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Perception and Respiratory Responses of the Upper Airway Mechanism to Added Resistance With Aging

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Objectives: To assess breathing behaviors and perception of added respiratory loads in young compared to old individuals, and to determine whether aging affects the perception and response to changes in nasal airway resistance.

Study design: In a clinical study, 40 young (11–20 years) and 40 older (59–82 years) subjects were evaluated during rest breathing and during the application of added airway resistance loads.

Methods: The pressure-flow technique was used to measure airflow rate (mL/s) and oral-nasal pressures (cmH_2O) to calculate nasal resistance ($cmH_2O/L/s$). To create calibrated resistance loads for the test conditions, we used a device modified from a precision iris diaphragm.

Results: During rest breathing airflow rate was significantly lower for the younger group compared to older group. Using the loading device, 11–20-year-olds detected increased resistance at the level of 2.26 $cmH_2O/L/s$ compared to 4.55 $cmH_2O/L/s$ in 59–82-year-olds. In contrast to the younger group, mean airflow rate was higher during expiration than during inspiration among 59–82-year-olds except at rest breathing.

Conclusions: The data revealed that the perception and respiratory response to increased airway resistance changed with aging. Younger subjects were more sensitive to changes within the airway. In both groups, subjects responded to increased airway resistance by decreasing airflow rate. However, expiratory phase became more active than inspiratory phase only in the older group.

Key Words: Nasal resistance, nasal airflow rate, threshold load, pressure-flow technique, weber fraction.
Level of Evidence: N/A

INTRODUCTION

Although most healthy individuals are primarily nasal breathers, airway impairment caused by allergies or infection results in a change to both nasal and oral breathing. Combined nasal and oral breathing also occurs during exercise,[1] when breathing colder air,[2,3] or in supine position.[4–6] Also, nasal airway impairment in connection with mucosal swelling due to allergies can trigger mouth breathing.[7,8] Switching from nasal to nasal and oral breathing occurs when nasal resistance reaches a threshold level which differs slightly among individuals and age.[9–11] A variety of techniques have been used to determine thresholds including body plethysmography and several rhinomanometric approaches.[12–16] An increase in nasal airway size with age in children has been reported in several studies in different population groups.[17–24] Once adulthood is reached, there is little change in nasal airway size[25] although there are inconsistencies between nasal airway resistance and age.[26,27] Other parameters of respiratory function have been less studied using aging as a factor.

Ventilatory responses due to external mechanical loading have been studied experimentally,[13,15,28,29] in patients with increased airway resistance [7,10,30,31] or with neurological abnormalities.[32] In young adults Bennett et al.[33] showed that mean non-elastic resistance was 1.5–3.4 $cmH_2O/L/s$ and the 50% detection represents 25% change in non-elastic resistance. Wiley and Zechman[9] found that the 50% detection represents about 25–30% change in non-elastic load. All these studies indicate that breathing pattern changed although there is some disagreement on which variable is monitored and regulated during breathing.

The purpose of the present study was to assess breathing behaviors and the perception of added respiratory loads and, in particular to determine whether sensitivity and compensatory mechanisms change with aging.

MATERIALS AND METHODS

Two different age groups were compared with each other: 40 adolescents and 40 older adults, representing a homogenous

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population of Caucasian origin. The younger group included 40 healthy volunteers, 21 girls and 19 boys, with a mean age of 17.6 (SD 2.1) years and age range from 11.2 to 20.3 years. Forty older adult subjects, 29 women and 11 men, on an average 69.9 (SD 5.9) years of age, ranging from 59 to 82 years, participated in this study. Height (cm) was measured. A structured questionnaire was used to get information about history (0 = no, 1 = yes) of allergies, nasal symptoms, smoking habit and medical conditions including asthma, heart disease, rheumatism, diabetes, as well as lung, thyroid gland, and biliary diseases. In the younger group, 11 subjects had seasonal allergies and 14 individuals smoking habit, in the older group the corresponding numbers were 9 and 4, respectively. None in the younger group while 13 subjects in the older group had chronic medical conditions, controlled by medication. Two older adults but none of the adolescents reported asthma. To include the volunteers in the study, they had to be free from nasal symptoms and seasonal allergies at the time of the measurements.

Airflow rate and oral and nasal pressures were recorded using the pressure-flow technique originally described by Warren et al.[15] using the PERCI-PC and PERCI-SARS software (Microtronics Co., Chapel Hill, NC). The intraclass correlation value of 0.80 (95% CI 0.58–0.94) has proved the reproducibility of the method to be good.[2] The pressure drop across the nasal airway was measured by differential transducers connected to two catheters, by placing one catheter midway in the mouth and another catheter within a well-fitted nasal mask as in posterior rhinomanometry. Nasal airflow was measured with a heated pneumotachograph connected to the nasal mask which formed an airtight seal. Nasal airway resistance was determined using the following hydrokinetic equation:

$$R = \Delta P / V$$

where R = resistance cmH$_2$O/L/s, P = oral-nasal pressure (cmH$_2$O), and V = total airflow rate (mL/s).

The device used to create resistance loads was modified from a precision iris diaphragm (Model no. N36.624, o.d. 60 lever bridge) with a maximum opening of 8.0 mm diameter, corresponding an area of 0.50 cm^2, that could be opened and closed in 0.2 mm increments in the diameter. The diaphragm was mounted halfway between the nasal mask and the pneumotachograph. The catheters of the pressure-flow instrumentation to measure pressures were connected to the tubing before and after the diaphragm. Table I presents data on the relationship between aperture area and resistance load, calibrated at an airflow rate of 500 mL/s. All measurements were recorded in an upright position in periods of 10 seconds for each subject. After recording rest breathing, the device to create added resistances was added, and the aperture size of the diaphragm was manually adjusted in a random sequence of higher and lower loads. In each instance, the loaded condition was compared to a control, "unloaded," condition with the diaphragm wide open. The subjects were asked to indicate when they detected a change in resistance. The same value had to be detected three times consecutively to be accepted as a threshold value.

The increment threshold for detecting a difference in nasal resistance was calculated for each individual as a Weber Fraction:

$$WF = (Ri - Ro)/Ro$$

where Ri = the resistance of the system corresponding to the just noticeable resistance during added load plus nasal resistance during rest breathing, and Ro = the resistance of the system corresponding to the diaphragm setting maximally open plus nasal resistance during each individual's rest breathing.

Ethical approval for this study was granted by the Research Ethics Committee of the University of Kuopio and the Kuopio University Hospital, Kuopio, Finland, and the informed consent forms were signed by the participant or the parent.

TABLE I.
Relation Between Cross-Sectional Area and Resistance with the Device Used to Create Added Resistance with Different Iris Setting, Calibrated at 500 mL/s.

Cross-Sectional Area of the Diaphragm (cm^2)	Resistance (cmH$_2$O/L/s)
0.50	2.2
0.48	2.5
0.45	2.9
0.43	3.4
0.41	3.6
0.38	4.2
0.36	4.6
0.34	5.1
0.32	6.3
0.31	7.3
0.28	8.9
0.26	9.5
0.25	10.2
0.23	12.9
0.21	16.4
0.20	19.1
0.18	22.1
0.16	25.1
0.15	30.6
0.14	36.9
0.13	46.3

Statistical Methods

Differences between inspiratory and expiratory values of resistance and airflow rate during rest breathing and at three test conditions were assessed by paired t-test. Linear regression models were used to estimate associations between respiratory variables (resistance, airflow rate as well as the differential [inspiration minus expiration] values of resistance and airflow rate) during rest breathing and at the three test conditions according to age group (1 = 11–20-year-olds, 2 = 59–82-year-olds) and gender (0 = females, 1 = males), with occurrences (0 = no, 1 = yes) of smoking habit and any medical condition (see Materials and Methods) as confounding factors, with height (cm) as covariate. Because none of the adolescents but 13 individuals among older adults had chronic diseases, controlled by medication, linear regression models were performed also separately for the older group. None of the adolescents and two older adults had asthma, the number of individuals being too small to be included in the analyses. For all analyses, *p*-values ≤ 0.05 were considered statistically significant.

RESULTS

Table II shows mean values of nasal resistance and airflow rate during inspiration and expiration at rest breathing and all test conditions, namely at: 1) the unloaded condition with the diaphragm the device to create resistance loads wide open; 2) at the time when

TABLE II.
Differences Between Inspiratory and Expiratory Airflow Rate (mL/s) and Nasal Resistance (cmH$_2$O/mL/s) Values Among the Younger (11–20 yrs) and Older (59–82 yrs) Study Groups at Different Load Conditions.

	Adolescents (n = 40)			Older adults (n = 40)		
	Inspiration mean (SD)	Expiration mean (SD)	p*	Inspiration mean (SD)	Expiration mean (SD)	p*
Rest breathing						
Resistance	2.10 (1.64)	1.77 (1.46)	0.000	2.34 (2.61)	2.00 (2.46)	$<$0.001
Airflow rate	431 (103)	387 (125)	0.000	490 (149)	486 (206)	0.827
Unloaded condition						
Resistance	1.54 (0.27)	1.40 (0.33)	0.000	1.75 (0.35)	1.55 (0.57)	0.001
Airflow rate	318 (58)	312 (73)	0.504	351 (82)	385 (108)	0.002
Loaded just before detection						
Resistance	2.10 (0.65)	1.95 (0.77)	0.005	4.13 (1.98)	4.70 (3.24)	0.038
Airflow rate	300 (62)	295 (64)	0.340	308 (82)	318 (110)	0.290
Loaded at detection						
Resistance	2.26 (0.73)	2.17 (0.85)	0.103	4.55 (2.29)	5.45 (4.13)	0.017
Airflow rate	302 (61)	303 (65)	0.953	303 (84)	315 (117)	0.212

*by paired t-test.

added resistance was detected; and 3) just before detecting the change, for both groups separately.

When comparing the inspiratory and expiratory variables (Table II), among 11–20-year-olds inspiratory resistance values were higher compared to expiration. The difference was statistically significant at all conditions except when the individuals detected the added respiratory load. Inspiratory airflow rate was higher than expiratory airflow rate but differed significantly only during rest breathing. For 59–82-year-olds, inspiratory resistance was significantly higher at rest breathing and at the unloaded condition but significantly lower at detection of the load and just before detection compared to expiration. For the older group, inspiratory airflow rate was lower compared to expiratory values except during rest breathing, and differed significantly only at the unloaded condition.

When comparing differential (inspiration minus expiration) values of the respiratory variables between the groups, linear regression models showed that the older group had significantly higher differential resistance at detection of the added load and just before detection and differential airflow rate at unloaded condition (Table III).

During inspiration at rest breathing and all test conditions (Table II), resistance values for the younger group were lower, 2.10, 1.54, 2.10, and 2.26 cmH$_2$O/L/s, respectively, compared to the corresponding values of older adults, 2.34, 1.75, 4.13, and 4.55 cmH$_2$O/L/s. Linear regression models showed that the difference between the groups was statistically significant at all

TABLE III.
Associations between differential (inspiration–expiration) resistance and airflow values (cmH$_2$O/L/s) according to age groups (1 = 11–20 yrs, 2 = 59–82 yrs) and gender (0 = female, 1 = male), considering the effects of smoking habit (0 = no, 1 = yes) medical history (0 = no, 1 = yes, see Subjects and Methods), with height (cm) as a covariate by linear regression analysis. Only statistically significant associations are given.

Dependent/Independent variable	Standardized coefficients Beta	p-value
RESISTANCE (cmH$_2$O/L/s)		
Loaded just prior to detection		
Group	0.277	0.020
Gender	0.339	0.026
Loaded at detection		
Group	0.301	0.013
AIRFLOW RATE (mL/s)		
Unloaded condition		
Group	0.283	0.020

TABLE IV.
Associations between respiratory responses to added loads during inspiration according to age groups (1 = 11–20 yrs, 2 = 59–82 yrs) and gender (0 = female, 1 = male), considering the effects of smoking habit (0=no, 1=yes) and medical history (0 = no, 1 = yes, see Subjects and Methods), with height (cm) as a covariate by linear regression analyses. Only statistically significant associations are given.

Dependent/Independent variable	Standardized coefficients	p-value
RESISTANCE (cmH$_2$O/L/s)		
Unloaded condition		
Group	0.318	0.008
Loaded just prior to detection		
Group	0.592	$<$0.001
Loaded at detection		
Group	0.594	$<$0.001
AIRFLOW RATE (mL/s)		
Rest breathing		
Group	0.266	0.032

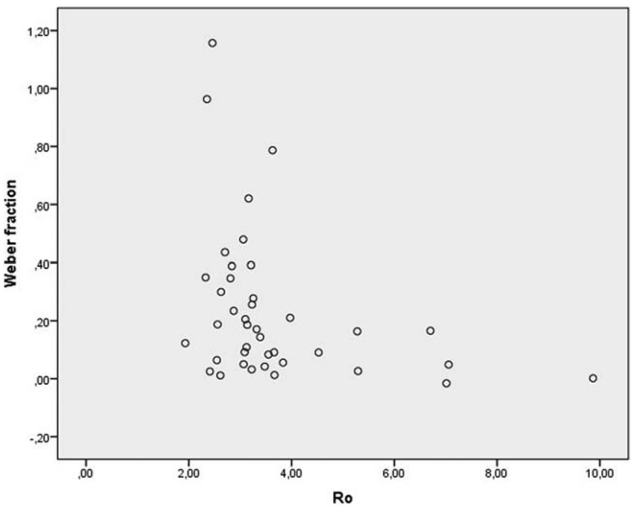

Fig. 1. Scattering of Weber fraction according to baseline resistance ($cmH_2O/L/s$) in 40 adolescents and young adults.

conditions except during rest breathing (Table IV). Inspiratory airflow rate was lower for the adolescents compared to the older adults (Table II) but linear regression models (Table IV) showed that it was statistically significantly different only at rest breathing (431 and 490 mL/s, respectively), and decreased to about the same values of 300 and 308 mL/s just prior to detection, and to 302 and 303 mL/s, respectively, at detection of the added load.

The only statistically significant effect of gender was on differential resistance just prior to detecting the added load. Height, smoking habit, upper airway allergies, or other nasal symptoms did not have a statistically significant effect on any of the respiratory variables. Among older adults, history of chronic diseases was related to nasal airflow only at the unloaded condition ($p = 0.035$).

Weber fraction, the just noticeable difference in added upper airway resistance, varied from -0.02 to 1.16 in adolescents and from 0.01 to 2.48 in older adults. The mean values were 0.23 (SD 0.26) for adolescents and 0.84 (SD 0.79) for older adults ($p < 0.001$). Scattering of Weber fraction according to baseline resistance values illustrated the constant nature of Weber fraction (Fig. 1) among adolescents, while there was a wider inter-individual variation among older adults (Fig. 2), indicating that higher added loads were needed for detection of change.

DISCUSSION

We determined that a sample size of 40 in each group was sufficient for this clinical study which, while non-invasive, was very time consuming for each subject. Power analyses confirmed this assumption. Earlier studies[7,10,13,31,32] involved groups from 8 to 51 subjects. In the present study, all participants were clinically healthy and free of nasal symptoms at the time of the measurements. Previous studies have shown that when individuals with acute nasal congestion are excluded, medical history was not associated with measurements of nasal patency in children.[22,34]

The questionnaire on medical history did not include psychological factors, including anxiety disorders, which can affect perception of breathing and alter respiratory mode[35]. Also, use of anxiolytes is unknown because they were not separated from other medicines. When recording rest breathing followed by test measurements, performed by the same experienced examiners, special attention was paid to that the study subjects were relaxed.

The finding that in the present sample among older adults, history of chronic diseases was related to nasal airflow only at the unloaded condition could bias the comparisons slightly. Linear regression models showed that other variables of the medical history as well as smoking habit did not have significant effects on respiratory variables.

In studies on respiratory function, body size has been measured as height, weight, or body mass index (BMI). Somewhat surprisingly, stature, estimated in the present study as height, was not related to respiratory function which is parallel with findings of Zapletal and Chapulova[36] in 2–19-years old study group. In 108 20–45-year old adults it has been reported that nasal resistance decreased when the height and weight increased except in individuals with weight of 85–95 kg.[37] Our finding is parallel with studies using BMI in adult population[38,39] and also with results on subjects with sleepapnea and BMI ≥ 30 kg/m[2,40] but contradictory to a study on sample of wide age range, from 16 to 82 years.[41] When diagnosing problems in the upper airway, body size may only have significance when subjects are obese.

In our study groups, gender distribution was even among adolescents, while majority of the older subjects were women which is typical in older western populations. Only one variable associated with gender was statistically significantly different, nasal resistance just prior to detection of an added load.

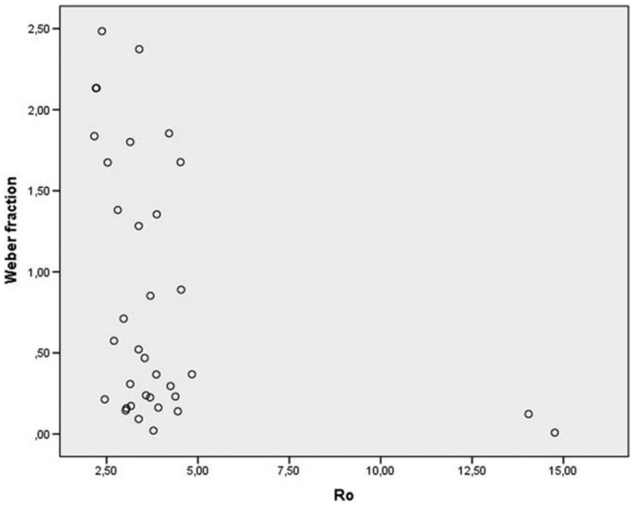

Fig. 2. Scattering of Weber fraction according to baseline resistance ($cmH_2O/L/s$) in 40 older adults.

This study revealed that older individuals detected added load at much higher resistance, 4.55 compared to 2.26 $cmH_2O/L/s$ in adolescents, indicating less sensitivity in the perception of increased nasal resistance in older adults. Both groups responded in similar fashion to increased load resistance by decreasing airflow rate to about 300 mL/s prior to detection indicating that there is a physiologic response to the change even before one is aware of a change in the airway environment. Thus, despite the higher airflow rate in older adults during rest breathing and despite their weaker perception of changes in upper airway resistance, the physiologic response to changes was surprisingly similar in both age groups not only at detection of the added load but also with added load prior to detection of change.

Attempts to correlate subjective sensation of nasal obstruction with objective measurements, whether defined as nasal resistant dependent on minimum nasal cross-sectional area when nasal mucosa is included in the measurements as in our method, or as nasal airflow volume or rate, are undermined by wide interindividual variation in respiratory variables and by the complex nature of sensory neural functions.[42] Still, threshold values could provide helpful guidelines. The threshold for increased nasal resistance to provoke an individual to switch from nasal to oral breathing with its' harmful effects has been suggested to be around 3.5–4.5 $cmH_2O/L/s$ in adults,[43] and has been reported to be 4.7 $cmH_2O/L/s$ in adolescents.[44] Thus, among the present study groups the 59–82-year-olds but not the 11–20-year-olds would probably change their breathing mode at the time of perception of increased resistance.

In the present study, resistance values were higher during inspiration compared to expiration. However, in the older group, resistance values during expiration were higher just prior to detection and at detection. Airflow rates were higher during inspiration than expiration in adolescents at all test conditions except at detection of the added load when the values were almost equal. On the contrary, among older adults, airflow values were higher during expiration than inspiration except at rest breathing. Only a few studies have investigated individuals' ventilatory responses to added loads during inspiration and expiration. In agreement with our findings in adolescents, Ferris et al.[45] reported that nasal resistance was higher during inspiration compared to expiration, and Muza et al.[46] found that peak inspiratory airflow was consistently higher than peak expiratory flow. Contrary to our findings, healthy adults showed expiratory resistance values to be significantly higher than inspiratory values[9] and to be more sensitive for expiratory than inspiratory loads.[47] In agreement with our findings, Tack et al.[48] compared younger and older adults and reported a difference for resistance, sensation intensity and peak mouth pressure loads.

In the present study, a Weber fraction was utilized to describe perception of the just noticeable increase in respiratory resistance. Weber's law expressing that the ratio of the increment threshold to the background intensity has been reported to be also valid in studies of perception of added loads to inspiratory resistance.[9–11] In individuals with asthma, the threshold values of detection have been reported to vary widely and to be much higher compared to controls, possibly partly due to chronic adaptation to the increased airway resistance.[10] In their study, Weber's law seemed to be applicable when bronchodilatation was not used. Hallani et al.[7] reported contradictory findings, namely enhanced detection of added nasal resistance in asthmatics compared to healthy subjects. In our study, Weber' law applied reasonably well among adolescents but not among the older group. The Weber fraction was clearly higher for older adults than adolescents, indicating that sensitivity to changes in airway resistance declines with aging.

Altogether, the clearly higher threshold for perception of increased upper airway resistance and increased effort for expiration in older people may pose a health hazard in individuals with cardiovascular or respiratory diseases during physical activities or stressful conditions.

CONCLUSIONS

This study revealed that aging significantly decreases the sensitivity to the recognition of changes in upper airway resistance. Before perception of an increased applied load, both groups attempted to compensate for the increase in resistance by lowering airflow rate. This respiratory response occurred at a lower load in the younger group but the differences in respiratory rate change were similar. That is, there was a lower sensitivity in the older group but the response was similar.

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