Research Article

Examination of Comfort Parameters Used in Mattresses and Investigation of the Effects of the Relationship Between Comfort and Support on User Experience

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Abstract

Good sleep is undoubtedly of great importance for human life. Conversely, poor sleep negatively affects the quality of life. The sleep phase, one of the most crucial stages of human life, is extremely important. An adult sleeps 7-9 hours a day. Considering this duration, we spend one-third of our day sleeping. Therefore, selecting the right mattress is essential for healthy sleep.

For a healthy spine, it is necessary to choose a high-quality mattress that suits our body type. The sleeping position and posture of individuals can change during sleep. The right mattress should maintain and support the correct position of the spine regardless of the sleeping position and adapt to changes in sleeping posture.

Studies conducted on mattresses focus on meeting the comfort and support expectations of individuals and ensuring body relaxation. When choosing a mattress, individuals typically prefer ones that support and envelop their bodies, while also fulfilling their comfort requirements. Each person has different body indices and needs, leading to varying comfort and support demands. This reveals the necessity of having a wide range of mattress options.

In this study, mattress layers were created from different mattress materials. The relationship between the physical compatibility, comfort perception, and body support of these mattress layers for users was investigated. Based on the data obtained from the research, comfort parameters were examined, and the impact of the relationship between comfort and support on users was evaluated.

Keywords: *Mattress, Comfort , Support, Comfort and Support, Mathematical Modeling*

1. Introduction

Sleep is one of our basic needs, allowing our bodies to rest. A comfortable mattress is essential for quality sleep. As people's living standards have increased, the features they seek in a mattress have also expanded. Attributes such as the appearance, comfort, support, functionality, and product quality of mattresses are becoming increasingly important [12].

In today's fast-paced world, it is necessary to accomplish multiple tasks to keep up with the demanding pace of life. In this busy tempo, the sleep process needs to be efficient to prepare for the new day[14]. Therefore, mattresses that meet comfort and support requirements are becoming increasingly preferred by people to enhance sleep quality.

Deun et al. [1] developed a mattress system that optimizes spinal alignment and automatically adjusts the stiffness of eight comfort zones. This system consists of 165 sensors and eight actuators, detecting body movements and posture changes using sinking data from the mattress surface to optimize alignment. Eleven participants slept in a sleep laboratory for three different nights (adaptation night, reference night, and active support (ACS) night). According to the subjective data from the participants, the active support night showed improvements in sleep quality, while objective data indicated a trend of increased sleep quality on the adaptation night.

Hu et al. [2] examined the effect of mattress firmness on sleep comfort among middle-aged and elderly women, aiming to provide guidance for mattress selection in this age group. Based on user experience and body pressure test results conducted with 46 women aged 40-65, they observed that mattress firmness significantly influenced comfort and that participants generally preferred medium or high firmness mattresses.

Bolton et al. [3] investigated the effectiveness of reducing spinal curvature in the side-sleeping position for individuals with chronic lower back pain (LBP) in alleviating pain and improving sleep quality. Additionally, they explored whether sleep positions, nocturnal movements, and body temperature were associated with pain in individuals with chronic LBP. The results indicated that the experimental mattress was associated with 18% lower pain scores ($p<.05$) and 25% higher comfort scores ($p<.01$). However, no difference in morning back pain or sleep quality was found between their own mattress and the experimental mattress.

Park et al. [4] studied the effect of mattress height on subjective comfort in three different sleep positions. They asked 64 participants (29 men and 35 women aged 25-50) to evaluate the comfort of nine body regions. For objective assessment, they examined pressure distribution according to the three sleep positions. Pressure distribution and subjective evaluations were measured in two conditions: before and after adjusting the mattress height. The results showed that participants preferred a W-shaped sleeping position for back and side-lying positions, while they preferred a U-shape for prone position. Mattress height was significantly associated with participants' subjective evaluations and pressure ratios according to these positions.

Wu et al. [5] assessed sleep comfort in the supine position and investigated a new method for improving mattress design. Based on body models scanned in a standing position and measurements of mattress and body pressure distribution, they calculated the sinking of the mattress's top surface. Comfort was evaluated by comparing the back surface and mattress sinking using Pearson's correlation coefficient. The results indicated that all participants felt more comfortable on latex foam mattresses, which was consistent with the findings of pressure distribution and spinal alignment.

Shore et al. [6] examined the effects of mattress firmness on spinal alignment in the human body. The study included 59 healthy individuals. Spinal movements in the upper and lower thoracic, lumbar, and pelvic regions were recorded using a ten-camera infrared motion analysis system. They determined each participant's neutral posture with a static spine image taken in a standing position. Three different firmness levels (soft, medium, and firm) were tested using the same gel foam comfort layer. They measured different body types by assessing participants' height, weight, shoulder width, and hip circumference. No significant difference was found in overall spinal alignment between mattress firmness levels; however, notable alignment differences were observed among different body types.

Naddeo et al. [7] reviewed new research trends on evaluating individuals' comfort perception using objective, predictive techniques. A comprehensive literature review identified some unexplored aspects of comfort perception and evaluation. The researchers expanded the Vink–Hallbeck model, creating a comfort perception and evaluation matrix, emphasizing that the element of "expectation" plays a significant role in the final perception of comfort and discomfort. They noted that expectation originates from pre-acquired data in individuals' minds and affects the comfort experience.

Kim et al. [8] aimed to identify the mattress that best suits the physical and psychological conditions of participants using five different firmness levels. User experience was analyzed using measurements such as electromyography of back muscles, heart rate variability, and oxygen saturation. Body pressure distribution was measured to examine dermal discomfort. They also conducted a survey to record past personal experiences and developed a selection rule with four independent variables to find the best mattress. They calculated the Body-Mattress Compatibility Score (BMCS) and compared it with subjective satisfaction scores. The results showed that ten participants had the same score, while the other ten had only a one-point difference.

Yoshida et al. [9] developed three Finite Element Method (FEM) models representing the body shapes of three different male subjects to investigate the relationship between sleep comfort of mattresses and the findings of FEM analysis with sensory test results. They found that FEM analysis results in the neck region were consistent with sensory test results, demonstrating that mattress preferences of subjects could be predicted using FEM analysis. This study proved that FEM analysis is a valuable tool for examining mattress comfort.

In the detailed literature review above, studies were conducted on the effects of comfort and support terms used in mattresses on mattress materials.

2. Materials and Methods

In this study, a Design of Experiments (DOE) was created in Minitab using various mattress materials. The experiment involved three different types and three different heights of foam, as well as two types of springs (Bonnell springs and pocket springs). Bonnell springs were used at four different heights, while pocket springs were used at a single height.

[a] [b] [c]

Figure 1: a) Foam, b) Pocket Spring, c) Innerspring (Manufacturer: Yataş Group - Turkey)

2.1. Methods Used to Determine Comfort and Support Parameters

2.1.1. Mattress Pressure Force Measurement Device Studies

In the experimental design created using different mattress materials, the push force exerted by the mattress layer combinations in response to pressure was measured by compressing them to a specific extent using a mattress pressure force measurement device.

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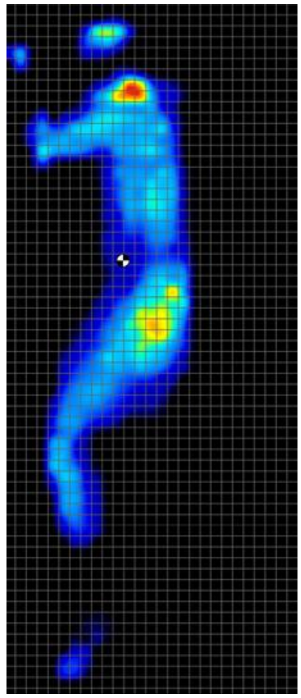

Figure 2: Representation Of Body Pressure Map Image (Manufacturer: Yataş Group - Turkey)

2.1.3 K1 and K2 Coefficients Used in Determining the Relationship Between Comfort and Support Parameters

In this study, two new coefficients, K1 and K2, specially formulated within our organization, have been defined to evaluate the comfort and support performance of mattresses. These coefficients were used to assess the behavior of mattresses under different compression loads and to evaluate comfort and support levels.

The K1 coefficient was developed to measure the comfort performance of the mattress's top layer. This coefficient is calculated by dividing the push force obtained during the compression of the top layer, created using different materials, up to a height of 4.5 cm, by the height of compression. In other words, the K1 coefficient represents the elasticity of the top layer and its response to pressure. The value of this coefficient reflects the resistance and comfort level of the comfort layer at the moment of compression.

The K2 coefficient was developed to evaluate the performance of the support layer, which is the bottom layer of the mattress. It is calculated by dividing the push force generated during the compression of the mattress up to 10 cm by the height of compression. In this way, the K2 coefficient represents the resistance of the support layer at the moment of compression and the support performance within the mattress.

This method allows the K1 and K2 coefficients to objectively evaluate the comfort and support performance of different layers of the mattress. Specifically, the separate analysis of the comfort and support layers contributes to the development of more optimal mattress designs from the perspective of user experience. Therefore, these coefficients provide an important tool for assessing and optimizing the impact of different materials on mattress performance.

Table 1: K1 and K2 Coefficient Data

Sample	K1 (N/cm)	K2 (N/cm)
1	6,68	14,6
2	6,42	13,3
3	7,05	14,4
4	5,23	13,8
5	5,10	13,1
6	5,23	14,0
7	7,19	21,5
8	8,41	20,2
9	8,51	19,8
10	6,08	14,8
11	5,86	15,0
12	5,51	14,8
13	4,35	13,8
14	5,27	15,4
15	5,78	15,0
16	5,37	17,4
17	6,00	16,2
18	5,26	16,2
19	6,04	15,6
20	7,93	15,6
21	6,17	16,0
22	7,84	25,4
23	7,14	30,2
24	6,71	25,0
25	6,24	18,3

2.1.4 Foam Indentation Force Deflection

In this study, the Indentation Force Deflection (IFD) parameter was used to evaluate the hardness and softness levels of foams. IFD is a value that measures the resistance exhibited by a foam during compression and is considered an important indicator in determining the foam's comfort or support performance. In this context, three different IFD values were examined: 25% IFD, 40% IFD, and 65% IFD.

The 25% IFD value represents the force required to compress a foam to 25% of its thickness. This measurement is used to assess the initial sensation of the foam's surface and the immediate comfort it provides to the user. A lower 25% IFD value indicates that the foam is softer and more comfortable, while a higher value suggests a firmer and more resistant foam.

The 40% IFD value refers to the force needed to compress the foam to 40% of its thickness. This value is used to evaluate the behavior of the foam's middle layers and analyze its supportive characteristics. The 40% IFD measurement offers a combined assessment of both comfort and support features, providing a more accurate reflection of the sensation a user would experience during prolonged sitting or lying down.

The 65% IFD value expresses the force required to compress the foam to 65% of its thickness. This measurement assesses the resistance of the foam's deeper layers and its overall support capacity. A high 65% IFD value indicates a firmer and more supportive foam, while a lower value suggests a foam that is more compressible and offers a softer structure.

These different IFD measurements are essential for evaluating whether the foams used contribute to the comfort and support properties. Specifically, in mattress designs, the 25% IFD represents immediate comfort sensation, the 40% IFD represents medium-level support and comfort, and the 65% IFD represents maximum support capacity. Therefore, analyzing the different IFD levels plays a critical role in assessing and optimizing the overall performance of the foams used in this study.

Table 2: Foam IFD Values

Top Layer	IFD /25	IFD /40	IFD /65
Foam1	60	75	130
Foam2	130	155	260
Foam3	95	115	210

2.1.5 Subjective Data

In the study, 26 healthy volunteer subjects participated. The subjects evaluated mattress layers with different hardness levels both by lying down and sitting. Four different categories were defined for hardness assessment, and the participants were asked to classify each mattress layer according to the rating system. The hardness categories were as follows:

- Hard: 400 points
- Medium-Hard: 300 points
- Medium: 200 points
- Soft: 100 points

The participants considered the overall feel of the mattresses while scoring them. The collected data allowed for a subjective evaluation of mattress comfort, while also revealing how different mattress layers were perceived by the users.

Table 2: Foam Comfort Sensation Data

Sample	Comfort Sensation Lying Down	Comfort Sensation Sitting Down
1	300	300
2	300	300
3	100	100
4	100	100
7	200	300
8	200	200
9	400	400
10	400	400
13	100	100
14	100	100
17	200	400
18	400	400
23	100	100
24	100	100
27	400	300
28	200	200
29	300	400
30	400	400
31	400	300
32	300	200
33	300	300
34	300	200
35	400	400

3. Results

As a result of the study, layers made of different mattress materials were designed, and these layers were evaluated by participants both objectively (quantitative) and subjectively (qualitative). Additionally, based on these evaluations and other methods mentioned above, comfort parameters were analyzed comprehensively, and a mathematical model was created to explain the relationship between comfort and support.

3.1 Support Layer Regression Analysis Result

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Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
13,8468  83,60%     80,13%      75,37%

Regression Equation

Support Layer Force (N) = 270,2 + 27,45 Wire + 2,425 IFD 1/25
                          - 1,087 IFD1 /65 + 14,99 IFD 2/25 - 11,38 IFD 2/40
                          - 0,768 IFD2 /65 - 4,333 Support Layer Height
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Figure 2

In Figure 2, the formula for the mattress support layer was obtained as a result of the regression analysis. According to the analysis results, the independent variables explained 80% of the dependent variable and predicted it with 75% accuracy. Based on this result, the dependent variable, the Mattress Support Layer, was found to be directly proportional to the wire diameter and the IFD (25%) value of the lower foam used in the comfort layer, and inversely proportional to the IFD (40%) and IFD (65%) values of the foam used in the upper layer.

3.1.2 Regression Analysis Result for K1 Value

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Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0,980321  81,89%     78,05%      72,34%

Regression Equation

K1 (N/cm) = 21,37 - 1,084 Wire + 0,1710 IFD 1/40 + 0,2269 IFD 2/40
            - 3,188 Comfort Layer Height - 0,0520 IFD1 /65 - 0,0783 IFD2 /65
            - 0,4323 Support Layer Height
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In Figure 3, as a result of the regression analysis, the explanatory power of the independent variables on the dependent variable was determined to be approximately 78%, and the model's prediction accuracy was found to be 72%. According to these findings, the K1 value stands out as an effective dependent variable influencing comfort. It was determined that the K1 value is directly proportional to the IFD (%40) value of the foam forming the comfort layer, while it shows an inverse relationship with the IFD (%65) values of the foams and the wire diameter used in the spring.

3.1.3 Regression Analysis Result for K2 Value

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Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
8,46853  75,89%     70,78%      62,71%

Regression Equation

K2 (N/cm) = 107,3 + Wire + 0,477 IFD 1/40 + 0,373 IFD 2/40
            - 12,96 Comfort Layer Height - 0,128 IFD1 /65 - 0,043 IFD2 /65
            - 3,344 Support Layer Height
```

In Figure 4, according to the results of the regression analysis, the independent variables explain approximately 70% of the dependent variable, and the model provides a prediction accuracy of 62%. Based on the findings, the K2 value has been identified as a dependent variable influencing comfort. The K2 value is directly proportional to the IFD (%40) value of the foam forming the comfort layer, while it shows an inverse relationship with the IFD (%65) values of the foams and the wire diameter used in the spring.

3.1.4 Relationship Of K1 And K2 Coefficients With Support And Comfort

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Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0,182184  92,56%     91,73%      86,76%

Regression Equation

Comfort (kPa) = -2,085 + 0,1548 Comfort Layer Height
                + 0,1441  Support Layer Height + 0,4566 K1 (N/cm) - 0,02050 K2 (N/cm)
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In Figure 5, the results of the regression analysis show that the independent variables explain 92% of the dependent variable, and the model has a prediction accuracy of 86%. Based on these findings, it has been established that the comfort value, expressed in kPa, is directly related to the K1 and K2 coefficients. The K1 coefficient has been identified as a parameter affecting the comfort layer, while the K2 coefficient has been determined as a parameter affecting the support layer.

4. Discussion and Conclusion

As a result of the study, it was determined that comfort is directly related to the coefficients K1 and K2 and that these coefficients are expressed through a formula with the mattress support. Combining the coefficients K1 and K2 through this formula provided a more comprehensive model that mathematically explains the interaction between the comfort level and the mattress support. This new model was presented as a critical tool that can be used to provide the desired comfort and support level in the design of the mattress and thus it was shown that this mathematical formula will guide the new mattress design.

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