Effects of pillows on sleep ergonomics

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2020

MASTER THESIS

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LUND
UNIVERSITY

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Published by
Department of Design Sciences
Faculty of Engineering LTH, Lund University
P.O. Box 118, SE-221 00 Lund, Sweden

Subject: Technical Design (MMKM10)
Division: Product Development
Supervisor: Ingrid Svensson
Examiner: Axel Nordin

Abstract

Pillows are an important part of sleeping comfort. The goal of the master thesis was to get a better understanding of pillows for **IKEA**. To reach that goal, a customer study of 20 customers was performed. Information about and measurements of each customer were collected in order to find a pattern between data and opinions of pillows. Each customer laid on a mattress and tried five different pillows and answered questions about each pillow. A multiple regression analysis was created to find if there was a pattern. The analysis suggested that there is an indication that the ergonomic pillows are more likely to have a pattern. A customer survey with 199 responses was created to act as a complement to the study. The survey emphasized how unpredictable people's habits are. Simulations were created to get a better understanding specifically about the side lying position. The simulations were performed both with a dummy with average BMI as well as with high BMI to find the similarities or differences between them for the ergonomic pillows. In the case with dummy with high BMI, a misalignment between the mattress and the spine was observed which indicates discomfort. The average BMI had a straighter spine, indicating in comfort. A measurement of the distance between neck and shoulder and the angle, indicates that shape does have an affect on giving a better spine alignment. Specific ergonomic values could not be determined, like anthropometry. The main outcome of this thesis is that customers personal opinions are important and they may not always choose a pillow based solely on great ergonomics.

Keywords: *pillow, sleeping comfort, simulation, ergonomics, customer study, customer survey*

Sammanfattning

Kuddar är en viktig del i sovkomfort. Målet med detta examensarbete är att få en bättre förståelse av kuddar för **IKEA**. För att uppnå detta mål, utfördes användarstudie med 20 deltagare. Information och mätningar samlades in för varje deltagare för att försöka hitta ett mönster mellan måtten och deras åsikter om kuddarna. Varje deltagare låg på en madrass och testade fem olika kuddar, samt svarade frågor om varje kudde. En multipel regressionsanalys utfördes för att försöka hitta ett mönster. Analysen gav en indikation för att man kan se ett mönster när det gäller de ergonomiska kuddarna. En enkät med 199 svar, skapades för att vara en komplement till användarstudien. Enkäten visade att människors preferenser är ganska oförutsägbara. Simuleringar skapades för att få en bättre förestående för specifikt sidoliggande sovposition. Simuleringarna gjordes både för en person med högt och normalt BMI för att hitta likheterna och olikheterna mellan dessa för ergonomiska kuddarna. Simuleringen med hög BMI gav en stor böjning i nacken, vilket indikerar obehag. Normala BMI, gav en mer ”rak” ryggrad, vilket indikerar komfort. Avståndet mellan nacken och axeln mättes och även vinkeln mellan, vilket visar på att formen av en kudde är viktig för att kunna ge en rakare ryggrad. Specifika ergonomiska värden kunde inte bestämmas, så som antropometri. Resultaten från detta examensarbete visar att kundernas personliga åsikter är viktigt vid val av kudde och de väljer kanske inte alltid kudde baserat på vilken som är mest ergonomisk lämplig.

Nyckelord: *kudde, sovkomfort, simulering, ergonomi, användarstudie, enkät*

Acknowledgements

I would like to start by expressing my gratitude to **IKEA** and Praveen Kulkarni for collaborating in this thesis. Praveen's support and expertise is a key part of this thesis. Especially his technical support in LS-DYNA has been really helpful. Since this master thesis project has gone beyond the original timeline, I am grateful that **IKEA** and Praveen have been supportive even through the summer.

I would like to thank Ingrid Svensson, my supervisor, who supported me throughout this project. She helped me in times of struggle and had patience even when the thesis dragged through the summer into fall. Ingrid also helped me by extensively proof-reading the thesis. I would also want to extend my thanks to Erik Lindström, Professor, Mathematical statistics, Lund University, for answering specific questions about statistical analysis.

Thanks to Joel Elinder, whose master thesis project for **IKEA** is the foundation for the simulation. He answered my questions about his simulation even when he had already graduated.

Finally, thanks to everyone who gave their time and participated in the customer study and survey.

Lund, September 2020

Xia Tran

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List of acronyms and abbreviations

BMI - Body mass index
CI or CIs - Confidence Interval(s)
CPU - Central Processing Unit
CAD - Computer-aided design
IC or ICs - IKEA Constructor(s)
IKEA - Ingvar Kamprad Elmtaryd Agunnaryd

1 Introduction

1.1 Background

The **IKEA** vision is to create a better everyday for people. The business idea is - "to offer a wide range of well-designed, functional home furnishing products at prices so low, that as many people as possible will be able to afford them" [1]. Currently, **IKEA** offers a quality range of ergonomic pillows in addition to a variety of mattresses. To have a good night's sleep it is important to have a right combination of mattress and pillow. They would like to take a step further in order to understand the impact of pillows on the overall sleep ergonomics.

1.2 Purpose and goal

The aim of this thesis project is to create a better understanding of pillows and to come up with an objective way to measure the impact. The thesis findings will help the development of future products.

1.3 Approach

The process of this master thesis starts with research around pillows and and their effect on sleep ergonomics as well reading through information given by **IKEA**. Then based on that, a customer study will be created and conducted. Once the customer study is done, an analysis of the results will be made to get a better understanding of the pillows. A customer survey will also be created as a complement to the study. Simulation of the pillows will be created to see if the results match up with reality. The thesis is therefore divided into each of these parts.

1.4 Delimitation

A delimitation needs to be done to limit the scope of the project.

General limitations:

- Number of pillows used in the thesis

Limitations for the customer study:

- Healthy individuals

Limitations for simulations:

- Sleeping position - focus on side sleeping position

2 Comfort

Limited studies of pillows made by ICs were done. The parameters that define comfort for pillows are:

- **Support**: Good enough support so that the head is not angled in a weird position.
- **Habit**: Former used pillows and behaviour/usage affect preferred pillow choice.
- **Height**: Pillow height depends on habits, tilting, pain/stiffness, sleeping position and body type.
- **Softness**: How soft a pillow should be (the firmness) is a very important factor for many customers.
- **Position**: Position depends on habit, pillow height, pain/stiffness, bed type and body type. Position and pillow height are very much connected.

Their studies also showed that the customers in general have stronger opinions about which pillow they prefer compared to their opinions about bed types, suggesting that it is highly subjective and related to personal preferences.

These parameters will be used in the customer study to find if there exist factors that determine which pillow that is chosen as the most suitable.

3 Literature review

The general existing research around pillows are limited. Most of them are mainly health-issue related articles. The thesis is more interested in healthy individuals and their relations to every-night use of pillow. Some of the main interest will be brought up around pillow and sleep in general.

Articles mainly mentions **spine alignment**. The cervical spine should be aligned with the thoracic spine for side sleeping position. For supine sleeping position, the spine should maintain its natural position [2]. The different regions of the spine can be seen in Figure 1. It was found that the pillow height affects the alignment of the upper cervical spine [3]. For neck fatigue, height of the pillow mattered for the side position. Shoulder pain occurs due to improper height of pillow for side sleepers [4]. A cervical spine in misalignment can create discomfort, while a misalignment of a joint could cause pressure to the nerve which would then interfere with impulse transmission [5].

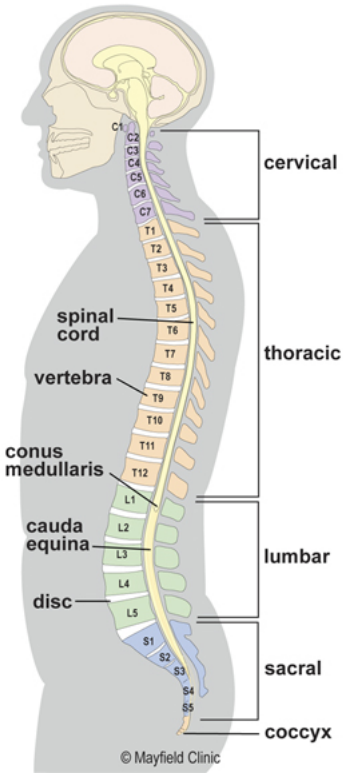


Figure 1: Vertabral column and the different regions.

Research has shown that a change in **material** in pillow alters the support significantly, specifically from similar pillows of foam, latex, polyester or feather. In the same study, it was shown that for side-lying position the cervical-thoracic slope does not alter significantly when using different **shapes** of pillow foam [6]. Pillow shape and material plays an important role to maintain a neutral spine alignment, pillow temperature and pillow comfort [7].

For healthy side-sleepers, there have been findings that suggest that the **choice of pillow** may be the only reason why they could have had a a bad nights sleep if there is no known reason of disrupted sleep [8]. For overall sleep quality, pillow is only one factor.

Temperature has been found to be a factor in sleep quality. The skin temperature does have an effect on sleep depth and the parts in the brain that regulates sleep [9]. A cold condition was perceived as more comfortable than warm condition [10]. Those studies show mainly temperature does matter. There is a correlation between changes in temperature and sleep initiation [10]. It is suggested that a colder pillow temperature may improve sleep quality. The colder pillow indirectly cools down body temperature and improves the sleep quality [11].

As for **anthropometry**, there is no correlation between that and pillow height preference [5]. Body measurements in general can not predict an optimal pillow height. The measurements included in the study were BMI, body length, weight, neck length and thickness.

Sleeping position do change frequently during the night. Neck pain and shoulder pain can occur if a proper pillow height is not used [4]. **Support** is needed to prevent or minimize biomechanical stresses which in turn causes increasing cervical stiffness, headache and scapular/arm pain [8]. Pressure can be measured as support. High pressure gives good support but could be less tolerated due to decreased fluid flow in the soft tissue under pressure [3].

4 Pillows

The selection of pillows was made by **IKEA**. A total of five pillows were used:

Regular

- SKOGSFRÄKEN LOW
- SKOGSFRÄKEN HIGH

Ergonomic

- KLUBBSPORRE
- MJÖLKKLOCKA
- ROSENSKÄRM

The regular pillows, Figure 2a and 2b, are the same pillows, but with different heights. The stuffing is a mix of cotton and lyocell [12, 13].

(a) SKOGSFRÄKEN LOW **(b)** SKOGSFRÄKEN HIGH

Figure 2: Regular pillows

The ergonomic pillows, Figure 3, are all foam pillows [14–16]. Each have two different surfaces. Klubbsporre has one damping foam surface (Figure 3a) and one with a gel layer that is cooler (Figure 3b) [14]. Mjölkklocka has one surface meant for a supine sleeping position and one for side sleeping position [15]. Rosenskärm has a low and a high surface[16].

(a) KLUBBSPORRE

(b) KLUBBSPORRE gel side

(c) MJÖLKKLOCKA

(d) ROSENSKÄRM

Figure 3: Ergonomic pillows

Video of the two different sides of Mjölkklocka:
`https://mmapi.ikea.com/im/productfilms/videos/fe001044.mp4`

Video of the two different sides of Rosenskärm:
`https://mmapi.ikea.com/im/productfilms/videos/fe001048.mp4`

5 Customer study

The customer study was based on findings in the literature review and ICs findings regarding comfort. The goal of the customer study was to use the answers to get a better understanding of the pillows and use those answers to help verify the simulations.

5.1 Data and measurements

For each customer, data and measurements were gathered to figure out if each of these had meaning in if the customer liked the pillow or not.

The data gathered about the customers:

- Age
- Gender
- Weight
- Height
- Shoulder width
- Top of head to top of shoulder
- From neck to shoulder

Age and gender are basic information that could that could influence the choice of pillow[17]. Weight and height were not measured but were given by the customers themselves. There was no opportunity to measure weight and height at the **IKEA** of Sweden offices. A measuring tape was used to measure shoulder width, top of head to top of shoulder and from neck to shoulder. These measurements were considered to may affect the opinions of pillows.

5.2 Questions

For all of the questions a semi-structured interview style was used. By doing this, more information regarding the person and the pillows could be established [18].

The pre-questions:

1. How do you usually sleep? Which position?
2. Does the position change during sleep?
3. Do you use more than one pillow? How many?
4. What kind of pillow are you currently using? Material, height, shape.
5. How regularly do you change your pillow?
6. Is there a specific way you usually arrange your pillow?
7. Do you have any pain when you wake up? Where?
8. How many hours do you sleep in average?
9. Is your current pillow comfortable?
10. Does temperature affect your sleep? If it does, do you correct it?
11. When you buy a pillow, how do you pick one?
12. In regards to comfort, which one do you find the most important, the mattress or pillow?
13. Do you think pillow has an impact on comfort?

The pre-questions would give an insight of the customers habits and if these habits would affect their opinions about a pillow.

The questions used for each pillow:

1. **Support**
   - A Do you get support in the neck, head and shoulders?
2. **Height**
   - A Is this height comfortable for this position? Why?
   - B In the angle you are right now, do you think it would be comfortable all night?
3. **Position**
   - A In this position, is the pillow comfortable?
4. **Material**
   - A What do you think of this material?
   - B Is the material comfortable?
5. **Softness**
   - A Is the pillow soft enough or too soft? In what way?
   - B Do you sink down too much or is it good?
   - C Can you easily breathe?
6. **Pressure**
   - A Where do you feel uncomfortable pressure? Describe? Shoulder, neck, head, face.
7. **Temperature**
   - A Is the pillow a suitable temperature?
   - B Does it feel like that the pillow gets warm too quickly?

These questions were asked for each pillow. The formulation of the questions were based mostly on ICs findings. The main goal of these questions was to find out if each data/measurements and habit could contribute to finding a pattern of opinion of each the pillows.

Final questions:

- Which pillow is the most comfortable? Why?
- What is your preferred neck angle when sleeping?
- If none of them was the perfect one, how would the ideal pillow be?
- What is the most important part of a pillow for you?

The final questions are important to see if there would be a pattern between the customers especially about the angle and to be able to connect that to the simulations. The pillow preference is important to note to see if they would choose a pillow of the ones in the study or if they still would pick their own pillow, or something else.

5.3 Performing the customer study

The pillows along with the mattress, Högvåg firm, was used in the customer study. Högvåg firm was used because it is the mattress that will be used in the simulation.

Due to COVID-19 [19], a conscious choice was made to make sure that the customers measured themselves. Distance was kept in order to minimize the risk of getting COVID-19. To get a consistent measurement of each customer, specific instructions were made. Between each customer study, sheets were changed to keep the study as hygienic as possible.

During the customer study, the customer was asked to lay in the same sleeping position as they should have done before. Then, they answered the questions about each pillow and then responded to the final questions.

5.4 Statistical analysis

It became apparent that the customers had different opinions even if they had the same measured body parameters. The idea was to use the answers to find which parameters gave similar results. Since there was no pattern, a better way of analyzing the answers needed to be done. One way to analyze the results is statistical analysis.

To be able to use statistical analysis, each answer needed to have a number. It would have been easier if the customer study had utilized a likert scale, then those answers could have been directly used in statistical analysis. To get around this issue, each answer was assigned a number instead, based on what was answered.

Each parameter was assigned a number 1-5, Table 1.

Table 1: How each opinion was assigned.

Number	**1**	**3**	**5**
Support	Lacked support	Enough support	Too much support
Height	Too low	Perfect height	Too high
Position	Not comfortable	In between	Comfortable
Material	Not comfortable	In between	Comfortable
Softness	Too hard	Perfect softness	Too soft
Pressure	No pressure	Slight pressure	A lot of pressure
Temperature	Not comfortable	In between	Comfortable

See Table 2 of an example of how each answer was interpreted.

Table 2: Example of how each opinion was assigned.

Customer #13, Skogsfräken low			
Parameter	**Questions and answers**		**Number**
Support	Q:	Do you get support in the neck, head and shoulders?	**1**
	A:	It's too shallow for me, I don't feel anything.	
Height	Q:	Is this height comfortable for this position? Why?	**1**
	A:	I need a little bit higher, it sinks down too much, no.	
	Q:	In the angle you are right now, do you think it would be comfortable all night?	
	A:	Not comfortably but I could do that.	
Position	Q:	In this position, is the pillow comfortable?	**1**
	A:	Not really.	
Material	Q:	What do you think of this material?	**5**
	A:	It's pretty solid material.	
	Q:	Is the material comfortable?	
	A:	That I would probably say.	
Softness	Q:	Is the pillow soft enough or too soft? In what way?	**3**
	A:	Soft enough, for me it is too soft.	
	Q:	Do you sink down too much or is it good?	
	A:	Sink down too much.	
	Q:	Can you easily breathe?	
	A:	I don't feel a difference.	
Pressure	Q:	Where do you feel uncomfortable pressure? Describe. Shoulder, neck, head, face?	**3**
	A:	No.	
Temperature	Q:	Is the pillow a suitable temperature?	**5**
	A:	Yes.	
	Q:	Does it feel like that the pillow gets warm too quickly?	
	A:	It doesn't feel too warm.	

5.4.1 Regression analysis

In this project, ANOVA (Analysis of variance) and p-values were first considered to be used. But after a consultation with Erik Lindström, Professor, Mathematical statistics, Lund University, a recommendation was made to use regression analysis and confidence intervals instead.

A linear regression analysis tells the relationship between a dependent variable y, and one or more independent variables X [20].

The intended way of analysing in the beginning was to look at if data and measurements affect opinions about the different parameters. The idea was to look at how age affect what they think about the support, height, position, material, softness, pressure and temperature separately. Then do the same for the different data and measurements. This means using a simple linear equation [21], such as:

$$y = \beta_0 + \beta_1 x + \epsilon \tag{1}$$

where y is the response, β_0 is the constant, β_1 is the slope, x is the observed value and ϵ is the error term.

When using the simple linear equation or plotting to see if there is linearity, there is no clear pattern. The danger with using the simple linear equation is that the interpretation of the confidence interval can be misinterpreted if the other variables play a part. The customers would often answer the question with other parameters within the response. It showed that the opinions of each parameters played a part in each other (Table 3). The customer answered the question along with another trait of the pillow, which indicates that all these parameters are connected for the pillows.

Customer #16, Skogsfräken low	
Q:	Do you get enough support in the neck, head and shoulders?
A:	No, just for the head, I think it's very soft.

Table 3: Example of how the answer included other parameters.

The multiple linear regression was implemented instead. Multiple regression takes the other variables into consideration. Multiple regression [20] is given by:

$$y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_p X_{ip} + \epsilon_i \tag{2}$$

where $i = 1, \ldots, n$.

5.4.2 Confidence interval

The **definition** of confidence interval (CI):

"An *interval estimation* for a parameter is an interval with random variables as limits. The *confidence level* for the interval estimation is the probability that the interval shall contain the parameter in question. The observed interval estimation is called a *confidence interval* for the parameter." [22].

If the confidence interval contains **0**, it means that there there is **no significance**.

The regression analysis was done in Matlab, see Appendix A. To get a visual result, the confidence intervals where plotted in a graph to easier find the confidence intervals that did not contain 0.

5.5 Results

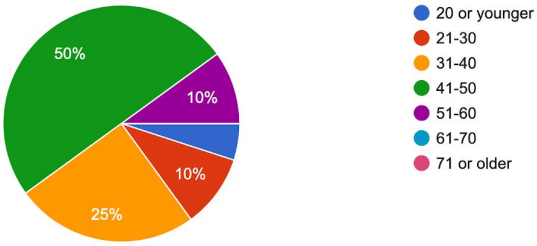
The results are divided into three parts. The data that is collected about each participant in the costumer study and their answers to the pre-questions are presented in part 1. Part 2 contains the results from the regression analysis and part 3 the results from the final questions.

5.5.1 Participants

5.5.2 Participants

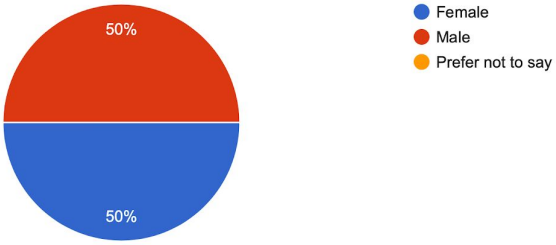
Age

20 responses



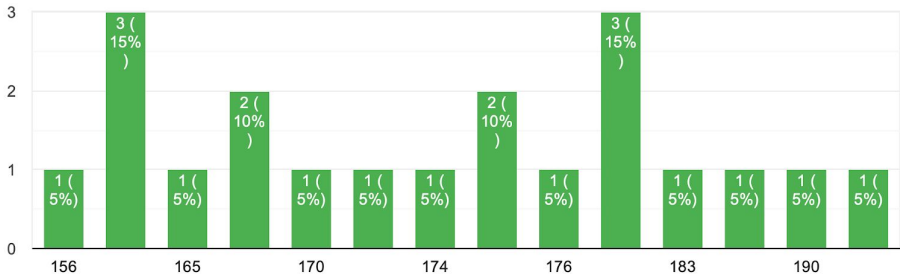
Gender

20 responses



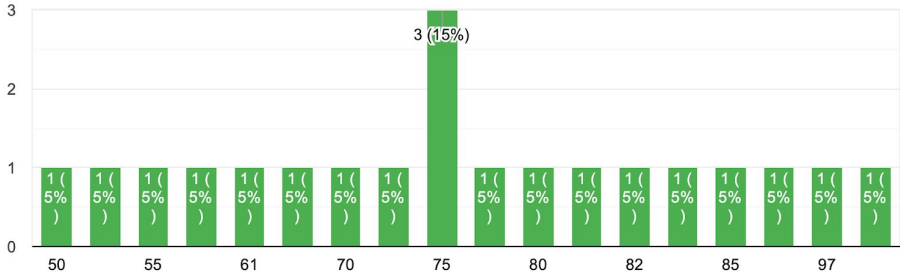
Height (in centimeters)

20 responses

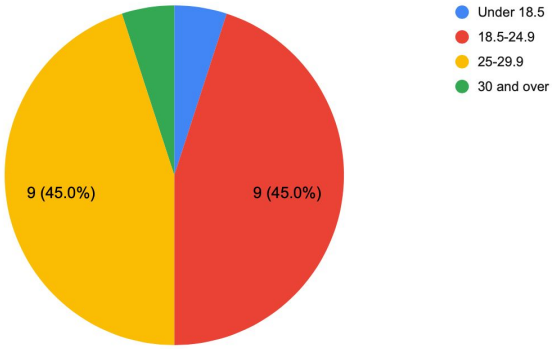


Weight (in kg)

20 responses

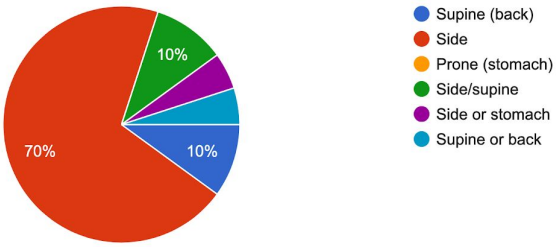


BMI



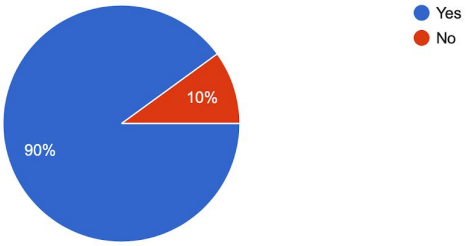
In which position do you usually sleep?

20 responses



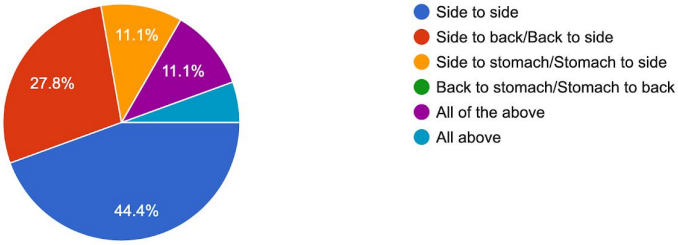
Does your sleeping position change during the night?

20 responses



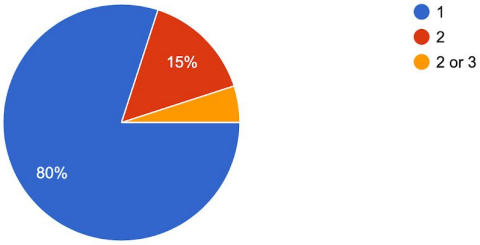
If your sleeping position changes during the night, how does it change?

18 responses



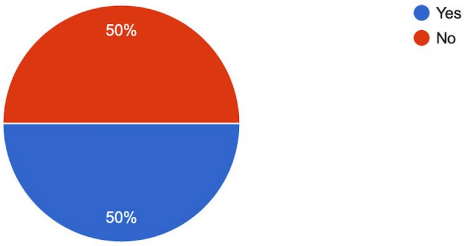
How many pillows do you use when you sleep?

20 responses



Is there any specific way you arrange your pillow when you sleep?

20 responses



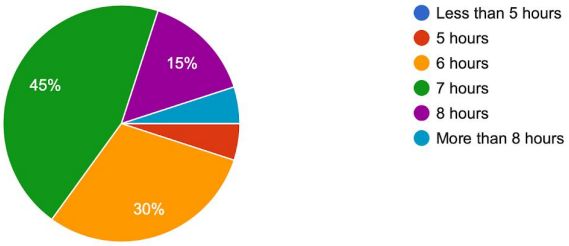
If you answered "Yes" in the previous question, then how do you arrange it?

10 responses

Fold it
On top of each other
Pull it towards the neck
Fix it so it's more support for the neck
Arm under pillow when i sleep on my stomach
Two on top of each other
Two pillows next to each other
Pack it up to make it "higher"

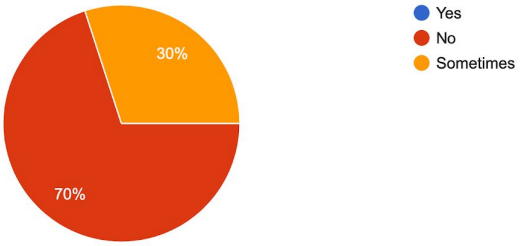
How many hours do you sleep in average per night?

20 responses



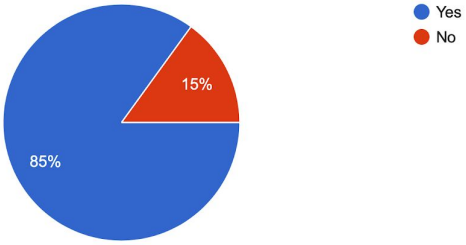
Do you have any neck pain when you wake up?

20 responses



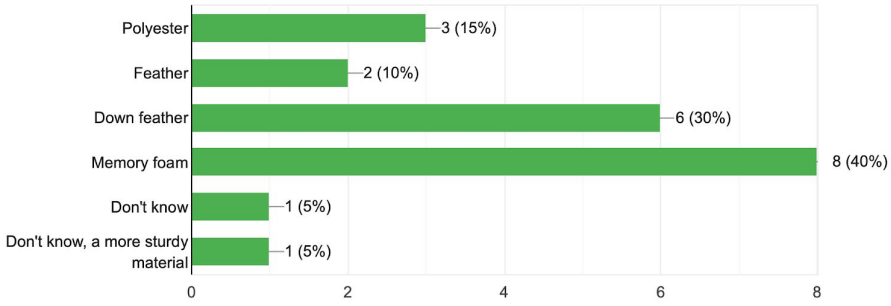
Does the temperature of the pillow affect your sleep?

20 responses



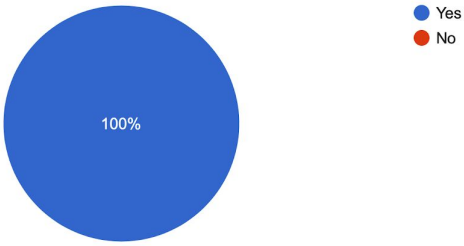
What material does your pillow consist of? (Pick several if it's a combination of material)

20 responses



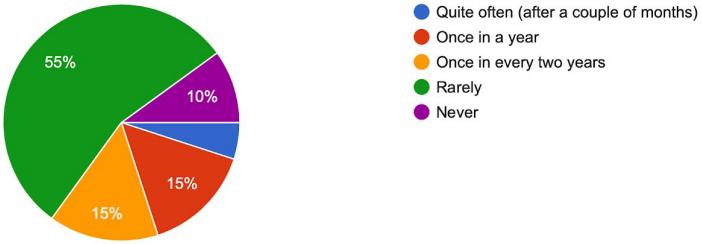
Is your current pillow comfortable?

19 responses



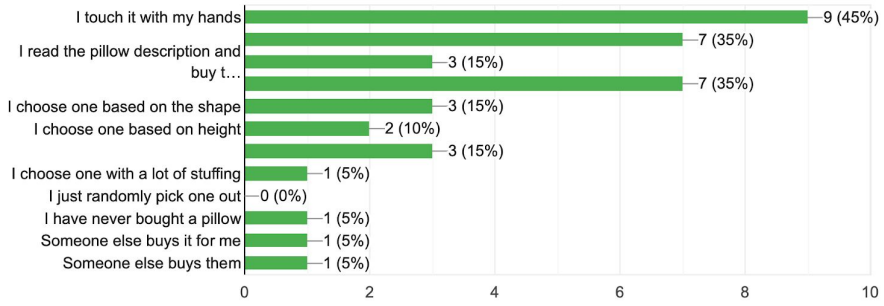
How often do you buy a new pillow?

20 responses



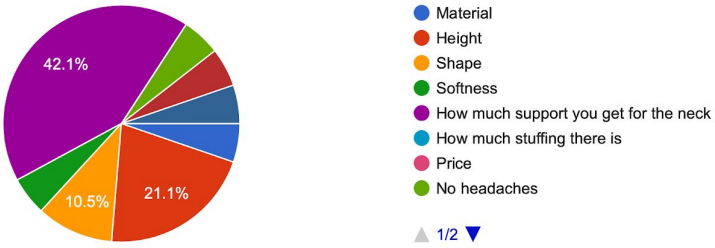
When you buy pillows, how do you choose which one to buy?

20 responses



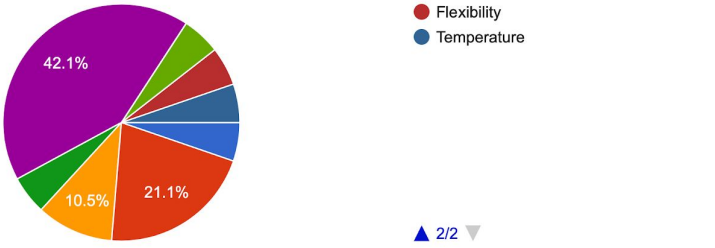
If you had to pick the most important selection criteria for your pillow, which one is it?

19 responses



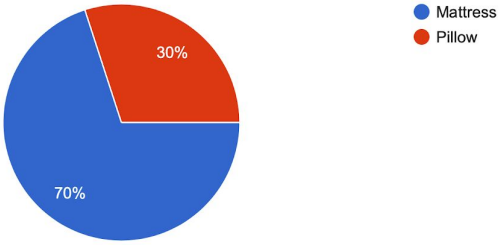
If you had to pick the most important selection criteria for your pillow, which one is it?

19 responses



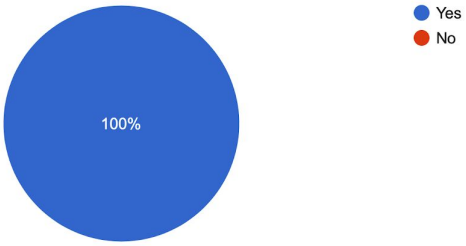
In regards to comfort, which is the most important to you?

20 responses



Do you think pillow has an impact on comfort?

20 responses



5.5.3 Regression analysis

For each pillow, the confidence interval for data vs. parameter was plotted, such as Table 4. This was done purely to get visualisation of the intervals and make it easier to find which ones that did not contain 0. Using the Matlab code, specific confidence interval numbers can be generated.

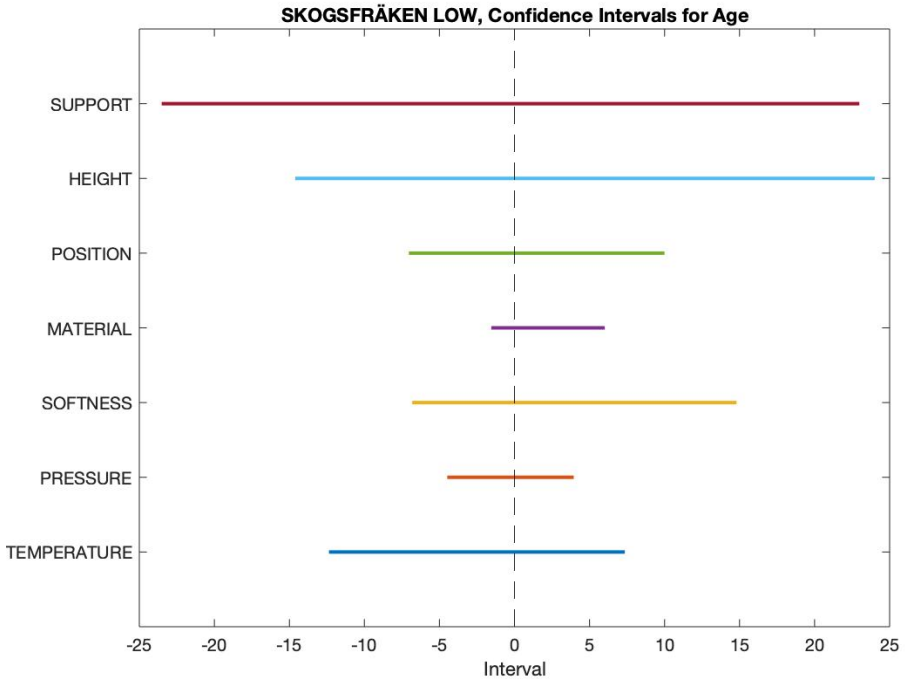


Figure 4: Confidence interval for Skogsfräken low, Age

The significant confidence intervals were put in Table 4, to get an overview of all the ones that were significant. The only one that had no significance is Skogsfräken high.

Table 4: Summary of the results from the regression analysis.

Pillow	Age	Gender	Height	Weight	BMI	Shoulder width	Head to shoulder	Neck to shoulder	Sleeping position
Skogsfräken low						Position	Position		
Skogsfräken high									
Klubbsporre		Softness					Position Softness		Softness Position Material Pressure
Klubbsporre cold	Softness				Softness				
Mjölkklocka supine		Pressure		Support Pressure	Support Pressure		Material Pressure	Pressure	
Mjölkklocka side			Pressure	Pressure					Support Height
Rosenskärm low				Pressure	Support Pressure	Pressure			Softness
Rosenskärm high					Temperatu	Position Pressure	Position	Position	

5.5.4 Final questions

The general outcome of the final questions:

- There were a lot of pillows that they did like.
- For some of the customers, they really disliked some of the pillows.
- 45% would say that the perfect pillow is something similar to the pillow they liked the most in the study. In this 45%, some of them have the same pillow as in the study. If you remove those whose perfect pillow is their own pillow, only 15 % would consider the perfect pillow to be one they tried in the study.
- 80% considers their own pillow or something similar, as the perfect pillow.
- In regards to angle of the head, most of them did not know what they preferred. Some did say 90°, some said angle downwards and some said upwards.

5.6 Discussion

The goal of the customer study was to get a big range of diverse customers. A range of age, gender, and BMI was achieved. But age and gender were slightly more focused in some groups. Due to COVID-19 [19], there were a limited number of customers who could participate in the study. The results of the customer study only pertains to this sample size. It is important to acknowledge that the sample size and distribution do not correlate to the customer survey. In this instance, a larger sample size needs to be considered to mimic reality.

The customer study was performed on **IKEA** employees, and it should be noted that most of the customers are Caucasian and living in Sweden. It could have been a different result if performed on people with other habits. Culturally, people are used to different beds and pillows which affects their opinions about what kind of pillow they prefer.

As seen in Table 4, there is a possibility that the ergonomic pillows are more likely to have parameters that related if you like a pillow or not. Skogsfräken low can be counted out even though a pattern could be seen for it. The reason is that during the customer study, it was noted that a lot of the customers wanted to fix the pillow but did not. They would have probably changed their opinion if they had scrunched up the pillow or folded it, to create better support. If they had done that, the results would be different and probably a lot of them would have had liked the pillow. The difference between the regular and the ergonomic pillows are that the regular are more modular. Due to it's material and shape, the regular pillows can for example create a different height, create more support for a specific area, easier to stack several of them and so on. That is why they are more unlikely to have specific measurements or anthropometry that determines if a regular pillow is more suitable.

The main takeaway from the final questions in themselves is that the majority of participants liked one or the other of the pillow selection. They would more likely choose a similar pillow as their own when asked how the perfect pillow should be. It also shows that customers do not really know what angle they prefer, hence the difficulty to connect this to the simulation.

5.7 Conclusion

Based on this customer study, the statistical analysis indicates that the ergonomic pillows are more likely to have data/measurements that correlates to their opinion. It is more likely that a pattern between data/measurements and opinion exist for the ergonomic pillows. It is important to note the CIs were large, which means that the results are not reliable. To get a smaller CI, a bigger sample size of customers is needed. A smaller CI range is more reliable.

6 Customer survey

Due to COVID-19 [19], the probability of getting enough customers to participate was low. In an effort to gain more data, a customer survey was created based on the customer study. The difference between the survey and the study is that the possibility to collect answers about the **IKEA** pillows are not present. The data that was gathered would be able to tell about the habits of the customers and that would possibly give another outcome if they would have tried the pillows.

The exact same questions were used as the pre-questions, but a range was asked about their own pillows. The survey was created using Google Forms. By using this method, it could be sent out to an array of people and not keep it confined to one specific group of people. A triangulation of data was created [18].

The survey can be seen in Appendix B.

Or follow the link to the survey: `https://forms.gle/VwjFtRR8sd51fmJL8`

6.1 Results

See Appendix C.

6.2 Discussion

The results of the customer survey show how difficult it is to predict habits. The main takeaway from the customer survey is that people are really different and so are their habits. If the goal of the thesis was to simulate exactly how a person sleeps, there is so many things to take into consideration. Some of the big differences that could hinder a simulation and that show how different people are:

- 89.9% of the respondents changes their sleeping position during the night.
- The different sleeping position that changes during the night; from side to side, supine to side, prone to side and so on.
- Number of pillows used when sleeping, 45.5% of the respondents use two or more pillows.
- 50.8% of the respondents arrange their pillow in a specific way.
- For some of the respondents is the pillow most important while the mattress most important for others.

What has come out of the customer survey is that 99.5% think that the pillow has an impact on comfort. This is a confirmation of the fact that the pillows are important for feeling comfort.

The customer survey was sent out through the author's Facebook and Facebook group, which meant a lot of students. To get a variety of customers, the survey was

also mailed out to **IKEA** employees. If the customer survey had cast a broader net, there could have been more spread in responses.

6.3 Conclusion

The customer study highlights the unpredictable behaviour of customers. To use simulation as a part of understanding the pillow usage, it is important to know that customers do not only sleep in one position and do not only have one pillow. Their sleeping position, even though they state it as supine, side or prone, can be altered by having an arm under a pillow or folding the pillow.

7 Simulation

Author's note: *Simulation in itself is not the main subject, but the setting up of a simulation model that works and analysing the results are. An assumption is made that the reader in general knows and understands the basics of simulation. A recommendation is to read Joel Elinder's master thesis [23], since this simulation setup is based on his master thesis.*

The simulations were set up according to Joel Elinder's master thesis. To set up the pillow and side-laying dummy in the simulation, it needed some amendments. Due to the outcome of the statistical analysis, the focus is on the ergonomic pillows. The simulation will not run the cold side of Klubbsporre since the simulation will only run the foam materials.

7.1 Software

For the simulation part of the thesis, LS-DYNA and hypermesh were used. LS-DYNA is a finite elemente program that can simulate real life problems [24]. HyperMesh is a pre-processor for finite element analysis. It imports CAD-files and exports solver decks [25]. The pillows where meshed using HyperMesh. CAD-files created by **IKEA** were meshed and then exported as LS-DYNA-files.

7.2 Pillow mesh

Running the simulation with the pillow, it got stuck at "Running...0%". A d3hsp file was generated. In that file the errors could be found. Error was NaN. By using ∗**CONTROL_SOLUTION** and **ISNAN**=1, then running the simulation again, the mesALL-file will tell where the first issue arises. It could be seen that the elements for the pillow were the issue. By changing the mesh size of the pillow to 15 instead of 10, the simulation ran further then 0%. It is important to know that the simulations will crash without a pillow. There will eventually be instabilities around the neck area of the dummy.

7.3 Self contact and body placement

Self contact for the body is needed so that the upper leg and arm have contact with the body and does not completely go into each other. By adding a self contact, the leg and arm have contact with the rest of the body, Figure 5. To make the self contact work, **SOFT=1** in optional card A needs to be used. **SOFT=1** calculates the stiffness in contact and bases it on stability considerations by taking timestep into account [26].

The body was placed gently on the mattress to reduce oscillation.

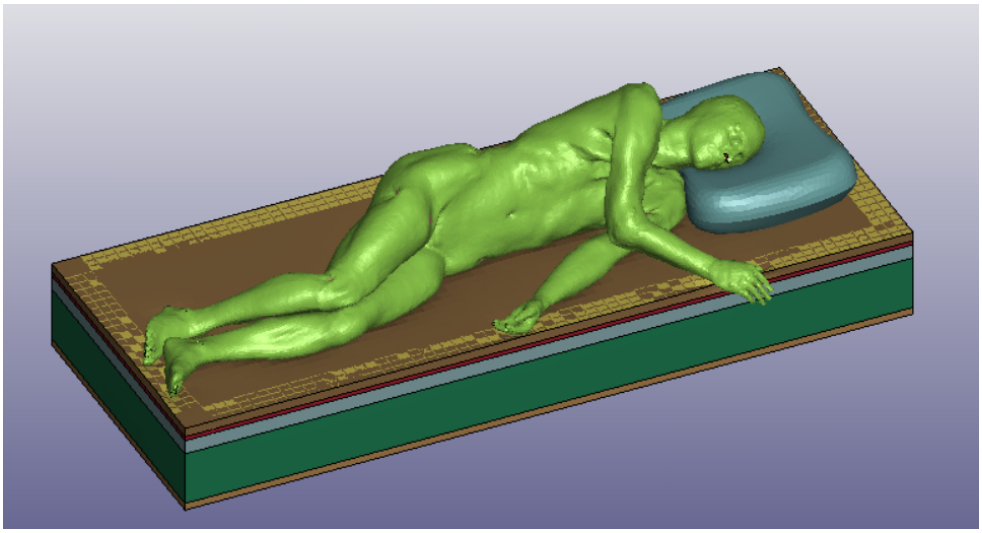


Figure 5: Average BMI | Self contact

7.4 Constrained nodes

Due to the slim side of the average dummy, it will eventually want to turn to its back once it hits the mattress. To solve this issue, five nodes on skin of the dummy were constrained so the nodes only move in z-direction Figure 6. For future reference, an attempt to place nodes on the back (constrained in y-direction) of the dummy failed for this simulation, the simulation crashed. A variation of placements of the nodes was tried. The placement of the nodes in Figure 6 could last the longest, about 5.5s, without crashing.

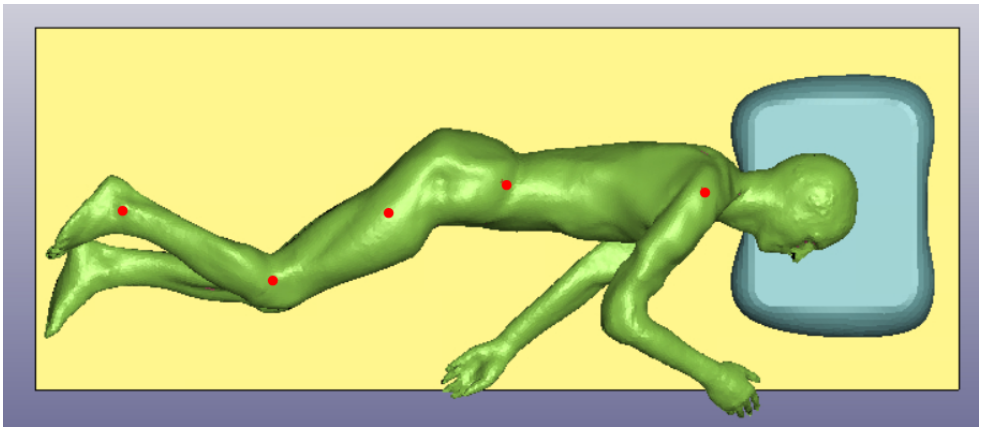


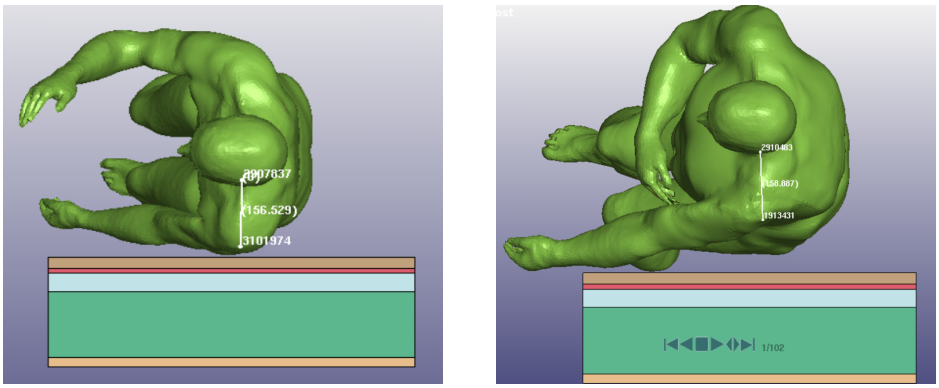
Figure 6: Placement of constrained nodes

7.5 Pillow placement and contact

For each of the simulations, the body was kept at the same place on the mattress, and the pillows were switched out. The pillow was placed as close as possible to the mattress, but without touching it. An assumption was made that the pillow would fall onto the mattress once the weight of the head hits the pillow. There are two contacts for the pillow, pillow to mattress and body to mattress. For both contacts, ∗**CONTACT_AUTOMATIC_SURFACE_TO_SURFACE** was used. **SOFT=1** was used again. **SOFT=2** is also possible along with other settings. But **SOFT=1** uses the Young's modulus of the material and not the load curve.

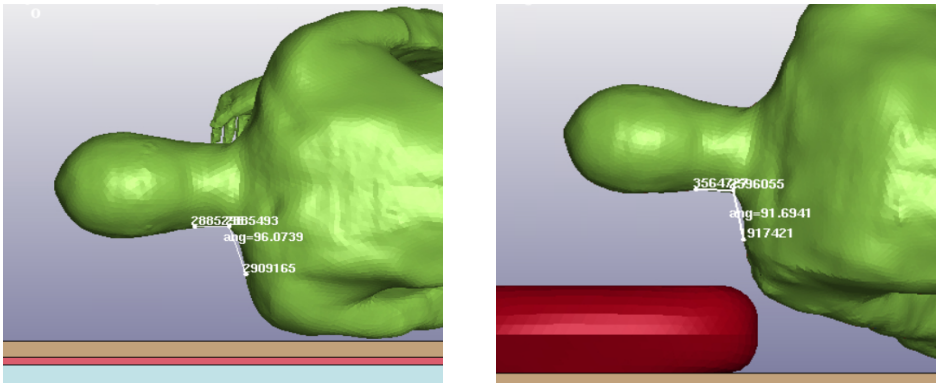
7.6 Measurements and spine alignment

From the simulation, measurements were made to analyze the results. To make sure that the values could be compared to each other, the measured nodes were the exact same nodes for each pillow. Due to the average and high BMI dummy having different node numbers, the same nodes could not be found between the dummies. The measurements are the neck to shoulder and angle, Figure 7 and 8. Along with the measurements, the spine alignment was looked into separately. As mentioned in the literature review, the cervical and thoracic vertebrae should be aligned for side sleeping position. The measurements from neck to shoulder were made to compare how much the shoulder was pushed into itself from the mattress/pillow combination. The angle between them is more correlated to the spine alignment and to see how much the angle between shoulder and neck changed for each pillow.



(a) Average BMI **(b)** High BMI

Figure 7: Neck to shoulder measurement



(a) Average BMI **(b)** High BMI

Figure 8: Angle between shoulder and neck

7.7 Results

For a termination at 5s, the simulations for each dummy along with each pillow, result in **Finished (Normal Termination)**, i.e. the simulation runs without crashing. At 5 seconds, the average BMI simulations are sufficiently at a steady state (Figure 9) The high BMI dummy reaches a steady state at about 4s (Figure 10), but in this case, 5s was chosen for both dummies to show the difference in time. If the high BMI simulation runs with the termination time of 4s, the running time is about 2h 0min. Steady state was defined as sufficient when the body to mattress contact was leveled out. See Table 5 for the different simulation times.

The current working simulation model that **IKEA** has, is a supine sleeping dummy. It runs on 1h 4min. This is a side position which means that the dummy reaches a steady state later and the running time is longer. The need to reduce **TSSFAC** due to instabilities also makes the running time longer.

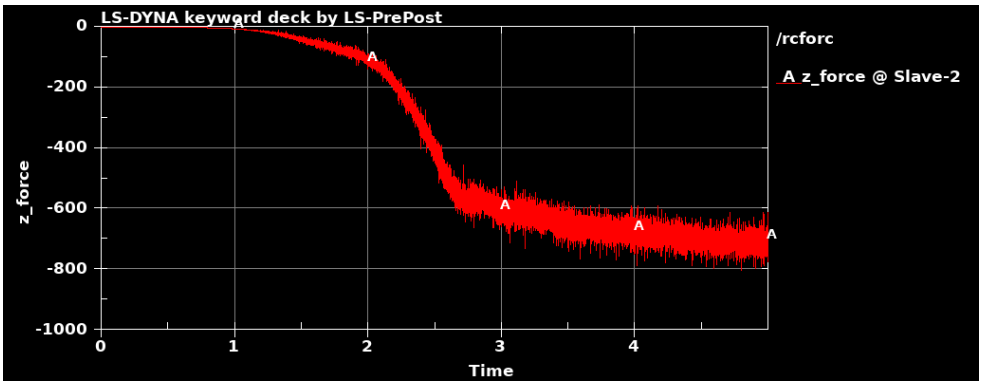


Figure 9: Steady state for the average BMI dummy, using Klubbsporre.

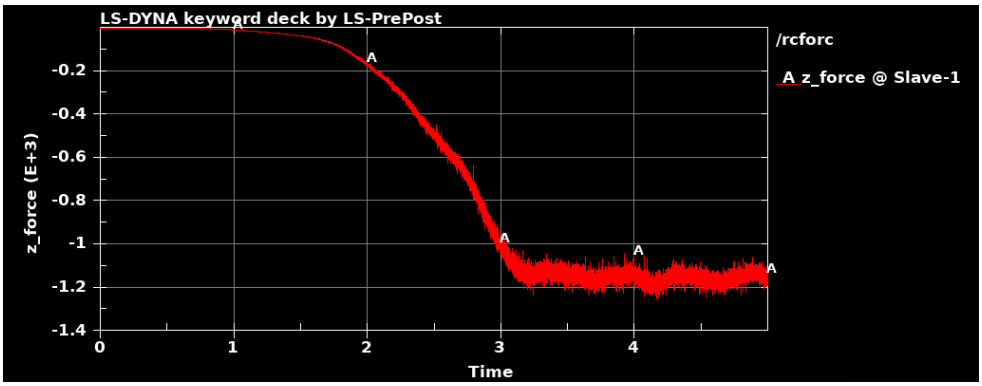


Figure 10: Steady state for the high BMI dummy, using Klubbsporre.

Table 5: Approximate running time for each model at 5s termination with 20 CPU. The simulation running time differs slightly depending on which pillow is used in the simulation.

BMI	**Running time**
Average	2h 15min
High	2h 30min

7.7.1 Average BMI model

The spine alignments can be seen in Figures 11, 12, 13, 14 and 15. The neck to shoulder measurement and the angle between neck and shoulder can be seen in Table 6.

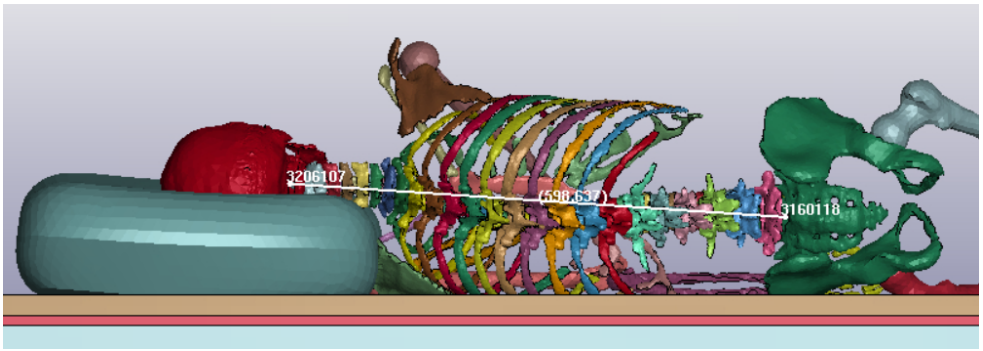


Figure 11: Spine alignment | Average BMI | Klubbsporre

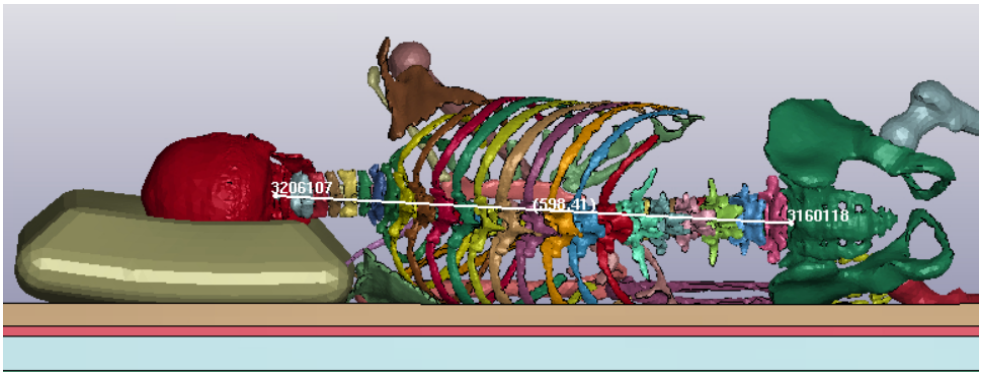


Figure 12: Spine alignment | Average BMI | Mjölkklocka supine

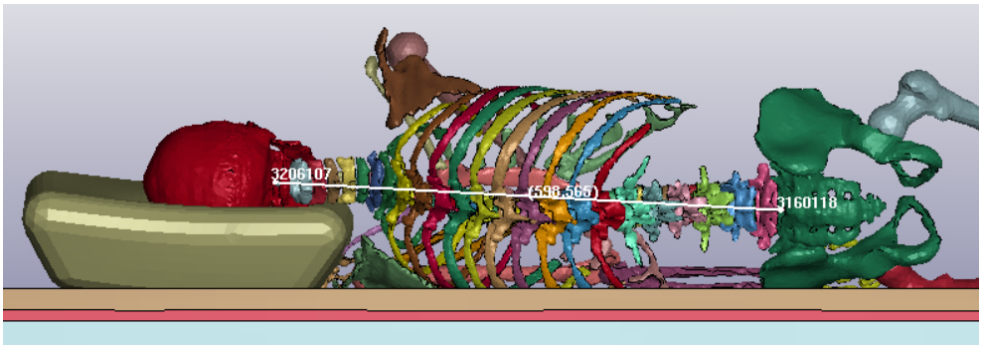


Figure 13: Spine alignment | Average BMI | Mjölkklocka side

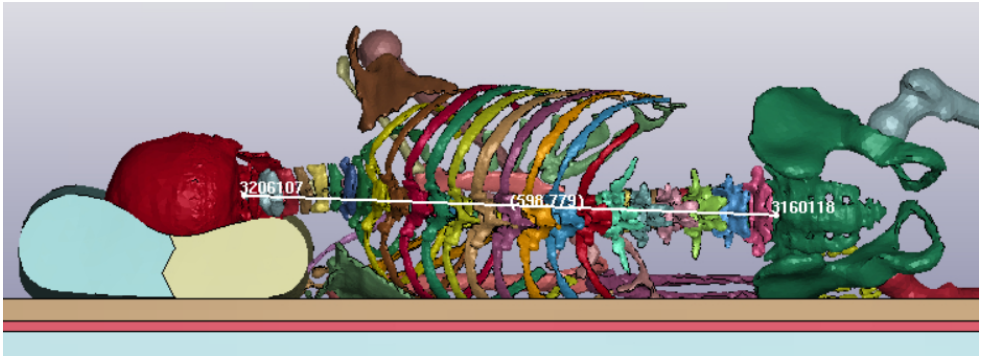


Figure 14: Spine alignment | Average BMI | Rosenskärm low

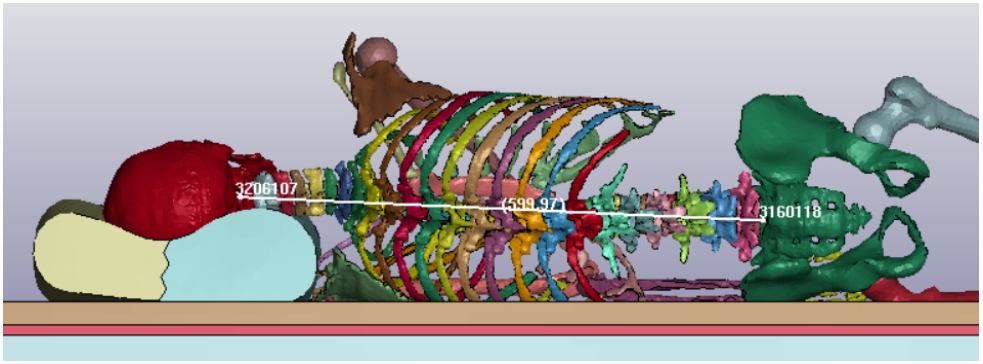


Figure 15: Spine alignment | Average BMI | Rosenskärm high

Table 6: Measurements | Average BMI

Pillow	**Neck to shoulder [mm]**	**Angle [°]**
-	156.529	96.0739
Klubbsporre	130.056	51.5894
Mjölkklocka supine	130.802	46.2062
Mjölkklocka side	131.158	48.7533
Rosenskärm low	129.45	44.6917
Rosenskärm high	130.004	49.748

Based on the simulations, the average BMI model lacks slightly in support. The spine is not fully aligned and especially Rosenskärm low is the worst choice for the average BMI side sleeper, both in neck to shoulder measurement and angle. Klubbsporre and Rosenskärm high should feel quite similar, due to the similar distance between neck and shoulder and degree of angle between them.

7.7.2 High BMI model

The spine alignments can be seen in Figures 16, 17, 18, 19 and 20. The neck to shoulder measurement and angle between neck and shoulder can be seen in Table 7.

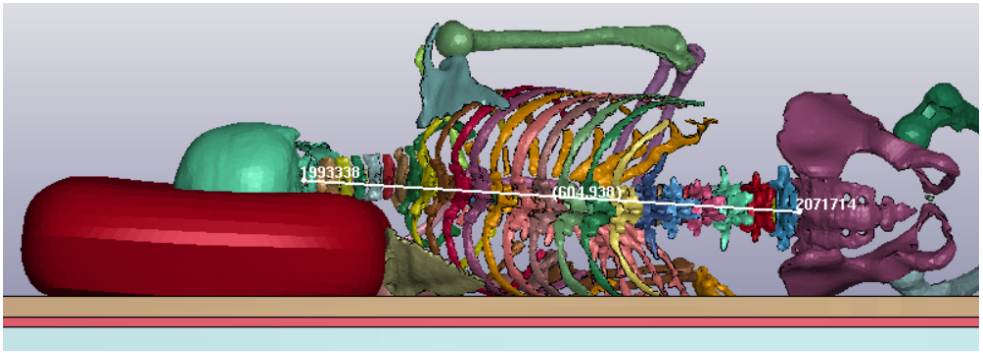


Figure 16: Spine alignment | High BMI | Klubbsporre

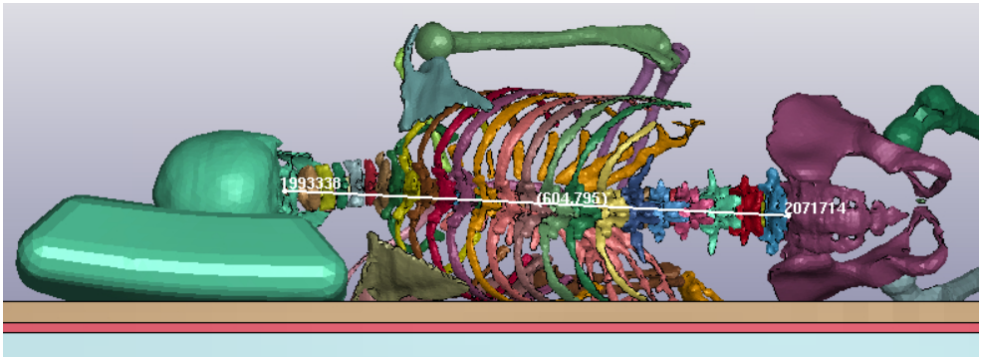


Figure 17: Spine alignment | High BMI | Mjölkklocka supine

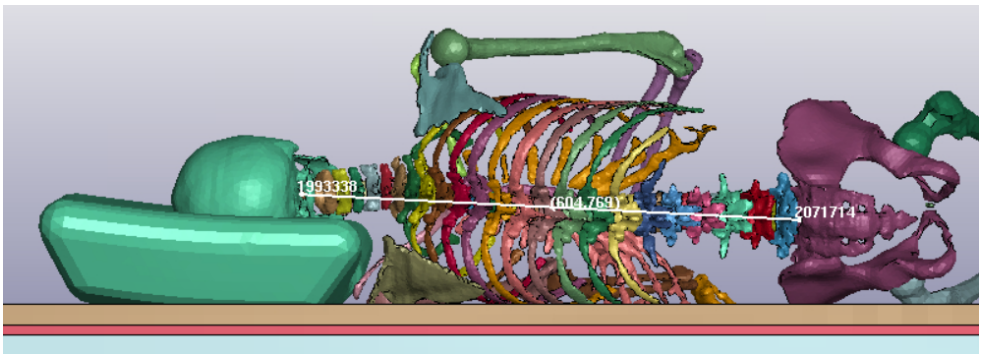


Figure 18: Spine alignment | High BMI | Mjölkklocka side

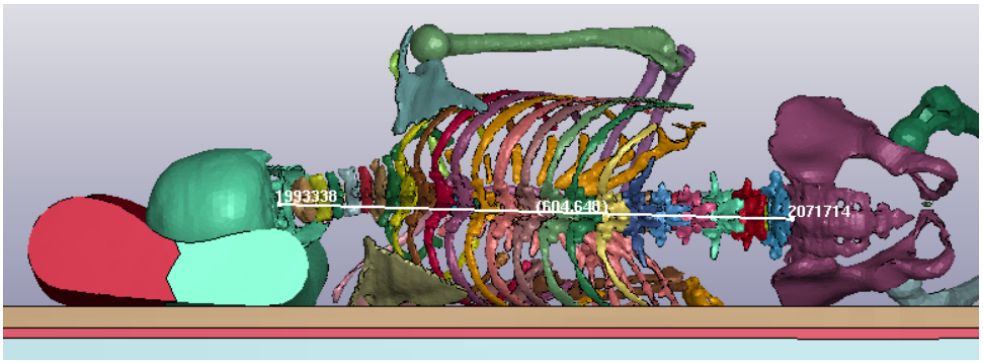


Figure 19: Spine alignment | High BMI | Rosenskärm low

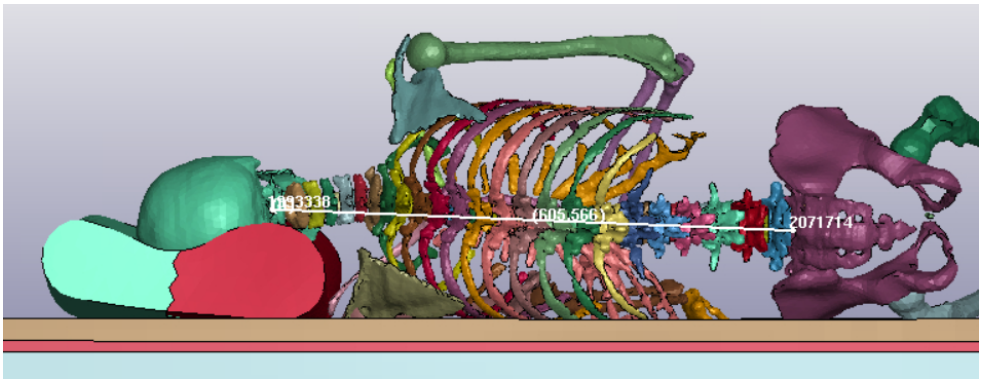


Figure 20: Spine alignment | High BMI | Rosenskärm high

Table 7: Measurements | High BMI

Pillow	**Neck to shoulder [mm]**	**Angle [°]**
-	158.857	91.6941
Klubbsporre	125.789	52.3981
Mjölkklocka supine	118.734	51.5225
Mjölkklocka side	119.108	54.8069
Rosenskärm low	114.886	38.5712
Rosenskärm high	119.276	43.8168

Based on the simulations, the high BMI model lacks in support. The spine is not aligned and especially Rosenskärm is the worst choice for the high BMI side sleeper, both in neck to shoulder measurement and angle. Klubbsporre is the only one with the high neck to shoulder measurement, but the angle is lower than Mjölkklocka side.

7.7.3 Comparing with individual customers from the customer study

A decision was made to try to validate the simulation with the customers from the study. A comparison of opinions based on BMI, weight and neck to shoulder measurement. Comparing only with male side sleepers since the simulation are male. It is difficult to compare everything, therefore the comparison will only look into position, and if they thought the pillow was suitable for their sleeping position.

BMI

In the customer study, there are 3 male customers that fall in the range of average BMI, 18.5-24.9 [27]. there are 7 male customers that fall in the range of high BMI, 25 and over [27]. See Table 1, to see what each number represents. By looking at Table 8, it is comparable with the simulation. Klubbsporre seems to be the most comfortable along with Mjölkklocka supine. But there is some difference in opinion between the customers for Mjölkklocka Side and Rosenskärm low. Rosenskärm high in the simulation has a similar outcome as Klubbsporre. Here it does not. Hinting at in real life that there may be an opinion about Rosenskärm high that can not be seen in this simulation specifically. For the high BMI in Table 9, there seems to be an outlier, customer #6, which makes it hard to compare it with the simulation. Even removing the outlier, the customers have mostly different opinions about every pillow except Klubbsporre. Rosenskärm was deemed to be the worst for side sleepers with high BMI, but 4 of them thought that the pillow was comfortable.

Table 8: Average BMI

Customer #	**2**	**15**	**17**
BMI	23,15	21,61	24,21
Opinion			
Klubbsporre	5	5	5
Mjölkklocka supine	5	3	5
Mjölkklocka side	1	3	5
Rosenskärm low	5	1	1
Rosenskärm high	1	1	1

Table 9: High BMI

Customer #	**5**	**6**	**7**	**8**	**12**	**14**	**18**
BMI	25,31	26,87	29,32	29,29	25,35	31,51	29,41
Opinion							
Klubbsporre	5	1	5	5	5	5	5
Mjölkklocka supine	2	1	5	5	5	5	2
Mjölkklocka side	1	1	5	5	5	5	1
Rosenskärm low	5	1	3	3	5	1	1
Rosenskärm high	5	1	5	5	5	1	1

Weight
The weight of the simulation models was measured in LS-DYNA. The average BMI weighs 81 kg. The high BMI weighs 126 kg. No customer falls close to 126 kg. Only the average BMI model will be compared here. They seem to agree on Klubbsporre and in Mjölkklocka. Rosenskärm is more divisive. Comparing this with simulation model, average BMI, there should be more of a pattern.

Table 10: Weight

Customer #	**5**	**15**
Weight [kg]	82	83
Opinion		
Klubbsporre	5	5
Mjölkklocka supine	2	3
Mjölkklocka side	1	3
Rosenskärm low	5	1
Rosenskärm high	5	1

Neck to shoulder
There are two male customers close to the measurement of the simulation models. The simulation models have almost the same neck to shoulder measurement, 156 and 158 mm. They both agree on Klubbsporre and Rosenskärm, Table 11. Mjölkklocka is divisive.

Table 11: Neck to shoulder

Customer #	**17**	**18**
Neck to shoulder [mm]	150	160
Opinion		
Klubbsporre	5	5
Mjölkklocka supine	5	2
Mjölkklocka side	5	1
Rosenskärm low	1	1
Rosenskärm high	1	1

7.8 Discussion

From the results of the spine alignment, it can be seen that none of the cervical spines are 100% aligned with thoracic spines. So, the question is whether that can be achieved or not. It is important to note that a simulation is a simulation and that reality may have some slight differences. Based on the results of the simulation, the average dummy needs a softer mattress or slightly firmer pillows to get a more aligned spine. The high dummy needs firmer pillows or a softer mattress. Since **IKEA** has previously found that firmer beds are more fitting for higher BMI's, the choice for the high dummy is to maybe have two pillows stacked on top of each other or just a firmer pillow. This fact emphases the importance importance of mattress/pillow combination.

It is also important to put emphasis on that the simulation shows one sleeping position, a very specific one. For people who maybe put their arms under their pillow, the simulation would have been completely different.

Comparing the simulation models to each other, since they have about the same neck to shoulder measurement, it shows that BMI or weight matters when it is about mattress and pillow.

Comparing the results of the simulation with the actual customers, there is an indication that a customer's personal preference may be more important. Looking at Rosenskärm high for the average BMI, they should like it, but most of them do not. *What is the reason behind it?* It could be due to that the measurements give an indication that it gives enough support for the neck but it gives high pressure. But as research has shown, high pressure gives good support but could be less tolerated [8].

7.9 Conclusion

The simulation models show that there are pillow/mattress combination more ergonomically suited towards certain BMI or weight. Comparing those results with real customers opinion gives a different outcome. The customers have slightly different opinions, which hints at that the customer's personal opinion matters.

8 Future improvements

If the customer study were to be conducted again, a larger sample size needs to be done. Larger sample size would give a more accurate view of how reality truly is. To do a likert scale as well as asking the question would make the analysing process quicker. That requires more time to actually conduct the customer study.

It would have been beneficial to let the customer spend more time lying on the pillow. If the customer study would be done again, that is a suggestion that should be taken into consideration. Maybe temperature could be more researched into then. Temperature is an important part of sleep, but that is the only parameter that lacked concrete opinion since the customers felt like they did not lie on the pillow long enough to form an opinion. The customers lied on the pillow for about 5-10 min, so a longer amount of time is needed.

The measurements could be done more precisely. It was really tried to achieved identical measurements in this thesis but due to the customers measuring themselves, it is not really likely that they all measured exactly the same way.

Since the customer study and the customer survey have shown how different everybody's habits are, and that they play a role in the pillow choice, there should be some consideration if the customer study is worth the time and effort to be done again. The habits are so different and unpredictable. A suggestion would be to focus on the simulations and verify those. People are more inclined to pick out what they are used to or just like.

The simulations need to be verified with real humans. A way to do that would be to use sensor mats with a person similar built as the simulation model. Due to the limited time for this thesis, that could not be performed. It is important to note that only male dummies were used in this simulation due to time restriction. Female dummies could give different results and that is something that should be further analyzed. When simulations with female dummies will be done in the future, the results could be compared with the females from the customer study. Further research should be done about the mattress/pillow combinations, because that is an important part. Pressure should also be looked into, and figure out how that plays a part in this.

9 Conclusion

The results of the study and survey still show that it is difficult to predict something that is so subjective. A customer study may not always be beneficial and it is time consuming to perform a customer study and analysing it.

The goal of this project was to find an objective way to measure the impact of the pillow. Even though the goal was not completely met, a better understanding of the pillow and its impact was made. Hopefully in the future, **IKEA** has a use of this master thesis and its findings.

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Figure references

Figure 1 Vertabral column. Adopted from [28].

Figure 2a Pillow by **IKEA**. Adopted from [12].

Figure 2b Pillow by **IKEA**. Adopted from [13].

Figure 3a Pillow by **IKEA**. Adopted from [14]-

Figure 3c Pillow by **IKEA**. Adopted from [15].

Figure 3d Pillow by **IKEA**. Adopted from [16].

Appendix A: Matlab code of regression analysis

```
%data importet from excel file
%data and measurements for each customer in column factors

AGE = Age;
%converting genders into numbers
i_female = find(Gender=='Female');
i_male = find(Gender=='Male');
G = [];
G(i_female) = 1;
G(i_male) = 0;
GENDER = G';
HEIGHT = Height;
WEIGHT = Weight;
BMI;
SW = Shoulderwidth;
HTS = Headtoshoulder;
NTS = Necktoshoulder;
%converting sleepingposition into numbers
i_supine = find(Sleepingposition=='Supine');
i_side = find(Sleepingposition=='Side');
i_side_supine = find(Sleepingposition=='Side/supine');
i_side_prone = find(Sleepingposition=='Side/prone');
S = [];
S(i_supine) = 1;
S(i_side) = 2;
S(i_side_supine) = 3;
S(i_side_prone) = 4;
SP = S'; %sleepingposition into numbers

XX = ones(1,20)'; %intercept

%SKOGSFR KEN LOW

SL_OPINIONS = [XX SL_Support SL_Height SL_Position SL_Material
    SL_Softness SL_Pressure SL_Temperature];

[b_age_sl,bint_age_sl] = regress(AGE,SL_OPINIONS)%age
[b_gender_sl,bint_gender_sl] = regress(GENDER,SL_OPINIONS)%gender
[b_height_sl,bint_height_sl] = regress(HEIGHT,SL_OPINIONS)%height
[b_weigt_sl,bint_weight_sl] = regress(WEIGHT,SL_OPINIONS)%weight
[b_bmi_sl,bint_bmi_sl] = regress(BMI,SL_OPINIONS)%BMI
[b_sw_sl,bint_sw_sl] = regress(SW,SL_OPINIONS)%shoulder width
[b_hts_sl,bint_hts_sl] = regress(HTS,SL_OPINIONS)%head to shoulder
[b_nts_sl,bint_nts_sl] = regress(NTS,SL_OPINIONS)%neck to shoulder
[b_sp_sl,bint_sp_sl] = regress(SP,SL_OPINIONS)%sleeping position

%SKOGSFR KEN HIGH

SH_OPINIONS = [XX SH_Support SH_Height SH_Position SH_Material
    SH_Softness SH_Pressure SH_Temperature];

[b_age_sh,bint_age_sh] = regress(AGE,SH_OPINIONS)%age
[b_gender_sh,bint_gender_sh] = regress(GENDER,SH_OPINIONS)%gender
[b_height_sh,bint_height_sh] = regress(HEIGHT,SH_OPINIONS)%height
[b_weigt_sh,bint_weight_sh] = regress(WEIGHT,SH_OPINIONS)%weight
[b_bmi_sh,bint_bmi_sh] = regress(BMI,SH_OPINIONS)%BMI
[b_sw_sh,bint_sw_sh] = regress(SW,SH_OPINIONS)%shoulder width
```

```
[b_hts_sh,bint_hts_sh] = regress(HTS,SH_OPINIONS)%head to shoulder
[b_nts_sh,bint_nts_sh] = regress(NTS,SH_OPINIONS)%neck to shoulder
[b_sp_sh,bint_sp_sh] = regress(SP,SH_OPINIONS)%sleeping position

%KLUBBSPORRE

K_OPINIONS = [XX K_Support K_Height K_Position K_Material K_Softness
    K_Pressure K_Temperature];
K_OPINIONS_COLD = [XX K_Support_Cold K_Height_Cold K_Position_Cold
    K_Material_Cold K_Softness_Cold K_Pressure_Cold K_Temperature_Cold];

[b_age_k,bint_age_k] = regress(AGE,K_OPINIONS);%age
[b_gender_k,bint_gender_k] = regress(GENDER,K_OPINIONS);%gender
[b_height_k,bint_height_k] = regress(HEIGHT,K_OPINIONS);%height
[b_weigt_k,bint_weight_k] = regress(WEIGHT,K_OPINIONS);%weight
[b_bmi_k,bint_bmi_k] = regress(BMI,K_OPINIONS);%BMI
[b_sw_k,bint_sw_k] = regress(SW,K_OPINIONS);%shoulder width
[b_hts_k,bint_hts_k] = regress(HTS,K_OPINIONS);%head to shoulder
[b_nts_k,bint_nts_k] = regress(NTS,K_OPINIONS);%neck to shoulder
[b_sp_k,bint_sp_k] = regress(SP,K_OPINIONS);%sleeping position

[b_age_k_cold,bint_age_k_cold] = regress(AGE,K_OPINIONS_COLD);%age
[b_gender_k_cold,bint_gender_k_cold] = regress(GENDER,K_OPINIONS_COLD);
    %gender
[b_height_k_cold,bint_height_k_cold] = regress(HEIGHT,K_OPINIONS_COLD);
    %height
[b_weigt_k_cold,bint_weight_k_cold] = regress(WEIGHT,K_OPINIONS_COLD);%
    weight
[b_bmi_k_cold,bint_bmi_k_cold] = regress(BMI,K_OPINIONS_COLD);%BMI
[b_sw_k_cold,bint_sw_k_cold] = regress(SW,K_OPINIONS_COLD);%shoulder
    width
[b_hts_k_cold,bint_hts_k_cold] = regress(HTS,K_OPINIONS_COLD);%head to
    shoulder
[b_nts_k_cold,bint_nts_k_cold] = regress(NTS,K_OPINIONS_COLD);%neck to
    shoulder
[b_sp_k_cold,bint_sp_k_cold] = regress(SP,K_OPINIONS_COLD);%sleeping
    position

%MJ LKKLOCKA

M_OPINIONS_SUP = [XX M_Support_Sup M_Height_Sup M_Position_Sup
    M_Material_Sup M_Softness_Sup M_Pressure_Sup M_Temperature_Sup];
M_OPINIONS_SIDE = [XX M_Support_Side M_Height_Side M_Position_Side
    M_Material_Side M_Softness_Side M_Pressure_Side M_Temperature_Side];

[b_age_m_sup,bint_age_m_sup] = regress(AGE,M_OPINIONS_SUP)%age
[b_gender_m_sup,bint_gender_m_sup] = regress(GENDER,M_OPINIONS_SUP)%
    gender
[b_height_m_sup,bint_height_m_sup] = regress(HEIGHT,M_OPINIONS_SUP)%
    height
[b_weigt_m_sup,bint_weight_m_sup] = regress(WEIGHT,M_OPINIONS_SUP)%
    weight
[b_bmi_m_sup,bint_bmi_m_sup] = regress(BMI,M_OPINIONS_SUP)%BMI
[b_sw_m_sup,bint_sw_m_sup] = regress(SW,M_OPINIONS_SUP)%shoulder width
[b_hts_m_sup,bint_hts_m_sup] = regress(HTS,M_OPINIONS_SUP)%head to
    shoulder
[b_nts_m_sup,bint_nts_m_sup] = regress(NTS,M_OPINIONS_SUP)%neck to
    shoulder
[b_sp_m_sup,bint_sp_m_sup] = regress(SP,M_OPINIONS_SUP)%sleeping
```

```
    position
99
100 [b_age_m_side,bint_age_m_side] = regress(AGE,M_OPINIONS_SIDE)%age
101 [b_gender_m_side,bint_gender_m_side] = regress(GENDER,M_OPINIONS_SIDE)%
    gender
102 [b_height_m_side,bint_height_m_side] = regress(HEIGHT,M_OPINIONS_SIDE)%
    height
103 [b_weigt_m_side,bint_weight_m_side] = regress(WEIGHT,M_OPINIONS_SIDE)%
    weight
104 [b_bmi_m_side,bint_bmi_m_side] = regress(BMI,M_OPINIONS_SIDE)%BMI
105 [b_sw_m_side,bint_sw_m_side] = regress(SW,M_OPINIONS_SIDE)%shoulder
    width
106 [b_hts_m_side,bint_hts_m_side] = regress(HTS,M_OPINIONS_SIDE)%head to
    shoulder
107 [b_nts_m_side,bint_nts_m_side] = regress(NTS,M_OPINIONS_SIDE)%neck to
    shoulder
108 [b_sp_m_side,bint_sp_m_side] = regress(SP,M_OPINIONS_SIDE)%sleeping
    position
109
110 %ROSENSK RM
111
112 R_OPINIONS_LOW = [XX R_Support_Sup R_Height_Sup R_Position_Sup
    R_Material_Sup R_Softness_Sup R_Pressure_Sup R_Temperature_Sup];
113 R_OPINIONS_HIGH = [XX R_Support_Side R_Height_Side R_Position_Side
    R_Material_Side R_Softness_Side R_Pressure_Side R_Temperature_Side];
114
115 %previos names for low and high are supine and side, changed it to low
    and
116 %high for rosensk rm
117 [b_age_r_sup,bint_age_r_sup] = regress(AGE,R_OPINIONS_LOW)%age
118 [b_gender_r_sup,bint_gender_r_sup] = regress(GENDER,R_OPINIONS_LOW)%
    gender
119 [b_height_r_sup,bint_height_r_sup] = regress(HEIGHT,R_OPINIONS_LOW)%
    height
120 [b_weight_r_sup,bint_weight_r_sup] = regress(WEIGHT,R_OPINIONS_LOW)%
    weight
121 [b_bmi_r_sup,bint_bmi_r_sup] = regress(BMI,R_OPINIONS_LOW)%BMI
122 [b_sw_r_sup,bint_sw_r_sup] = regress(SW,R_OPINIONS_LOW)%shoulder width
123 [b_hts_r_sup,bint_hts_r_sup] = regress(HTS,R_OPINIONS_LOW)%head to
    shoulder
124 [b_nts_r_sup,bint_nts_r_sup] = regress(NTS,R_OPINIONS_LOW)%neck to
    shoulder
125 [b_sp_r_sup,bint_sp_r_sup] = regress(SP,R_OPINIONS_LOW)%sleeping
    position
126
127 [b_age_r_side,bint_age_r_side] = regress(AGE,R_OPINIONS_HIGH)%age
128 [b_gender_r_side,bint_gender_r_side] = regress(GENDER,R_OPINIONS_HIGH)%
    gender
129 [b_height_r_side,bint_height_r_side] = regress(HEIGHT,R_OPINIONS_HIGH)%
    height
130 [b_weight_r_side,bint_weight_r_side] = regress(WEIGHT,R_OPINIONS_HIGH)%
    weight
131 [b_bmi_r_side,bint_bmi_r_side] = regress(BMI,R_OPINIONS_HIGH)%BMI
132 [b_sw_r_side,bint_sw_r_side] = regress(SW,R_OPINIONS_HIGH)%shoulder
    width
133 [b_hts_r_side,bint_hts_r_side] = regress(HTS,R_OPINIONS_HIGH)%head to
    shoulder
134 [b_nts_r_side,bint_nts_r_side] = regress(NTS,R_OPINIONS_HIGH)%neck to
    shoulder
```

```
135 [b_sp_r_side,bint_sp_r_side] = regress(SP,R_OPINIONS_HIGH)%sleeping
        position
```

Appendix B: Customer survey

The customer survey in a printable version.
The online version: `https://forms.gle/VSRe1nCcCv5B6e3E6`.

Effect of pillow on sleep ergonomics

I am currently doing my master thesis project at IKEA of Sweden. The thesis is about the effect pillows have on sleep. The answers are anonymous. Thank you for taking the time to do this survey!

1. Age

Mark only one oval.

- ◯ 20 or younger
- ◯ 21-30
- ◯ 31-40
- ◯ 41-50
- ◯ 51-60
- ◯ 61-70
- ◯ 71 or older

2. Gender

Mark only one oval.

- ◯ Female
- ◯ Male
- ◯ Prefer not to say

3. Height (in centimeters)

_____

4. Weight (in kg)

_____

Sleep

5. In which position do you usually sleep?

Mark only one oval.

- ◯ Supine (back)
- ◯ Side
- ◯ Prone (stomach)
- ◯ Other: _____

6. Does your sleeping position change during the night?

Mark only one oval.

- ◯ Yes
- ◯ No

7. If your sleeping position changes during the night, how does it change?

Mark only one oval.

- ◯ Side to side
- ◯ Side to back/Back to side
- ◯ Side to stomach/Stomach to side
- ◯ Back to stomach/Stomach to back
- ◯ Other: _____

8. How many pillows do you use when you sleep?

Mark only one oval.

- ◯ 1
- ◯ 2
- ◯ Other: _____

9. Is there any specific way you arrange your pillow when you sleep?

Mark only one oval.

- ◯ Yes
- ◯ No

10. If you answered "Yes" in the previous question, then how do you arrange it?

_____

_____

_____

_____

_____

11. How many hours do you sleep in average per night?

Mark only one oval.

- ◯ Less than 5 hours
- ◯ 5 hours
- ◯ 6 hours
- ◯ 7 hours
- ◯ 8 hours
- ◯ More than 8 hours

12. Do you have any neck pain when you wake up?

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Sometimes

13. Does the temperature of the pillow affect your sleep?

Mark only one oval.

- ◯ Yes
- ◯ No

Pillow

14. What material does your pillow consist of? (Pick several if it's a combination of material)

Tick all that apply.

- ☐ Polyester
- ☐ Feather
- ☐ Down feather
- ☐ Memory foam

Other: ☐ _____

15. What shape is your pillow?

Mark only one oval.

Option 1

Option 2

Option 3

Option 4

Other: _____

Option 5

16. What height do you consider your pillow to be?

Mark only one oval.

- ◯ Low
- ◯ Medium
- ◯ High

17. Is your current pillow comfortable?

Mark only one oval.

- ◯ Yes
- ◯ No

18. How often do you buy a new pillow?

Mark only one oval.

- ◯ Quite often (after a couple of months)
- ◯ Once in a year
- ◯ Once in every two years
- ◯ Rarely
- ◯ Never

Pillow selection

19. When you buy pillows, how do you choose which one to buy?

Tick all that apply.

- [ ] I touch it with my hands
- [ ] I put it against my head and try to get a feeling if it's a comfortable pillow
- [ ] I read the pillow description and buy the one that fits my sleeping position
- [ ] I choose one based on the material
- [ ] I choose one based on the shape
- [ ] I choose one based on height
- [ ] I choose one based on the softness
- [ ] I choose one with a lot of stuffing
- [ ] I just randomly pick one out
- [ ] Other: _____

20. If you had to pick the most important selection criteria for your pillow, which one is it?

Mark only one oval.

- ◯ Material
- ◯ Height
- ◯ Shape
- ◯ Softness
- ◯ How much support you get for the neck
- ◯ How much stuffing there is
- ◯ Price
- ◯ Other: _____

21. How firm do you like your pillow?

Mark only one oval.

- ◯ So soft that I sink down quite a bit
- ◯ Not too soft or too hard
- ◯ I prefer harder pillows
- ◯ Other: _____

22. In regards to comfort, which is the most important to you?

Mark only one oval.

- ◯ Mattress
- ◯ Pillow

23. Do you think pillow has an impact on comfort?

Mark only one oval.

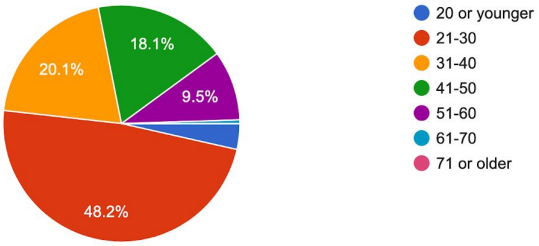
- ◯ Yes
- ◯ No

Appendix C: Results from the customer survey

The results from the customer study. For questions "Weight (in kg)" and "If you answered 'Yes' in the previous question, then how do you arrange it?", there are more answers. Those questions had write-in answers hence the difficulty to show them all, 197 and 102 responses respectively.

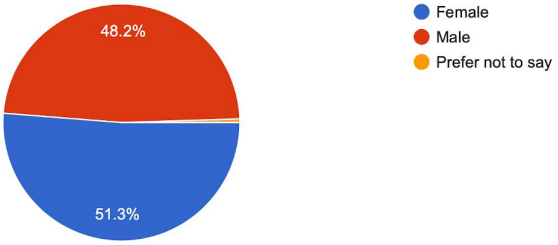
Age

199 responses



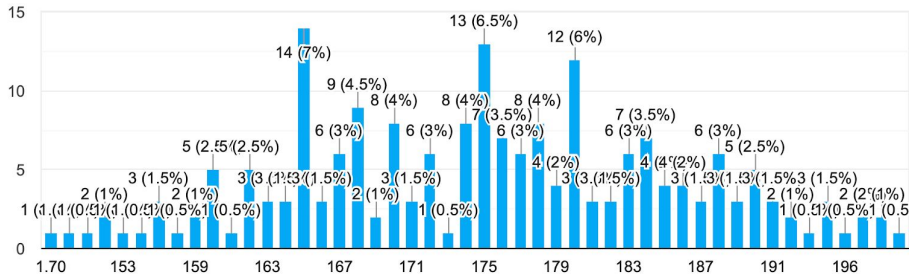
Gender

199 responses



Height (in centimeters)

199 responses



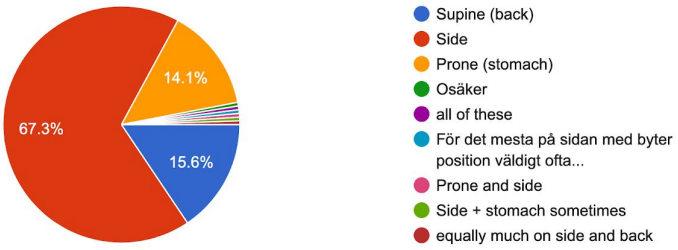
Weight (in kg)

197 responses

53
45
140
91
49
89
115
81
52

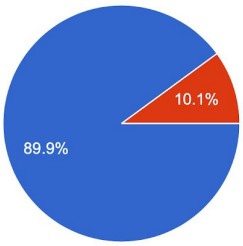
In which position do you usually sleep?

199 responses



Does your sleeping position change during the night?

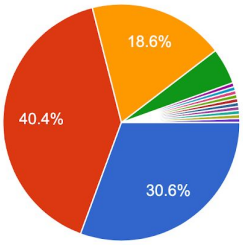
199 responses



Yes
No

If your sleeping position changes during the night, how does it change?

183 responses

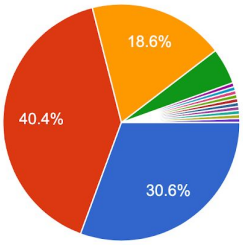


Side to side
Side to back/Back to side
Side to stomach/Stomach to side
Back to stomach/Stomach to back
Vet inte/olika
all of these
Åt alla håll.
depends on the temperature - some c…

▲ 1/2 ▼

If your sleeping position changes during the night, how does it change?

183 responses



Side to back/Side to stomach
It changes both between sides and to back/stomach
Side to side to abck to side to stomach, all positions are used
Dont know, I'm asleep
All of the above
the 2 first

▲ 2/2 ▼

How many pillows do you use when you sleep?

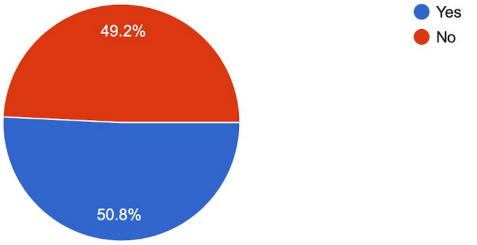
198 responses

How many pillows do you use when you sleep?

198 responses

Is there any specific way you arrange your pillow when you sleep?

199 responses



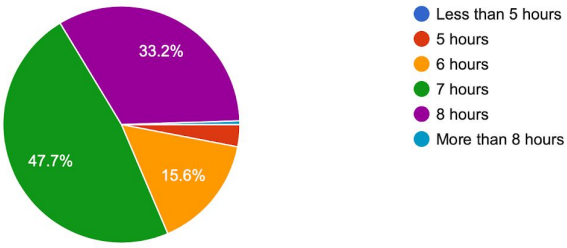
If you answered "Yes" in the previous question, then how do you arrange it?

102 responses

On top of each other
Next to each other
To give my Beck support
As flat as possible
one under my head, one between legs
I have a ergonomic pillow but still I put my arm under it
Memory foam under head. Hugging second pillow.
I´ll flip it so I get the cold side upwards.
Two, side by side

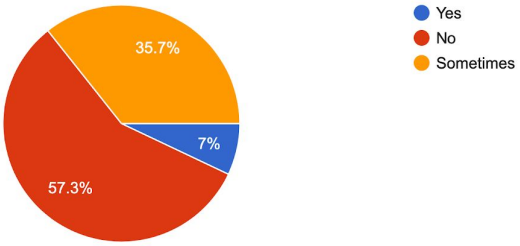
How many hours do you sleep in average per night?

199 responses



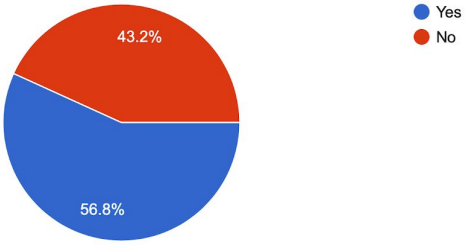
Do you have any neck pain when you wake up?

199 responses



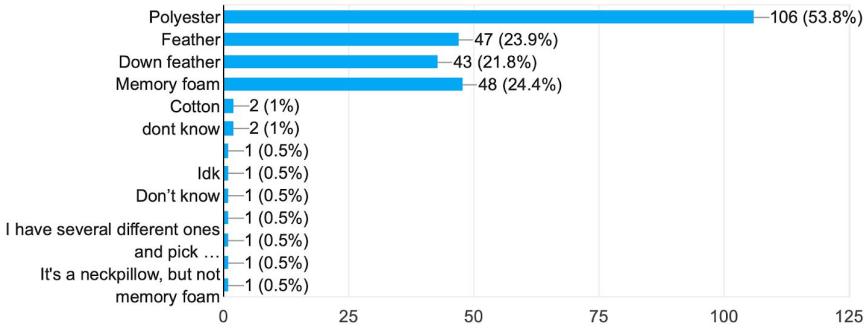
Does the temperature of the pillow affect your sleep?

199 responses



What material does your pillow consist of? (Pick several if it's a combination of material)

197 responses

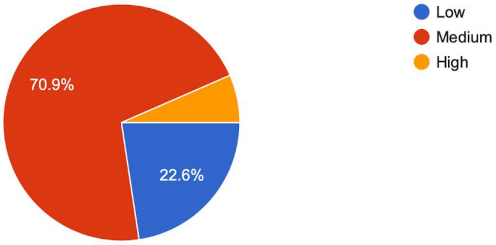


What shape is your pillow?

199 responses

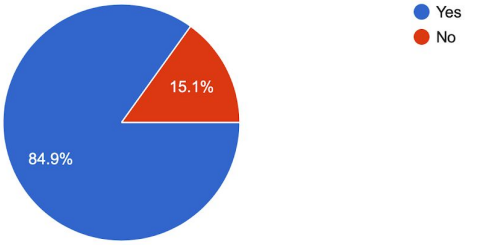
What height do you consider your pillow to be?

199 responses



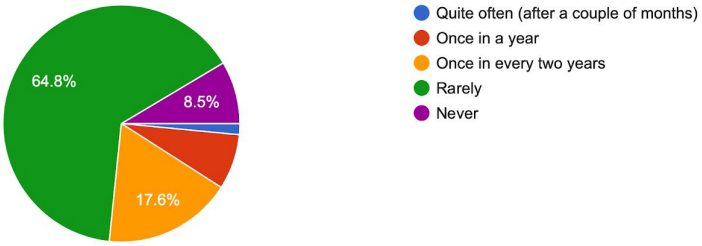
Is your current pillow comfortable?

199 responses



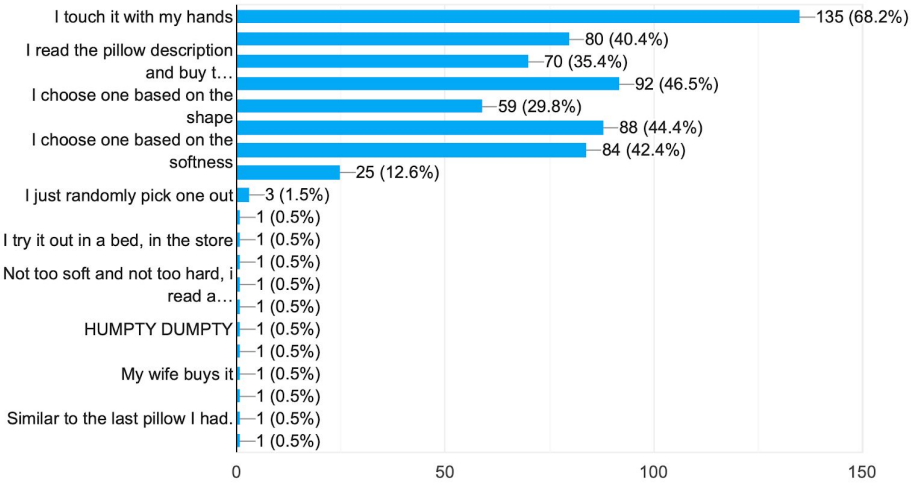
How often do you buy a new pillow?

199 responses



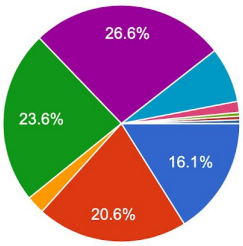
When you buy pillows, how do you choose which one to buy?

198 responses



If you had to pick the most important selection criteria for your pillow, which one is it?

199 responses

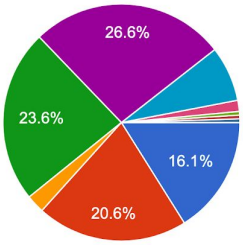


- Material
- Height
- Shape
- Softness
- How much support you get for the neck
- How much stuffing there is
- Price
- The construction of a pillow!

▲ 1/2 ▼

If you had to pick the most important selection criteria for your pillow, which one is it?

199 responses

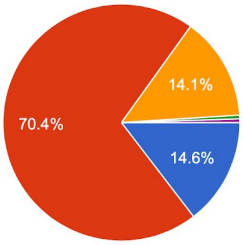


- Comfort
- I'm allergic/astmatic so I can't have a down pillow

▲ 2/2 ▼

How firm do you like your pillow?

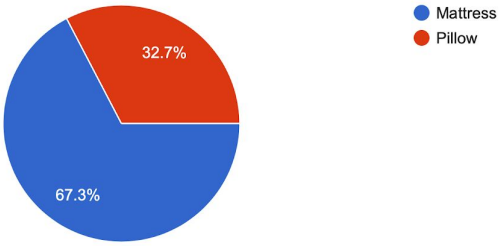
199 responses



- So soft that I sink down quite a bit
- Not too soft or too hard
- I prefer harder pillows
- A firm but not hard pillow
- Quite soft, but not so soft that I can feel the bottom of the bed through the pillow. Perfect would be the softness of pillow that you get at a nice hotel.

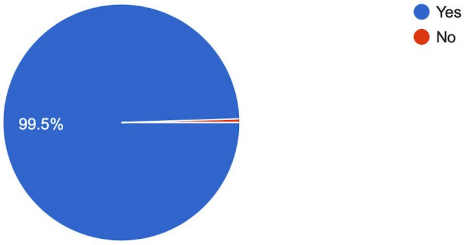
In regards to comfort, which is the most important to you?

199 responses



Do you think pillow has an impact on comfort?

199 responses



Appendix D: Project plan

Appendix D.1: Initial project plan

Timeplan																			
	31/1 - 9/2	10/2 - 16/2	17/2 - 23/2	24/2 - 1/3	2/3 - 8/3	9/3 - 15/3	16/3 - 22/3	23/3 - 29/3	30/3 - 5/4	6/4 - 12/4	13/4 - 19/4	20/4 - 26/4	27/4 - 3/5	4/5 - 10/5	11/5 - 17/5	18/5 - 24/5	25/5 - 31/5	1/6 - 7/6	8/6 - 12/6
Activity\Week	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Project planning																			
Literture review																			
Plan and design customer study																			
Do customer study and analyze results																			
Learn software																			
Validate feedback																			
Material testing																			
Write report																			
Prepare presentation																			
Presentation																			
Opposition																			

Appendix D.2: Final project plan

Timeplan																			
	31/1 - 9/2	10/2 - 16/2	17/2 - 23/2	24/2 - 1/3	2/3 - 8/3	9/3 - 15/3	16/3 - 22/3	23/3 - 29/3	30/3 - 5/4	6/4 - 12/4	13/4 - 19/4	20/4 - 26/4	27/4 - 3/5	4/5 - 10/5	11/5 - 17/5	18/5 - 24/5	25/5 - 31/5	1/6 - 7/6	8/6 - 14/6
Activity\Week	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Project planning																			
Literture review																			
Plan and design customer study																			
Do customer study and analyze results																			
Create customer survey and get responses																			
Analyze customer survey																			
Learn software																			
Validate feedback																			
Material testing																			
Write report																			
Prepare presentation																			
Presentation																			
Opposition																			
	15/6-21/6	22/6-28/6	29/6-5/7	6/7-12/7	13/7-19/7	20/7-26/7	27/7-2/8	3/8-9/8	10/8-16/8	17/8-23/8	24/8-30/8	31/8-6/9	7/9-13/9	14/9-20/9	21/9-27/9	28/9-2/10			
Activity\Week	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40			
Project planning																			
Literture review																			
Plan and design customer study																			
Do customer study and analyze results																			
Create customer survey and get responses																			
Analyze customer survey																			
Learn software																			
Validate feedback																			
Material testing																			
Write report																			
Prepare presentation																			
Presentation																			
Opposition																			