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Airway constriction in asthma during sustained emotional stimulation with films

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Abstract

Background: Individuals with asthma have been shown to respond to unpleasant stimuli with bronchoconstriction, but little is known about the time course of responding during sustained emotional stimulation and whether it varies with patients' experience.

Objective: To examine the time course of oscillatory resistance (R_{os}) during emotionally evocative films in 15 asthma patients and 14 healthy controls.

Method: Participants viewed unpleasant, surgery, and neutral films, each ranging 3–5 minutes in duration. R_{os} and the respiratory pattern (respiration rate, tidal volume, minute ventilation) were monitored continuously. Following each film, participants rated their affective response and symptoms. The time course of R_{os} during films was explored using multilevel modeling.

Results: Compared to neutral film sequences, unpleasant films (including those with surgery scenes) elicited a uniform pattern of initial increases in R_{os} with peaks within the first 1–2 minutes, followed by a gradual decline. Increases were more pronounced in asthma and during surgery films. Including additional respiratory parameters as time-varying covariates did not affect the temporal course of R_{os} change. The rate of decline in R_{os} (after the initial increase) was less in participants who experienced greater arousal and in patients who reported more shortness of breath. Patients more susceptible to psychological triggers in daily life showed slower rates of decline in R_{os} .

Conclusion: The temporal course of bronchoconstriction to unpleasant stimulation is highly uniform in asthma, with strong constriction in early stages of stimulation. More sustained constriction in emotion-induced asthma could be a risk factor for developing asthma exacerbation in daily life.

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Keywords

Asthma; emotion; airway obstruction; respiratory resistance; respiration; asthma trigger

Emotional states reduce airway caliber in asthma. Clinical observations and patient interviews have provided evidence for a wide range of emotional states capable of producing asthma symptoms or bronchoconstriction (e.g., Knapp & Nemetz, 1960; Rees, 1980). Both experimental studies of emotion induction (e.g., Levenson, 1979; Ritz et al., 2000; 2001; 2010; Tal & Miklich, 1976; von Leupoldt and Dahme, 2005) and ambulatory studies (Sandberg et al., 2000; Apter et al., 1997; Ritz and Steptoe, 2000; von Leupoldt et al., 2006) largely concur that negative affect, in particular, leads to decrements in lung function, whereas effects of positive stimulation have been more variable (Liangas, Morton, & Henry, 2003; Ritz & Steptoe, 2000; Ritz et al., 2010). Experimental studies have used a variety of stimuli, including picture viewing, viewing of film sequences, and autosuggestion with self-referring statements and little differences have been found between various discrete negative emotional states such as depression/sadness, fear, anger, or disgust, suggesting a more global susceptibility of the airways to arousal of a negative (and sometimes also positive) valence. In terms of the induction technique, film sequences were particularly effective. Moreover, in two studies with emotional film presentations, resistance increases to unpleasant films were found to be correlated positively with patient self-report of frequent emotional asthma triggers in daily life (Ritz et al., 2006, 2010). In addition, airway responses induced by unpleasant films in asthma were associated with lung function declines during intense negative mood states in daily life (Ritz and Steptoe, 2000). The same studies did not find effects for picture material, as was the case in another study (von Leupoldt et al., 2006). Thus, laboratory-induced airway responses to negative emotional films appear to be relevant for our understanding of the daily life experience of emotion-induced asthma.

Although airway obstruction to emotional stimuli is well documented, little is known about the time course of airway constriction during sustained affective stimulation. However, this would be important in at least two ways. First, knowledge about the dynamics of constriction during ongoing psychological stimulation can help understand the full consequences of emotion-induced asthma. Although it appears that patients exhibit particularly strong airway constriction in reaction to emotional stimuli, it is not known whether this translates into a sustained constriction. To date, typical analyses of emotional airway effects have focused on average obstruction during a given stimulation period, but it is unclear whether constriction is sustained during stimulation, whether it follows a typical temporal course, or whether its course varies with aspects of patients' experience. If constriction was only of a short, phasic nature, it would trigger symptoms only briefly, if at all, and would therefore be less of a grave problem for patients (provided that the constriction is not extreme). Second, in planning future studies on emotion-induced asthma with varying stimulus materials, it is critical to know about the actual time course of airway constriction and the time frame within which the maxima of responding can be captured.

A recent study of airway responses to emotional film presentation (Ritz et al., 2011) replicated earlier findings of airway constriction during unpleasant material, particularly

during surgery films. The aim of our present analysis was to examine data from this study using multilevel modeling to determine the exact time course of airway obstruction in participants with asthma (and in healthy controls) while they watched various types of film clips. Given the strong evidence of the importance of negative affective states for airway constriction and the greater clinical importance of negative emotion, we restricted our analysis to unpleasant film sequences, including surgery films, and compared them to neutral film clips. We expected a certain amount of variability in the temporal dynamics of airway responses to the continuous film presentations, which, in line with prior unsystematic observations in our laboratory, would mostly show stronger airway constriction in earlier stages of stimulation. We also hypothesized that stronger and more sustained airway constriction would be associated with more intense symptoms, higher emotional arousal, and a greater susceptibility of patients to emotional asthma triggers in daily life.

Methods

Methods of this study were described in detail before (Ritz et al., 2011). Here we restrict ourselves to data that are relevant to the present analysis of the time course of airway constriction during viewing of unpleasant and neutral films in individuals with asthma and healthy controls. We chose to not include the blood-injury-injection (BII) phobia patient group of the original study because of the focus on emotion-induced asthma and on the time course of airway constriction in asthma. In addition, some BII phobia patients terminated the surgery film prematurely, thus not providing enough data to properly study the time course of R_{OS} . However, all of the asthmatic and control group subjects in the original study were included.

Participants

Participants were adults with and without asthma, recruited from the community through targeted fliers, posters, as well as newspaper and on-line advertisements. Inclusion criteria were age between 18 and 60 years, non-smoking, and no history of epilepsy or seizures. Patients who had taken systemic corticosteroids in the previous three months (indicating severe or uncontrolled asthma) were excluded from the study. All patients were seen by a clinical psychologist and a physician for diagnosis and evaluation of their disease history and manifestation. Asthma severity was rated based on symptoms, functional limitations, bronchodilator use, and lung function (National Heart, Lung, and Blood Institute and World Health Organization, 2002). Participants were reimbursed \$60 for their participation. The protocol was approved by the institutional review boards of Stanford University and the VA Palo Alto Health Care System. All participants gave informed consent.

Emotional film presentation

We used films to experimentally induce affective states. Film scenes were extracted from commercially available movies and medical education materials, or adopted from other laboratories (Gross and Levenson, 1995; Rottenberg et al., 2007). Material considered in the present analysis fell in three broad categories: two sequences of an unpleasant nature (high school bullying scene, 260 s; a boy who cries about the death of his father, 270 s), two neutral sequences (excerpts from an economics lecture 170 s; screen saver with colorful

sticks, 180s), and two surgery scenes (open heart surgery, 270 s; hip graft surgery, 300 s), containing needle/injection scenes, cutting through tissue, and spilling blood. The last category was included because prior research indicates a specific sensitivity of asthma patients to blood and injury images (Ritz et al., 2000). We compared these thematically different unpleasant film clips (bullying, mourning, 2 surgery scenes) because this prior work had shown that responses of the airways to emotional films are largely driven by negative arousal rather than particular discrete unpleasant emotional states such as anger, anxiety, or depression. For the purpose of this study we therefore decided to choose film clips that fell into the global category of negative emotional valence and that had been shown to be particularly evocative in prior research (e.g., Ritz et al., 2000).

Each participant first viewed one film in each category. In each group (asthma and controls) about half of the participants viewed one film and the other half viewed the other film. Next, each participant viewed the second film in each category with the additional instruction to view it while tensing the leg muscles at approximately 30–50% of the individual's maximum effort. These sequences were originally included to explore whether static leg muscle tension might help reduce airway obstruction, because initial phases of exercise or static tension had been shown to dilate the airways (e.g., Beck et al., 1994; Ritz et al., 1998). However, because this question was not directly relevant to the primary aims of the present analysis, the film sequences with muscle tension were only considered in supplementary analyses. The order of the films was randomized, and the assignment of individual films to instructions (film viewing vs. film viewing with tension) was approximately balanced. Additional positive and asthma-related film sequences were also shown, but will not be analyzed here. We chose to focus on unpleasant films for several reasons. First, although there are indeed studies that also show bronchoconstriction due to positive emotional states (Liangas et al., 2003; Ritz et al., 2000; von Leupoldt et al., 2006), the literature is less consistent and our recent study with a larger sample of asthma patients did not find substantial increases in resistance to positive films or pictures (Ritz et al., 2010). Second, airway responses to unpleasant emotional states are of a greater clinical importance given their link to common psychopathology (anxiety, depression) in asthma patients and associated consequences for disease management (Goodwin, Jacobi, & Thefeld, 2003; Opolski & Wilson, 2005). Third, given that this constituted a secondary analysis of previously published data, we wanted to restrict the number of statistical tests performed to avoid being overly exploratory and to reduce the chance of Type 1 error. Fourth, although power should not be a problem given longitudinal design with multiple measurement occasions (Mass & Hox, 2005), the sample was relatively small adding to our concern about exploring too many questions with too few cases.

Instrumentation

Respiratory Resistance.—Throughout the films, respiratory resistance was measured continuously using the single-frequency (10 Hz) forced oscillation technique (Siemens Siregnost FD 5; for descriptions of the technique see Korn et al., 1979). During the measurements, participants breathed ambient air oscillating at 10 Hz through a mouthpiece and an elastic tube with their nose occluded. To reduce upper airway shunt, cheeks were stabilized externally using modified headphones. The FD5 device calculates resistance from

the pressure signal recorded at the entrance of a Y-tube that is connected on one side to the mouth and on the other to a reference arm. The oscillatory flow is known and impedance of the reference arm is constant, thus, resistance of the airways can be calculated from the pressure signal only (see also Ritz et al., 2002). The recorded “oscillatory resistance” (R_{os} ; expressed in $\text{kPa} \cdot \text{L}^{-1} \cdot \text{s}$) equals the impedance of the total respiratory tract and includes contributions from lung tissue and the chest wall. Compared with other techniques for mechanical lung function measurement (such as spirometry, body plethysmography), the forced oscillation technique has the advantage of providing a continuous breath-by-breath index of changes of the airway caliber.

Respiratory Pattern.—Because of known influences of the respiratory pattern on respiratory resistance (Nadel and Tierney, 1961; Brusasco and Pellegrino, 2003; Scichilone et al., 2007), respiration was monitored using a pneumatic belt system measuring thoracic and abdominal movements (James Long Company, Caroga Lake, NY). For calibration, participants briefly breathed air in and out of a fixed volume bag (800ml). Respiration rate (RR) and tidal volume (V_T) were extracted breath-by-breath from the calibrated curve, and minute ventilation (V'_E) was calculated by product of RR and V_T .

Biosignal Recording and Processing.—The analog output of the oscillo-resistometer and the two channels of the pneumatic belt system were recorded with a Vitaport 2 digital recorder/analyzer (16-bit A/D converter, 512 Hz sample rate) attached to a PC. For storage, sampling rate was reduced to 32 Hz. The R_{os} signal was edited for glottic closure and swallowing artifacts (rapid 1–1.5 s spikes in resistance that exceeded the upper limits of the measurement range), and analyzed using customized MATLAB software (Gerlach et al., 2006).

Psychological Measures.—Before the experiment, patients completed the Asthma Trigger Inventory (ATI, Ritz et al., 2006), a psychometrically validated questionnaire capturing patients’ retrospective report of how frequently major asthma triggers induced or exacerbated their asthma symptoms in daily life. The 10-item psychological trigger subscale ($\alpha=.94$) was analyzed in the present study. Following each film, participants rated their feelings of pleasantness, arousal, and being in control (dominance vs. submissiveness dimension of affect) using the Self Assessment Manikin (SAM; Hodes et al., 1985). The three bipolar scales were scored with 1 assigned to the ‘unpleasant’, ‘calm’, and ‘feeling controlled’ pole and 9 to the ‘pleasant’, ‘excited’, and ‘feeling in-control’ pole. A number of additional 11-point unipolar scales inquired about discrete emotional states and symptoms. For these, we restricted the present analysis to “shortness of breath” and “chest tightness” (anchors: 0=‘not at all’, 10=‘extremely’). The ATI was incomplete for two patients, as were the film ratings for one.

Procedure

Participants were scheduled for laboratory assessments in the afternoon. Patients were instructed to withhold their short-acting bronchodilators for 8 hours before the session and postpone their daily dose of long-acting bronchodilator until after the session. In the case of symptoms requiring reliever medication, they were offered to reschedule their appointment.

As a safety measure, patients were encouraged to bring their reliever medication to the laboratory session and to keep it within reach. After providing informed consent, participants completed the questionnaire package that included the ATI (for the patients with asthma). Films were viewed in a sound-attenuated chamber which included a comfortable armchair and a television screen (approximately 40cm diagonal) placed approximately 1.5m in front of it. During film presentations, the experimenter operated the recording equipment in an adjacent room, from where he was able to observe the participants through a one-way mirror and communicate with them by intercom. Following participant instruction in how to use oscillo-resistometer tube and mouth piece, sensor attachment, and calibration, a series of 10 films were shown, 3 of which were the unpleasant, neutral, and surgery-related films used in the present analysis. The 3 film clips were randomized together with the other 2 in the same set (which were positive, asthma-relevant). Overall, there were 2 similar sets of 5 film clips, each set consisting of 1 unpleasant, 1 neutral, 1 surgery, 1 pleasant, and 1 asthma-relevant. For one set, participants were instructed to simply view the clips. For the other set, they were to view them while tensing their leg muscles. There were no systematic differences in the position of the 3 selected film clips within each set. Between films, patients rested and filled in rating scales about their affect (including SAM scales) and symptoms (including unipolar scales for shortness of breath and chest tightness) during the respective film. Overall breaks between films varied between 3–5 min, depending on the time individuals required for the ratings as well as the subsequent check-in by the experimenter inquiring about participants' general state and symptoms. We did not check on return to baseline R_{OS} , because prior research had shown that R_{OS} is typically attenuated within the first minute of recovery from a stress task or film viewing (Kotses et al., 1987; Ritz et al, 2000). The work on rating scales and brief interaction with the experimenter added time to that and also served as a distractor from the immediate emotional experience of the material. Adding a return-to-baseline check would also have complicated the measurement protocol, requiring further measurement sequences with breathing through the mouth piece and tube, which might have been counterproductive by reducing the participants' motivation and inducing fatigue. R_{OS} measurement were continued for 1 min after film offset and earlier findings were replicated that during this period emotion stimulation effects on R_{OS} were markedly reduced (Ritz et al., 2011). Analysis of recovery trajectories was not included here because longer recovery assessments of at least 2–3 min (before transitioning to the participants' film ratings) would be needed for exploring recovery in a meaningful way.

Data Analysis

The time course of R_{OS} during viewing of the three films sequences (unpleasant, neutral, and surgery) was explored with multilevel modeling (MLM, Hox, 2002) in two ways: first a fine grain analysis of the complete film time course was conducted using successive 10-s averages (averaging shorter intervals was not deemed as useful because of respiratory cycle fluctuations of R_{OS}). For better comparability, data from the films within each film category (unpleasant, surgery, and neutral) were cut to the length of the shorter film within that category. In our second set of analyses, the first 3 min of presentation were analyzed in 30-s segments for all three film categories to explore the usefulness of shorter vs. longer presentation times for eliciting tonic elevations in R_{OS} . The three minute time period was

chosen because this was the maximum length allowing for direct comparison between films, the neutral films being the shortest (170 s, just under 3 minutes). In this comparison, the neutral films only contributed 20 s of data for the last 30-s interval.

MLM was used for the analyses because it allows inclusion of all participants even if they have missing data points (see also Results). It also allows the calculation and comparisons of the growth curves for each film despite different lengths. MLM has also been shown to produce unbiased and accurate estimates of regression coefficients in small sample sizes ($N=30$) much like that in the present data ($N=29$) (Mass and Hox, 2005). The MLM analysis was followed by calculation of within-individual effect sizes of airway responses to surgery and unpleasant film compared to the neutral film for each 30-s segment.

For the fine-grain analysis of the complete film length, the successive 10-s interval for each film comprised level 1 of the MLM, with individuals comprising level 2. Dummy variables at level-1 were used to code the unpleasant and neutral films vs. the surgery film. The surgery film was selected as the “reference” case instead of neutral because we expected that the surgery and unpleasant films would follow similar growth curves. If that was the case, interaction terms between the unpleasant film dummy variable and the growth curve parameters (described below) would be nonsignificant, and hence would be able to be dropped from the final model. This will allow a simpler final model. Linear and quadratic time terms were included to allow for a curvilinear growth curve for R_{os} over time. Interaction terms between the dummy variables and the growth curve variables allowed the growth curve to vary by film. In addition to providing fixed effects for this model (which reflect the weighted *average* of each effect across the participants), MLM assesses the variability of each effect between individuals, which allows us to test whether the variability (variance) of each effect is significant across participants.

The analysis of 30-s intervals followed the same structure. In addition, for each of the six 30-s intervals in these analyses, effect sizes (Hedges' g) were calculated for differences between the means of the neutral vs. the unpleasant and surgery films within each group by $(M_1 - M_2)/SD$, with SD calculated by $\sqrt{(SD_1^2 + SD_2^2) - 2r * SD_1 * SD_2}$, where M_1 and SD_1 were the surgery (or unpleasant film) mean and standard deviation, M_2 and SD_2 the neutral film mean and standard deviation, and r the correlation between surgery (or unpleasant) and neutral film values.

In supplementary analyses, all 6 film sequences (including the three sequences with the instruction to tense leg muscles) were analyzed. A dummy variable was included at level-1 coding leg tension (0=no tension, 1=tension), and then interactions were formed between the tension dummy variable and all of the other parameters used in the analysis of the 10-s data. With these analyses we explored whether the time course of airway constriction was affected by participants' voluntary contraction of leg muscles.

Additional analysis sought to determine the extent to which respiratory parameters influenced the observed time course of R_{os} changes during films. For that, RR , V_T and V'_E were included as time-varying covariates (Singer and Willett, 2003) in the MLM analysis that modeled the change in the 10-s assessments of R_{os} over time. Substantial changes in the

growth curve parameters for R_{os} would indicate that the observed changes in R_{os} over time were in part due to respiratory changes.

We also examined whether the ATI psychological subscale and experience of pleasantness, arousal, control, shortness of breath, and chest tightness were related to the temporal trajectories of R_{os} across films. ATI was added as a level-2 predictor of the intercept and the level-1 slopes of the changes of R_{os} over time for each film. Then non-significant ATI interactions were dropped, and the final model was recomputed. In further analyses, each of the 5 self-report measures (pleasantness, arousal, control, shortness of breath, and chest tightness) was added as a level-1 moderator of all the level-1 growth curve parameters in the MLM analysis modeling the change in R_{os} over time. Significant interactions between a self-report measure and growth curve parameters would indicate a relationship with changes of R_{os} over time. Participants with missing data in the ATI or rating scales of affect and symptoms were necessarily excluded from the respective analyses.

For each finding presented in the Results, we report a “ b ”, “ $t(n)$,” and a “ p ”. The “ b ” is the unstandardized regression coefficient representing the finding from the MLM analysis (e.g., the linear rate of change in R_{os} over Time), the $t(n)$ is the t -statistic for the regression coefficient with “ n ” degrees of freedom, indicating whether or not the regression coefficient was significantly different from 0 and the p level reported is for the 2-tailed t -test.

Results

Basic sample characteristics

The final sample consisted of 15 individuals with asthma and 14 healthy controls. Basic sample characteristics are presented in Table 1. Participants were mostly female and White, with 12.0% being Asian, and 3.4% African-American. Asthma severity was rated as intermittent to moderate persistent. Most patients took inhaled corticosteroids and/or short-acting bronchodilators. Individuals with asthma showed a higher R_{os} during neutral films (during viewing only condition) than healthy controls (0.462 vs. 0.339 kPa•L⁻¹•s), $t(27)=2.43$, $p=.022$. There were no group differences in V_T (440 vs. 415 ml), RR (14.5 vs. 15.9 breaths/min), or V'_E (6.0 vs. 6.4 l/min). None of the patients needed to use their reliever medication at any time during the laboratory session.

Time course of R_{os} across films in successive 10-second averages.

Visual inspection of the 10-s averages of R_{os} across the duration of surgery and unpleasant film presentation (Figures 1 and 2 upper panels) suggests an initial increase in R_{os} over neutral levels followed by a gradual decline in values. This steady decline is not readily seen in healthy controls, but R_{os} during surgery and unpleasant films was somewhat elevated over levels during neutral film in this group. The proportion of missing 10-s intervals due to artifacts or equipment failures was relatively small, with 3.6% for unpleasant, 1.2% for surgery, and 1.0% for neutral films.

Level differences.—Results of the final model (Figures 1 and 2 lower panels) indicated that R_{os} was significantly higher for asthma patients than for controls across all films (and this difference was not significantly different between films), $b=.115$, $t(27)=2.53$, $p<.05$.

Overall, the average R_{os} values for the unpleasant film and the neutral film were lower than those for the surgery film for both groups, $b = -.035$, $t(27) = 4.44$, $p < .001$, and $b = -.048$, $t(27) = 3.94$, $p = .001$, and the average R_{os} level for the unpleasant film was higher than the average level for the neutral film, $b = .026$, $t(27) = 2.06$, $p < .05$.

Trends across time.—The growth curve for the unpleasant film was not significantly different from that of the surgery film ($ps > .45$), so those interaction terms were dropped. The quadratic component of the neutral film growth curve also was equivalent to that of the other films, so that interaction term was dropped. Thus, the only differences between the growth curves of the various films was in the level (delineated above) and in the linear trend over time of the neutral film [Footnotes 1, 2]. The linear trend of R_{os} was significant and decreasing for asthma patients while watching surgery and unpleasant films, $b = -.003$, $t(27) = 3.84$, $p = .001$, but not while they were watching neutral ones ($p = .80$), and not for controls watching any film ($ps > .10$). There also was a significant quadratic trend for asthmatics only, $b = .0001$, $t(27) = 2.84$, $p < .01$, indicating that the decrease in R_{os} over time leveled off similarly for all films, but only for asthmatics. In addition, chi square tests of the random effects in the models showed significant variability of all these effects across participants (all $ps < .01$). Thus, for example, the linear trend of R_{os} over time averaged $-.003$, but the between-participant variability of this linear slope was also significant, indicating that there were significant differences between participants in the extent to which R_{os} decreased over time.

Analysis of R_{os} in the first three minutes of the films using 30-second averages

Results for the 30-s averages largely corresponded to those for the 10-s averages (see Table 1). Given that we restricted this analysis to the first 3 min of presentation, the quadratic trend for surgery films in asthma patients disappeared, but the trend was still seen for the unpleasant film, reflecting the fact that the decline in R_{os} leveled off earlier than for the surgery film, $b = .0036$, $t(28) = 3.13$, $p < .005$. MLM analyses also showed that, although constriction in response to the surgery film declined over time toward the levels of the

¹The final MLM level 1 model was:

$$R_{osij} = b_{01} + b_{11} * \text{Time}_{ij} + b_{21} * \text{Time}_{ij}^2 + b_{31} * \text{DU}_{ij} + b_{41} * \text{DN}_{ij} + b_{51} * \text{Time}_{ij} * \text{DN}_{ij} + e_{ij}$$

Where:

Time_{ij} = the time of assessment j for individual i , centered at 120 s into the films to avoid multicollinearity between the Time and Time^2 terms,

DU_{ij} = dummy code for the unpleasant film for individual i at assessment j : 1 for the unpleasant film, 0 for other films.

DN_{ij} = dummy code for the neutral film for individual i at assessment j : 1 for the neutral film, 0 for other films.

Each level-1 regression coefficient (b_{ki}) had a corresponding level-2 model, each having the same form, which was:

$$b_{ki} = \gamma_{k0} + \gamma_{k1} * \text{Asthma}_i + \mu_{ki}$$

Where Asthma_i is the asthma status of individual i : 0 for asthma patients, 1 for controls, and k refers to the k th regression coefficient (0–5) in the level-1 model. For models involving the respiratory parameters (e.g., V_T) as time varying covariates, an additional term was added to the level 1 model above (e.g., $b_{6i} * V_{Tij}$, where V_{Tij} was the tidal volume for subject i at assessment j). Centering Time at 120s does not impact the shape (plot) of the growth curve, which is invariant to how Time is centered. However, centering does impact the point estimates of the intercept and the linear slope. When Time is centered at its mean value in the sample (which was approximately 120s in this sample), the point estimate of the linear slope represents the average linear change over the time period in the sample.

This final model includes the $\text{DN} * \text{Time}$ interaction, but not the $\text{DU} * \text{Time}$ interaction, since the $\text{DU} * \text{Time}$ interaction was not significant. Similarly, neither the $\text{DU} * \text{Time}^2$ nor the $\text{DN} * \text{Time}^2$ interactions were included in the final model because they were not significant.

²There were 2 different films for each type of film (surgery, unpleasant, neutral). The order in which the 2 films of each type were seen was counterbalanced across all the subjects. Dummy variables coding the order of presentation of each type of film were added to the analyses to determine if the film order impacted scores (or if the reactions to the 2 films of each type were different). No significant differences were found ($ps > .08$).

neutral film, R_{OS} levels were still higher while watching the surgery film than the neutral film even at the last 30-s increment (between 150 and 180s), $b = -.048$, $t(28) = 3.50$, $p < .005$. Percentage change from neutral levels and effect sizes (Table 2) suggested that constriction was most pronounced for both groups during the first 2 minutes of the surgery film, with average maximum increases around 20% for asthma patients and 10% for healthy controls.

Supplementary analysis exploring leg tension effects on the R_{OS} time course.

There were no significant interactions between leg tension and any of the growth curve parameters for any of the films. When all the non-significant interactions between the leg tension dummy variables and the growth curve parameters were dropped, the combined results were very similar to the analysis of the film viewing without the leg tension instruction, the significant effects being identical in both.

Respiratory pattern effects

RR and V_T did not show systematic changes between or within films. Including them as time-varying covariates did not alter the observed R_{OS} changes between or within films. Despite this, there was a significant overall negative association between R_{OS} and V_T , $b = -.0005$, $t(28) = -2.25$, $p < .05$, indicating that a 100 ml increase in V_T was related to a 0.005 $kPa \cdot L^{-1} \cdot s$ decrease in R_{OS} . V'_E showed a gradual overall increase over time for the surgery and unpleasant films, for both asthma patients and controls, $b = 36.8$, $t(27) = 3.12$, $p = .005$, and was significantly related to R_{OS} ($b = -.000004$, $t(27) = 3.57$, $p = .001$), but including it as time-varying covariate of R_{OS} again did not alter R_{OS} differences between, or R_{OS} trajectories within, films ($b = -.0025$, $t(27) = 3.82$, $p = .001$ vs. $b = -.0026$, $t(27) = 3.84$, $p = .001$, for R_{OS} within-film time effect with and without covariate). RR was not related to R_{OS} scores over time.

Including tension sequences in a supplementary analysis did not substantially alter this pattern of findings. For V'_E , only a tension main effect was obtained ($b = 772.2$, $t(28) = 4.12$, $p < .001$). For the analysis of R_{OS} with V'_E as a time-varying covariate, the time course within films closely reflected the analysis without tension sequences.

Relationship of R_{OS} trends with emotion and symptom ratings

For both patients with asthma and controls, higher ratings of arousal after the films were generally related to less quadratic flattening of the curve ($b = -.00003$, $t(1943) = 2.98$, $p < .01$) indicating that R_{OS} tracked closer to a straight, flat line with higher arousal scores. Feelings of control were generally related to lower overall R_{OS} scores for both asthma patients and healthy controls ($b = -.008$, $t(1937) = 2.54$, $p = .01$.) [Footnote 3]

Higher ratings of shortness of breath were associated with higher R_{OS} across both groups ($b = .022$, $t(1939) = 2.51$, $p = .01$) and slower decreases (less negative linear slopes) in R_{OS} over the surgery and unpleasant but not neutral film presentation for patients with asthma ($b =$

³The association between lower R_{OS} and higher feelings of control might have been because men (with anatomically higher lung volumes and thus lower R_{OS}) reported higher control, but additional analyses showed that the association was independent of sex. Also lung volume could be increased (and R_{OS} thereby decreased) by taking deep breaths, a common lay strategy for mastering anxiety and increasing one's sense of control. However, V_T showed no significant association with feelings of control.

002, $t(1939)=3.28$, $p=.001$). The only finding for chest tightness was that higher chest tightness was related to greater rates of increase in R_{OS} over time for asthmatics watching neutral films ($b=.002$, $t(1935)=3.47$, $p<.001$).

Relationship of R_{OS} trends with patient susceptibility to emotional asthma triggers

ATI moderated the R_{OS} slope over time in both no tension and combined tension/no tension analyses. The linear decrease in R_{OS} over time for surgery and unpleasant films was less the higher the ATI score, $b=.001$, $t(11)=2.22$, $p<.05$. To elucidate the effect of ATI scores on decrease in R_{OS} , we divided patients into 3 approximately equally sized groups: low ATI (mean=0.05, $n=4$), medium ATI ($M=0.40$, $n=4$) and high ATI ($M=0.95$, $n=5$). The average slope of decline in R_{OS} for those three groups was $b=-.0031$, $-.0027$, and $-.0021$, respectively, which translated into an overall decrease in R_{OS} (in a 3 minute period) of $-.053$, $-.046$, and $-.035$ $\text{kPa}\cdot\text{L}^{-1}\cdot\text{s}$, respectively, for patients in each group. In addition, the quadratic flattening of the curve was less the higher the ATI score, $b=-.0001$, $t(11)=-2.81$, $p<.05$, being closer to a straight, flat declining line with higher ATI scores.

Discussion

Our study showed a surprisingly uniform activation pattern of the airways of the average individual with asthma during continuous emotional stimulation with films of unpleasant content. Maximal airway constriction was reached within the first 2 minutes of stimulation and then slowly tapered off. Overall constriction was stronger for surgery films than for other unpleasant film material, but the temporal pattern of changes was similar for both types [Footnote 4]. These findings indicate that airway constriction is not stable during emotional stimulation but peaks in an early phase after stimulus onset. Both too long and too short stimulation periods may yield suboptimal results. Thus, studies using brief picture presentations of 10–20 s have observed smaller effects than film studies (Ritz, 2004). On the other hand, calculation of average respiratory resistance over longer film presentations may also underestimate the extent of airway constriction that is triggered by emotional stimulation. Indeed, 13 of the 15 asthma patients showed increases in R_{OS} during the early phase of the surgery film compared to neutral film control. [Footnote 5]. At maximum constriction during the surgery film, the average resistance increase exceeded typical

⁴.Moreover, as the supplementary analysis showed, the response trajectories were also highly comparable between the two individual surgery films and unpleasant films. The latter in fact elicited differing discrete emotional states (measured by additional unipolar rating scales: unpleasant film 1 elicited significantly more anger than unpleasant film 2 (2.0 vs. 0.7 on a 0–10 scale, $t(27)=2.57$, $p=.016$), whereas unpleasant film 2 elicited marginally more sadness than unpleasant film 1 (2.7 vs. 2.0, $t(27)=2.03$, $p=.052$). Average neutral film ratings were 0.8 for anger and 0.4 for sadness.

⁵.A common metric for determining clinical significance of findings in pulmonology has been the percentage of reduction in spirometric lung function, typically in forced expiratory volume in the first second (FEV_1). Although the comparison of findings between these two very different assessment techniques is burdened with some uncertainty, and despite the arbitrariness of cut-off scores and their variability across studies (e.g., for exercise induced asthma, anything between 6 and 25% FEV_1 decrease had been proposed; Weiler et al., 2010), an attempt could be made to link up with this clinically oriented literature. A comparison between impulse oscillometry and spirometry by Singh et al. (2006) found 12% FEV_1 reduction to be roughly equivalent to 30% increase in resistance at 5 Hz oscillation frequency. In our sample, 4 patients (26.6%) reached peak increases exceeding 30% at one point. It should be noted that due to a negative frequency dependence of resistance with lower values at higher oscillation frequencies (see e.g., Ritz et al., 2010), the comparison with 5 Hz rather than 10 Hz (which was not provided by Singh et al., 2006) is likely to underestimate the amount of FEV_1 change we may have seen in our participants. The findings compare well with other studies showing that typically around 20–40% of participants meet similar criteria of clinically significant bronchoconstriction due to psychological stimulation (Isenberg et al., 1992; Ritz & Steptoe, 2000) or that report psychological states as major triggers of their asthma (Ritz et al., 2006).

thresholds for perception of noticeable differences in obstruction, as they have been reported from studies with added resistive loads (Dahme et al., 1996). This speaks to the clinical relevance of these changes for perceiving symptoms of obstruction, as do the observed associations of resistance trajectories with shortness of breath in asthma patients.

The uniform response trajectories to unpleasant and surgery films (with or without accompanying muscle tension) for patients with asthma may indicate that we observed a relatively general response characteristic of the airways to emotional stimulation. R_{OS} values were also elevated briefly at the beginning of the neutral film. This might have been caused by initial anticipatory anxiety. The films were presented in a randomized form without the participants being able to predict the nature of the upcoming film. The brief elevation may have been due to uncertainty about the content of the film, which would have abated quickly after the neutral nature of it (economy lecture, screen saver) had become apparent. Healthy participants also showed higher values in the initial 30–120 seconds of the films, but analyses indicated that the slope of decline did not reach statistical significance. This may in part be due to the small sample size of the study and/or the smaller overall levels of airway constriction reached in healthy people. However, the distinction between films, with the surgery film reaching the highest and the unpleasant film intermediate levels, was also seen in healthy controls. Other studies have observed qualitative, but not necessarily quantitative similarities between individuals with and without asthma to emotional or cognitive challenges (Ritz et al., 2000; 2010). Perhaps modulation of central nervous system pathways that govern airway constriction, particularly the vagal preganglionic nuclei in the nucleus ambiguus and their input from other brainstem and suprapontine regions, may be affected by atopy or other aspects of the asthmatic disease processes (Haxhiu et al., 2005; Wilson et al., 2007), thus leading to stronger excitatory vagal outflow to the airways across a range of emotional states. Neuroimaging studies may shed more light on central nervous system pathways in asthma patients in coming years (Rosenkranz and Davidson, 2009).

Another interesting finding of our present analysis was the association of R_{OS} trajectories with psychological variables. Higher arousal and more shortness of breath were related to more sustained airway constriction, the latter being only experienced by patients. It might seem reasonable to assume that stronger arousal led to more constriction and that more constriction subsequently led to stronger symptoms of shortness of breath, but a reverse causality cannot be excluded. Unfortunately, our data cannot inform us about the directionality of effects, because self-report was only collected after the films to avoid interference with the emotional experience. It should also be noted that although R_{OS} changes and their association with shortness of breath showed a specificity for asthma patients and emotional films (surgery and unpleasant versus neutral), this was not the case for arousal. This may simply be an example for a respiratory parameter showing a closer association with respiratory sensation than with an emotional experience. However, more work is needed to elucidate the associations between bronchoconstriction, emotion, and respiratory sensation.

Even more intriguing, patients that reported experiencing emotional asthma triggers more frequently in daily life also showed more sustained airway constriction during film presentation in the laboratory. The initial analysis of the present data (Ritz et al., 2011) did

not replicate earlier findings (Ritz et al., 2006; 2010) of higher overall R_{os} during unpleasant films in those patients who had more frequent emotional asthma triggers, perhaps because of the overall smaller number of patients in this compared to the earlier studies. However, the findings from the current analysis add to our knowledge of typical airway responses of these patients. Sustained constriction to emotional stimuli is likely to translate into more symptoms and a greater vulnerability to exacerbations in specific situations, especially when psychological and other common trigger factors interact. Such emotional reactions may place an undue burden on patients' daily activities. It could be speculated that the association observed between emotional trigger reports and elevated anxiety and depressive mood (Ritz et al., 2008; Wood et al., 2007) is a consequence of such reactions. Overall, our findings add to an existing body of evidence for a critical role of stress and negative emotions in asthma (e.g., Chen and Miller, 2007; Feldman et al., 2005; Lavoie et al., 2006; Marshall, 2004; Wright, 2010) by illustrating the typical time course of airway obstruction during ongoing emotional simulation and demonstrating that perceived emotional arousal, shortness of breath, and proneness to emotional asthma triggers in daily life are associated with more sustained airway constriction. An extension of this research may directly assess real-life high affect episodes and their psychophysiological consequences using novel methods and analytic strategies (Wilhelm & Grossman, 2010). Indeed, earlier findings indicate that focusing on episodes of strong affect and the associated lung function decline in daily life can corroborate laboratory findings of film-induced respiratory resistance increases (Ritz & Steptoe, 2000).

Surgery films elicited a stronger increase in R_{os} than generally unpleasant or neutral films. The particular potency of surgery films (or other stimulus material such as pictures of blood, wounds, or mutilations, Ritz et al., 2000) may be due to the specific capability of this stimulus type to enhance vagal excitation (Engel, 1978). Vagal excitation is a major source of airway smooth muscle constriction (Barnes, 1986; Canning, 2006) and a recent study demonstrated that respiratory resistance increases to the same surgery films used in this study can be abolished by cholinergic blockade with ipratropium bromide (Ritz et al., 2010). In the latter study, airway responses to this film material were not correlated with nonspecific airway hyperreactivity to methacholine or airway inflammation measured by exhaled nitric oxide, suggesting that central vagal excitation (rather than peripheral end-organ dysregulation) was the main source of airway constriction. If central nervous system processes provided an independent contribution to bronchoconstriction in some individuals with asthma, new therapeutic strategies would be required that extend beyond the biomedical approach of treating peripheral organ dysfunction or damage and that target relevant aberrations in CNS processes (e.g. behavioral or experiential intervention techniques).

The role of sympathetic effects in the observed airway response pattern is probably less prominent, given that there is no known direct sympathetic innervation of the airway smooth muscle (Barnes, 1986; Canning, 2006). Circulating catecholamines or sympathetic innervation on the level of the ganglia could be a source of dilating influences on the airways, but to explain the observed bronchoconstriction, a temporary *reduction* of such influences during unpleasant stimulation would have to be assumed. Inhibitory noncholinergic activity also contributes to airway tone, but these influences are difficult to

study because of the lack of dynamic noninvasive indicators in psychophysiology. One current practical limitation in studying the contribution of the autonomic nervous system (ANS) branches is the target organ specificity of indicator variables. There is often discordance between organ sites with respect to the amount of sympathetic and parasympathetic excitation at a given time point (Morrisson, 2001; Ritz, 2009). Although selective indicators are available for both ANS branches at the level of the heart (e.g. respiratory sinus arrhythmia, preejection period, or T-wave amplitude), none have been tested for the airways so far. In any case, the observed response dynamics of the airways to films was more compatible with an ANS mechanism of constriction, rather than a constriction triggered by mediator release, such as the early phase allergic response of the airways, which develops after minutes of stimulus application (Grainge & Howarth, 2011) rather than seconds.

Respiratory pattern parameters did not change significantly within and between films, except for a general increase of $\dot{V}_E$ over the course of surgery and unpleasant films for both patients and healthy controls. No influences of respiratory parameters on the R_{OS} trajectories were found across conditions. However, overall negative associations between R_{OS} and $\dot{V}_T$ or $\dot{V}_E$ were observed, which may have resulted from phasic reductions in R_{OS} through occasional deep breaths that did not affect the overall rate of decline in R_{OS} . Bronchodilation by deep breaths has often been demonstrated in healthy individuals and patients with intermittent to mild-persistent asthma (Nadel and Tierney, 1961; Brusasco and Pellegrino, 2003; Scichilone et al., 2007). In general, a larger airway diameter should result in lower resistance values (Forster et al., 1986). Bronchodilatory influences of deep inspiration are attenuated or even abolished in moderate persistent to severe asthma (Scichilone et al., 2007), but the bronchodilatory effects across both groups were probably demonstrated because the exclusion of recent oral corticosteroids led to a lack of severe asthma cases in our sample. The fact that no respiration rate influences on R_{OS} were found confirms a recent study with paced breathing that showed only minimal effects on R_{OS} (Ritz and Dahme, 2009). These findings support the interpretation of the R_{OS} trajectories as being mediated by changes in autonomic outflow rather than by respiratory adjustments.

The results of this investigation should be interpreted with some caution because our sample size was relatively small. However, previous research has shown that MLM models with sample sizes as small as ours produce unbiased estimates of regression coefficients even with far fewer data points per participants than in the present study (Mass and Hox, 2005). Further, estimates of regression coefficients for growth curve parameters are more accurate when there are more assessment points (Singer and Willett, 2003). Given that our growth curve parameters were estimated with a very large number of data points (17–28 each), our estimates should be relatively accurate. Finally, the total number of data points used in our analyses ranged from 2436 (for analyses not including leg tension) to 4872 (for those including leg tension), thus providing a very large number of data points for each of our comparisons.

In conclusion, increases in airway obstruction during sustained unpleasant stimulus presentation show an initial peak within the first 2 minutes, which gradually abates. The rate of decline depends on patients' experience of arousal and shortness of breath: when these

sensations are stronger, the obstruction is sustained longer. In addition, patients who suffer more from psychological asthma triggers in daily life, have a slower reduction of the initial obstruction during unpleasant stimulation. Sustained obstructions in psychosocial settings may make patients particularly vulnerable for experiencing symptoms in those settings and create an additional burden on their social life.

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Highlights

- During sustained stimulation with emotional films, asthma patients show an initial airway constriction which gradually declines after 2–3 minutes
- Airway constriction was stronger during surgery films than generally negative films, but the overall temporal trajectory throughout films was comparable
- Rate of decline in airway constriction in later stages of stimulation was less in participants who experienced greater arousal as well as patients who reported more shortness of breath during the films and emotional asthma triggers in daily life

Figure 1. Average time course of respiratory resistance across successive 10-s intervals (upper panel) and corresponding multilevel modeling trends (lower panel) for surgery, unpleasant, and neutral films for individuals with asthma

Figure 2. Average time course of respiratory resistance across successive 10-s intervals (upper panel) and corresponding multilevel modeling trends (lower panel) for surgery, unpleasant, and neutral films for healthy controls

Table 1.Demographic and disease manifestation variables in asthma patients ($n=15$) and healthy controls ($n=14$).

	Asthma	Control	<i>p</i> -level for sample differences [*]
Age, years (<i>M, range</i>)	40.1 (20–55)	36.4 (22–57)	0.462
Sex, women (%)	73.3	71.4	1.000
Race, 100% White (%)	86.6	71.4	1.000
Ethnicity, at least 50% Hispanic (%)	86.6	92.8	1.000
Age asthma onset (<i>M, range</i>)	17.5 (0–40)	NA [†]	NA
Family history of asthma, positive (%)	66.7	NA	NA
Seasonal variations in asthma (%)	66.7	NA	NA
Symptoms, >2 times/week (%)	53.3	NA	NA
Daily activities, limited >2 times/week (%)	53.3	NA	NA
Night time symptoms, >1 time/week (%)	46.6	NA	NA
Anti-asthmatic medication			
Short-acting bronchodilators	80.0	NA	NA
Long-acting bronchodilators	33.3	NA	NA
Inhaled corticosteroids	80.0	NA	NA
Leukotriene inhibitors	40.0	NA	NA
Antihistamines	20.0	NA	NA
Mast cell stabilizers	13.3	NA	NA

^{*} *p*-levels for sample differences from *t*-test or χ^2 -test

[†] NA: not applicable, not assessed in the control group

Table 2.

Within-individual change scores, percentage change, and effect sizes (Hedge's g) for successive 30-s averages of R_{OS} from neutral to surgery or unpleasant film

seconds	0–30	31–60	61–90	91–120	121–160	161–180
Asthma						
Surgery						
(kPa•L ⁻¹ •s)	0.069	0.087	0.098	0.070	0.061	0.037
range	–.059 – .276	–.056 – .356	–.023 – .283	–.054 – .285	–.065 – .261	–.150 – .218
%	14.3	19.1	21.7	15.5	13.6	7.1
g	1.62	0.84	1.10	0.83	0.62	0.37
Unpleasant						
	0.041	0.048	0.031	0.019	0.013	–0.005
range	–.030 – .174	–.078 – .267	–.040 – .143	–.062 – .145	–.095 – .162	–.130 – .133
%	8.5	10.5	6.9	4.2	2.9	–1.0
g	0.65	0.59	0.61	0.34	0.20	–0.07
Control						
Surgery						
(kPa•L ⁻¹ •s)	0.026	0.046	0.039	0.037	0.015	0.027
range	–.048 – .145	–.030 – .231	–.073 – .169	–.055 – .151	–.079 – .094	–.054 – .117
%	7.5	13.2	10.3	9.5	4.4	8.2
g	0.50	0.70	0.64	0.45	0.33	0.29
Unpleasant						
	0.017	0.004	0.003	0.009	–0.001	0.001
range	–.061 – .116	–.077 – .071	–.046 – .055	–.048 – .098	–.089 – .071	–.047 – .102
%	4.5	1.2	0.9	2.7	–0.3	3.0
g	0.38	0.09	0.09	0.23	–0.02	0.11