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Pattern of respiratory muscle activity during exercise tests in children born prematurely

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A B S T R A C T

Introduction: Preterm children display only slightly lower exercise capacity than term children do during their development, despite their previous cardiopulmonary impairments. This raises doubts about the role of the respiratory muscles' influence on exercise capacity. This study aimed to compare respiratory muscle activity in preterm and term children using an exercise test.
Methods: This cross-sectional study involved comparison of 35 term children and 39 matched preterm children aged 6–9 years, who were born prematurely with a birth weight <1500 g. An adapted treadmill incremental test was utilized and surface electromyography of the sternocleidomastoid (SCM), upper trapezius (UT), and rectus abdominis (RA) muscles was performed. The root mean square was calculated every minute and compared between and within groups. A Monte Carlo simulation was also applied, and the area under the curve was calculated to evaluate the differences between groups.
Results: During the entire exercise, the SCM muscle activity was higher in preterm children with a larger area under the curve than in the term children. There was no difference in the RA and UT muscle activity between groups throughout the test.
Conclusion: The results suggest a greater contribution of the SCM muscle sin preterm children's performance than in term children's performance during high-intensity exercises.
Trial registration: Brazilian Clinical Trial Registry (ReBec) - RBR-89hr2h.

1. Introduction

Exercise capacity can be expressed as the amount of physical effort that can be sustained during a certain activity (American Thoracic Society and American College of Chest Physicians, 2003; Armstrong and Welsman, 2006), and it is influenced by pulmonary, cardiovascular, and musculoskeletal conditions. During exercise, the respiratory muscles are progressively recruited in the frequency and volume of chest muscle contractions as speed increases.

Studies in adults and children have shown that during rest, only the diaphragm and external intercostals are active, while other respiratory muscles remain at rest. However, during intensive exercise, the abdominal muscles, can contribute to increases in the respiratory rate and tidal volume (Verges et al., 2006) as activation of accessory breathing muscles (the sternocleidomastoid [SCM] and trapezius muscles) occurs with an increase in loads (Aslan et al., 2019; de Sá et al., 2017; De Waal et al., 2017; Sekiguchi et al., 2018; Washino et al., 2019).

In children born prematurely due to a large ventilatory demand during the neonatal period, there is a need of an increasing in respiratory muscle recruitment during this period (Maarsingh et al., 2000, 2006). This may persist for long time and may lead to adaptations to pulmonary function alteration and increase in working of breathing, causing thoracic musculoskeletal changes in medium and long term. In studies of our group, we've demonstrated that about 40% and 70% of children less than 1 year old born

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prematurely had abnormal pulmonary function and thoracic changes such as shoulder elevation, respectively. In those former studies, these alterations were associated to the need for mechanical ventilation in the neonatal period and/or bronchopulmonary dysplasia (Davidson et al., 2012; Gonçalves et al., 2018). These findings may suggest that preterm infants might develop hypertrophy of accessory muscles as ECM and trapezius as a consequence of respiratory impairments (Davidson et al., 2012). In this sense, the best way to evaluate the actual performance of the respiratory muscles is through electromyography (EMG). This exam might provide a better understanding of the respiratory pattern and its control during heavy physical activities. Furthermore, EMG evaluation have shown a good correlation between pulmonary conditions and muscles action (Maarsingh et al., 2000, 2006; Fokkema et al., 2006; Hutten et al., 2010).

In this context, understanding the pattern of respiratory muscles action during high performance in child born prematurely it would be useful to plan and step some intervention to improve postural and biomechanics pattern.

Therefore, to test the hypothesis that preterm children behave differently in their breathing strategy to achieve adequate ventilation, especially when the load on the respiratory system is further increased, we compared the EMG of the 2 main accessory respiratory muscles and 1 expiratory muscle that are mainly recruited during heavy exercise in children.

2. Methods

2.1. Study design and participants

This was a cross-sectional study that included children aged 6–9 years born before 37 weeks of gestation, with a birth weight of< 1500 g who were followed up at the Neonatal Outpatient Clinic at the Federal University of São Paulo, SP, Brazil. The control group was composed of healthy term children of the same age.

This study was approved by the Ethics Committee of the Federal University of São Paulo, and Informed Consent forms were signed by parents or guardians, and assentiment form was obtained from children included in the study and it was registered in Brazilian Clinical Trial Registry (ReBec) on number RBR-89hr2h.

Exclusion criteria were respiratory disorders such as wheezing and/or respiratory distress in the 2 weeks prior; acute pulmonary disease diagnosed by a physician; neurological and/or cognitive impairment that prevented understanding of the test; gait dysfunction; fractures and lower limb surgery in the previous 6 months; hemodynamic alterations at rest such as tachycardia and/or hypertension (National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents, 2004); and hospitalization in the previous 3 months.

The children's demographic and clinical data were collected by chart review and/or interviews with parents or guardians. Weight and height measurements were obtained using an eye-level mechanical beam physicians' scale with a height rod (FilizolaPL200, São Paulo, Brazil) by 2 unblinded researchers who had been previously trained to perform these measurements according to World Health Organization recommendations (WHO Expert Committee, 1995).

After these measurements, the children remained seated for 10 min before collection of data on the following vital signs: blood pressure, heart and respiratory rate, and degree of dyspnea perception at rest using a visual analogue scale (VAS) (Lee et al., 2016; Camargo Corcioli et al., 2017).

2.2. Exercise treadmill test

Before beginning the treadmill test, the children were instructed to wear shorts and comfortable shoes and allowed no vigorous physical activity 2 h before the test.

An adaptation of the Balke treadmill test was used to evaluate the children's respiratory muscle activity (Wasserman et al., 2005). A mobile and gradual handrail was fixed on the treadmill in order to allow the children to hold a front handrail, maintaining shoulder flexion between 30 and 45°, with their hands supported throughout the test.

After the rest stage, a warm up stage (1.0 mph) was performed for 3 min. This was followed by the exercise stage where the speed was increased in accordance with an incremental protocol (Karila et al., 2001) based on a fixed speed of 3.5 mph for children aged 6 and 7 years and 4.0 mph for children aged 8 and 9 years. After the first minute of the exercise stage, a 2° grade increase was initiated every minute until a 10° grade was reached. If children reached the maximum grade, the speed was increased by 0.5 mph every minute until maximum effort was attained (Wasserman et al., 2005; Powers, 2015). The test was completed after 5min of recovery (speed 1.0mph and 0° grade).

The degree of the children's efforts was verified and their maximum heart rate (HR_{max}) for their ages was calculated and verified throughout the test (Karila et al., 2001)for their safety.

The test was interrupted if: severe fatigue and/or respiratory effort occurred (estimated by a VAS >7) (Lee et al., 2016; Camargo Corcioli et al., 2017), the child requested it, or 85% HR_{max} for their age was reached.

2.3. Surface electromyography data collection

A signal acquisition system: 830C EMG system® (São José dos Campos, Brazil), containing 6 channels was used to collect and process the electromyography (EMG) signals. The established frequency for the acquisition of EMG recordings was 2 kHz, with a band pass filter with cut-off frequencies of 20–500 Hz, an amplifier gain of 1,000, and a common rejection mode ratio of <120 dB. All data were acquired and processed using a 16-bit analog-to-digital converter.

Three superficial muscles were analyzed: the SCM, upper trapezius (UT), and rectus abdominis (RA). Initially, local cleansing was performed using alcohol followed by slight skin abrasion to reduce impedance. A 4.2-mm diameter Medi-trace™ 100 double self-adhesive pediatric Ag/AgCl electrode with a conductive hydrogel surface composition (Kendall, Mansfield, Canada) was placed on each muscle with a center-to-center distance of 20 mm according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) (Hermens et al., 2012) by a single researcher. Muscle palpation and a series of isometric contractions for the specific muscles were also used for signal validation.

Data acquisition was recorded during the entire test and was analyzed according to a mathematical routine previously developed where the root mean square (RMS) calculation included 30 s of each minute normalized by the grade of the treadmill. Exercise period was analyzed up to the 6^{th}minute and final exercise minute was defined as the last minute before recovery period.

2.4. Statistical analysis

To characterize the sample, a descriptive analysis using mean and standard deviation or median and quartile (Q1-Q3) was performed for numeric variables and using number and frequency for categorical variables. Continuous data were analyzed using the

Student's *t*-test or the Mann-Whitney test. The chi-squared test or Fisher's exact test was used for categorical variables.

The normality of EMG data showed asymmetrical distributions according to the Shapiro-Wilke test. The Mann-Whitney test followed by a Monte Carlo simulation (10,000 cases) was applied in order to verify the difference between groups per minute [rest, warm up, exercise (1st to 6th minute), and the final stage] and to analyze the sample power of the study (Williams et al., 2007).

Repeated measures were contrasted by the Friedman's test and differences between the measures in each group were tested by the Wilcoxon test with p-values adjusted according to the number of repetitions of the measures.

The area under the curve (AUC) was calculated according to the trapezius method to analyze the amount of electrical signal of each muscle and then compared between the preterm and term groups.

Data analyses were performed using SPSS 22® (IBM, New York, USA) and p-values were considered at 5%.

3. Results

Ninety-three children, 46 (49%) females and 47 (51%) males, were recruited for this study, but 9 (9.6%) parents of children in the preterm group declined participation. Of the remaining 84 children, 7 (8.1%) presented with loss of EMG signal during the test (1 from the term group and 6 from the preterm group), 2 (2.3%) discontinued the test before completion (1from each group) due to tachycardia and/or fatigue before the 6thmin (a pre-condition of an adequate maximum test) (Powers, 2015; VanBrussel et al., 2019), and 1 (1.2%) child in the term group presented with resting tachycardia; all 10 were excluded. Finally, 74 (77.9%) children were examined: preterm group, n = 38; term group, n = 36.

There were no differences between groups in relation to general conditions or levels of physical activity, except for birth weight and gestational age (Table 1).

Regarding the clinical status in the neonatal period, 21 (55.3%) children in the premature group presented with respiratory distress syndrome, 11 (28.9%) presented with patent ductus arteriosus, 14 (36.8%) preterm children required mechanical ventilation for a mean of 7 ± 10 days, 16 (42.1%) were oxygen dependent 28 days after birth, and 10 (26.3%) were oxygen dependent at 36 weeks (calculated using the corrected gestational age). The duration of hospitalizations in the neonatal unit for those born prematurely was 58 ± 22 days.

During the exercise stage, the preterm group showed statistically higher SCM EMG activity from the 1stto the 6th stage compared to the term group (Fig. 1), but there was no difference in RA and UT EMG activity between groups throughout the test (Figs. 2 and 3).

According to within group analysis, the preterm group showed lower SCM EMG activity at rest and during warm-up compared to the exercise stage. The final stage showed statistically higher SCM EMG activity values than the 2nd, 3rd, 4th, 5thor 6th exercise stage. At the recovery stage, the SCM EMG activity continued to be high. The term group had a similar pattern in terms of differences between rest and warm-up compared to the exercise stage except at the recovery stage where it showed lower SCM activity values than at the 5th and 6th minute and the final stage (Fig. 1).

Similar to the SCMEMG, the UT muscle EMG activity at rest and

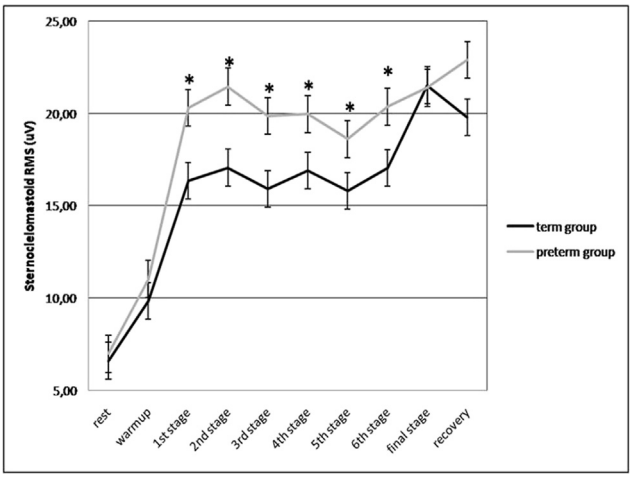

Fig. 1. Sternocleidomastoid EMG activity during treadmill exercise tests in the preterm and term groups. *p < 0.05 preterm vs. term group. Values in the median and interquartile range 25–75%.

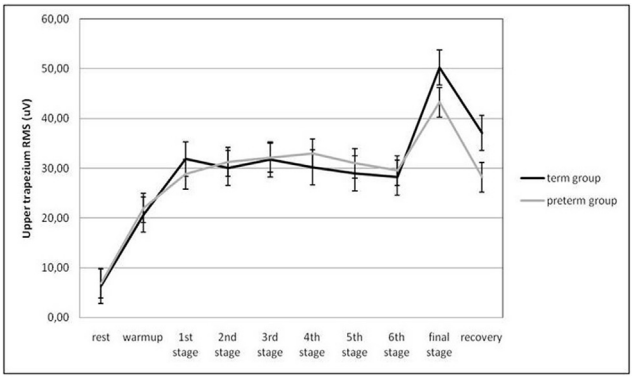

Fig. 2. Upper trapezius EMG activity during treadmill exercise tests in preterm and term children.

Table 1
Clinical characteristics, levels of physical activity, and respiratory muscle tests for preterm and term groups.

	Preterm group (n = 38)	Term group (n = 36)	p-value
Age, (years)[a]	7.67 ± 1.04	7.89 ± 1.13	0.375
Weight, (kg)[a]	26.06 ± 6.53	27.98 ± 7.34	0.239
Height, (m)[a]	1.24 ± 0.07	1.28 ± 0.09	0.080
Gestational age, (weeks)[a]	30.10 ± 2.60	38.61 ± 1.14	<0.001
Birth weight, (g)[a]	1169 ± 213	3168 ± 334	<0.001
Female, n (%)[b]	19 (50.0)	14 (40.0)	0.391
BMI (kg/m^2) [a]	16.60 ± 2.61	16.79 ± 2.67	0.769
Physical activity (h/week) [a]	3.26 ± 1.46	3.83 ± 1.58	0.161
Need for hospitalization after NICU discharge, n (%)[b]	8 (21.1)	2 (5.6)	0.082

BMI: Body mass index, NICU: neonatal intensive care unit.
[a] Student's *t*-test.
[b] Fisher's exact test.

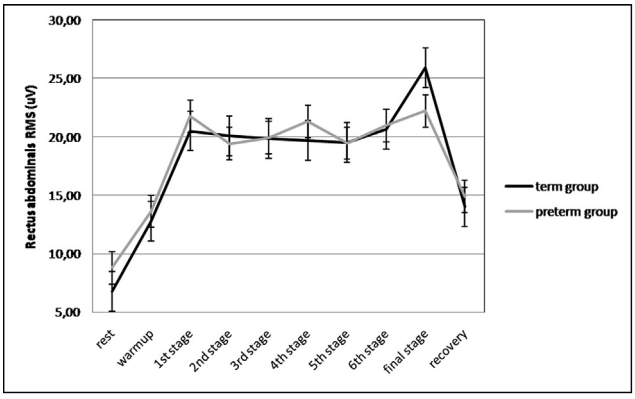

Fig. 3. Rectus abdominis EMG activity during treadmill exercise tests in the preterm and term groups.

warm-up was lower than during the final and recovery stages in both groups. However, the UT muscle EMG activity at the final stage was higher than that at the recovery stage in the preterm group; however, it was lower during the 2nd to 6th minute exercise stages than that at the final and recovery stages in the term group (Fig. 2).

The RA muscle EMG activity at rest was lower than that at exercise, warm-up, final, and recovery stages in both groups. The pattern of RA muscle on warm-up stage was similar to the recovery stage, but less intensive than the exercise and final stages in both groups. However, the preterm group showed lower RA EMG activity values at the recovery stage than at the exercise stage, and the term group showed higher RA EMG activity at the final stage than at the exercise stage (Fig. 3).

The AUC analysis of respiratory muscle EMG showed that only the SCM EMG curve had higher values in the preterm group than in the term group (Fig. 4).

4. Discussion

To our knowledge this is the first study to assess electrical activity of respiratory muscles during exercise tests in children born prematurely. Our results showed a significant increase in inspiratory and expiratory muscle activity during the test in both groups, but the preterm group showed higher SCM EMG activity when intensive physical exercise was performed, which reinforced our previous hypothesis that preterm children might engage in a different breathing pattern strategy in order to maintain their respiratory and aerobic capacity when an abrupt and rapid need of breathing occurs, especially during exercise tests or respiratory

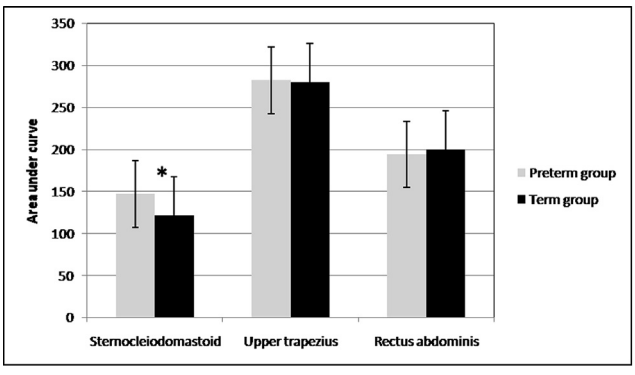

Fig. 4. Area under the curve for the EMG activity of the sternocleidomastoid, upper trapezius, and rectus abdominis muscles in the preterm and term groups.

distress. Our findings suggested that preterm children develop a different interaction between the respiratory muscles and lung mechanics control as an attempt to maintain a relatively normal lung volume by altering breathing patterns and dynamical elevation of lung volume. This mechanics might explain why preterm children have shown similar pulmonary function and aerobic capacity compared to term children despite their pulmonary problems during neonatal period. However, the adaptative mechanics could lead to an increase of cost in working of breathing, that could worse in long term.

It is well known that the respiratory muscles exhibit continuous and phasic contractile activity (Dempsey, 2006), and their activation can affect exercise performance at high intensity (McMahon et al., 2002; Verges et al., 2006; Bailey et al., 2010). Similarly, the inspiratory accessory muscles act continuously as they have a double function as respiratory and postural muscles: acting as head and neck stabilizers and thoracic cage elevators. Studies with adults have shown that during physical exercise or episodes of respiratory obstruction, the inspiratory muscles are recruited to overcome resistive loads to maintain ventilation (Illi et al., 2012; Petrovic et al., 2012). Studies have pointed out similar results in infants and children with asthma (Maarsingh et al., 2000), dyspneic infants and toddlers (Maarsingh et al., 2006), and oral-breathing children (Trevisan et al., 2015). These results could be attributed to the load increment imposed on the respiratory muscles because of the increasing speed of inspiratory flow, there by activating a greater number of motor units (Tomich et al., 2007).Therefore, this could have occurred in both groups when they increased their inspiratory and expiratory muscle EMG activity during the tests.

Our results showed significantly higher SCM EMG activity in the preterm group than in the term group during the exercise test. Most investigators consider SCM to be one of the most important accessory respiratory muscles that are recruited when exposed to resistive loads since they are responsible for elevation of the first rib and lifting of the sternum, thereby increasing the upper anteroposterior diameter of the rib cage (Dempsey, 2006; Sekiguchi et al., 2018; Washino et al., 2019). Studies using preterm infants with respiratory issues have shown that they attempt to control their pulmonary volume by using different breathing strategies and different respiratory muscle activation patterns (activation of inspiratory muscles much earlier during expiration) compared to those used by healthy infants (Hutten et al., 2010; de Jongh et al., 2013). This mechanism could be the result of a weakened diaphragm that requires the recruitment of neck muscles such as the SCM (Sekiguchi et al., 2018; Washino et al., 2019). Based on these studies, it is possible that in our preterm group, the occurrence of respiratory impairment during the neonatal period associated with small lungs and high thoracic compliance required more breathing effort with excessive energy expenditure, leading to greater electrical activity in the SCM muscle (De Waal et al., 2017) that might persists in to childhood (Davidson et al., 2012). This pattern produces impairment in the chest wall kinematics and in the ventilatory conditions which increases working of breathing (de Sá et al., 2017). Thus, it was properly to develop exercises and/or protocols to promote an improvement in contractile capacity and stabilization of this muscle, increasing in thoracic expandability, providing benefits in the performance of respiratory mechanics.

Surprisingly, there was no difference in the UT muscle EMG activity between groups, even though it was the most recruited muscle during the exercise tests in both groups (Fig. 4). In daily life, the trapezius muscle demonstrates low threshold recruitment and low recruitment dominance (under 25% of maximal voluntary contraction). However, when shoulder pain and/or biomechanical dysfunction occurs, a different recruitment of upper and lower trapezius muscle activity is required to maintain muscle

performance (Falla et al., 2007). It is possible that as the test progressed, some balance was established between the upper and lower trapezius muscles, but no difference was found between groups.

In the present study, the RA muscle EMG activity also showed no difference between groups despite an increase in muscle activity after warm-up in both groups. Usually, abdominal muscles act as expiratory muscles and they are at rest during basal breathing. However, during heavy exercise, these muscles could be recruited to assist in the expiratory phase of respiration and may be required to adequately empty the lung and maintain end-expiratory lung volume (Verges et al., 2006; Zsoldos et al., 2010). This electrical activity could increase 2- to 3-fold compared to baseline in exercises at 40 and 80% of the maximal capacity (Choukroun et al., 1993). It is possible that respiratory and postural coordination could produce excessive levels of abdominal muscle EMG activity compared to adults during intensive exercise (Abraham et al., 2002), and this muscle pattern could be similar in both groups.

In order to verify our findings, AUC analysis confirmed that only the SCM EMG activity was significantly higher in the preterm group compared to the term group. These results reinforced the importance of the SCM for increasing respiratory recruitment.

Additionally, there were no AUC differences in the UT and RA EMG activity between groups. It is possible that the increased SCM recruitment was sufficient to meet the needs of premature children to perform the test.

The hands of participants being supported by a handrail could also influence EMG muscle activity. However, we were attentive to arm positions, placing them at the same level, and maintaining shoulder flexion between 30° and 45° for all children. Moreover, when the SCM and UT EMG activities were observed at rest, the signals were very low (silence activity), indicating that the children's arms were relaxed in both groups.

A Monte Carlo simulation was used to analyze the sample power of this study, which displayed a non-normal distribution. Based on our sample, the Monte Carlo simulation (with 10,000 cases) showed that only the SCM EMGs would show some difference between groups (Williams et al., 2007).

The choice of a high-intensity exercise treadmill test allowed analysis of the children's performances over a short duration and involved mostly type II fibers, characterized by fast contraction and less fatigue resistance, as in accessory inspiratory muscles (Polla et al., 2004; Falla et al., 2007).

4.1. Limitations of the study

Since the study design excluded children with cognitive or motor impairment, the most seriously ill children in the outpatient clinic could not be evaluated, which could have generated different results. Another possible influence of the results was anxiety and/or excitement before and during the test once we know that this statement could alter cardiovascular conditions, than, these conditions could change the results.

4.2. New perspectives to exercise test in children

On the other hand, this study allowed development of a feasible method for evaluating electrical muscle activity during an intensive exercise test in small children with low height (all of them were less than 1.30m). A secure exercise test in treadmill must be done using a hand drill. Then, the low height needs some adaptations to conduct a safe and reproductive test. Before the final protocol, we adapted a mobile and gradual handrail to reach the best performance without arms fatigue. Another adaptation was the Balke protocol. We realized that when treadmill was over 10° grade elevation, children asked for stopping test because of quadriceps muscle fatigue due to excessive knee flexion during running. Then we decided to conduct the test until 10° grade elevation and after this grade, we increased velocity in 0.5mph every minute. Then we have another alternative to test aerobic capacity instead cycle ergometer.

4.3. Clinical relevance

The different pattern of SCM muscle activity demonstrated in our study, bring some concerns about preterm children development. This result shows, indirectly, that hypertrophy in this muscle might lead to diaphragm muscle impairment once the excessive use of upper thoracic and/or neck muscles lead to an inspiratory position that could inactive and/or misleading synergism with abdominal and diaphragm muscles. This condition leads to an increased energetic consumption and improper lung ventilation [14]. These accessory muscles promote mobility in upper rib cage during inspiration, making the respiration superficial, that requires increase in respiratory rate and minute volume. Thus, it would be desirable to improve these biomechanics to reduce working of breathing and increase lung function.

On this way, physical therapy may contribute for postural realignment and breathing training, reducing cervical muscles activity for breathing.

Another therapy could be the cardiopulmonary rehabilitation, as an alternative to improve their aerobic capacity as described in other pulmonary problems as asthma and chronic obstructive pulmonary disease.

5. Conclusion

Children born prematurely presented higher SCM recruitment than those born at term, suggesting an important contribution of neck muscles in preterm children when performing high intensity exercises.

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Declaration of competing interest

None.

References

Abraham, K., Feingold, H., Fuller, D., Jenkins, M., Mateika, J., Fregosi, R., 2002. Respiratory-related activation of human abdominal muscles during exercise. J. Physiol. 541, 653–663.

American Thoracic Society, American College of Chest Physicians, 2003. ATS/ACCP statement on cardiopulmonary exercise testing. Am. J. Respir. Crit. Care Med. 167, 211–277.

Armstrong, N., Welsman, J.R., 2006. The physical activity patterns of European youth with reference to methods of assessment. Sports Med. 36, 1067–1086.

Aslan, S.C., McKay, W.B., Singh, G., Ovechkin, A.V., 2019. Respiratory muscle activation patterns during maximum airway pressure efforts are different in women and men. Respir. Physiol. Neurobiol. 259, 143–148.

Bailey, S.J., Romer, L.M., Kelly, J., Wilkerson, D.P., DiMenna, F.J., Jones, A.M., 2010. Inspiratory muscle training enhances pulmonary O(2) uptake kinetics and high-intensity exercise tolerance in humans. J. Appl. Physiol. 109, 457–468, 1985.

Camargo Corcioli, A., Varanda Pessoa-Santos, B., Nency Takara, G., Amorim Pires Di Lorenzo, V., Jamami, M., 2017. Reported dyspnea and fatigue using different scales during the physical effort in COPD. Fisioter. Mov. 30, 207–217.

Choukroun, M.L., Kays, C., Gioux, M., Techoueyres, P., Guenard, H., 1993. Respiratory muscle function in trained and untrained adolescents during short-term high intensity exercise. Eur. J. Appl. Physiol. Occup. Physiol. 67, 14–19.

Davidson, J., Garcia, K.M.B., Yi, L.C., Goulart, A.L., dos Santos, A.M.N., 2012. Prevalence and factors associated with thoracic alterations in infants born

prematurely. Rev. Assoc. Med. Bras. 58, 679–684.
Dempsey, J.A., 2006. Is the healthy respiratory system (always) built for exercise? J. Physiol. 576, 339–340.
Falla, D., Farina, D., Graven-Nielsen, T., 2007. Experimental muscle pain results in reorganization of coordination among trapezius muscle subdivisions during repetitive shoulder flexion. Exp. Brain Res. 178, 385–393.
Fokkema, D.S., Maarsingh, E.J.W., van Eykern, L.A., van Aalderen, W.M.C., 2006. Different breathing patterns in healthy and asthmatic children: responses to an arithmetic task. Respir. Med. 100, 148–156.
Gonçalves, D. de MM., Wandalsen, G.F., Scavacini, A.S., Lanza, F.C., Goulart, A.L., Solé, D., Dos Santos, A.M.N., 2018. Pulmonary function in former very low birth weight preterm infants in the first year of life. Respir. Med. 136, 83–87.
Hermens, H., Freriks, B., Merletti, R., Rau, C., Disselhorst-Klug, C., Stegeman, D.F., Hägg, G., 2012. Recommendations - Sensor Placement. http://www.seniam.org/.
Hutten, G.J., Van Eykern, L.A., Latzin, P., Thamrin, C., Van Aalderen, W.M., Frey, U., 2010. Respiratory Muscle Activity Related to Flow and Lung Volume in Preterm Infants Compared with Term Infants.
Illi, S.K., Held, U., Frank, I., Spengler, C.M., 2012. Effect of respiratory muscle training on exercise performance in healthy individuals: a systematic review and meta-analysis. Sports Med. 42, 707–724.
de Jongh, B., Locke, R., Mackley, A., Emberger, J., Bostick, D., Stefano, J., Rodriguez, E., Shaffer, T., 2013. Work of Breathing Indices in Infants with Respiratory Insufficiency Receiving High-Flow Nasal Cannula and Nasal Continuous Positive Airway Pressure.
Karila, C., de Blic, J., Waernessyckle, S., Benoist, M.R., Scheinmann, P., 2001. Cardiopulmonary exercise testing in children: an individualized protocol for workload increase. Chest 120, 81–87.
Lee, K.A., Hicks, G., Nino-Murcia, G., 2016. Validity and reliability of a scale to assess fatigue. Psychiatr. Res. 36, 291–298.
Maarsingh, E.J., van Eykern, L.A., Sprikkelman, A.B., Hoekstra, M.O., van Aalderen, W.M., 2000. Respiratory muscle activity measured with a noninvasive EMG technique: technical aspects and reproducibility. J. Appl. Physiol. 88, 1955–1961, 1985.
Maarsingh, E.J., Oud, M., van Eykern, L.A., Hoekstra, M.O., van Aalderen, W.M., 2006. Electromyographic monitoring of respiratory muscle activity in dyspneic infants and toddlers. Respir. Physiol. Neurobiol. 150, 191–199.
McMahon, M.E., Boutellier, U., Smith, R.M., Spengler, C.M., 2002. Hyperpnea training attenuates peripheral chemosensitivity and improves cycling endurance. J. Exp. Biol. 205, 3937–3943.
National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents, 2004. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. Pediatrics 114, 555–576.
Petrovic, M., Reiter, M., Zipko, H., Pohl, W., Wanke, T., 2012. Effects of inspiratory muscle training on dynamic hyperinflation in patients with COPD. Int. J. Chronic Obstr. Pulm. Dis. 7, 797–805.
Polla, B., D'Antona, G., Bottinelli, R., Reggiani, C., 2004. Respiratory muscle fibres: specialisation and plasticity. Thorax 59, 808–817.
Powers, S.H.E., 2015. Exercise Physiology: Theory and Application to Fitness and Performance, eighth ed. McGraw-Hill, College.
de Sá, R.B., Pessoa, M.F., Cavalcanti, A.G.L., Campos, S.L., Amorim, C., Dornelas de Andrade, A., 2017. Immediate effects of respiratory muscle stretching on chest wall kinematics and electromyography in COPD patients. Respir. Physiol. Neurobiol. 242, 1–7.
Sekiguchi, H., Tamaki, Y., Kondo, Y., Nakamura, H., Hanashiro, K., Yonemoto, K., Moritani, T., Kukita, I., 2018. Surface electromyographic evaluation of the neuromuscular activation of the inspiratory muscles during progressively increased inspiratory flow under inspiratory-resistive loading. Physiol. Int. 105, 86–99.
Tomich, G.M., França, D.C., Diario, A.C., Britto, R.R., Sampaio, R.F., Parreira, V.F., 2007. Breathing pattern, thoracoabdominal motion and muscular activity during three breathing exercises. Braz. J. Med. Biol. Res. 40, 1409–1417.
Trevisan, M.E., Boufleur, J., Soares, J.C., Haygert, C.J., Ries, L.G., Correia, E.C., 2015. Diaphragmatic amplitude and accessory inspiratory muscle activity in nasal and mouth-breathing adults: a cross-sectional study. J. Electromyogr. Kinesiol. 25, 463–468.
VanBrussel, M., Bongers, B.C., Hulzebos, E.H.J., Burghard, M., Takken, T., 2019. A systematic approach to interpreting the cardiopulmonary exercise test in pediatrics. Pediatr. Exerc. Sci. 31, 194–203.
Verges, S., Schulz, C., Perret, C., Spengler, C.M., 2006. Impaired abdominal muscle contractility after high-intensity exhaustive exercise assessed by magnetic stimulation. Muscle Nerve 34, 423–430.
De Waal, C.G., Hutten, G.J., Kraaijenga, J.V., De Jongh, F.H., Van Kaam, A.H., 2017. Electrical activity of the diaphragm during nCPAP and high flow nasal cannula. Arch. Dis. Child. Fetal Neonatal Ed. 102, F434–F438.
Washino, S., Mankyu, H., Kanehisa, H., Mayfield, D.L., Cresswell, A.G., Yoshitake, Y., 2019. Effects of inspiratory muscle strength and inspiratory resistance on neck inspiratory muscle activation during controlled inspirations. Exp. Physiol. 104, 556–567.
Wasserman, K.H.J., Sue, D.Y., Whipp, B.J.C.R., 2005. Principles of Exercise Testing and Interpretation: Including Pathophysiology and Clinical Applications, third ed. Revinter, Rio de Janeiro.
WHO Expert Committee, 1995. Physical status: the use and interpretation of antropometry. Bentell.
Williams, M.S., Ebel, E.D., Wagner, B.A., 2007. Monte Carlo approaches for determining power and sample size in low-prevalence applications. Prev. Vet. Med. 82, 151–158.
Zsoldos, R.R., Kotschwar, A., Kotschwar, A.B., Rodriguez, C.P., Peham, C., Licka, T., 2010. Activity of the equine rectus abdominis and oblique external abdominal muscles measured by surface EMG during walk and trot on the treadmill. Equine Vet. J. 42, 523–529.