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Different breathing patterns in healthy and asthmatic children: Responses to an arithmetic task

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Summary Asthma patients have been reported to be sensitive to breathlessness, independent of the degree of airway obstruction. Paying attention and task performance may induce changes in breathing pattern and these in turn may mediate such a feeling. The present experiment investigates whether strained breathing induced by an arithmetic task was different in children with asthma compared to healthy children.
Methods: Seven healthy and eight asthmatic but symptom-free school children were equipped with electrodes for surface electromyographic (EMG) measurements of diaphragm, abdominal and intercostal (IC) muscles and with a strain gauge to monitor the pattern of breathing at rest and during an arithmetic task. The relative duration of exhalation and the relative speed of exhalation are used as measures of straining. The phase angle of maximal respiratory muscle activities relative to the maximal chest extension (MCE) are additional discriminating parameters.
Results: Asthmatic children breathed more slowly and already at rest the phase of their respiratory muscle activity appears to be different. While in healthy children the maximal activity of the (left)abdominal muscles occurred $5 \pm 29\%$ later than the MCE, in children with asthma the maximal activity occurred $26 \pm 30\%$ of the cycle earlier than MCE. In children with asthma the activity of the IC muscles starts weaning already at $10 \pm 30\%$ before MCE, in contrast to the healthy children in which intercostal muscle weaning starts only at $1 \pm 24\%$ after MCE. During arithmetic, the significant difference between the groups in this respect disappeared.

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Conclusion: Children with asthma show, even at rest, signs of respiratory muscle straining, probably in order to keep close control over the airflow in a similar way as healthy children during mental tasks. Such a 'careful' breathing pattern may work to prevent airway irritation also when they are free of symptoms.

Introduction

Asthma patients may experience stress-induced breathlessness without increased airway obstruction. Biased symptom perception with emotional breathing patterns may fully account for this feeling.[1,2] The respiratory pattern always is extremely flexible, which is necessary for speech and food intake,[3] but the inhibition of breathing is known to be associated with fear, not only in the laymen's proverb, but also scientifically reported with the majority of panic attack patients.[4,5] High end-tidal CO_2 at rest is associated with negative emotions and a tendency to worry[6] and acute respiratory inhibition is associated with attentional load.[7,8] But also a more general emotionally based modification of the breathing pattern is well established.[9,10] In many people, straining or respiratory inhibition induced by environmental circumstances might be such an emotional breathing pattern. Characteristics of strained breathing, its behavioral and physiological triggers and possible harmful effects have been reported and reviewed earlier.[11] These findings led to the hypothesis that strained breathing might trigger feelings of breathlessness in asthma patients. Asthma patients would feel more breathless with the same breathing pattern or they might employ a different breathing pattern in response to the same stimuli.

To test this hypothesis, straining was promoted in asthmatic and healthy children by performance of an arithmetic task. In previous work we suggested that processing of information, rather than stimulus response sequences, would stimulate straining.[11] A mental arithmetic task could easily be designed in such a way that no responses were necessary within sessions. Respiratory muscle surface electromyographics (EMGs) have proved to be valuable in previous experiments assessing airway patency in asthmatic children[12] and the same measures to quantify muscle activity have been used again. Straining was assessed by monitoring the decline in inspiratory muscle activity in the course of the expiratory phase. Although recently attention has been paid to muscle workload and fatigue in connection with COPD,[13,14] only a few studies successfully applied phase angles to monitor respiratory effort[15–17] and its possible changes due to asthma have rarely been studied. The phase angle represents the timing of the maximal respiratory muscle activity relative to the moment of maximal chest extension (MCE). As such, the phase angle gives an indication of the efficiency of respiratory effort. For example, abdominal tension in the inspiratory phase must be compensated for by inspiratory muscles. Presently, the described parameters will be employed to analyze the breathing patterns of asthmatic and healthy children both at rest and during task performance in order reveal subtle but clear specificities of the asthma breathing pattern.

Methods

Subjects

Healthy (age range 9–13 years, $n = 7$) and asthmatic children (age range 9–14 years, $n = 8$) without acute manifestations volunteered to do mental arithmetic while their breathing pattern was monitored. The asthmatic children were diagnosed as having asthma according to the International Consensus Report on Diagnosis and Management of Asthma.[18] These children were allergic or non-allergic and showed a forced expiratory volume in 1 s (FEV_1) > 70% of the predicted value (% pred.).[19] Children with other systemic diseases were excluded from the study. The asthmatic children used inhaled corticosteroids and used bronchodilator therapy on demand. Inhaled corticosteroid therapy was continued during the study. The parents of the children were asked to withhold bronchodilator therapy for at least 24 h prior to the measurements. All asthmatic children were in a stable phase of the disease and had not suffered from respiratory infections for at least 1 month. The Medical Ethics Committee of the Academic Hospital of Amsterdam approved the study. Informed consent from the children and their parents was obtained.

Breathlessness

Before and after the performance of the arithmetic task, self-report measures of breathlessness were scored on a modified Borg scale consisting of 10 descriptions of breathlessness of increasing degree.[20]

Arithmetic task

A task consisted of one or two digit numbers, to be subtracted from two digit numbers at the easy level. The tasks appeared on the screen one by one, while a marker indicated the time left until the appearance of the answer and the next task. The subject was asked to remember the number of correct answers out of a series of 10 tasks, so no response was required during the series. Subsequently, a choice could be made for a more difficult next series of tasks or to repeat at the same level once. Increasing the level meant more digits in the numbers used. All subjects completed at least two series of tasks. The 2–4 series were recorded until the subject did not want to increase the level or could not complete the session. Only the recordings during first and the last series were analyzed because we considered the highest level chosen as comparable difficulties for the different subjects. After the experiment was finished, seven questions were asked about the perceived difficulty of the task and the effort made. Each question was scored on a 1–4 scale.

Recordings

A magnetometer respiration band (Respiband, SensorMedics, Bilthoven, The Netherlands) was placed around the chest at the level of the nipples to record breathing movements. The EMG recordings were made with pairs of single electrodes (disposable Neotrode, ConMed Corporation, New York, USA). For the diaphragm EMG, two electrodes were placed bilaterally on the costal margin in the nipple line (DF = frontal diaphragm) and two electrodes bilaterally on the back at the same level (DD = dorsal diaphragm). For the EMG of the intercostal (IC) muscles, two electrodes were placed each in the second intercostal spaces left and right, about 3 cm parasternal. Pairs of electrodes, 4 cm apart, were placed on the rectus abdominis muscles on the right (AR) and left (AL) sides at the level of the umbilicus. The common electrode was placed at the level of the sternum.

All signals were DC amplified and digitized at 400 Hz using patient-safe equipment developed especially for these experiments as described extensively before.[21] Data processing and recording were made on PC using Poly 5.0 software (Inspektor Research Systems, Amsterdam, The Netherlands).

Experimental protocol

All subjects were familiar with the experimental environment. They came with a parent who stayed during the measurements. After connection to the measuring devices, the subjects participated in respiratory measurements reported elsewhere[12] and subsequently were asked to sit at a laptop computer in an upright position with their hands resting on their legs. Every child was asked to relax for 5 min prior to the test. Meanwhile the operator carefully and quietly repeated the described procedure to the child. The children were asked not to move or talk during the measurements. Then the arithmetic program was started and the children completed the first series. Subsequently, the experimentor asked for the number of good answers, helped them to change the level as they wished and started the next series. When the level got too difficult or the child did not want to continue, the experiment was terminated and the electrodes and respiration bands removed.

Data analysis and statistics

Data analysis was performed as published before.[12,21] The EMG and chest band sampling starts at a trigger event, marking the beginning of a breath, and stops at the beginning of the next one. Trigger events may be time-marked and labeled in two ways: (1) a peak-to-bottom detection algorithm on average EMG or chest band, with automatic comment annotation and (2) visual peak-to-bottom detection on either raw or average EMG and chest band, with manual comment annotation. The data in the sample buffers are re-sampled to a normalized interval time by use of linear interpolation. Then the sample buffers are added to averaging buffers. The trigger point of an averaging sweep is derived from the chest band at the start of an inspiration. We used about 5–8 tidal breathing movements for analysis. Episodes with movement artifacts were recognized from the EMGs and discarded. The EMG values are expressed as the 10 log's of the EMG-measurement units and standardized as EMGAR scores representing the ratio of the mean peak to bottom values in the task condition over the mean peak to bottom values in the resting condition. Statistics of the inspiratory and expiratory times, the breath period and the parameters to analyze strained breathing: the relative expiration time (Exp/Cycle, inverse of duty cycle) and the percentage of volume yet to be exhaled at $\frac{1}{3}$ and at $\frac{2}{3}$ of the expiratory phase (%Vex.33 and %Vex.67)[11] were exported in a spreadsheet format. Also of the averaged EMGs, the relative strengths at $\frac{1}{3}$ and $\frac{2}{3}$ of the expiratory phase were determined.

The phase angle of maximal EMG activities is expressed as a percentage of the cycle relative to the moment of MCE, 100% corresponding with 360°, a positive phase difference indicating that the maximal muscle activity occurs later than the moment of MCE.

All data were statistically analyzed with SPSS. One-way or two-way analyses of variance (ANOVA) are used as mentioned with the results. Post hoc tests were corrected according to Bonferroni or Tamhane's T2 depending on Levines test for homogeneity of variances.

Results

Asthmatic children breathe more slowly during this experiment. Their breathing period (cycle time) (3.5 ± 0.6 s) is significantly longer than of healthy children (3.1 ± 0.5 s) (2way Anova, $F_{(1,46)} = 5.96$, $P = 0.019$). As illustrated in Fig. 1 there is no additional task effect.

Timing of respiratory muscle activity

The phase angle of maximal respiratory muscle activity, relative to MCE, is significantly different in asthmatic compared to healthy children as indicated in Table 1. Figure 2A illustrates that during the arithmetic task, the maximal activity of the IC muscles kept occurring earlier in the asthma group than in the healthy group, despite that, the task effects were not statistically significant.

Asthmatic children showed a strong tendency for abdominal strain already during inspiration, while in healthy children maximal abdominal tension occurred during expiration as expected. Figures 2B and C illustrate how these differences seem to level out during the arithmetic task. Post hoc analysis reveals that, within the asthma group, the left abdominal phase shows a significant task effect, maximal tension occurring later with task performance ($F_{(1,14)} = 6.67$, $P = 0.022$) (Fig. 2C), but for the right abdominals this did not reach significance ($P = 0.066$, Fig. 2B).

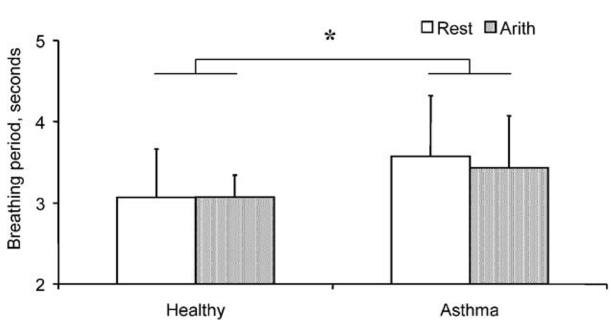

Figure 1 Breathing period in healthy and asthmatic children (mean ± SD). The group difference is significant (*), the task effect of arithmetic exercises is not.

During the arithmetic task, the inspiratory diaphragm activity, which shows a regular curve shape at rest, becomes more irregular and more evenly distributed over the breathing cycle. In most cases a clear maximum could no longer be determined and further analysis was impossible. In three children with asthma and in one healthy child, the signal reversed about 180° in phase, so the maximum diaphragm activity appeared during expiration, while weaning occurred during inspiration (Fig. 3). The phase angle of the dorsal diaphragm was significantly different from the phase at rest for all subjects (1way Anova, $F_{(2,17)} = 6.51$, $P = 0.008$).

Respiratory muscle tension

During arithmetic, the tension of the right abdominal muscles, as indicated by the EMGAR scores, tended to be higher in the healthy group (1.82 ± 1.22) compared with the asthma group (0.86 ± 0.84) (1way Anova $F_{(1,17)} = 4.16$, $P = 0.057$). This was independent of task performance (2way Anova interaction or task n.s.). The amplitudes of other EMGs did not show any significant task effects.

Analysis of expiratory straining

The relative length of expiration, as derived from the chest band, is depicted in Fig. 4. Straining is more pronounced in the healthy group, but overall statistical significance is low ($P = 0.105$). Only a pairwise comparison of values in the asthma group at rest and the healthy group during the task is significant (1way Anova, $F_{(1,19)} = 6.26$, $P = 0.022$), indicating a tendency for a higher level of straining in the healthy group during the arithmetic task.

At $\frac{1}{3}$ of exhalation, the chest extension was reduced to 64 ± 13% and at $\frac{2}{3}$ of exhalation to 26 ± 11% of the maximum. The concurrent decline of diaphragm activity over the expiratory phase is analyzed in Fig. 5. It illustrates that both frontal and dorsal diaphragm activity reduce more quickly during expiration in asthmatic children than in healthy children, especially at $\frac{1}{3}$ of

Table 1 Phase angles of maximum respiratory muscle activity at rest. Percentage of the cycle, relative to the moment of maximal chest extension (negative indicates earlier).

Muscle	Healthy	Asthma	Anova *F*-statistic and significance
Intercostal	$-1\pm24\%$	$-13\pm30\%$	$F_{(1,42)}=4.52$, $P=0.04$
Right abdominal	$10\pm28\%$	$-13\pm24\%$	$F_{(1,42)}=4.01$, $P=0.052$
Left abdominal	$5\pm29\%$	$-26\pm30\%$	Interaction $_{\text{(groupxtask)}}$ $F_{(2,42)}=3.44$, $P=0.041$

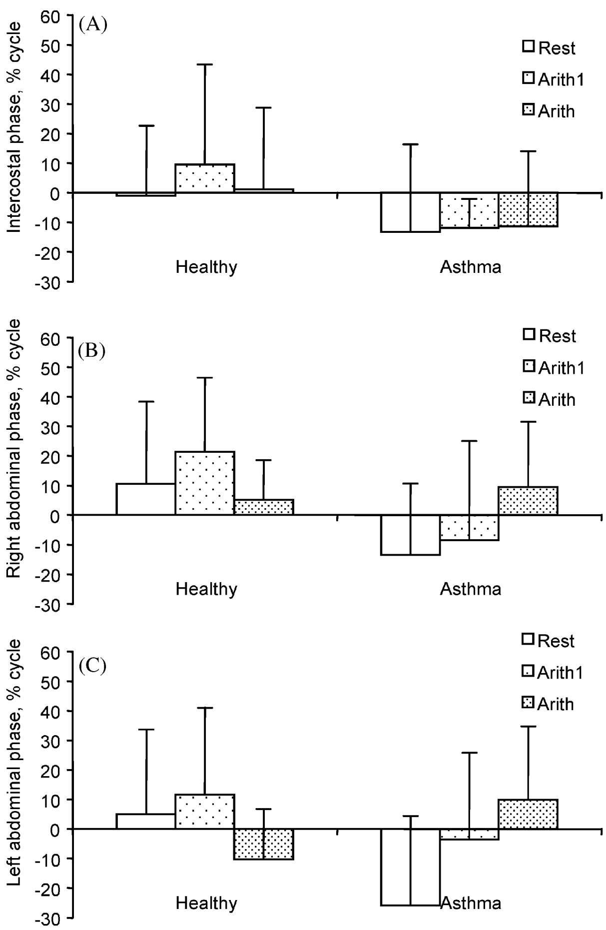

Figure 2 Phase shifts in the respiratory muscle maximal activities. Phase shifts are expressed as percentage ± SD of the breathing cycle for each of the experimental conditions: Rest, first task recording (Arith1) and last task recording (Arith). A negative phase difference indicates a maximum muscle activity before the MCE. Compared to Healthy, the Asthma group tends to have an earlier maximal activity which is significant in IC muscles (panel A) and right abdominal muscles (panel B). In the left abdominal muscles (panel C) a significant interaction appeared. The statistics are given in Table 1.

exhalation (2way Anova dorsal-$F_{(1,40)}=4.28$, $P=0.045$; frontal-$F_{(1,40)}=185.25$, $P=0.006$).

At $\frac{2}{3}$ of exhalation, task effects are interfering, which results in a statistically significant interaction asthma × task for the dorsal diaphragm activity (Fig. 5C) (2way Anova $F_{(1,40)}=6.60$, $P=0.014$), but no significance for the frontal diaphragm (Fig. 5D) (asthma × task $P=0.086$). Post hoc testing revealed that at this moment in the cycle, the dorsal diaphragm activity was still high in healthy children at rest, but that it was already reducing during arithmetic ($P=0.013$) and in the asthma group at rest ($P=0.041$).

Task difficulty, effort and breathlessness

As reported in Table 2, actual breathlessness scores were low and after the task, all subjects reported the same score as before. The reported effort with the calculations, the number of calculations made and the number of errors were not statistically different between asthmatic and healthy subjects, though the asthma group showed a tendency towards more effort and less errors. The time spent on the task, from the beginning of the first series to the end of the last recording, was equal in both groups.

Discussion

Children with asthma breathed more slowly during the experiment and they showed a different muscle control over their respiratory movement in comparison with the healthy group. With asthma, the maximal activity of the counteracting intercostal and abdominal muscles occurred well before the maximal extension of the chest, while in healthy children maximal muscle tension coincided with MCE. During arithmetic, abdominal tension becomes more elevated in healthy than in asthmatic children. In some subjects, healthy and asthmatic, this coincides with a shift of the maximal diaphragm activity to the expiratory phase, apparently compensating for a high abdominal strain. A relation between breathing pattern and breathlessness could not be established presently.

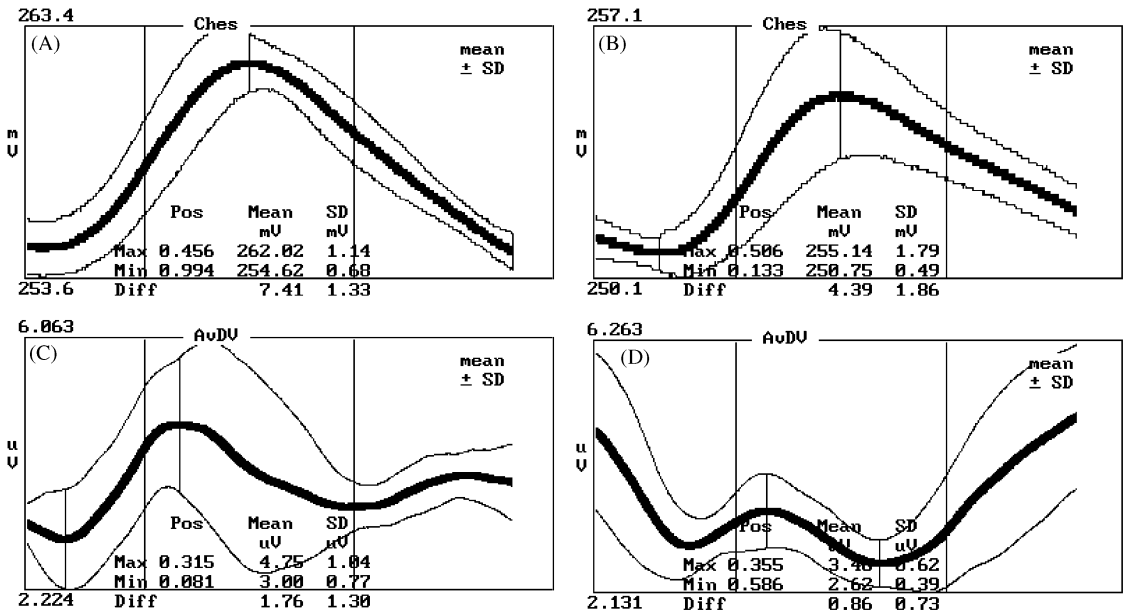

Figure 3 Typical example of the phase reversal of the dorsal diaphragm activity as recorded in one subject, which occurred in four subjects during arithmetic. The curves represent mean amplitudes in mV $\pm$95% confidence limits of seven subsequent respiratory cycles: Chest extension measured with the strain gauge at rest (A) and during the arithmetic task (B); and frontal diaphragm EMG at rest with a peak during inspiration (C) and during the task with a maximal activity during exhalation, but also with a small hump at the moment of the original maximum (D).

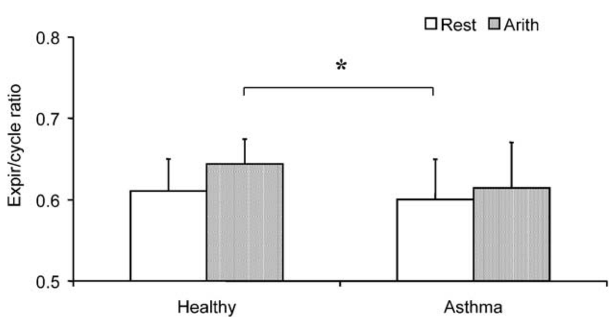

Figure 4 The relative duration of the expiratory phase (time factor of straining, mean $\pm$ SD). The tendency for a relatively long exhalation during arithmetic in the healthy group is significantly different from the rest value in the asthma group (*), but a two-way Anova is not significant.

Interpretation of the results

During normal expiration, the diaphragm activity regularly declines to its minimal level under the influence of the weaning activity of the postinspiratory medullary neurons. This is considered to be the primary determinant of expiratory airflow.[22] When breathing is strained, the pursed lips or a narrowed glottis gets in control of expiratory flow and an increased intrathoracic pressure will reduce diaphragm tension, as has been demonstrated during positive pressure ventilation.[23] In the present experiment, this type of early decreasing diaphragm activity was observed not only in the healthy children during arithmetic, but also in the children with asthma, both at rest and during the task (Fig. 5). Also, for asthma patients, the complementary force of the abdominal muscles comes in a different phase. The peaks occur earlier. The abdominal muscle activity usually is considered to be expiratory and indeed in healthy children its peak does occur shortly after the MCE. But with asthma, at rest, it comes early (Figs. 2B and 2C), well within the inspiratory phase, and it coincides with the more early peak of the IC muscles (Fig. 2A).

It is apparent that in the children with asthma the chest extension still increases while the strength of intercostal activation is already weaning (Fig. 2A). A possible cause is the intraabdominal pressure used for exhalation, in combination with a high resistance in the respiratory tract, which typically applies to asthma patients in general. However, such a chest extension would be prevented when abdominal pressure was made by a high tension in the straight abdominal muscles and indeed, at rest there was no difference in tension between the groups and during arithmetic the increase in abdominal tension was even lower in the asthma group. This indicates that asthma patients perform a strained-like breathing pattern, though not with a lot of strain in the abdominal

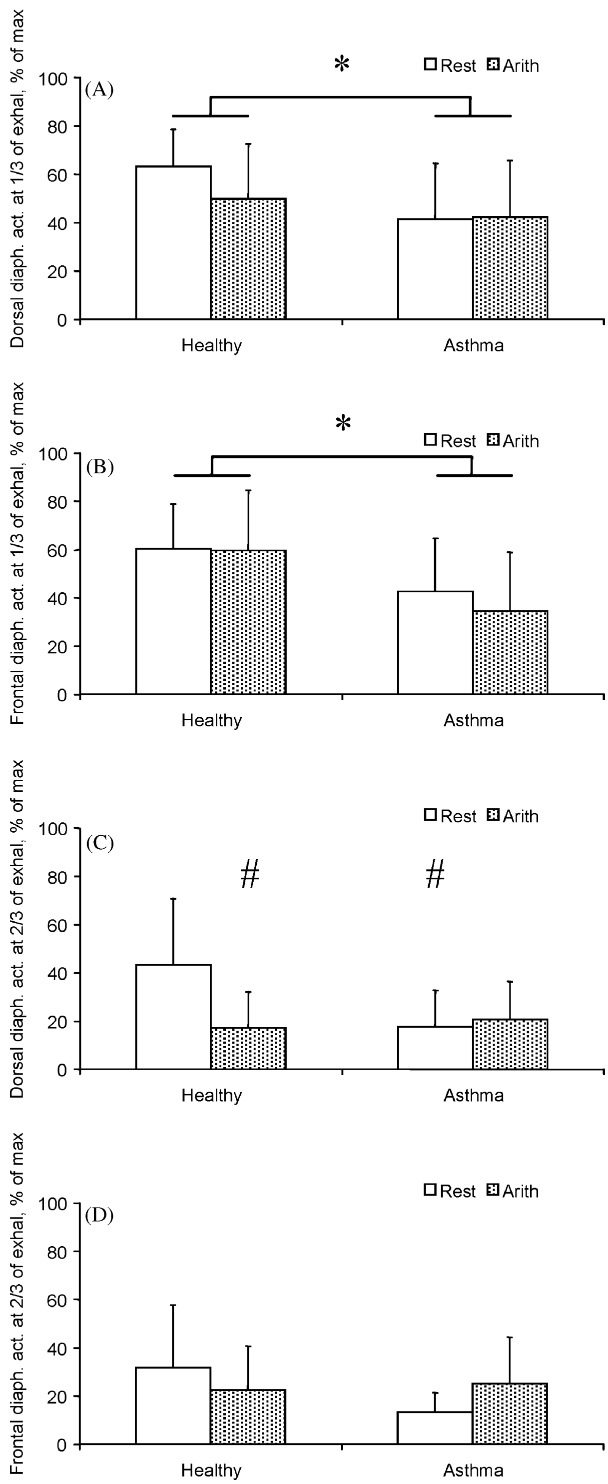

Figure 5 Weaning of diaphragm activity at $\frac{1}{3}$ (A) and (B) and $\frac{2}{3}$ of expiration (C) and (D), percent of max EMG signal $\pm$ SD. Postinspiratory diaphragm activity is inhibited when expiratory flow is regulated by an airway obstruction. Reduced activity appears during arithmetic in healthy subjects, which may be caused by an increased glottis resistance. Asthma patients show a reduced diaphragm activity already at rest (see discussion). $*$ = significant group difference, # = significantly different from healthy rest values.

muscles. Increased cocontraction of antagonists is a means to increase movement accuracy, as has been demonstrated in arm movements.[24] A well-controlled breathing pattern might serve an increased airflow-control during exhalation, thus preventing excessive turbulence or irritating movement of mucus.

It is noteworthy that the different breathing pattern of asthmatic children became more normal during the task. An explanation would be that the asthma group is more susceptible to the stress of the experimental environment, so that the straining would be a specific response and that the task works as a distraction. Psychometric measures might have revealed such effects. However, we do not think such differences are likely because, to our knowledge, a higher susceptibility to environmental cues has not been reported in asthma patients in general and an unvoluntary preselection in our experimental subjects seems unlikely. Also this would still require a second explanation concerning the task effect in healthy children. It seems more likely that the interaction between central nervous task requirements and the generation of the breathing rhythm[25] is different in asthmatic children because of their physical limitations.

Originally, a motive for this study was the suggestion that straining during a task would make asthma patients feel more breathless, which would explain that their sensitivity for feelings of breathlessness was found to be independent of airway narrowing.[1,2] However, the breathing pattern as analyzed above indicates that some characteristics of straining are present, but the relative length of expiration (Fig. 4) is not elevated in the asthmatic children, and the tendency for a lower abdominal tension during the task means the opposite of straining. So the straining responses are different in the asthma group and the very low breathlessness scores did not change as a result of the task. Hence we have to reject the original hypothesis as too simple.

Effects of straining

Straining has been described in goats after systemic infusion of catecholamines (α-2)[26–28] and in neonatal lambs,[29–31] but descriptions of straining in humans are scarce.[4,32] It may be functional by stimulating cognitive performance in various ways: due to cerebrovascular CO_2 reactivity, hypoventilation results in increased cerebral perfusion, independent of arterial O_2 saturation,[33,34] and active glottal closure, maintaining lung volume, has been reported as beneficial for oxygen saturation.[35] A

Table 2 Breathlessness and task performance.

	Borg score	Sums made	Errors	Effort	Task time (min)
Asthma	1.50±1.29	27.2±8.7	5.3±1.9	13.5±2.0	5.99±2.16
Healthy	0.36±0.75	29.3±7.4	7.3±2.0	9.6±4.6	6.22±2.23
t-test *P* value	0.07	0.67	0.13	0.07	0.85

restriction of venous return from the head as a result of increased respiratory pressure [36] probably increases local perfusion pressures in the head.[37]

Pursed lips breathing is a way of straining advised for its positive effects on ventilation, but the underlying changes in respiratory muscle coordination and possible hemodynamic consequences have hardly been studied.[38] How strongly airway pressure may inhibit the rate of breathing is demonstrated by the occurrence of periodic breathing in sleeping, healthy subjects after application of assisted breathing.[39] Straining in healthy subjects may be supported by such reflexes,[11] but given a healthy vital capacity it will not endanger O_2 supply. The slower breathing in the asthmatic subjects (Fig. 1) may indicate the action of such airway pressure reflexes, though presently this did not induce breathlessness.

Whether a strained breathing pattern, when it is habitual, could have consequences on the long term is unclear. Given the complex network of cardiovascular and respiratory reflexes associated with breathing, it might result in changes in hemodynamics or full lung capacity which cannot be investigated with only the present set of measured parameters.

Critique of methods

The analysis software required a sequence of 5–8 undisturbed respiratory cycles, with closely matching periods, to calculate EMGARs and relative amplitudes in the expiratory curve. Because of the high variability of breathing during the task, it was not easy to find long series and the duration of the arithmetic task was too short to do a replicate calculation within a task period. This prevented distinguishing of subject-specific response types which may be important because not all children strain in the described way. Figure 3 shows that in some subjects, an elevated abdominal strain during arithmetic was compensated for by a high diaphragm tension during expiration with probably no elevation of intrathoracic pressure. This way of straining during arithmetic could not be attributed specifically to asthmatic or healthy children. Nevertheless, it indicates that statistical dispersion may increase unnecessarily when individually different response types are neglected. To improve the quality of data, we are developing software for automatic signal detection and processing.

Conclusion

Timing and strength of respiratory muscle activity appeared to be different in a group of asthmatic children, although they were free of symptoms during the experiment. The breathing pattern may serve the prevention of airway irritation. When an arithmetic task was performed, the pattern of asthmatic children tended to shift towards the normal pattern of the healthy control group, whereas healthy children tend to develop more straining during the task. No relation between breathing pattern and breathlessness was found. Although a careful breathing pattern may be functional in asthma patients, possible side effects of habitual straining should be given attention.

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