Extended essay

Title: The effect of smoking on vital capacity of teenagers

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> > Subject: Biology

Research question: To what extent does smoking cigarettes affect vital capacity in teenagers?

Word Count: 3909





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INTRODUCTION

The Purpose of Lungs and the Respiratory System

Lungs are sometimes described as one of the "vital organs" (Rettner), that is, they are absolutely necessary to sustain life. They perform a variety of functions, among them being blood storage and filtration, a part in the immune system, and others (Puttaswamy, Krovvidi); however, their main purpose and the reason for their indispensableness is their role in the *gas exchange*. This process includes the intake of oxygen into the bloodstream and removal of carbon dioxide from the body. Oxygen is essential for aerobic respiration during which glucose is broken down in the presence of oxygen, resulting in generation of energy in the form of ATP. This energy is then used for all life processes such as movement, growth and metabolism ("Respiration"). A by-product of aerobic is respiration is carbon dioxide. If present in higher concentration, CO_2 has negative effects on the human body such as acidosis, causing a decrease in the pH of naturally alkaline blood by forming bicarbonate ions (HCO₃⁻). It also acts as an asphyxiant (#WYO60-EA06-18), meaning that it replaces oxygen, prevents it from binding to haemoglobin and may lead to suffocation. Thus, it must be eliminated from the body. This is achieved through breathing, or ventilation via respiratory system. Therefore it is crucial for respiratory system to be in a perfect condition.

Mechanism of Breathing

During inhalation (breathing in), the air enters through the nose or the mouth, passes

through the pharynx and into a trachea supported by cartilaginous rings. At one point, carina, the trachea splits into the left and right bronchi that, in the lungs, divide further into smaller bronchioles (airways) and end in tiny air sacs called alveoli. When the air reaches the alveoli, gas





Fig. 1. Diagram of the respiratory system



exchange takes place (Kimball). Due to partial pressures in both oxygen and carbon dioxide, diffusion through thin blood barrier can occur (Farabee). Oxygen diffuses from alveoli into surrounding capillaries and carbon dioxide diffuses out of the blood stream to be exhaled.

In order to breathe, a pressure difference between the exterior and interior of the body is required. This is reached by altering the volume of the lungs. Since there is an inverse relationship between volume and pressure, when lungs enlarge, pressure will decline inside them. To counteract this, air is sucked in and we inhale. The expansion and contraction of lungs is achieved by expansion of the rib cage and muscle contraction, mainly the diaphragm, a flat tissue layer dividing the thoracic and abdominal cavity. It is curved upwards, and so when it contracts, it flattens out, leaving more space for lungs which subsequently expand. At times of rest, the diaphragmatic movement is dominant. When ventilation becomes deeper (e.g. during physical activity), chest muscles participate as well (Johnson). This is to enable the rib cage and subsequently the lungs to expand more in order to allow more air enter the body, as more oxygen is used up during exercise.

Ventilation is regulated by a part of the hindbrain, medulla oblongata, which also controls the heartbeat. It "stimulates the intercostal muscles and diaphragm" (Kimball). It should be noted that ventilation is adjusted according to the level of CO_2 , not oxygen, as medulla is sensitive to changes in pH caused by changing concentrations of HCO_3^- ions (as discussed above).

Lung Volumes and Capacities

After exhalation, the lungs are not completely empty. In fact, about 1200 ml of residual air will remain even after forced exhalation (Sheffield). Were it not for this residue, the lung tissues would stick together ("Gas Exchange"). The residual volume (RV) cannot be directly measured as the air does not leave the body. This means that the total lung capacity (TLC) is rather calculated than measured.



There are other functions of the ventilation that can be measured. They are called other volumes or capacities, the former being just one function, while the latter a sum of two or more functions ("Gas Exchange").



Fig. 2. Overview of lung volumes and capacities as seen on spirometer.

Fig. 2. shows the graph of a breathing pattern with the various volumes and capacities. They key concepts are the following:

- Tidal Volume (TV) is the amount of air inspired and expired during a normal breath.
- Inspiratory and Expiratory Reserve Volumes (IRV and ERV) measure the volume of air that can be inhaled or exhaled (respectively) beyond a normal breath.
- Residual volume (RV): discussed above.
- Vital Capacity (VC): TV + IRV + ERV.

Factors Determining Vital Capacity

As mentioned in the previous paragraph, RV remains about 1200 ml in both men and women. Therefore, it is the vital capacity that matters when determining the health of the respiratory system. It should be clear that VC is affected by a number of factors, both physiological, and pathological, i.e. disease. The latter will be discussed later in this essay.



1. Height

It should seem logical that with increasing height, one's vital capacity should increase as well, as there is more space for the lungs. However, when we look at the relationship of functional residual capacity (volume of remaining air after a normal exhalation) and body height in infants (Fig. 3.), it is clear that not only does functional residual capacity (FRC) increase non-linearly as the body length grows, the correlation becomes less strong. Assuming that VC behaves similarly, the data suggests that height does affect vital capacity, but there are other factors that need to be considered.



Fig. 3. Graph of FRC against body length in infants and children

2. Sex

"The average volume of VC is 4.5 litres in males and 3.3 litres in females" (Pal & Pal 151). Men generally have larger VC as their chest is larger and subsequently their lungs as well.

3. Age

Since height is also a determinant of VC (see 1.), VC depends on age, too. In infants and children, the body proportions are much different to those in adults. The relative proportion of head gradually becomes smaller, while that of legs grows larger, contributing to bigger standing height (Quanjer, "Standing"). Also, the thorax and the lungs are elastic in adolescents, but infants' lungs are flaccid, and with age the elastic properties diminish again (Quanjer, "Lung"). Thus, it can be expected that larger residual volume will remain, leading to a decrease in VC.



4. Body fat

Quanjer points out that "in males, fat deposition is predominantly central", i.e. abdominal. The abdominal fat will exert pressure on the thoracic cavity from below, decreasing VC.

5. Physical activity

VC is generally higher in sportsmen, especially swimmers, as this category exercises their chest muscles regularly (Pal & Pal 151).

6. Geographical area

People living in higher altitudes experience lower oxygen concentration. As the result, less oxygen will be able to diffuse into the bloodstream. To cope with this problem, people living in the mountains develop larger lung capacity ("Gas Exchange").

Lung Diseases and Effect on Lung Capacities

In order to describe the effect of pulmonary diseases on vital capacity, it is necessary to distinguish between two main types of respiratory diseases – obstructive and restrictive respiratory disease.

Restrictive pulmonary disease is characterized by a decrease in the compliance, or elasticity of the lung. The causes may be either intrinsic (Caronia et al.), affecting the lung parenchyma, "portion of the lung involved in gas transfer—the alveoli, alveolar ducts and respiratory bronchioles" (Jones et al.), or extrinsic, which include diseases of the chest wall, pleura or nervous system. Whatever the cause, the effect is the same – as the lungs are not able to expand fully, total lung capacity is reduced. Rate of ventilation is unaffected (Singh & Soni 114), yet since TLC is smaller, VC must be reduced as well.

On the other hand, obstructive lung disease is characterised by difficulties when breathing out. Usually, this is due to narrowing of the airways, either due to inflammation (Leader) or mucus (Davis). The most common obstructive lung diseases are asthma, bronchiolitis, emphysema, and chronic bronchitis. If two or more of these diseases come in combination, they lead to chronic obstructive pulmonary disease (COPD) (Leader). Since obstructed airways make it problematic for the patients to breathe out fully and powerfully, larger residual volume remains ("Obstructive Lung Disease"). From Fig. 2. it can be seen that TLC = VC+RV, so naturally, if RV increases, VC must decrease.



Cigarettes and Relationship to Lung Health

American Lung Association estimates that there are about 600 ingredients in a single cigarette, yet the number increases more than 11-fold when it is burned. 69 of the chemicals have been confirmed to be carcinogenic. In fact, estimated 90% of all lung cancers are caused by smoking (Mlčoch). However, smoking also affects lungs in other ways. American Cancer Society notes that smokers have the greatest risk of getting COPD and, in fact, cigarette consumption is responsible for 80-90% of deaths related to COPD. The mechanism by which smoking contributes to COPD is simple. Acidic components of smoke irritate bronchi and bronchioles and at the same time paralyse cilia which remove waste from the breathing system, so mucus and inflammation builds up in the airways, which results in chronic bronchitis. ("Smoking and Its Effects"). Tar, another part of cigarette smoke, covers alveoli which are then in risk of breaking down (emphysema) and surface area for gas exchange is reduced ("Smoking and Its Effects").

Importance of Examining Vital Capacity in Teenage Smokers

Based on 2012 statistics, there are about 1.3 billion smokers worldwide and approximately 2.3 million in the Czech Republic. What is alarming, however, is the number of underage cigarette users – 250,000 (Mlčoch), and the position of the Czech Republic in world smoking statistics – 12th, according to Britské listy.

My long-time interest has been to promote the hidden negative effects of smoking. It is important to realise that there are numerous ways in which cigarettes affect the quality of life. While some of them cannot be seen at first sight, as their consequences will only be seen later in life, other problems arise early and can be measured, such as the variations in vital capacity. Examining the effect of smoking in teenagers and presenting the actual results to them may act as the prevention and/or an incentive to quit smoking.



RESEARCH QUESTION

"To what extent does smoking cigarettes affect vital capacity in teenagers?"

HYPOTHESIS

From the information above, it should be clear that there are many factors which affect vital capacity. Although smoking is one of them, not all smokers will have similar VC. Several predictions can be made.

- 1. Vital capacity of physically active non-smokers is predicted as the highest of all measured groups due to effective chest muscles.
- 2. Vital capacity of **physically active smokers** is predicted to be **similar** to that of **physically non-active non-smokers**, as the effect of smoking is counteracted by the exercise.
- 3. Vital capacity of physically non-active smokers is predicted as the lowest of all measured groups due to the depositions of tar and effect of other substances. However, since smokers usually suffer from obstructive, not restrictive, lung disease, the decrease in VC should not be dramatic.



VARIABLES

Independent	Smoking habits	Exercise habits	
Dependent	Vital lung capacity		
Controlled	Age	Geographical area	Respiratory health

Reasons and method for controlled variables: The age range needs to be fairly limited due to VC varying with age. Thus, only students aged 15-19 will take part in the experiment. As for geographical area, it could be seen above that the place of residence affects VC of an individual, therefore, all participants will be chosen from a small area around Ostrava, Czech Republic, and their origin will be Caucasian. Measure of physical activity is based on American Heart Association which recommends "at least 30 minutes of moderate-intensity aerobic activity at least 5 days per week for a total of 150 [minutes]", which is 2.5 hours per week (rounded to 3). Finally, respondents who will indicate a respiratory problem in the questionnaire will be excluded from the experiment, since their results could distort the data.

Body fat is omitted, as adding another variable would require a much larger sample.

METHODOLOGY

Apparatus

- Questionnaire
- LabQuest 2
- Spirometer
- Mouthpiece
- Nose clip
- Tissues



Procedure

Part 1: Questionnaire

Set up and distribute a questionnaire (see Appendix) for recording:

- Gender
- Age
- Height
- Regular smoking habit (yes/no)
- Exercise habit (3+ hours/week)
- Respiratory problems (yes/no) those will not take part in Part 2

Based on the data obtained from the survey, the rest of the test subjects will be divided into four groups based on common characteristics:

- 1. Physically non-active non-smokers
- 2. Physically active non-smokers
- 3. Physically non-active smokers
- 4. Physically active smokers

Part 2: Experiment

Before the experiment

- Make the participants acquainted with the procedure and the orders which will be given during the measurement. Check if they are relaxed.
- Calibrate the spirometer.
- Check for any air leaks.

Procedure

- 1. Let the test subject stand straight, facing forward.
- 2. Close his/her nostrils with a nose clip.



- 3. Let the test subject place mouthpiece into his/her mouth and get familiar with breathing into the device.
- 4. After a normal inhalation, order the person to breathe out slowly but as deeply as possible.
- 5. After the exhalation, order to inhale as deeply as possible, again in a slow manner. Do not let the subject hold breath for too long after the exhalation.
- 6. After a complete inhalation, tell the person to blow out as powerfully as possible. The exhalation should last as long as possible, ideally 6 seconds or more (Quanjer).
- 7. After a short rest, perform two more trials.

The test is marked as successful if the difference between the trials is not larger than 200 ml (Quanjer). If there is a larger difference, perform more trials.



Fig. 4. A subject performing spirometry test.



PROCESSING DATA

- Using data from Wang et al (1993), and Abramowitz et al (1965), I plotted two graphs of predicted vital capacity – one for males aged 15-19, and one for females of the same age. I also plotted predicted VC for three heights – 165, 175 and 185 cm for males, and 155, 165, and 175 for females. I chose those two sources for a) topicality and b) the values were approximately average compared to other sources.
- 2. From the three successful trials, I calculated mean vital capacity:

$$\overline{VC} = \frac{VC_1 + VC_2 + VC_3}{3}$$

- 3. I plotted the mean data on the graphs and used four different symbols to note the nature of the test subject:
 - \blacktriangle physically active non-smoker
 - physically active smoker
 - ◆ physically non-active non-smoker
 - - physically non-active smoker
- 4. The vertical error bar has been set to ± 200 ml, which is the allowed deviation for the vital capacity (see *Procedure*).
- 5. I calculated each subject vital capacity in terms of percentage of predicted capacity:

% of predicted VC = $\frac{Mean VC}{Predicted VC} \times 100$



PROCESSED DATA

Males

	Height/cm	Smoker yes/no	Physically	
Age/years			active yes/no	Mean VC/ml
19	167	Yes	Yes	3912
19	170	Yes	No	4473
19	178	No	Yes	7144
19	180	No	Yes	6311
16	172	No	No	3628
15	166	No	Yes	3018
16	185	No	No	6029
15	173	No	Yes	4917

Table 1: Males: Data of age, height, smoking and exercise habits, and mean VC

Age/years	VC at 165cm/ml	VC at 175 cm/ml	VC at185 cm/ml
15	3870	4580	5360
16	4060	4730	5460
17	4230	4860	5550
18	4290	4910	5590
19	4340	5060	5780

Table 2. Males: Predicted vital capacities based on Wang at al. and Abramowitz





Graph 1. Males: Mean vital capacities against predicted vital capacities





Graph 2. Males: Comparison of physically active non-smokers against other groups

Test subject specification	Mean VC in terms of % predicted VC
15 years old, 166 cm	76.6
15 years old, 173 cm	111
19 years old, 180 cm	116
19 years old, 178 cm	135

Table 3. Mean vital capacity in terms of percentage of predicted vital capacity





Graph 3. Males: Comparison of physically active smokers against physically non-active non-smokers

Test subject specification	Mean VC in terms of % predicted VC
16 years old, 172 cm, ♦	80.3
19 years old, 167 cm, ■	87.3
16 years old, 185 cm, ♦	110

Table 4. Mean vital capacity in terms of percentage of predicted vital capacity

Graph 4. Males: Comparison of physically non-active smokers against other groups

Test subject specification	Mean VC in terms of % predicted VC
19 years old, 170 cm	95.2

Table 5. Mean vital capacity in terms of percentage of predicted vital capacity

Females

Age/years	Height/cm	Smoker yes/no	Physically active yes/no	Mean VC/ml
19	163	No	No	3002
19	165	No	Yes	4437
18	165	No	No	3362
17	164	Yes	No	3404
16	164	No	Yes	2508
16	165	No	No	4037
19	159	No	No	4036
15	170	Yes	Yes	3594
15	169	Yes	No	3467
16	165	Yes	No	3575
18	168	Yes	Yes	3680
19	162	Yes	Yes	3416

Table 6. Females: Data of age, height, smoking and exercise habits, and mean VC

Age/years	VC at 155 cm/ml	VC at 165 cm/ml	VC at 175 cm/ml
15	3100	3530	3990
16	3140	3580	4050
17	3170	3630	4120
18	3160	3620	4110
19	3220	3750	4290

Table 7. Females: Predicted vital capacities based on Wang at al. and Abramowitz

Graph 5. Females: Mean vital capacities against predicted vital capacities

Graph 6. Females: Comparison of physically active non-smokers against other groups

Test subject specification	Mean VC in terms of % predicted VC
16 years old, 164 cm	70.8
19 years old, 165 cm	118

Table 8. Mean vital capacity in terms of percentage of predicted vital capacity

Graph 7. Females: Comparison of physically active smokers against physically non-active non-smokers

Test subject specification	Mean VC in terms of % predicted VC
19 years old, 163 cm, ♦	82.2
18 years old, 165 cm, ♦	92.9
19 years old, 162 cm, ■	95.2
15 years old, 170 cm, ■	95.6
18 years old, 168 cm, ■	97.9
16 years old, 165 cm, ♦	113
19 years old, 159 cm, ♦	118

Table 9. Mean vital capacity in terms of percentage of predicted vital capacity

Graph 8. Females: Comparison of physically non-active smokers against other groups

Test subject specification	Mean VC in terms of % predicted VC
15 years old, 169 cm	93.5
17 years old, 164 cm	95.1
16 years old, 165 cm	99.9

Table 10. Mean vital capacity in terms of percentage of predicted vital capacity

ANALYSIS

Males vs Females

- Measured VC of males has a considerably wider range than that of females (4126 ml vs 1929 ml), although the range of heights is similar (14 cm for males, 11 cm for females).
- Based on the questionnaire (see appendix), there are less male smokers than female smokers (2 vs 8).

Males – physically active non-smokers

- One male's VC was only 76.6% of the predicted value, the lowest of all measured male values. This outlier probably has some pulmonary disease, although he did not note this in the questionnaire.
- The other three non-smokers' VCs were the three highest of all measured male capacities with 135%, 116%, and 111% of predicted value.

Males – physically active smokers vs physically non-active non-smokers

- The smoker surpassed one non-smoker and fell behind the other non-smoker.
- The smoker was 7% better than the worst non-smoker, but 22.7% worse than the best non-smoker.
- The smoker's VC was below average.

Males - physically non-active smokers

• The smoker's VC was below average.

Males in order from the biggest to smallest % of predicted VC (omitting the outlier, as I didn't want to include people with respiratory problems)

- 1. Physically active non-smoker
- 2. Physically active non-smoker
- 3. Physically active non-smoker
- 4. Physically non-active non-smoker

- 5. Physically non-active smoker
- 6. Physically active non-smoker
- 7. Physically non-active non-smoker

Females – physically active non-smokers

- One female's VC was only 70.8% of the predicted value, the lowest of all measured female values. This outlier probably has some pulmonary disease, although she did not note this in the questionnaire.
- The other female's VC was the highest of all measured female capacities with 118% of predicted value.

Females – physically active smokers vs physically non-active non-smokers

- All three smokers surpassed two non-smokers in VC and fell behind two other nonsmokers.
- The smoker with the best vital capacity was 15.7% better than the worst non-smoker, but 20.1% worse than the best non-smoker.
- None of the smokers had above average capacity (highest measured had 97.9% of predicted capacity).
- The two top subjects (non-smokers) both had above average capacity (118% and 113%).

Females – physically non-active smokers

- None of the smokers had above average capacity (highest, 99.9%, was average).
- 2 out of 3 non-active smokers had lower capacity than active smokers.

Females in order from the biggest to smallest % of predicted VC (omitting the outlier, as I didn't want to include people with respiratory problems)

- 1. Physically active non-smoker
- 2. Physically non-active non-smoker
- 3. Physically non-active non-smoker

- 4. Physically non-active smoker
- 5. Physically active smoker
- 6. Physically active smoker
- 7. Physically active smoker
- 8. Physically non-active smoker
- 9. Physically non-active smoker
- 10. Physically non-active non-smoker
- 11. Physically non-active non-smoker

EVALUATION

It is clear that in both males and females, the highest vital capacity was found in physically active non-smokers, whose VC was always above the predicted values (136% maximum, 110% minimum). This supports the hypothesis that the vital capacity of such people should be large due to the effect of exercise on their chest muscles.

It is interesting to note the two outliers whose vital capacity was severely below average (76.6% and 70.8% of predicted value). Because both are physically active non-smokers, there surely must be another factor affecting their VC. I would estimate that it will be some kind of an undiagnosed respiratory disease, although I would not guess if an obstructive or restrictive one, that would require further testing.

The comparison of physically non-active non-smokers and physically active smokers is not clear cut. In fact, the two females and the male with lowest vital capacities are actually non-smokers (82.2%, 92.9% and 80.3% respectively). However, the best results in this group also belong to non-smokers (118%, 113%, and 110%). The smokers rank somewhere in the middle, and their results differ greatly from the non-smokers. This is better illustrated on the females, as there was a larger number of participants and a bigger proportion of smokers. The best ranking smoker (97.9%) was only 5% better than the non-smoker ranking below her (92.9%), but 15.1% worse than the non-smoker ranking above her (113%). The difference between the other two smokers and the participant with 92.9% of predicted capacity are even

subtler, 2.7% and 2.3%. This mean that we can put physically non-active non-smokers into two groups – above average and below average. Then we can group the active smokers with the 'below-average' portion of the non-smokers. This partly corresponds to my hypothesis that active smokers and non-active non-smokers will have similar vital capacities, but I did not count on the fact that there will be such dramatic differences within the non-smoker group.

The range of non-active non-smoker vital capacities is much larger than range of active smokers' capacities (118-80.3=37.7% difference vs 97.2-87.3=maximum 9.9% difference). It is debatable whether those non-active non-smokers with 80.3% and 82.2% of predicted capacities might also suffer from a pulmonary disease, since their VC is so low, but even if we exclude them, the range is 118-92.9=25.1%, so still considerably larger. What could be the source of the wide vs narrow range? It could be that smoking does decrease one's vital capacity, but the physical activity counteracts it and then the VC settles on a certain value. This would need further research. As for the wide range in non-smokers, their vital capacity could be affected by a variety of other factors, including physical constitution, genetic influences, or even musical activities. (One would suppose that playing a wind instrument could increase VC, but it has been suggested that it in fact has very little effect (Fuhrmann, Franklin and Hall 761-767).)

The results of physically non-active smokers were varied. While 3 out of 4 smokers ranked in the bottom half, one female smoker was actually 4th out of 11 participants. In fact, none of the non-active smokers ended up worst, whether male or female. This **refutes my hypothesis that physically non-active smokers will have the lowest vital capacity out of all groups**, but there are several notes to be made. None of the smokers had above average VC (the best one, 99.9%, was average), which was expected. I also did not take into consideration the duration of the smoking habit. Since the participants were teenagers, they cannot be smoking for too long. It would be worthwhile to repeat the experiment in the future and compare the results.

EVALUATION OF EXPERIMENTAL DESIGN AND SUGGESTIONS FOR IMPROVEMENT

There were 41 people who responded to the questionnaire, but in the end, only 20 participated in the experiment, 12 females and 8 males. To make the results more statistically significant, more subjects should take part. However, it was very difficult to communicate with the responders. Most questionnaire responders did not answer my invitation to experiment. In some smokers, it was because of the fear of being "revealed", although the data are anonymous. Anyway, with larger participation rate, not only would the results be more reliable, but more variables could be controlled in order to avoid fluctuations, especially duration of smoking habit and amount of body fat.

Secondly, since this study is primarily focused on the effect of smoking, a bigger proportion of smokers should be included. Ideally, the ratio of smokers to non-smokers could be 1:1; however, not that many teenagers smoke, so the experiment better reflects the actual ratio.

Thirdly, more males should be involved next time, especially smokers. However, since only 2 males marked themselves as smokers, compared to 8 females, this could be an actual trend among teenagers. It would be interesting to further investigate if the proportion of male smokers really is smaller than proportion of females.

Finally, there are many different data available for the prediction of vital capacity. Although I tried to use the newest ones, and those with median values, and I took into account the race of the test subjects, it is possible that the predicted values for this region are different. In this case, the results could be skewed; however, there are no available data for the vital capacity of the teenagers in the Czech Republic.

CONCLUSION

- 1. As predicted in the hypothesis, physically active non-smokers have the highest vital capacities out of all groups. This is most likely due to their powerful chest muscles.
- 2. Physically non-active non-smokers can be divided into 'above-average' and 'below' average groups, which was not a part of the prediction. However, we can group the 'below-average' non-smokers with physically active smokers, which partially supports the hypothesis that active smokers and non-active non-smokers will

have roughly same VC, which may be caused by the effect of exercise counteracting the effect of smoking. The variations in non-smokers could be caused by genetic factors, physical constitution, or other variables.

- 3. Physically non-active smokers did not have the smallest vital capacity when compared with predicted VC. This contradicts the hypothesis that non-active non-smokers will have the lowest VC out of all groups. This could be caused by the short duration of the smoking habit.
- 4. None of the smokers, whether active or non-active, had above average VC. This suggests that smoking does reduce vital capacity.
- 5. There are arguably **more female smokers than male smokers**. The reason for this is unknown and it would be worthwhile of further investigation.
- 6. There were two outliers with **extremely low vital capacities**. Although they did not indicate respiratory problems in the questionnaire, their results could possibly indicate a pulmonary disease, although it is unclear if an obstructive or restrictive one.

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Appendix: RAW DATA

Sex *

Male

Female

Age *

If you're approaching birthday, round up (e.g. 16.8 to 17)

Height in cm *

Are you a regular cigarette smoker? *

Yes

No

Are you regularly physically active? (3+ hours per week) *

- Yes
- No

Do you suffer from any respiratory diseases? (e.g. asthma) *

- Yes
- No

Fig. 4. The pre-experiment questionnaire.

		Hoight	Are you a regular	Are you regularly physically active? (3+	Do you suffer from any respiratory			
Sex	Age	in cm	smoker?	week)	(e g asthma)	Trial 1	Trial 2	Trial 3
Male	19	167	Yes	Yes	No	3.976	3.87	3.89
Female	18	158	Yes	Yes	No			
Male	15	179	No	Yes	No	4,188	4,114	4,268
Female	15	163	No	Yes	No			
Female	18	178	No	No	No			
Male	16	184	No	Yes	No			
Female	19	163	No	No	No	3,066	2,949	2,99
Male	20	173	No	Yes	No			
Male	19	170	Yes	No	No	4,415	4,537	4,467
Male	18	183	No	Yes	No			
Female	19	164	No	Yes	No			
Female	19	165	No	Yes	No	4,372	4,438	4,502
Female	18	168	No	Yes	No			
Female	16	167	No	Yes	No			
Female	18	173	No	No	No			
Female	16	175	No	No	No			
Female	18	165	No	No	No	3,385	3,412	3,289
Male	16	180	No	Yes	No			
Male	17	185	No	Yes	No			
Female	17	164	Yes	No	No	3,46	3,332	3,419
Female	16	164	No	Yes	No	2,43	2,537	2,558
Female	16	165	No	No	No	4,187	4,013	3,911
Male	19	178	No	Yes	No	7,155	7,129	7,149
Male	19	180	No	Yes	No	6,323	6,389	6,22
Female	19	162	No	No	No	4,025	4,113	3,971
Male	16	172	No	No	No	3,6	3,659	3,624
Male	16	189	No	Yes	No			
Male	19	172	No	Yes	No			
Male	15	170	No	No	No			
Female	15	170	Yes	Yes	No	3,527	3,643	3,611
Male	16	186	No	Yes	No			
Male	15	166	No	Yes	No	3,126	2,992	2,937
Female	15	169	Yes	No	No	3,408	3,348	3,645
Female	16	165	Yes	No	No	3,669	3,551	3,505
Female	18	168	Yes	Yes	No	3,687	3,648	3,705
Female	19	162	Yes	Yes	No	3,456	3,354	3,439
Male	16	185	No	No	No	5,807	6,174	6,107
Male	15	173	No	Yes	No	4.942	4.83	4.987

Table 11. Raw data from participants of questionnaire and results of three successful trials

(where performed)

