire. Blood pressure, heart rate, and SpO_2 remained within normal values during data collection time.

Table 1
Demographic, anthropometric and spirometric data of the 16 participants evaluated.

CHARACTERISTIC	Mean (SD)
Sex	8M/8W
Age (years)	28 (5)
BMI (Kg/m^2)	23 (3)
FEV_1 (L)	3.87 (0.59)
FEV_1 (% predicted)	97.58 (5.83)
FVC (% predicted)	95.30 (5.66)
FEV_1/FVC	0.85 (0.06)
HAP	91 (3)

Data are expressed as mean (standard deviation). M: men; W: women; BMI: body mass index; FEV_1: forced expiratory volume in first second; FVC: forced vital capacity; FEV_1/FVC: ratio of FEV_1 to FVC; HAP: Human Activity Profile.

3.1. Comparisons between breathing exercises and quiet breathing

Table 2 presents the absolute values of the variables of breathing pattern, chest wall motion, and asynchrony during the quiet breathing period and during the performance of the exercises. All exercises promoted a statistically significant increase in V_{cw}, minute ventilation, T_i, and V_{cw}/Ti associated with a significant reduction of respiratory rate.

Regarding chest wall motion, $V_{RCp\%}$ increased significantly during the performance of all exercises compared with quiet breathing, while $V_{RCa\%}$ increased significantly during the performance of FIS and SMI exercise. For $V_{AB\%}$, a significant reduction was observed during the performance of all exercises as compared with quiet breathing.

In the analysis of thoracoabdominal asynchrony, no statistically significant differences were observed during the performance of the exercises compared with quiet breathing for PhAng between the rib cage and abdomen. During the performance of FIS and VIS, a significant reduction in PhAng between RCp and RCa compared with quiet breathing was observed. Regarding PhRIB between the rib cage and abdomen, no significant differences were observed during the performance of the exercises compared with quiet breathing. The PhRIB between RCp and RCa was significantly reduced during the performance of all exercises as compared with quiet breathing.

3.2. Comparisons between breathing exercises

Comparisons among exercises were performed using deltas calculated as the difference between each exercise and the resting period prior to it. Fig. 1 presents the results for the breathing pattern variables. No significant differences were observed for V_{cw}, minute ventilation, and respiratory rate for any of the comparisons. The use of VIS promoted a significantly higher Ti and lower V_{cw}/Ti compared with FIS, with no significant difference in the other comparisons.

Fig. 2 presents the results for the percentage contributions of each compartment of the chest wall to the tidal volume. No significant differences were observed among the three exercises for any analysed variable.

Figs. 3 and 4 present the results for thoracoabdominal asynchrony variables, PhAng and PhRIB, respectively. No significant differences in these variables were observed for any of the comparisons performed.

The rating of perceived exertion to breath according to the modified Borg 0–10 Scale was significantly higher after the performance of FIS compared with VIS (1.64 ± 1.22 vs 1.09 ± 0.76; $p =$ 0.02) and to SMI exercise (1.64 ± 1.22 vs 1.03 ± 1.30; p = 0.003).

Table 2
Breathing pattern, chest wall motion and chest wall asynchrony at quiet breathing and during breathing exercises performance.

	BASELINE PRIOR FIS	FIS	P	BASELINE PRIOR VIS	VIS	P	BASELINE PRIOR SMI	SMI	P
V_{cw} (L)	0.57 (0.27)	2.91 (0.75)	≤ 0.01	0.54 (0.18)	2.82 (0.76)	≤ 0.01	0.55 (0.18)	2.73 (0.93)	≤ 0.01
RR (bpm)	14.81 (5.40)	5.24 (1.13)	≤ 0.01	14.98 (4.85)	4.16 (1.27)	≤ 0.01	13.46 (4.20)	4.70 (1.09)	≤ 0.01
VE (L/min)	7.33 (1.76)	14.73 (3.42)	≤ 0.01	7.20 (1.23)	11.16 (2.97)	≤ 0.01	6.70 (1.25)	12.51 (4.67)	≤ 0.01
Ti (s)	1.90 (0.81)	4.01 (1.00)	≤ 0.01	1.85 (0.63)	5.23 (1.42)	≤ 0.01	2.08 (0.87)	4.52 (1.31)	≤ 0.01
V_{cw}/Ti (L/s)	0.32 (0.08)	0.74 (0.11)	≤ 0.01	0.31 (0.06)	0.56 (0.11)	0.001	0.29 (0.06)	0.65 (0.23)	≤ 0.01
V_{RCp}%	38.79 (13.02)	50.21 (4.52)	0.004	39.28 (12.61)	49.38 (6.22)	0.02	39.09 (14.83)	49.34 (7.01)	0.02
V_{RCa}%	8.50 (2.65)	11.19 (2.05)	0.003	8.73 (3.70)	9.81 (2.14)	0.20	8.86 (3.19)	11.24 (3.14)	0.008
V_{AB}%	52.72 (15.07)	38.64 (5.19)	0.003	52.01 (15.34)	40.84 (7.46)	0.02	52.06 (16.60)	39.46 (8.98)	0.01
PhAng									
RC x AB	12.97 (8.21)	8.90 (4.67)	0.07	12.12 (7.62)	8.63 (4.91)	0.10	12.53 (6.76)	12.04 (7.47)	0.47
RCa x RCp	8.96 (4.17)	4.25 (2.14)	0.001	8.97 (7.15)	4.37 (2.04)	0.02	8.34 (7.92)	5.29 (2.95)	0.18
PhRIB									
RC x AB	11.71 (7.00)	9.69 (4.09)	0.52	13.03 (7.17)	10.00 (6.05)	0.16	10.37 (4.94)	8.07 (3.60)	0.28
RCa x RCp	12.52 (8.74)	5.66 (3.11)	0.004	11.57 (7.51)	5.72 (3.61)	0.001	11.85 (6.53)	6.47 (5.85)	0.007

Data are expressed as mean (standard deviation). FIS: flow incentive spirometer; VIS: volume incentive spirometer; SMI: sustained maximal inspiration; V_{cw}: chest wall tidal volume; RR: respiratory rate; VE: minute ventilation; Ti: inspiratory time; V_{cw}/Ti: mean inspiratory flow; V_{RCp}%: percentage contribution of the pulmonary rib cage; V_{RCa}%: percentage contribution of the abdominal rib cage; V_{AB}%: percentage contribution of the abdomen; PhAng: phase angle; PhRIB: inspiratory phase ratio; RC: rib cage; AB: abdomen; RCa: abdominal rib cage; RCp: pulmonary rib cage. P: level of significance (< 0.05).

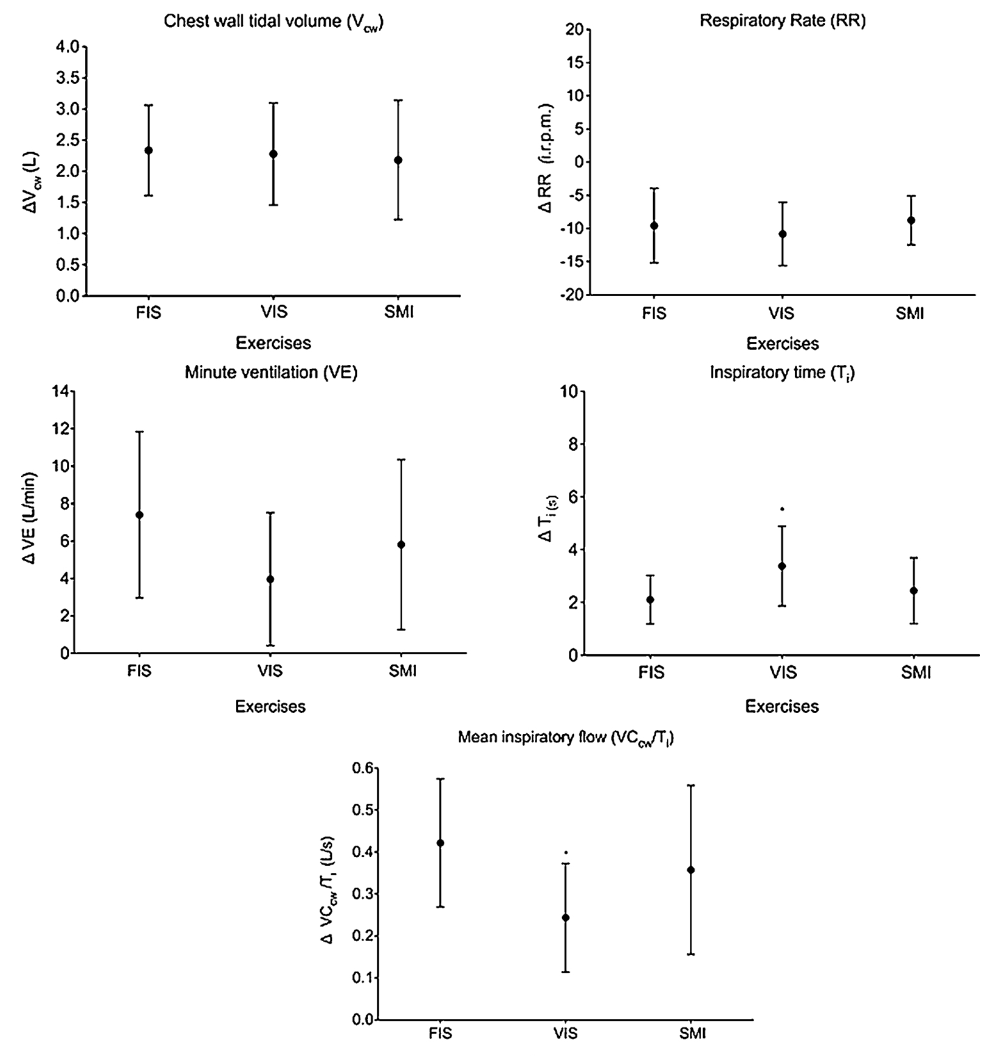

Fig. 1. Breathing pattern data for breathing exercises performance.
Data presented as mean and standard deviation for deltas, calculated as the difference between each exercise and the resting period prior to it. FIS: flow incentive spirometer; VIS: volume incentive spirometer; SMI: sustained maximal inspiration. * $p < 0.05$ for FIS x VIS.

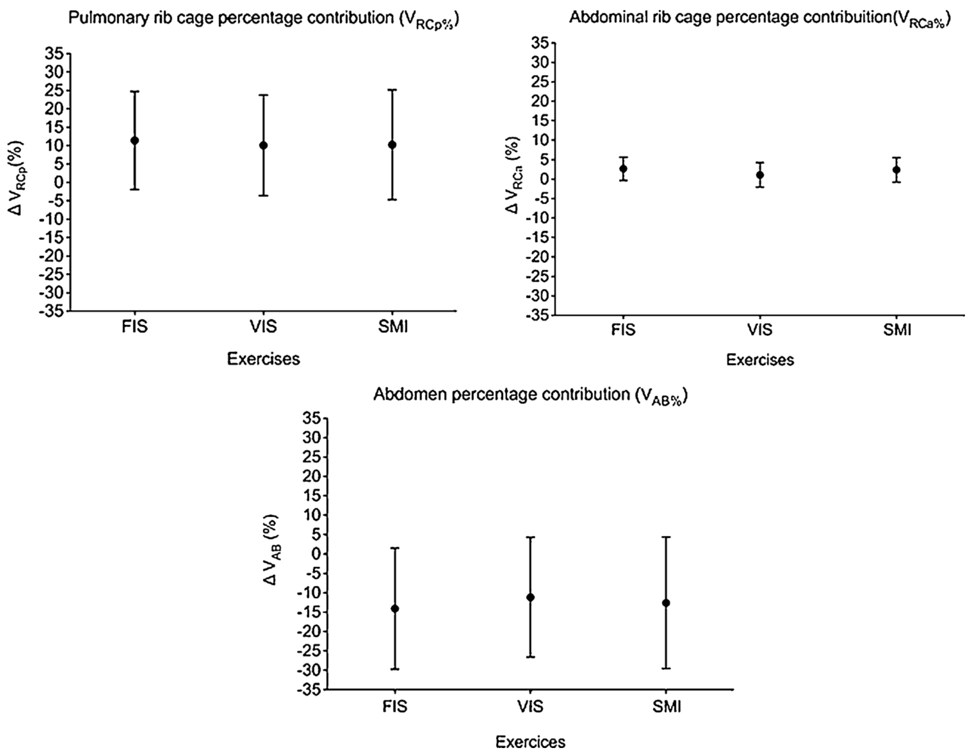

Fig. 2. Chest wall motion data for breathing exercises performance.
Data presented as mean and standard deviation for deltas, calculated as the difference between each exercise and the resting period prior to it. FIS: flow incentive spirometer; VIS: volume incentive spirometer; SMI: sustained maximal inspiration.

4. Discussion

4.1. Main findings

To the best of our knowledge, this is the first study to compare the effects of incentive spirometers (FIS and VIS) and the SMI exercise on breathing pattern, chest wall motion, and thoracoabdominal asynchrony. The main results of this study were as follows: a) The FIS, VIS, and SMI exercise caused significant increase in V_{cw}, minute ventilation, and Ti, in addition to a significant reduction in respiratory rate as compared with quiet breathing. b) VIS was greater than FIS in significantly increasing Ti and reducing V_{cw}/Ti. c) All exercises significantly increased the $V_{RCp\%}$ and significantly reduced the $V_{AB\%}$. d) None of the exercises caused changes in thoracoabdominal synchrony between the rib cage and abdomen.

4.2. Effects on breathing pattern

Considering the exercises' manoeuvre performance, the increase in V_{cw} was expected as was the respiratory rate reduction, because of the performance of a slow, deep inspiration up to total lung capacity, which was associated with a post-inspiratory pause.[9] Our results for V_{cw} and respiratory rate are in agreement with previous studies, which evaluated incentive spirometers or SMI (Tomich et al., 2007, 2010; Paisani et al., 2013; Vieira et al., 2014; Lunardi et al., 2014). Using respiratory inductance plethysmography, Tomich et al. (2017) evaluated the influence of FIS and VIS on breathing pattern and chest wall motion in healthy subjects and obese patients after gastroplasty (Tomich et al., 2010). In both studies, the participants were evaluated with a trunk inclination of 30°, and the spirometers significantly increased tidal volume and reduced the respiratory rate as compared with quiet breathing. Using optoelectronic plethysmography, Paisani et al. (2013) and Lunardi et al. (2014) also observed the same results for both adults and elderly persons, respectively, during incentive spirometer performance in the sitting position without back support. Vieira et al. (2014) evaluated the effect of four breathing exercises, including SMI, on breathing pattern and chest wall motion in conditions similar to those in our study and using the same measurement instrument. They also observed an increase of V_{cw} and a reduction in respiratory rate during SMI exercise performance as compared with quiet breathing. In the

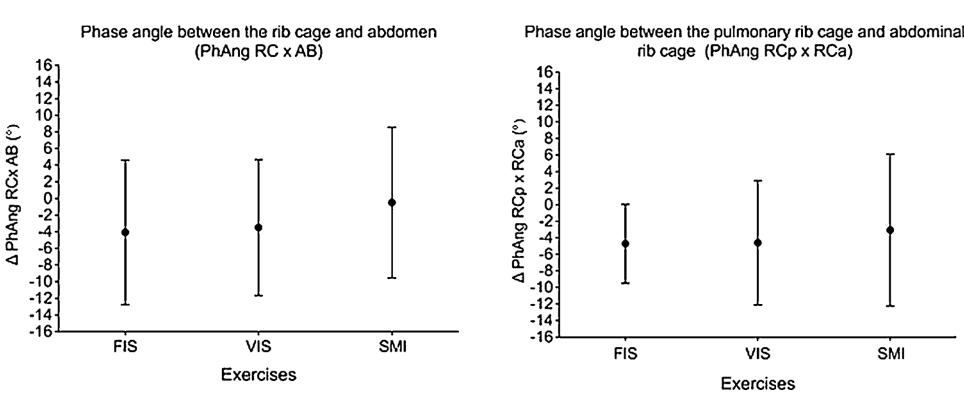

Fig. 3. Phase angle between rib cage and abdomen compartment and between pulmonary rib cage and abdominal rib cage compartments during breathing exercises performance.
Data presented as mean and standard deviation for deltas, calculated as the difference between each exercise and the resting period prior to it. FIS: flow incentive spirometer; VIS: volume incentive spirometer; SMI: sustained maximal inspiration.

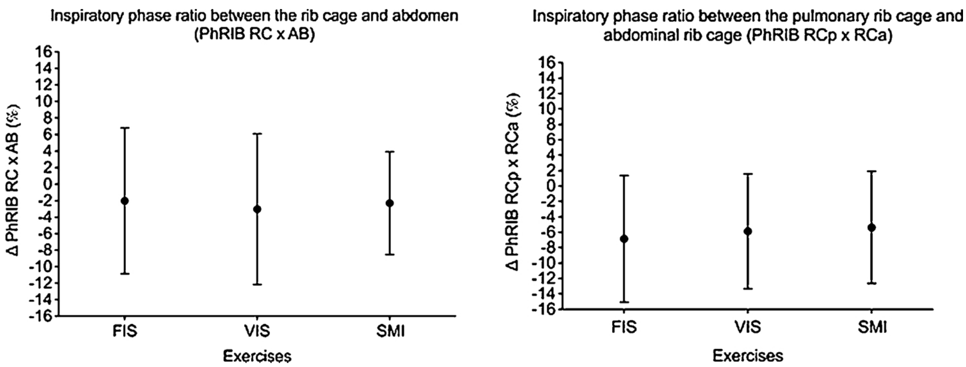

Fig. 4. Phase angle between rib cage and abdomen compartment and between pulmonary rib cage and abdominal rib cage compartments during breathing exercises performance.
Data presented as mean and standard deviation for deltas, calculated as the difference between each exercise and the resting period prior to it. FIS: flow incentive spirometer; VIS: volume incentive spirometer; SMI: sustained maximal inspiration.

exercise comparisons, no differences for these variables were observed. These results are different from previous studies, in which VIS was greater than FIS in increasing V_{cw} and reducing respiratory rate (Tomich et al., 2007, 2010; Paisani et al., 2013).

The V_{cw} increase observed for all exercises was sufficient to compensate for respiratory rate reduction and therefore to cause an increase in the minute ventilation compared with quiet breathing. Tomich et al. (2007) also observed a significant increase in minute ventilation with spirometers as compared with quiet breathing. In our study, no differences among exercises were observed for minute ventilation because of the similarity of the response for both V_{cw} and respiratory rate. These results are different from the study of Tomich et al. (2007), which observed a slighter reduction in respiratory rate during VIS performance, and, consequently, greater values of minute ventilation than during FIS.

The increase in Ti during exercise performance was as expected because of the given instruction to perform deep and slow inspirations. In general, our results are in accordance with previous studies that also observed an increase in Ti over the performance of these exercises compared with quiet breathing in different populations and positions and using different measurement instruments (Tomich et al., 2007, 2010; Paisani et al., 2013; Vieira et al., 2014). However, the literature is more consistent in reporting an increase in Ti during VIS performance as compared with quiet breathing. The increase in Ti during the performance of VIS was not observed in the elderly group by Lunardi et al. (2014). These authors suggested that this is due to physiological changes in the lungs and respiratory system observed with aging. Tomich et al. (2010); Paisani et al. (2013), and Lunardi et al. (2014) did not observe an increase in Ti during FIS performance compared with quiet breathing. Despite the fact that instructions for slow inspiration or slow and deep inspiration were given, it was not mentioned whether participants were able to raise the balls slowly and smoothly to generate a Ti increase.

All exercises increased V_{cw}/Ti compared with quiet breathing, similar to results shown in previous studies (Tomich et al., 2007; Paisani et al., 2013; Lunardi et al., 2014). In addition, during FIS performance, greater V_{cw}/Ti was observed as compared with during VIS. Tomich et al. (2007) also observed greater mean inspiratory flow during FIS performed when raising two balls. We believe these findings are related to the best feedback provided by VIS, which facilitates the performance of a deep inspiration while controlling the velocity of the inspiration. The same result was not observed for individuals after gastroplasty or for adults and elderly participants performing FIS in the sitting position (Paisani et al., 2013), in which the spirometers equally increased V_{cw}/Ti. In addition, it is important to highlight that similar to Parreira et al. (2005) and Tomich et al. (2010), the measured values obtained for inspiratory flow in the present study (740 mL/s) were lower than those required to raise three balls according to the manufacturer (1200 mL/s). The generation of a slow flow associated with the increase in Ti and the post-inspiratory pause might enable the redistribution of air for more peripheral areas and the recruitment of hypoventilated alveoli (McIlwaine et al., 2017). According to McIlwaine et al. (2017), a deep inspiration associated with a post-inspiratory pause is capable of triggering the collateral ventilation such as interalveolar pores of Kohn, bronchiole-alveolar communications of Lambert, and interbronchiolar pathways of Martin by generating a laminar flow, which in turn changes the time constants and allows the air to reach the more peripheral airways. Therefore, we may consider that VIS was the exercise that better met the principles proposed by the technique.

Previous studies have shown that FIS imposed greater work of breathing than VIS (Mang and Obermayer, 1989; Weindler and Kiefer, 2001). Using artificial lungs, Mang and Obermayer (1989) compared six different incentive spirometers and observed that FIS models imposed greater work of breathing when compared with VIS models. These authors also concluded that increased work of breathing by FIS was proportional to increased inspiratory flow. Weindler and Kiefer (2001) evaluated postoperative patients with moderate to high risk for pulmonary complications and observed the work imposed by FIS was twice as high as that of VIS. Later, Tomich et al. (2007) and Paisani et al. (2013), using electromyography, observed greater sternocleidomastoid muscle activity during the performance of FIS compared with VIS. In our study, the electromyography activity of accessory muscles was not evaluated, but FIS presented higher ratings of perceived exertion to breath according to the Borg scale when compared with the other exercises. This suggests that FIS further increased the demand on the respiratory system.

4.3. Effects on chest wall motion

All exercises increased $V_{RCp\%}$ and reduced $V_{AB\%}$ when compared with quiet breathing. This result corroborates the findings of Paisani et al. (2013), Lunardi et al. (2014), and Vieira et al. (2014), who also observed an increase in $V_{RCp\%}$ during incentive spirometer performance and during SMI exercise as compared with quiet breathing. Vieira et al. (2014) also observed a reduction in $V_{AB\%}$ when performing SMI exercise, similar to our results. The performance of the exercises proposed in this study does not require directing the ventilation to specific lung areas, such as diaphragmatic breathing, which instructions to perform the exercise includes directing the air to the abdomen. Instruction to reach total lung capacity was given, which might explain the increase in $V_{RCp\%}$.

Studies have demonstrated that posture influences chest wall motion with a greater contribution from the abdomen in more horizontal trunk positions (Wang et al., 2009; Romei et al., 2010). Therefore, in individuals in the supine position with 45° of trunk inclination during quiet breathing, the abdomen has a greater contribution for V_{cw}. During the performance of the exercises proposed in this study, the air may be directed to the rib cage, consequently reducing $V_{AB\%}$. Paisani et al. (2013) and Lunardi et al. (2014), contrary to our findings, observed an increase in $V_{AB\%}$ during the performance of the incentive spirometer compared with quiet breathing. These differences might be justified by the fact that exercises were performed in the seated position, in which the abdomen compartment contributes less to tidal volume at quiet breathing. Tomich et al. (2007) did not observe changes in rib cage or abdomen contributions during the incentive spirometer performance in the supine position with 30° of trunk inclination when compared with quiet breathing. We believe that this occurred because participants were instructed to perform the exercises avoiding rib cage displacement, therefore promoting redistribution of the air among all the compartments without predominance of any of them.

In some studies (Tomich et al., 2007, 2010; Yamaguti et al., 2016), individuals are instructed to perform incentive spirometers emphasizing the displacement of the abdomen over the inspiration. We believe this occurs because previous studies have shown that during deep breaths, the increase in $V_{AB\%}$ can be strongly related to the larger diaphragmatic excursion (Wang et al., 2009; Yamaguti et al., 2016). This information is especially important in subjects undergoing upper abdominal surgery. Diaphragmatic inhibition caused by anaesthesia, associated with reduced abdominal compartment displacement due to pain, results in reduced ventilation in basal regions of the lungs, predisposing patients to secondary pulmonary complications (Alaparthi et al., 2016). Therefore, in this population, the stimulation of deep breaths associated with directing the ventilation to the abdomen might be important to the reversion of this abnormal breathing pattern. However, this instruction is not included in the guideline for incentive spirometry performance (Restrepo et al., 2011). In addition, physiotherapists might use diaphragmatic exercise, which is a specific exercise, to increase the direction of ventilation for this compartment (Alaparthi et al., 2016).

4.4. *Effects on thoracoabdominal asynchrony*

Thoracoabdominal asynchrony was evaluated in this study using PhAng and PhRIB. PhAng is the most widely used index in the literature (Tomich et al., 2007; Paisani et al., 2013; Lunardi et al., 2014). However, for its calculation, it is assumed all curves of the respiratory cycle are sinusoidal, and therefore, non-sinusoidal curves may compromise its quantification (Vieira et al., 2014). In contrast to the results observed both for healthy individuals (Tomich et al., 2007) and individuals after gastroplasty (Tomich et al., 2010), in our study incentive spirometry did not increase the PhAng between the rib cage and abdomen. However, the participants were evaluated in the supine position with 30° of trunk inclination, and the measurement instrument used was different, which makes it difficult to compare the results. On the other hand, our findings were similar to those found by Vieira et al. (2014) for comparisons between SMI exercise and quiet breathing and by Paisani et al. (2013) for comparisons between incentive spirometer and quiet breathing using the same instrument of this study. Between the RCa and RCp compartments, SMI exercise was the only exercise that did not reduce asynchrony for PhAng, similar to the study by Vieira et al. (2014). To our knowledge, only this study has evaluated asynchrony between these compartments.

PhRIB is used for asynchrony quantification without assuming the curves have a sinusoidal pattern (Reber et al., 2002). Contrary to what was observed by Tomich et al. (2010), who found a significant increase in PhRIB between the rib cage and abdomen during FIS performance compared with quiet breathing, no differences were found in our study. Vieira et al. (2014), on the other hand, presented similar results to ours regarding the absence of a statistically significant change in PhRI between the rib cage and abdomen during SMI exercise performance compared with quiet breathing. To our knowledge, the study by Tomich et al. (2007) is the only study to evaluate the influence of incentive spirometers for this variable. However, the measurement instrument was inductive plethysmography, and the participants were positioned with greater trunk inclination.

4.5. *Study strengths and limitations*

Several studies on breathing exercises have been published (Lunardi et al., 2014; Alaparthi et al., 2016, 2013; Kumar et al., 2016; Lunardi et al., 2015; Overend et al., 2001). However, most were focused on studying the effects of these exercises on the prevention of postoperative pulmonary complications (do Nascimento et al., 2014), and only a small number of studies (Tomich et al., 2007; Paisani et al., 2013; Lunardi et al., 2014; Tomich et al., 2010; Vieira et al., 2014) have investigated the mechanisms involved in performing the exercises and the differences between them. In addition, there is great variability in the instructions given for the performance of the exercises, in the positioning of the participants, and in the measurement instruments used.

Our results confirmed once again the superiority of VIS compared with FIS for Ti and V_{cw}/Ti. Therefore, it is suggested that this resource may be the most appropriate to promote a slower and deeper inspiration according to the technique proposal. These results are possibly caused by the visual feedback provided by the instrument, which allows monitoring the flow quality and consequently promoting slower inspiratory flow.

Despite the fact that the literature is consistent in reporting VIS superiority when compared with FIS, FIS is still widely used by physiotherapists in clinical practice. This is possibly justified by the fact that VIS is considerably more expensive. In the attempt to present a cost-free alternative for clinical use to replace FIS, this study aimed to investigate the mechanisms involved in SMI exercise and to compare its effects with those promoted by the spirometers. Unexpectedly, our results showed that SMI exercise was also equivalent to VIS and therefore would be an interesting alternative for clinical use when there is an impossibility of acquiring both devices. However, the visual feedback provided by the devices should be considered, and futures studies evaluating patient compliance and preference when performing breathing exercises with or without devices should be performed.

Despite the unfavourable results for FIS as compared with VIS (Mang and Obermayer, 1989; Weindler and Kiefer, 2001; Tomich et al., 2007, 2010; Paisani et al., 2013; Lunardi et al., 2014), further studies focused on this device should be performed. Chang et al. (2010) suggested that the use of lower inspiratory flow is more determinant for chest wall motion than the type of device used, since lower inspiratory flows were associated with greater displacement of the abdomen than higher flows. In addition, they reported that the generation of higher flows, and not the device used, might result in accessory muscle activation, whereas lower flows may selectively activate the diaphragm. Therefore, future studies to compare the effects of elevating fewer balls and the differences in breathing pattern and chest wall motion should be conducted. We emphasize that in the present study, the instruction for three-ball elevation during FIS followed the recommendations of the manufacturer's manual; however, during the exercise, instructions to perform slow and deep breathing were reinforced while the balls were raised smoothly and uniformly. This reinforced instruction might have contributed to the results for FIS found in the present study, which were not as unfavourable as compared with VIS.

5. Conclusion

From our results, we conclude that SMI exercise was equivalent to the spirometers and might be an alternative in cases in which it is not possible for the patient to buy one of the devices. These findings may be used to help physiotherapists choose the most adequate method based on the intended goal.

Studies on patients with cardiorespiratory dysfunctions are important to understand the mechanisms involved in performing breathing exercises in this population.

Ethics approval

The study was approved by the Ethics Committee.

Conflict of interest

No conflicts of interest, financial or otherwise, are declared by the author(s).

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