

Human Activities can affect Human Lungs and Breathing (Matter of Public Health)

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ABSTRACT

This study explores Applied Physics showing how Physics is involved in human breathing and how it can help human towards their personal care about lung health. This work reports the change observed in speed, acceleration, and kinetic energy of human lungs during normal and conditioned breathing for multiple participants under several physical conditions to compare results of human breath in terms of human lung movements. It further gives the information of how time period, frequency of human breath, angular speed of lungs changes based on human activities and the value of force required by lungs for breathing change. The effect of physical exercise on human lung is also reported here in terms of power dissipation and spring constant of the lungs. This study shows a novel way of studying the Physics behind human lungs and breathing that can help human towards personal care in real life. It also shows how human breathing can affect public health in terms of their lifestyle and lung's types.

Keywords: Human breathing, lungs, Physics, exercise, mechanics, application in the real world, Personal care, public health.

INTRODUCTION

The lungs are essential to every living organism. Without breathing life could be sustained. Our bodies require substance from oxygen, with the help of our lungs we pump this necessary component into our lungs, and the blood stream absorbs the oxygen to carry it throughout the body with a simple chemical reaction of taking in oxygen, and producing waste material, known as carbon dioxide. [1]

During this exchange of gases, the lungs increase and decrease in size with each breath, involving repetitive inhales, and exhales and can be compared with the balloons. When a balloon is blow up it stretches, adapting to the situation and then once you let go the balloon returns to its constant or normal size. The change in size, whether it is a balloon or a human lung, is all about the ability of adapting to the situation or condition. In this study, the aim is to find how Physics is involved in human breathing and can be related to the human lungs and how exercise can improve the health of human lungs. [1] A typical behavior of human lung can be seen in the illustration show in Figure 1.

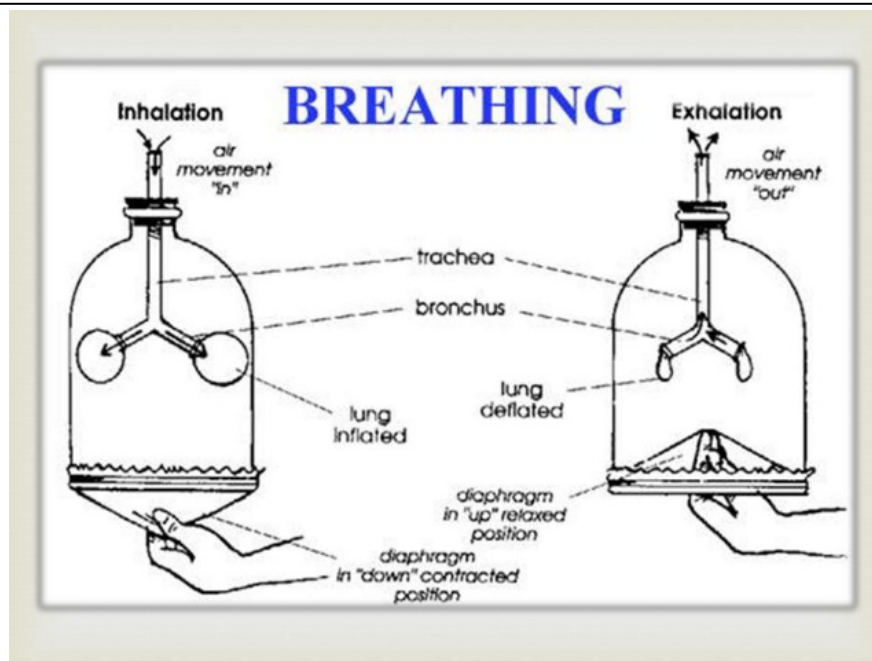


Figure 1: Typical inhalation and exhalation of human lungs during breathing shown with balloon in the picture. [2]

In regular breathing, human inhales, and exhales in terms of inflating and deflating lungs. Daily exercises are important part to keep human body fit and breathing normal. The rate of breathing can be affected by physical exercise and can change the number of inhales and exhales. Breathing and lung movement can be related to physics and its concepts of repetitive motion, angular & linear movement, speed of inflating-deflating, kinetic energy used, force required for lungs movement, power dissipated during lung movement, and flexibility of lungs. During breathing, the lung muscles are put to work of exhaling/inhaling and creating change in volume of lungs. In this study, we are showing a novel way of finding Physics behind human lungs that can affect human personal care towards lung health. A typical picture of human lungs can be seen in Figure 2.



Figure 2: Human lungs [2]

THEORY INVOLVED

The theory of human breathing can be related to the concepts of mechanics of repetitive motion of breathing, inflating/deflating of lungs, time period of one breath (T), frequency (f) that represents number of breaths in one second, angular speed (ω), linear speed (v) of lung's movement, acceleration (a) required by lungs and essential force (F) applied to the lungs during breathing. The theory and equations used in this study can be seen below where number of exhales (n) were counted for one minute (t):

- Time Period of one exhale = $T = t/n$
- Frequency of exhales (f) = $1/T$
- Angular speed of lung's movement (ω) = $2\pi f$
- Radius of the human lung (r) = 5.0 cm = 0.05 m (taken from the internet)
- Average mass of human lung (M) = 1.3 kg (taken from the internet)
- Speed of lung movement during breathing (v) = $r \cdot \omega$
- Acceleration of lung movement during breathing (a) = $r \cdot \omega^2$
- Force applied by lungs during breathing (F) = $M \cdot a$
- Max. Kinetic Energy of lung during breathing (K) = $1/2 \cdot M \cdot v^2$
- Power dissipated during breathing (P) = K/T

Lungs movement during breathing can be compared to a balloon and its flexibility in terms of spring constant (k). Following Hooke's law and repetitive motion, the angular speed (ω) can be related to the spring constant and the mass of the lungs: $\omega = \sqrt{k/M}$, and spring constant of the human lungs can be given as then,

- Spring constant of human lung during breathing = (k) = $M \cdot \omega^2$

EXPERIMENTAL METHOD AND RESULTS

For this study, the experiments were performed in four different steps.

Step (1): Effect of normal breathing on human lungs:

The number of exhales was counted for one participant for one minute for normal breathing without any physical exercise then repeated several times and then an average was taken. The average data details for one participant for normal breathing without doing any Physical exercise is given below in the table I.

TABLE I: Average Physical details of normal breathing

Avg. No. of Exhales in one min (t)	19
Period (T)	3.16 s
Frequency (f)	0.317 Hz
Angular speed (ω)	1.99 rad/s
Linear speed (v)	$9.94 \cdot 10^{-2}$ m/s
Radial acceleration (a)	0.20 m/s ²
Force applied (F)	0.257 N
Max. Kinetic Energy (K)	$1.28 \cdot 10^{-2}$ J
Power dissipated (P)	$4.06 \cdot 10^{-3}$ W
Spring constant of lung (k)	5.15 N/m

It can be seen from the table I that the time period for normal breathing for the person is 3.16 s and the force applied to the lungs during normal breathing is 0.257 N, and Power used is 4.06 mW and the spring constant is 5.15 N/m.

Step (2): The effect of various types of exercises on human lungs:

The same experiment was performed with the same person in different physical conditions and change in number of exhales were observed. All calculations were performed for different physical conditions under same environmental conditions with the same person and repeated to get a good average which is shown below in the table II.

TABLE II: Number of exhales for one minute in different physical conditions with same participant

Tasks (Conditions)	Trial 1	Trial 2	Trial 3	Average
Walking slowly (60s)	17	18	20	18.33
Speed Walking (60s)	20	22	24	22
Walking up flight of stairs	19	24	26	23
Walking down a flight of stairs	19	21	20	20
Running up a flight of stairs	19	20	20	19.66
Running down a flight of stairs	20	21	20	20.33
50 Jumping Jacks	25	26	24	25
100 Jumping jacks	27	25	27	26.33
25 Squats	18	19	16	17.66
50 Squats	20	22	19	20.33
10 High Jumps	24	22	26	24
20 High jumps	22	22	24	22.66

It can be seen that number of exhales increases when more power is used towards an activity towards exercise. More number of breaths indicate that lungs do more work and breath faster to fill more gas into the lungs.

Number of exhales were found minimum for 25 Squats and maximum for 100 jumping jacks for the same participant. All physical parameters were calculated for these two conditions of breathing to compare with normal breathing for the same participant and shown in the table III below. When two conditioned breathing were compared, the more exhales give higher spring constant whereas the least exhales give lower spring constant along with least speed and power dissipation.

TABLE III: Details for conditioned breathing with the same participant

Physical Parameter	25 Squats	100 Jumping Jacks
Avg. No. of Exhales in one min (t)	18	26
Period (T)	3.33 s	2.31 s
Frequency (f)	0.300 Hz	0.433 Hz
Angular speed (ω)	1.88 rad/s	2.72 rad/s
Linear speed (v)	9.42×10^{-2} m/s	0.136 m/s
Radial acceleration (a)	0.177 m/s^2	0.370 m/s^2
Force applied (F)	0.230 N	0.481 N
Max. Kinetic Energy (K)	5.77×10^{-3} J	2.40×10^{-2} J
Power dissipated (P)	1.73×10^{-3} W	1.04×10^{-2} W
Spring constant of lung (k)	4.59 N/m	9.62 N/m

The spring constant (k) of the lung can be related to the Young's modulus (Y) of elasticity using Hooke's law, stated as: where A is the cross-sectional area of the lung and the L is the diameter of the lung at the center.

$$k = \frac{YA}{L}$$

Using above value of spring constants, the Young's modulus of the lung can be calculated for three different conditions for the same participant as:

(a) Normal breathing: $Y = 6.56 \text{ N/m}^2$, (b) Squats breathing: $Y = 5.85 \text{ N/m}^2$, (c) Jumping Jacks breathing: $Y = 12.26 \text{ N/m}^2$

Step (3): The effect of Types of Lifestyles and Exercise Schedule on human breathing:

In this step, four different types of participants of almost same age group of young adults were picked who had different life style and exercise schedule to see how the difference of exercise schedule can change human breaths and were asked to exhale for one minute for normal breathing first and then under given physical conditions.

The experiments were repeated with them and then average was taken for each participant for normal and conditioned breathing. The details of the data taken for these five participants can be seen in the Tables from IV - VII.

TABLE IV: Details of participant # 1 who had average exercise schedule

Participant	Age	Lifestyle (conditions)	Fitness	Average
#1	18	Nonsmoker/ Fit	Average 3 hours exercise a week	
Normal	15	17	18	16.66
Task/Condition	Trial 1	Trial 2	Trial 3	
Walking down flight stairs	18	18	16	17.66
Walking up flight of stairs	18	18	16	17.66
Running down a flight	20	20	20	20
Running up a flight	20	20	18	19.33

TABLE V: Details of participant # 2 who was a smoker and had under average exercise schedule

Participant	Age	Lifestyle (conditions)	Fitness	Average
#2	19	Smoker	Under average 2 hours exercise a week	
Normal	21	19	20	19
Task/Condition	Trial 1	Trial 2	Trial 3	
Walking down flight stairs	19	22	22	21
Walking up flight of stairs	18	23	22	21
Jumping Jacks (10)	24	22	24	23.33
Jumping Jacks (20)	28	27	27	27.33
Walking Slow	26	27	25	26
Speed walk (60s)	28	24	26	26
High Jumps (10)	26	24	24	24.66
High Jumps (20)	28	28	25	27

TABLE VI: Details of participant # 3 who had a good schedule of exercise

Participant	Age	Lifestyle (conditions)	Fitness	Average
#3	20	Nonsmoker /Fit	Above average 4-6 hours exercise a week	
Normal	12	14	12	12.66
Task/Condition	Trial 1	Trial 2	Trial 3	
Walking down flight stairs	16	14	16	15.33
Walking up flight of stairs	16	18	16	16.66
Running down a Flight of stairs	20	22	26	22.66
Running Up a Flight of Stairs	24	24	24	24
Jumping Jacks (10)	34	38	34	35.33
Walking Slow	24	20	20	21.33
Speed walk (60s)	28	24	26	26
High Jumps (10)	32	32	32	32
Squats (10)	24	26	30	26.66
Lunges (10)	34	34	38	35.33

After looking data collected for multiple life style participants, it can be seen who has almost no daily routine of exercise breath faster in daily life for normal breaths whereas who has a good routine of exercise and maintained it in everyday life schedule has least number of breaths for normal breaths which means the human lungs take more gas in each breath and maintains good health for the participant # 3.

On the other hand, the participant who is smoker, actually provides a bad health to their lung by giving polluted air which makes him to increase number of breaths but also does exercise on daily basis which helps maintaining breathing health and has above average number of breaths in participant # 2. The participant # 1 maintains exercise routine and fit with the health shows an average number of breaths for normal breathing.

The participant # 4 (can be seen in the table shown below – Table VII) takes less air in each breath and may have some breathing issue in terms of consuming air in the lungs because of his life style as his exercise level is under average which doesn't keep his body healthy as it should be.

TABLE VII: Details of participant # 4 who had almost no schedule of exercise

Participant	Age	Lifestyle (conditions)	Fitness	Average
#4	21	Nonsmoker /not Fit	Under average 0-0.5 hour exercise a week	
Normal	30	34	36	33.33
Task/Condition	Trial 1	Trial 2	Trial 3	
Walking down flight stairs	30	34	36	33.33
Walking up flight of stairs	36	36	32	34.67
Running down a flight	40	40	40	40
Running up a flight	40	40	36	38.67
Walking up and then down a flight	32	36	36	34.67
Walking down and then up a flight	40	44	40	42

TABLE VIII: Data details for minimum and maximum number of breaths for different lifestyle participants

Participant s	Condition	Average exhale	$T = t/n$ (time period)	$f = 1/T$ (Freq.)	$\omega = 2\pi f$ (angular Frequency)	$k = M\omega^2$ (Spring Constant)
5	Avg. exercise, Nonsmoker/Fit	12	5 s	0.2 Hz	1.256 rad/s	2.05 N/m
6	No exercise, Not Fit	42	1.43 s	0.7 Hz	4.39 rad/s	25.60 N/m

Two new but very different participants were chosen for the data collection of the Table VIII. This table shows a comparison of number of exhales per min between participant # 5 and 6. Based on their life style. It can be seen in the table VIII that participant 5 has average exercise schedule, is non-smoker and a fit person whereas participant # 6 has no exercise schedule and has non-fit body. It is observed that the minimum number of exhales are 12 taken by participant # 5 and the maximum number of exhales are 42 for nonfit participant when compared with two different types of lifestyle and exercise schedule participants. More data details for these two numbers of breaths can be seen in the Table VIII. A large difference

between time period of breathing and angular speed and spring constant of the lungs can be seen for these two different participants.

Step (4): Effect of Types of breathing on large number of people:

Now the experiments of counting number of exhales were performed for 20 participants of almost same age group of 18-19 years old in the same environmental and physical conditions. They were asked to breath normally, then deep, and intense breaths, then shallow breaths to see how fast or slow human lungs can function during these types of breathing. The experiment was repeated for each breathing five times and then average was taken for all people and shown in the Table IX.

TABLE IX: Data details for average breathing rates for normal, deep, and shallow breathing for 20 people

Breathing Condition	Average of exhales	T (time period)	ω (angular Frequency)	k (Spring Constant)
Normal Breathing	18.30	3.28 (s)	1.91 (rad/s)	4.74 (N/m)
Deep Breathing	12.95	4.63 (s)	1.36 (rad/s)	2.93 (N/m)
Shallow Breathing	45.95	1.31 (s)	4.79 (rad/s)	29.83 (N/m)

DISCUSSION AND CONCLUSION

The lungs are a fascinating organ. The lung cycles oxygen through our body. The human body only requires 5% of the 21% of air that we inhale [3], due to air being made up of multiple waste components that the body does not need to function. With the collected data it can be concluded that the lungs are a very elastic tissue-based organ with lower spring constant. At a controlled rate, the lungs are working at a comfortable rate. Once an activity becomes more rigorous or is extended the lungs work harder to maintain the amount of oxygen circulating through the body. If an activity is difficult the rate in which a person breathes increases, meaning that the amount of breathes per minute is larger than the constant variable. [4-7]

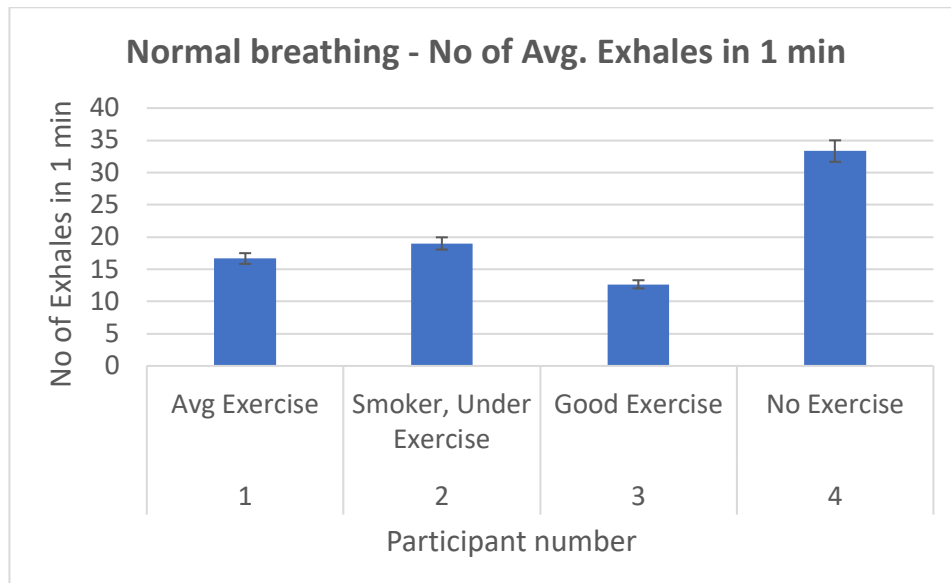
Looking at the results, the more exhales/inhales taken the smaller the time period is going to be per breath, yet, with if the breath rate increases the force, frequency, and spring constant increases. Taking data from the individual participants, it can be seen this in effect. Although the condition is the same, it changes based off the individuals breathe rate. From two different individuals we can see how breathe rate differs from person to person based on how strong and healthy lungs are, can be seen in Table X. If breaths are longer and less, the lungs hold gas and oxygen for longer time with greater amount and shows a smaller number of exhales whereas if lungs work faster with any exercise means needs more gas/oxygen and hold less gas for less time.

It can also be true if someone has breathing problem i.e., asthma or Bronchitis where lungs do not have ability to hold gas for long time or cannot get enough oxygen in every breath and hence human has to breath faster and faster. [5-7]

The effect of lifestyle on human breathing can be seen in detail in the tables from Table IV - VI for various types of daily activities. The summarized details of four types of people who have different lifestyles for normal breathing without doing any extra activity is given below in Table X. The Graph 1 plotted next to it shows the effect of lifestyle on their normal breathing.

TABLE X

Effect of Life style on Normal breathing at one place		
Participant #	Life Style	No of Avg Exhales in 1 min
1	Avg Exercise	16.66
2	Smoker, Under Exercise	19
3	Good Exercise	12.66
4	No Exercise	33.33

Graph 1**Figure 3: Showing how human lifestyle can affect human normal breathing.**

It can be seen from the Graph 1 or Figure 3 that people who does good exercise per day have lower breath rate with lower spring constant of the lungs whereas people who does no exercise or are smokers have higher breathing rate with higher spring constant. The spring constant shows the stiffness of the lungs which also indicates that lung has hard time in relaxing and expanding that is why people with bad lifestyle have higher breathing rates.

The Table XI shown the results of average exhales and spring constant of the lungs for two randon people who walked moderately while their breath were observed and number of breaths recorded.

It can be seen that two random people in public may have very different number of breathing rates. Where the 1st participant in the table XI have least and 2nd participant have highest breathing rate.

TABLE XI: Comparison between two participants with same conditioned breathing.

Participant s	Condition	Average exhale	T (s)	f (Hz)	ω (rad/s)	K (N/m)
1	Walking moderately	24.33	2.47	$4.04 \cdot 10^{-1}$	2.54	8.39
2	Walking moderately	45.33	1.32	$7.5 \cdot 10^{-1}$	4.71	28.84

This indicates that both of them have very different capacity of holding and expanding nature of the lungs. The lung with leas value of breathing rate shows more consistant breathing with lower stiffness and higher possibility of flexibility of the lung whereas the highest breathing rate shown stiffness of the lung and shallow breathing which can be seen peopl who suffer with Asthama or other respiratory issues.

Graph 2

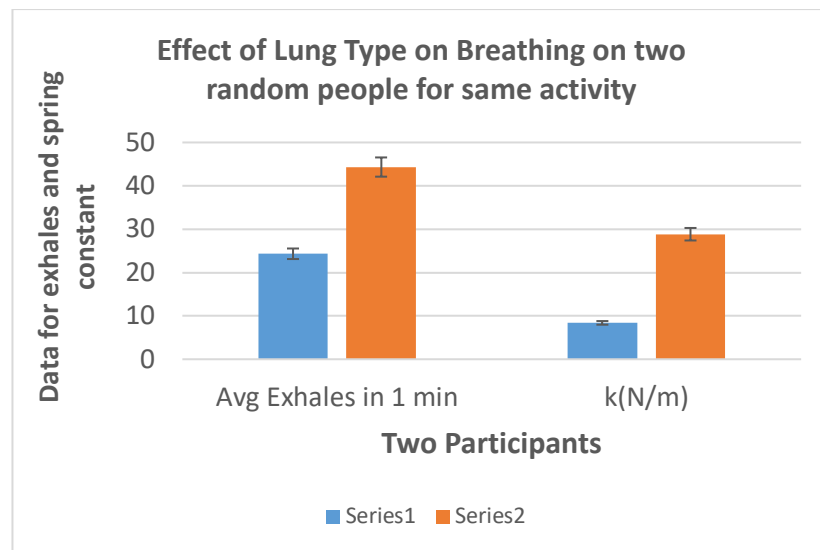


Figure 4: Showing effect of lung type of two random people breathing for same activity

The Graph 2 or Figure 4 shows the effect of type of lung on two random people's average normal breathing for same activity what they did while breath showing two very different capacity of stiffness of lungs of two people.

The Table IX shows the details of how breathing rates and number of average of exhales change based on types of breaths. When we excersie everyday, we do types of breathing i.e. shallow breath, deep breath and normal breath. All these three types of breaths were recorded for 20 people and then their values are reported in this table IX. It can be seen that deep breaths take

longer time and shallow breaths take shortest time to complete average breaths per minute which results as least number of exhales for deep breaths and highest number of exhales for shallow breaths.

This also indicates that lung is more flexible and expands more with least value of spring constant when people deep breath and lung doesn't expand more significantly with highest value of spring constant when people breaths are shallow. Shallow breaths indicate less healthy human body which might have respiratory issues like Asthama. The Graph 3 and Figure 5 shown the same results for three types of breathing for 20 people.

Graph 3

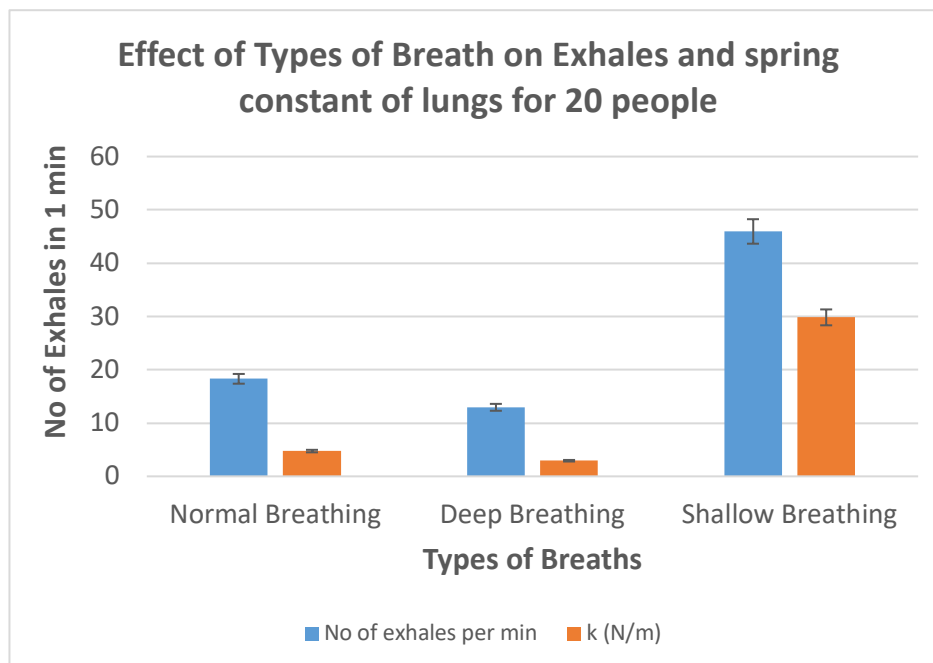


Figure 5: Showing effect of types of breath on number of exhales and spring constant of the lung for 20 people

In conclusion, after looking results of various types of participants, breathing, life style, exercise schedules and conditioned breathing, it can be said that if human maintains their life style with daily routine exercise schedule which makes their body and lungs fit, then lungs take more air with less number of exhales but if human body is sick or not maintaining a regular exercise schedule, will increase number of exhales per minute and indicate that lungs need more oxygen to work whereas if number of exhales are seen during exercise, it shows an increase because lungs work more and need more power and energy, hence need more oxygen and air through breathing. To maintain personal care and fitness, it is important to maintain at least average exercise schedule and no smoking to have good lung health. [6-7]

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