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Research article

Repeated abdominal exercise induces respiratory muscle fatigue

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Abstract
Prolonged bouts of hyperpnea or resisted breathing are known to result in respiratory muscle fatigue, as are primarily non respiratory exercises such as maximal running and cycling. These exercises have a large ventilatory component, though, and can still be argued to be respiratory activities. Sit-up training has been used to increase respiratory muscle strength, but no studies have been done to determine whether this type of non-respiratory activity can lead to respiratory fatigue. The purpose of the study was to test the effect of sit-ups on various respiratory muscle strength and endurance parameters. Eight subjects performed pulmonary function, maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) measurements, and an incremental breathing test before and after completing a one-time fatiguing exercise bout of sit-ups. Each subject acted as their own control performing the same measurements 3-5 days following the exercise bout, substituting rest for exercise. Following sit-up induced fatigue, significant decreases were measured in MIP [121.6 ± 26 to 113.8 ± 23 cmH_2O (*P* <0.025)], and incremental breathing test duration [9.6 ± 1.5 to 8.5 ± 0.7 minutes (*P* <0.05)]. No significant decreases were observed from control pre-test to control post-test measurements. We conclude that after a one-time fatiguing sit-up exercise bout there is a reduction in respiratory muscle strength (MIP, MEP) and endurance (incremental breathing test duration) but not spirometric pulmonary function.

Key words: Maximal inspiratory pressure, endurance breathing test, inspiratory muscles, sit-ups.

Introduction

Few studies have been conducted to evaluate non-respiratory exercises and how these affect respiratory muscle strength and endurance. Non-respiratory maneuvers have been found to activate the diaphragm to varying degrees depending on the type of exercise (Al-Bilbeisi and McCool, 2000; Strongoli et al., 2008). Al-Bilbeisi and McCool (2000) evaluated the use of sit-ups, bench press, biceps curls and a power lift to examine which had the greatest effect on transdiaphragmatic pressure (Pdi); concluding Pdi was at a maximum while inhaling during the sit-up exercise. In preliminary work in our laboratory, we evaluated several core exercises ranging in difficulty and found a wide range of transdiaphragmatic pressures elicited, with conventional sit-ups yielding the highest pressures (Strongoli et al., 2008).

Depalo et al. (2004) conducted a study that examined the effect of a 16 week sit-up and biceps curl training program on various respiratory measures including diaphragm thickness, maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP). Significant increases were seen in all measurements. The increase in diaphragm thickness was a novel finding, providing a solid link between training using a non-respiratory exercise and its direct effect on the hypertrophy of a key inspiratory muscle.

Previous studies provide conclusive evidence that abdominal muscles are key muscles in ventilation, but the effect ventilation has on expiratory muscle activity has not been examined to the extent as have inspiratory muscles. Suzuki et al. (1991) used expiratory loaded breathing bouts to exhaustion and found MEP to decrease following all loads used and MIP to decrease following the highest two of the three loads. Kyroussis et al. (1996) investigated the effect of maximal isocapnic ventilation (MIV) on abdominal muscle fatigue. Following two minutes of MIV, twitch gastric pressures (elicited via magnetic stimulation of abdominal muscles) demonstrated significant reductions from baseline and remained lower 90 minutes following the ventilation bout.

A study conducted by Hamnegard et al. (1996) provided a connection between maximum ventilation and respiratory muscle fatigue (specifically the diaphragm). Following a MIV bout lasting for two minutes, significant decreases in twitch transdiaphragmatic pressures were measured. Johnson et al. (1993) provided a similar connection. They used bilateral phrenic nerve stimulation (BPNS) before and after subjects exercised at 85 and 95 percent of VO_2 max for an extended period of time. Diaphragm fatigue resulted following the endurance exercise bout showing a relationship between ventilation (induced by the endurance exercise) and respiratory muscle fatigue.

The studies by Kyroussis et al. (1996) and Hamnegard et al. (1996) demonstrated fatigue was induced by maximal ventilation. We were interested, however, in another aspect of this question, the idea of using abdominal muscle exercise and examining the effect non-respiratory exercises to fatigue have on respiratory muscle strength (MIP, MEP) and endurance using an incremental breathing test (IBT). To our knowledge, this has not been studied. Further, respiratory endurance has not been studied in any way related to abdominal exercise. The purpose of the current study was, therefore, to examine the effect of sit-ups on four respiratory parameters, forced vital capacity (FVC), MIP, MEP, and an incremental breathing test (IBT). We hypothesized performing a sit-up bout to fatigue would produce a decrease in MEP (abdominal muscles being primarily expiratory), the incremental breathing test, the MIP measurement and elicit no change in FVC.

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Methods

Subjects

Eight healthy subjects (4 male, 4 female) between the ages of 21 and 53 years were recruited for the study. The subjects had a mean height of 1.75 ± 0.10 m and a mean weight of 64 ± 29 kg and all were in good health, with normal pulmonary function as defined by FVC and $FEV_{1.0}$ values ranging from 99.5 to 128.5 percent of predicted (Knudsen, et al 1976). The subjects regularly engaged in physical activity ranging from recreational running and cycling to competitive running, cycling, and swimming. The study was approved by the Institutional Review Board (IRB) at Northern Arizona University.

Study design

Subjects visited the lab three times. On the first visit subjects signed an informed consent document and had all procedures explained to them. Subjects were then given the opportunity to practice measurements (FVC, MIP, MEP and IBT in order) that would be conducted on exercise and control days.

The second visit was the exercise day. Subjects performed the same four measurements before and after a bout of sit-ups to task failure. Sit-ups were performed with arms crossing the chest and knees bent to approximately 90° with the subjects' feet anchored. Subjects sat up until the elbows touched the knees, leaving the torso approximately 75-90° from the floor. Subjects were also asked to inhale as they performed the ascending contraction and exhale as they relaxed and returned to the supine position (Al-Bilbeisi and McCool, 2000). Subjects performed 30 sit-ups per minute. This was completed in sets of 30 sit-ups with one minute rest between sets until they could no longer perform at least 15 sit-ups (a 50% reduction). The duration subjects performed sit-ups was monitored and recorded. A metronome set at sixty beats per minute was used to keep the subjects on a one second ascending contraction and one second descending relaxation, allowing two seconds to complete one full sit-up. When subjects could no longer keep pace, they performed sit-ups at their own pace. If the subject completed more than ten sets of sit-ups (300 total) on pace, recovery time was cut in half to 30 seconds. Subjects were stopped and time was recorded if 20 sets of sit-ups (600 total) were performed. At the end of the sit-up bout, subjects again completed the four measurements (FVC, MIP, MEP, IBT) within approximately ten minutes of the completion of the exercise.

The third visit was the control day. This session took place a minimum of three days following the exercise session to allow recovery. Subjects performed the same protocol as the exercise day substituting rest for sit-up exercise duration.

Measurements

Measurements conducted pre and post exercise and pre and post rest included FVC, MIP, MEP, and an IBT. FVC was measured using a standard spirometer (Spirometrics, Inc., Auburn, ME). Subjects were asked to inhale maximally then expire as quickly and as forcefully as possible and encouraged to continue until a plateau in the spirogram was observed. MIP was measured as outlined by the American Thoracic Society (ATS)/ European Respiratory Society (ERS) statement (2002) on respiratory muscle testing. Subjects were asked to exhale to residual volume (RV) and then inhale maximally against an occluded airway (S&M Instrument Company INC., Doylestown, PA). MEP was measured as outlined by the ATS/ERS statement on respiratory muscle testing. Subjects were asked to inhale to total lung capacity (TLC) and then maximally exhale against an occluded airway using the same apparatus that was used for the MIP measurement.

IBT was modeled after a study conducted by Vilozni et al. (1987). Subjects were asked to begin breathing at 20 $L{\cdot}min^{-1}$ for females and 30 $L{\cdot}min^{-1}$ for males for two minutes. When two minutes were complete, subjects were asked to increase breathing rates by 20 $L{\cdot}min^{-1}$ for women and 30 $L{\cdot}min^{-1}$ for men. Following each two minute stage the same increases were implemented and subjects continued until they could no longer achieve the target ventilatory level, this was considered fatigue (Bai, et al., 1984). Dead space was added to prevent subject discomfort. For ventilation levels up to 60 $L{\cdot}min^{-1}$, a 1100 ml tube was placed between the breathing valve and the subject, while for ventilation exceeding 60 $L{\cdot}min^{-1}$, a dead space tube of 1850 ml was used. Ventilation was measured using a volume meter (Rayfield Equipment, Waitsfield, VT) and displayed on-line in order to provide feedback for the subjects. Time to fatigue was recorded as ventilation duration.

Anthropometric measurements were used to estimate normal lung volumes. The MIP and MEP measurements were repeated three times pre and post exercise and control and the average of the two highest values within 5 cm H_20 was taken for each occasion. FVC was also repeated three times pre and post exercise and control and the highest value was recorded for each. IBT duration and maximum ventilation rate were recorded when the subject stopped the test.

Statistical analysis

Data for all measurements are presented as means ± standard deviation (SD) for the control and the exercise conditions. Statistics were calculated using a two-way [time (pre-post) x condition (sit-up vs control)] repeated measures ANOVA for each measurement (MIP, MEP, FVC, IBT). Where significant main effects were found, *post hoc* analyses were calculated using the Student-Neuman-Keuls method. A level of $p < 0.05$ was taken as significant for FVC and IBT duration. A level of $P < 0.025$ was taken as significant for MIP and MEP using the Bonferroni adjustment because of the related nature of the variables.

Results

All subjects completed the experimental protocol. There were no significant differences measured between the pretest exercise or control measurements, indicating that the exercise test did not affect the MIP, MEP, IBT or pulmonary function control test performed several days after the exercise. The number of sit-ups performed by the subjects ranged from 114 to 600. None complained of any sense of breathlessness, indicating that ventilatory demand was not an issue in the task.

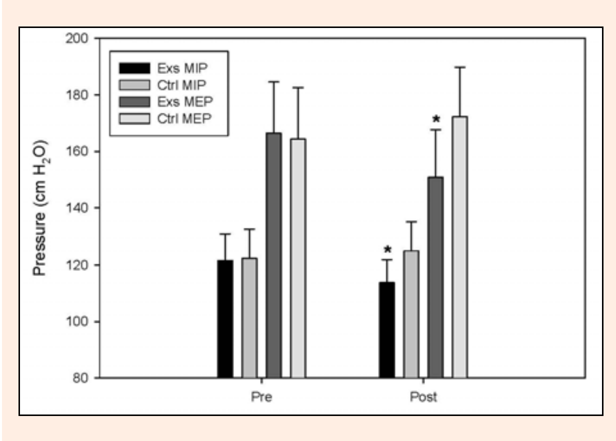

Figure 1. This figure shows pressures elicited during and after the exercise and control studies. Bars are according to legend * = different from Pre value.

Task failure induced via sit-up exercise was associated with decreases in respiratory muscle strength. MIP decreased 6.4% from 122 ± 26 to 114 ± 23 cmH_2O ($p < .025$). MEP decreased 9.4 % from 167 ± 51 to 151 ± 47 cmH_2O ($p < .025$) (Figure 1). Respiratory muscle endurance also decreased as a result of abdominal exercise. IBT duration decreased 11.5 % from 9.6 ± 1.5 to 8.5 ± 0.7 minutes (p < 05) as seen in Figure 2. No decreases were associated with fatigue in the FVC values. No significant differences were measured in any of the control measurements between days.

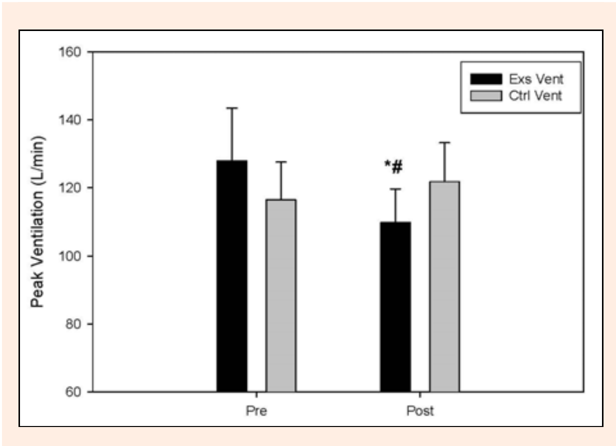

Figure 2. Peak ventilation achieved during the incremental breathing task. Bars are according to legend * = different from Pre value; # = different from control.

Discussion

The primary finding of this study was that the implementation of sit-up exercise to exhaustion induced significant decreases in measures of respiratory muscle strength (MIP, MEP) as well as respiratory muscle endurance as demonstrated by the IBT task. This was the first time decreases in respiratory muscle strength and endurance measures were recorded following a primarily non-respiratory maneuver (abdominal sit-ups). It was hypothesized that decreases would be seen in strength measurements since previous studies have shown that abdominal training elicited increases in respiratory strength measurements (Al-Bilbeisi and McCool, 2000; DePalo et al., 2004), however this was still a novel finding. Respiratory muscle endurance had not been studied in relation to any indices of abdominal exercise or training prior to the current study. Kyroussis et al. (1996) demonstrated an important link between maximum ventilation and abdominal muscle fatigue. They showed that two minutes of maximal isocapnic ventilation reduced twitch gastric pressures. In our study, we looked in the opposite direction and showed that abdominal exercise to task failure decreased inspiratory muscle strength.

The present findings support the idea respiratory muscles can be fatigued via a primarily non-respiratory maneuver. In this study, sit-ups to exhaustion resulted in significant decreases in achieved strength measures as shown by MIP (6.4% decrease) and MEP (9.4 % decrease). Respiratory muscle endurance measures were also decreased as elicited by the reduction in IBT duration (11.5% decrease).

Previous studies have shown similar results after a fatiguing bout of exercise. In a study conducted by Taylor et al. (2006), a mean reduction in MEP from 158 ± 13 to 145 ± 10 cmH_2O (an 8.2% decrease) followed 30 minutes of cycling exercise to exhaustion. That study, though, involved significant ventilatory demand, which would specifically fatigue both the inspiratory and expiratory muscles.

In another investigation conducted by Perret et al (1999), an exhaustive cycling bout of exercise resulted in reductions in time to task failure (364 ± 88 s before exercise to 219 ± 122 s five minutes post exercise, a 39% decrease) while breathing against a resistive device. Reduction in time to task failure was highly significant and showed greater results than the current study. However, the breathing protocol was a resistive protocol including cycling exercise whereas the current study used an incremental protocol (without resistance or exercise) to failure. There have been studies in which increased force, rather than flow, was used to cause fatigue. Roussos and Macklem (1977) showed that during a restricted breathing test, when transdiaphragmatic pressures exceeded 60% of maximal, fatigue ensued within approximately six minutes.

We chose to use the incremental breathing protocol in place of the maximum ventilation protocol as it was highly repeatable between subjects in our lab group; also notable was the apparent equality between pre-test and post-test IBT duration control values (9.2 ± 1.8 min versus 9.2 ± 1.1 min). Previous studies which used threshold loading were also a basis for the decision. In a study conducted by Martyn et al. (1987), the comparison of an incremental threshold loading endurance protocol with a maximal threshold endurance protocol demonstrated less intra-individual variability. Although the current study was not a threshold loaded respiratory endurance test the methods were similar to two different unloaded respiratory endurance tests. The MVV test conducted by Kyroussis et al. (1996) and the incremental protocol modeled after Vilozni et al. (1987) were two similar unloaded tests and again the incremental protocol appeared to have less intra-individual variability.

Although the measures of respiratory muscle strength and endurance were volitional the results exhibited were significantly decreased whereas measurements of lung volumes (which were also volitional) showed no change. Since the lung volume measurements are also volitional, this argues that simply global fatigue as a result of the sit-up bout was not the cause of the decreases in strength and endurance measurements seen in this study.

Decreases in the various measures following the abdominal fatigue bout could also be due to the demands of the incremental breathing task itself. This activity does result in some generalized fatigue as reported by the subjects. On the control day, though, (when no abdominal exercise was performed) the IBT duration, as well as the values for MIP and MEP were not different between the pre and post measurements.

A connection between abdominal muscle exhaustion and an incremental breathing task has not previously been studied. The diaphragm (being the main inspiratory muscle) is most active during inspiration contracting inferiorly causing the abdominal contents to move anteriorly (Ward et al., 1983). Inducing a bout of sit-ups where the subject must inhale while performing the exercise increases intra-abdominal pressure creating additional diaphragmatic resistance. Increased intra-abdominal pressure may be one of the underlying factors contributing to the decreases observed in respiratory muscle strength and endurance. Diaphragmatic fatigue was likely one of the main causes of the resultant fatigue incurred during the incremental breathing task; the other being related to the respiratory muscles that expand the chest wall.

Additional fatigue induced via inhalation during abdominal exercise can prove to be important in various areas of respiratory training. Those in disease states may benefit from this type of training if this activity is implemented during any core exercise they may employ. Further study of the idea (core training with inhalation) needs to be investigated in order to give validity to these claims. While sit-ups invoke activity in muscles other than the abdominal groups, we chose that exercise based on our preliminary work (Strongoli et al., 2008) which showed the highest transdiaphragmatic pressures and highest likelihood of activating the diaphragm during the activity.

Conclusion

We conclude that implementing a primarily non respiratory activity (sit-ups) induces fatigue on respiratory muscle endurance, consequently eliciting a reduction in time to fatigue on an incremental breathing protocol; also showing a reduction in respiratory muscle strength via MIP and MEP measurements. Further investigation is needed in order to examine the effect training will have on these respiratory parameters.

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Key points

- Exercise that is primarily abdominal in nature can lead to inspiratory muscle fatigue.
- This exercise also can cause expiratory muscle fatigue, which would be expected.
- This study shows a link between a predominantly non-respiratory exercise and decreases in both respiratory muscle strength and endurance.

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