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Original articles

Shape design of an optimal comfortable pillow based on the analytic hierarchy process method

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Abstract

Objective: Few studies have analyzed the shapes of pillows. The purpose of this study was to investigate the relationship between the pillow shape design and subjective comfort level for asymptomatic subjects.

Methods: Four basic pillow designs factors were selected on the basis of literature review and recombined into 8 configurations for testing the rank of degrees of comfort. The data were analyzed by the analytic hierarchy process method to determine the most comfortable pillow.

Results: Pillow number 4 was the most comfortable pillow in terms of head, neck, shoulder, height, and overall comfort. The design factors of pillow number 4 were using a combination of standard, cervical, and shoulder pillows. A prototype of this pillow was developed on the basis of the study results for designing future pillow shapes.

Conclusions: This study investigated the comfort level of particular users and redesign features of a pillow. A deconstruction analysis would simplify the process of determining the most comfortable pillow design and aid designers in designing pillows for groups.

Introduction

Currently, neck and shoulder ailments are often encountered among the population; therefore, several researchers believe that an appropriate choice of pillows will be associated with these ailments.[1-3] For example, Kawabata and Tokura[4] studied the thermal characteristic of a pillow on alleviating symptoms. The result showed

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that using a cool material lowered rectal, forehead, and whole body temperature and slowed the heart beat of subjects. It also enabled the subjects to sleep better. These results suggested that reducing the temperature of the pillow may improve the quality of sleep. Furthermore, the research of Okamoto et al[5] also showed that cool pillow design can reduce sweating and whole body temperature, and indirectly improve the quality of sleep. These findings suggest that thermal characteristic of pillows may be related to the type of materials used.

Studies by other researchers such as Ambrogio et al,[6] Persson and Moritz,[7] Erfanian et al,[8] and Palazzi et al[9] were focused on pillow support. These studies indicate that regardless if the subjects have neck or shoulder pain, they prefer pillows that provide support to the neck and thereby enhance the quality of sleep.

Research by Persson[10] indicated that 40 of 52 subjects gave positive feedback after using a specially designed pillow that provided neck support. As for Hannon's[11] research, he had reported that most people could not fall asleep because of a stiff neck and shoulder muscles that are not relaxed. He reported 14 unique postures that can help in relaxing joints and stiff muscles with proper support.

Furthermore, Kushida et al[12,13] reported that using a cervical pillow designed according to the dimension of the patient's head, neck, and shoulder could alleviate the symptoms of patients during the mild or moderately sleep-disordered breathing. In patients with mild sleep-disordered breathing, a cervical pillow helps reduces snoring and improves the quality and efficiency of sleep and the subjective-specific depth of sleep. Thus, these studies showed that the support provided by a pillow is strongly related to its shape. Different kinds of supports require different designs of shapes and sizes; and furthermore, the material of the pillow is also an important factor affecting pillow support.

In addition to temperature, support, material, and shape, time factor of exposure to a pillow is another critical factor that affects the acceptance of a pillow. The research of Shields et al[14] showed that some patients may initially find cervical pillows uncomfortable. However, patients accept them after an extended use; and they will eventually be acceptable at the end. Carskadon[15] performed a similar study with mattresses and found out that the mattress material affected the quality of sleep in subjects who could not adapt to a new bed; the material will affect the sleep quality at the early stages. However, after a period to adaptation, the mattress material already had no relations and did not affect sleeping. Furthermore, hard Chinese pillows such as those made of jade or ceramic were widely accepted in ancient China. Thus, these studies indicate that the time required for adaptation is an important factor that determines the comfort provided by pillows.

In a previous study comparing the shapes of pillow, Lavin et al[16] used 3 basic pillow designs: standard, water based, and roll pillow. Ten of 35 patients experienced severe discomfort with the roll pillow and discontinued its use. Hagino et al[17] reported that 2 patients could not adapt to a pillow design that provided neck support feature and, therefore, they stopped using them. Moreover, no significant statistic differences were observed.

In addition, Ambrogio et al used 3 types of neck support pillow designs on 35 fibromyalgia patients. His research showed that the primary factor of a good pillow design was comfort level with the fact that the comfortable pillow did not improve patient's symptoms.

Persson and Moritz[7] indicated that chiropractors or rehabilitation doctors often suggest that their patients use recommend pillows that provide neck support. However, all these recommendations were not based on any scientific data that proved that the quality of a pillow on the basis of its shape is better. With regard to a product design point of view, every product should be designed according to a target: a specific group of consumers. Because each target group has unique requirements, it is not realistic to have a single product that can satisfy all groups of consumers. Hence, it is important to identify the pillow design factors that affect a subject's comfort; and it is significant to design a better and properly suitable product. Therefore, the purpose of this study was to investigate the relationship between the pillow shape design and subjective comfort level in asymptomatic subjects.

Methods

First, shapes of basic pillows were incorporated by selecting several design factors. Thereafter, the target group was asked to experiment with these selected pillows; and the data were collected. The analytic hierarchy process (AHP) methods were used to analyze the collected data. Finally, the optimal pillow was designed on the basis of the study for future reference.

The ethics review group at National Cheng Kung University reviewed and approved this study. Subjects provided consent to participate.

Equipment

The independent variables of the experiment include the room temperature, which was maintained at 25°C.

The same platform and the 8 identical pillow compositions were used for all tests. A camera was used to shoot film and record the behavior of the subjects from a distance of 100 cm for the analysis of pillow height and angle, and the assessment scale was then recorded in AHP software. Two experimental assistants were used during the experiment; one of them assisted in the subjects in changing pillows, and the other is a recorder. The experimental environment setup is shown in Fig 1.

Experimental procedures

Subjects provided their personal information before the experiment. The questionnaire included information pertaining to height, sex, weight, age, sleep posture preferences (lying flat or on one side), and existing shoulder pain. Those with back problems were excluded from this experiment, and only patients who prefer to lie flat while sleeping were allowed to participate. This study used asymptomatic subjects to eliminate the effects of different symptoms for different patients.

All test subjects were required to wear shirts without collars and should maintain normal habits. They were prevented from performing any rigorous exercise before the experiment. They gave a report on the level of comfort in the short term in the head, neck, and shoulder and the experience shortly before falling asleep.

The dependent variables of the experiment include the subjective opinions of test subjects on the comfort level and relative height and angle of the pillow while lying flat. All subjects were required to complete the 28 pillow combination of the 8 basic pillow compositions in each comfort test. Each subject was asked to lie on each pillow composition for 1 minute. For instance, the test subject was asked to compare the comfort level experienced with pillow no. 1 and no. 2, followed by no. 1 and no. 3, then no. 1 and no. 4, and so on. Thereafter, the subject was asked to complete a report on the level of head comfort A, neck comfort B, shoulder comfort C, height comfort D, and overall comfort E. During the experiment, an assistant will aid in changing each pillow. The recorders will photograph the subjects and gather the data from the questionnaires.

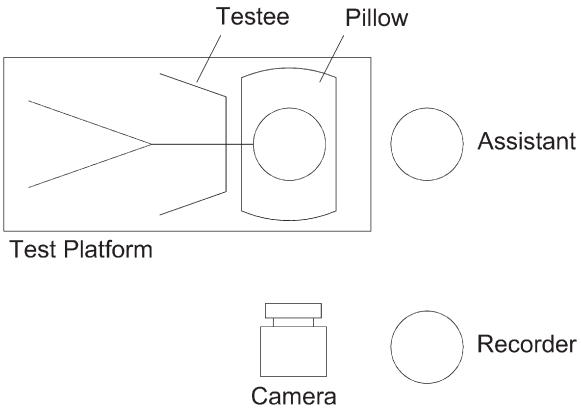

Fig 1. The disposition layout of the research laboratory: shows a pillow-changing assistant who changed the subjects' pillow, a recorder, and a subject. The experiment was performed in a permanently humid and thermostatic environment.

Data analysis

The collected data were analyzed through the AHP developed by Thomas L. Saaty [18,19] in 1970. The AHP is a technique that compares questions in pairs and transforms the answers into a tree-structuring hierarchy, which takes into consideration mutual influences and priorities of questions for making correct decision from a series of complex questions.

AHP structuring hierarchy of the pillow study

The first step is to involve the AHP structuring hierarchy (Fig 2). The alternatives are 8 pillow compositions based on 4 design factors, and the criteria involved the head comfort A, neck comfort B, shoulder comfort C, height comfort D, and overall comfort E. Thereafter, the expert opinions were used to determine the priorities of criteria. Finally, the best components of pillow were determined on the basis of the analysis.

Results

The demographics of the subjects were as follows: 16 men and 14 women; age, between 20 and 36 years;

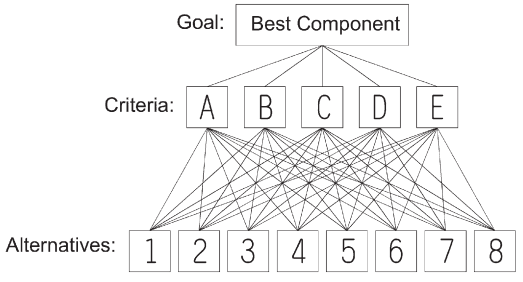

Fig 2. The study included 5 positions of comfort as criteria (A-E) to examine the 8 kinds of components pillow (no. 1-no. 8, alternatives), and the best components of pillow (goal) were determined by using AHP.

height, between 155 and 180 cm; and weight, between 46 and 90 kg. The subjects included both undergraduate and graduate students.

Pillow design factors

The experimental pillow was designed according to the report by Hannon.[11] The study described several kinds of support ways that enabled relaxing muscles around the upper extremity. Therefore, the study designed the following 4 design factors: standard, cradle, cervical, and shoulder pillow (Fig 3). The dimension of each design factor was determined on the basis of the anthropometry data reported by Alvin[20] (male, 50th percentile points). Furthermore, data obtained from the National Aeronautics and Space Administration[21] that described the neutral body posture in the weightless environment were also used in the design of the experimental pillows. Thus, the neutral body posture is the most comfortable state of a human body.

The experiment used 8 different pillow compositions based on the 4 basic design factors shown above. The pillow compositions were labeled as no. 1 through no. 8. Each pillow composition is graphically presented in Fig 4, and the testing situation is depicted in Fig 5.

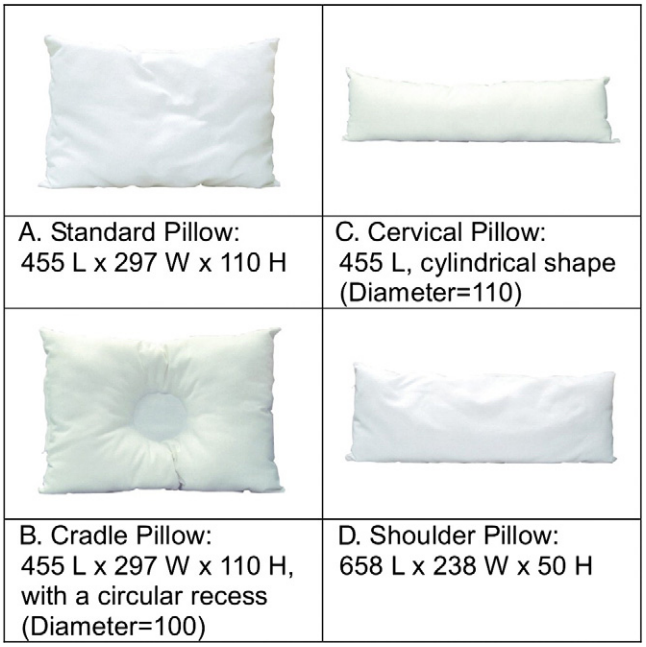

Fig 3. The 4 types of basic design factors of pillow: (A) standard pillow: 455 length (L) × 297 width (W) × 110 height (H); (B) cradle pillow: 455 L × 297 W × 110 H, with a circular recess (diameter = 100); (C) cervical pillow: 455 L, cylindrical shape (diameter = 110); and (D) shoulder pillow: 658 L × 238 W × 50 H (unit: millimeters). The complete pillow designs were made of 100% cotton and filled up with cotton, which was moderately soft. (Color version of figure is available online.)

Subjective questionnaire

This study used the AHP method of pairwise comparison to prioritize the characteristic of the 8 pillow compositions to help researchers understand the response or reaction of test subjects. A sample of the AHP assessment scale is shown in Table 1. For example, if pillow no. 1 provided better head comfort than pillow no. 2, the recorder shall sign in the column "1/5."

The test example of subject T11

Because of the huge amount of data gathered, the study shows the example of subject T11 to explain the process and the results. Besides, to ensure the efficiency of calculation analysis and to confirm its correlation with the consistence index, the investigators analyzed the data by using the AHP software

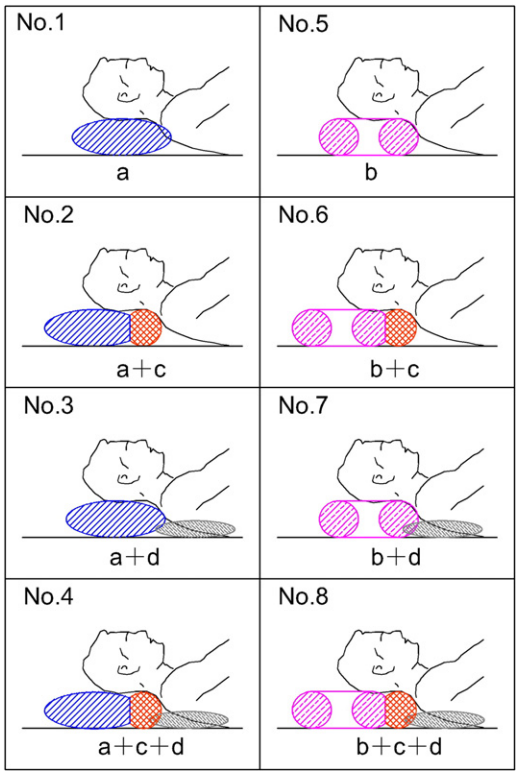

Fig 4. The 8 pillow compositions based on the 4 basic design factors. For example, pillow no. 4 is a combination of design factors a, c, and d. First, only standard pillow was tested; then, pillow designs with a combination of different design factors were tested as shown. (Color version of figure is available online.)

Fig 5. Left: subject no. T04 testing the pillow no. 2 (design factor a + c). Right: subject no. T08 testing the pillow no. 8 (design factor b + c + d). (Color version of figure is available online.)

during experiment. If the results of a subject failed to conform to the consistence index, the subject was asked to test again.

For example, subject T11 was first asked to complete the questionnaire regarding personal data to ensure that the subject had no shoulder or neck ailments and preferred to lie flat while sleeping. Next, subject T11 was then asked to lie flat on the test platform. The recorder will write down the comfort level comparison for each pillow in order. Meanwhile, the assistant will change the compositions of pillows for the subject. The results of pairwise comparison with respect to head comfort A, neck comfort B, shoulder comfort C, height comfort D, and overall comfort E for subject T11 are shown in Table 2.

The pairwise comparison for each comfort factor was determined by a rehabilitation doctor. The order of comfort was as follows: overall comfort E > height comfort D > neck comfort B > head comfort A > shoulder comfort C (as shown in Table 2). The final order of comfort was thus determined for all the 30 subjects.

The pairwise comparison of head comfort of subject T11 is shown in Table 3. The order was as follows: pillow no. 4 > no. 1 > no. 2 > no. 3 > no. 6 > no. 8 > no. 7 > no. 5.

The pairwise comparison of neck comfort of subject T11 is shown in Table 4. The order was as follows: pillow no. 3 > no. 4 > no. 1 > no. 8 > no. 2 > no. 6 > no. 7 > no. 5.

The pairwise comparison of shoulder comfort of subject T11 is shown in Table 5. The order was as follows: pillow no. 8 > no. 4 > no. 2 > no. 1 > no. 3 > no. 6 > no. 5 > no. 7.

The pairwise comparison of height comfort of subject T11 is shown in Table 6. The order was as follows: pillow no. 4 > no. 3 > no. 8 > no. 1 > no. 2 > no. 7 > no. 6 > no. 5.

The pairwise comparison of overall comfort of subject T11 is shown in Table 7. The order was as follows: pillow no. 4 > no. 8 > no. 3 > no. 2 > no. 1 > no. 7 > no. 5 > no. 6.

On the basis of the above data, the order of preference of pillow composition for subject T11 was determined and is shown in Table 8. The order was as follows: pillow no. 4 > no. 3 > no. 8 > no. 1 > no. 2 > no. 7 > no. 6 > no. 5.

Table 1 AHP assessment scale

	A has absolute importance	A has very strong importance	A has strong importance	A has weak importance	Equal importance	B has weak importance	B has strong importance	B has very strong importance	B has absolute importance	
No.	1/9	1/7	1/5	1/3	1	3	5	7	9	No.
Head comfort			○							2
Neck comfort				○						

Table 2 The results of pairwise comparison of each comfort factor

Comfort factor	A	B	C	D	E	Weight	Sort
A	1	1	3	1/5	1/5	0.090173	4
B	3	1	3	1/3	1/3	0.110616	3
C	1/3	1/3	1	1/7	1/9	0.038773	5
D	5	3	7	1	1/5	0.253329	2
E	5	3	9	5	1	0.507110	1

Consistency index: 0.088258.

Data analysis of 30 subjects

After the completion of the experiment, the average of 30 sets of data was calculated; and the subjective comfort arrangements of each pillow were determined, which are shown in Table 9. For example, the arrangement of comfort A for 30 subjects was as follows: pillow no. 4 > no. 3 > no. 2 > no. 1 > no. 8 > no. 6 > no. 7 > no. 5.

The 3 best arrangements were classified as the high-scores group; and the 3 worst arrangements, as the low-scores group. The arrangements of average subjective comfort in terms of head comfort A, neck comfort B, shoulder comfort C, height comfort D, overall comfort E, and alternatives are shown in Table 9. Pillow no. 4 was found to rank the highest in all categories. On the other hand, pillow no. 5 was found to be the least comfortable pillow design.

To determine the contribution of each design factor, this research gives a weight of 5 points assigned to sort 1, 3 points to sort 2, and 1 point to sort 3. In addition, a weight of 1 point was assigned to sort 6, 3 points to sort 7, and 5 points to sort 8 (Table 9). Thus, the top 3 best design combinations contributing to head comfort A in the high-scores group were as follows: sort 1: with pillow no. 4 (design factors: a + c + d), sort 2: with no. 3 (a + d), and sort 3: with no. 2 (a + c) (Table 9).

The sum of design factors is (a × 5 + c × 5 + d × 5) + (a × 3 + d × 3) + (a × 1 + c × 1) = 9a, + 0b, + 6c, + 8d. The comfort percentage of each design factor was then calculated; thus, the design factor "a" accounts for 39.13% of comfort (Table 10).

The results for head comfort A of 30 subjects (Table 10) suggest that a pillow with the design factor "b" is not preferred (69.23% in the low-scores group vs 0% in the high-scores group). However, a pillow with the design factor "a" is more satisfactory than other designs (high: 39.13% vs low: 0%). With regard to neck comfort B, a pillow with the design factor "c" is ranked the first of all (high: 37.5% vs low: 0%). Therefore, a pillow with the design factor "c" is most comfortable for the neck. With regard to shoulder comfort C, a pillow with the design factor "d" is ranked the first (high: 34.62%); however, this design had a percentage of 17.65% in the low-scores group. Thus, the result of shoulder comfort shows that no significance was observed. With regard to height comfort D, a pillow with the design factor "a" is ranked first (high: 40.91% vs low: 0%), whereas a pillow with the design factor "b" is ranked the last (high: 69.23% vs low: 0%). These data indicate that the design factor "a" is an important factor for height comfort.

The pillow height of each design was found to be directly proportional to the comfort rank (Table 11 and Fig 6). This concluded that comfort level increases with respect to the increase of pillow height.

With regard to overall comfort, pillow no. 4 was the most satisfactory, whereas pillow no. 5 was the least satisfactory. A pillow with the design factor "c" is ranked the first (high: 34.62% vs low: 0%). Moreover, a pillow with the design factor "b" is ranked the last (high: 0% vs low: 66.67%). Thus, a pillow without the design factor "b" and that provides cervical support may provide better overall comfort than the other pillows. Lastly, factors such as head angle, sex, height, weight, age, etc, of the 30 subjects did not significantly affect subjective comfort.

Table 3 The pairwise comparison of head comfort of subject T11

A	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	Weight	Sort
No. 1	1	1	1	1	7	5	7	5	0.227173	2
No. 2	1	1	1	1	7	1	3	3	0.156768	3
No. 3	1	1	1	1/5	7	1	5	3	0.136652	4
No. 4	1	1	5	1	9	5	7	5	0.286663	1
No. 5	1/7	1/7	1/7	1/9	1	1/5	1	1	0.027975	8
No. 6	1/5	1	1	1/5	5	1	1	1	0.076378	5
No. 7	1/7	1/3	1/5	1/7	1	1	1	1	0.040931	7
No. 8	1/5	1/3	1/3	1/5	1	1	1	1	0.047459	6

Consistency index: 0.087741.

Table 4 The pairwise comparison of neck comfort of subject T11

B	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	Weight	Sort
No. 1	1	1	1	1	5	3	5	1	0.161517	3
No. 2	1	1	1/7	1/5	5	1	3	1	0.084691	5
No. 3	1	7	1	1	9	5	7	3	0.282750	1
No. 4	1	5	1	1	7	5	7	1	0.229010	2
No. 5	1/5	1/5	1/9	1/7	1	1	1	1/5	0.030676	8
No. 6	1/3	1	1/5	1/5	1	1	1	1	0.054885	6
No. 7	1/5	1/3	1/7	1/7	1	1	1	1/5	0.033743	7
No. 8	1	1	1/3	1	5	1	5	1	0.122727	4

Consistency index: 0.083367.

Table 5 The pairwise comparison of shoulder comfort of subject T11

C	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	Weight	Sort
No. 1	1	1	1	1/3	5	3	7	1/5	0.107838	4
No. 2	1	1	1	1	5	3	7	1	0.151281	3
No. 3	1	1	1	1	5	3	7	1/9	0.090129	5
No. 4	3	1	7	1	7	7	9	1	0.264830	2
No. 5	1/5	1/5	1/5	1/7	1	1	1	1/7	0.028428	7
No. 6	1/3	1/3	1/3	1/7	1	1	1	1/9	0.033365	6
No. 7	1/7	1/7	1/7	1/9	1	1	1	1/9	0.023532	8
No. 8	5	1	9	1	7	9	9	1	0.300597	1

Consistency index: 0.092641.

Table 6 The pairwise comparison of height comfort of subject T11

D	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	Weight	Sort
No. 1	1	1	1/3	1/5	7	5	3	1	0.107250	4
No. 2	1	1	1/7	1/9	7	5	3	1/3	0.078136	5
No. 3	3	7	1	1	9	7	5	1	0.252537	2
No. 4	4	9	1	1	9	7	5	3	0.318669	1
No. 5	1/7	1/7	1/9	1/9	1	1	1/3	1/5	0.021277	8
No. 6	1/5	1/5	1/7	1/7	1	1	1	1/5	0.028273	7
No. 7	1/3	1/3	1/5	1/5	3	1	1	1/5	0.040087	6
No. 8	1	3	1	1/3	5	5	5	1	0.153770	3

Consistency index: 0.092959.

Table 7 The pairwise comparison of overall comfort of subject T11

E	No. 1	No. 2	No. 3	No. 4	no. 5	No. 6	No. 7	No. 8	Weight	Sort
No. 1	1	1	1/3	1/5	3	5	1	1/5	0.070494	5
No. 2	1	1	1	1/5	5	7	3	1/3	0.109941	4
No. 3	3	1	1	1/3	7	9	5	1	0.176933	3
No. 4	5	5	3	1	7	9	5	1	0.303524	1
No. 5	1/3	1/5	1/7	1/7	1	1	1	1/7	0.029621	7
No. 6	1/5	1/7	1/9	1/9	1	1	1/3	1/7	0.021811	8
No. 7	1	1/3	1/5	1/5	1	3	1	1/5	0.047142	6
No. 8	5	3	1	1	7	7	5	1	0.240535	2

Consistency index: 0.061056.

Table 8 The order of preference for subject T11

Sort	Pillow no.	Weight
1	No. 4	0.296097
2	No. 3	0.200793
3	No. 8	0.190442
4	No. 1	0.105450
5	No. 2	0.104916
6	No. 7	0.042397
7	No. 6	0.032475
8	No. 5	0.027429

Prototype for pillow design

On the basis of the research results, we suggest several design principles and strategies (presented in Table 12) and propose a design project (Fig 7). The pillow should have the design factors of "a", "c" and "d". Another design variable is the height of the pillow. The pillow height can be increased gradually which will provide support of the head and upper body at the same time. Note that the pillow should have sufficient width to provide full shoulder support as well.

Discussion

The initial problem in the present study was to find out the effect between different combinations of design factors on the subjective response. The experimental results show that pillow design preferences are shared by all participants. Each design factor composition has special meaning and was unique, which can be revealed by some of its features. In the past study, Persson and Moritz[7] indicated that there is no definite pillow shape that affects subject preference. It was thought that people choose pillows in a manner similar in which they selected the clothes they liked. Therefore, the present study was conducted under experimental conditions to eliminate the ambiguity of subjective preference. The research results indicate that through using the present experimental methods, the optimal pillow shape suitable for subjects could be determined.

Previous studies used commercial products for testing comfort.[6,7,16,17] Because these products were highly similar, the differences between them could not be easily distinguished; and thus, an influential design factor of pillow design could not be easily identified. However, the present study incorporates the importance of deconstruction analysis to investigate the effects of pillow design factors. The differences between feelings in the experience with each composition could be determined even though the designs were randomized. Furthermore, the present study suggests a possibility of customized pillow design with diverse features for different groups.

In addition, a number of previous studies used subjects' daily pillows as control pillows[10,16,17]; thus, if subjects were unsatisfied with their daily pillows, the testing pillow received a high rating, thereby possibly causing a placebo effect. Therefore, the present study used 4 pillow design factors to eliminate biased comparison under different basis and produce more accurate results.

Table 9 The average of each individual subjective comfort of 30 subjects

		A	B	C	D	E	Alternatives
High-scores group	Sort 1	No. 4	No. 4	No. 4	No. 4	No. 4	No. 4
	Average	0.237831	0.217938	0.209212	0.249676	0.232219	0.234676
	Sort 2	No. 3	No. 2	No. 8	No. 2	No. 8	No. 2
	Average	0.161123	0.157118	0.188263	0.136354	0.151860	0.144009
	Sort 3	No. 2	No. 8	No. 3	No. 1	No. 2	No. 8
	Average	0.158585	0.154047	0.147416	0.126355	0.143031	0.141517
	Sort 4	No. 1	No. 6	No. 2	No. 8	No. 3	No. 3
	average	0.139733	0.144597	0.135524	0.119202	0.127494	0.127001
	Sort 5	No. 8	No. 3	No. 1	No. 3	No. 6	No. 6
	average	0.110567	0.116189	0.106880	0.115466	0.111961	0.110748
Low-scores group	Sort 6	No. 6	No. 1	No. 6	No. 7	No. 1	No. 1
	average	0.096672	0.093031	0.088023	0.104778	0.095368	0.107406
	Sort 7	No. 7	No. 5	No. 7	No. 6	No. 7	No. 7
	average	0.056283	0.066852	0.077728	0.102027	0.083315	0.082438
	Sort 8	No. 5	No. 7	No. 5	No. 5	No. 5	No. 5
	average	0.039206	0.050228	0.046954	0.046142	0.054752	0.052205

Table 10 The calculations of comfort percentage of design factors in the high-scores group and low-scores group

		A (%)	B (%)	C (%)	D (%)	E (%)	Alternatives (%)
High-scores group	a	39.13	33.33	23.08	40.91	23.08	4.11
	b	0	4.17	11.54	0	11.54	5.26
	c	26.09	37.5	30.77	36.36	34.62	47.37
	d	34.78	25	34.62	22.73	30.77	5.26
	Total	100	100	100	100	100	100
Low-scores group	a	0	7.14	0	0	8.33	8.33
	b	69.23	57.14	52.94	69.23	66.67	66.67
	c	7.69	0	29.41	23.08	0	0
	d	23.08	35.71	17.65	7.69	25	25
	Total	100	100	100	100	100	100

Previous studies focused on sleep quality and neck ailments.[5-7,10,16,17] The subjects were primarily hospitalized patients and hospital staff. Subjects were not selected on the basis of consistency with in terms of the pain, symptoms, and the specific pillows were provided for specific patients. The present study chose a specific target group to simplify the test conditions; and thus, the results of the present experiment were specific and applicable to the specific chosen target group alone. This also implies that a certain type of pillow that is suitable to all target groups cannot necessarily be designed. The same study can be used for future research aimed at designing suitable pillows for different groups with regard to body mass, age, size, or work habits of different groups and pillows suitable for users with different demands.

Previous studies tend to test comfort by using subjective survey questionnaires for investigation.[6,7,16,17] Because most tests tend to perform over an extended period of time it may affect the subjects' response. Moreover, the acuity of human senses are greatly reduced during sleep cycle.[5] Therefore, the best response from the subjects should be obtained at the time shortly prior to the subjects falling asleep.

Short-term comparison of comfort simulates the purchase situation in which subjects may test a pillow before purchase. Experts recommend that customers must try to lie on the pillow and simulate the sleep experience when buying a pillow. In the present study, 2 pillows were compared over a short time; this approach is more objective than one in which many pillows are tested over a long period. Moreover, the results of the present study are more accurate because the contradictory results were eliminated with the AHP technique.

Limitations

The present study has certain limitations in this experiment. For instance, the subjects reported different comfort level statements for the same pillow during comparison. Therefore, if there are more types of pillows, more number of contradictions will be observed, thus becoming more difficult to test.

The present study excluded the test subjects who preferred to lie on the side while sleeping. Hence, it is only applicable to subjects who lie flat while sleeping. In future studies, the experiment should incorporate

Table 11 The average height of the 8 pillows tested by 30 subjects

Pillow	Average height (mm)
No. 1	21.12
No. 2	21.39
No. 3	21.40
No. 4	22.25
No. 5	20.06
No. 6	20.49
No. 7	20.44
No. 8	21.57

The height is the sum of the head and the pillow (units: millimeters).

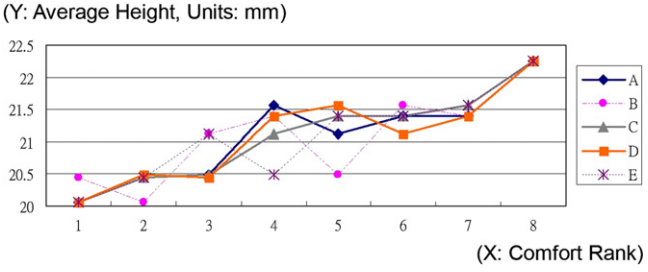

Fig 6. Chart of pillow's average height versus comfort rank. This chart shows a positive trend between the pillow height and comfort level. For example, the order of pillow design with respect to comfort level was sort 4 > 2 > 1 > 8 > 3 > 7 > 6 > 5 (Table 9). (Color version of figure is available online.)

Table 12 Comparison chart of research results and design strategy

Research results	Design strategy
Cradle pillow is not preferred.	Eliminate the design factor "b."
Cervical pillow is more comfortable for the neck.	Retain the design factor "c" to provide neck comfort.
Design factor "a" is an important factor for height comfort.	Retain the design factor "a" to provide height comfort.
The more height a pillow has, the higher the comfort level.	Increase the height to 13.2 mm 22.25 − 20.06 = 2.19 mm (difference in the height of pillow no. 4 and no. 5) 11 (original design) + 2.19 = 13.19 = 13.2
Pillow no. 4 is the most satisfactory.	Incorporate the design factor of pillow no. 4 ("a"+ "c"+"d").
Pillow without design factor "b" and that provides cervical support will have more comfort.	Eliminate the design factor "b" and retain the design factor "c."

both categories of sleep posture: flat and on one side. In addition, researchers should investigate the effect of the pillow materials within this process again to distinguish the comfortable level of pillow materials.

Conclusions

Previous studies on pillows were mostly conducted using commercial products for experiments, and very few people studies used redesigned pillows. In the present study, we used the experiment method and redesigned pillows, simplified the subjects group, and used deconstruction analysis. The results indicate that some subjects preferred a certain set of pillow design combinations. These findings suggest that various combinations may be designed and innovated for various groups. Based upon our findings, pillow no. 4 was the optimal and most comfortable pillow and was composed of the following design factors: "a" (standard pillow), "c" (cervical pillow), and "d" (shoulder pillow).

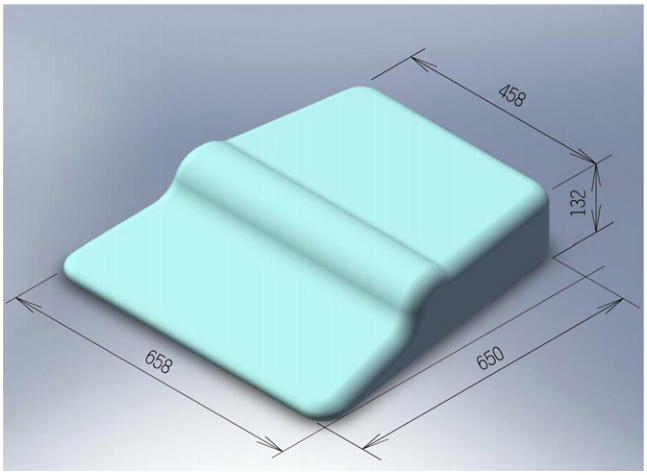

Fig 7. The research offers an example to determine the feasibility of designing the most suitable shape for a pillow on the basis of research results. According to these design strategies, the design of an optimal shape of pillow is depicted (unit: millimeters). (Color version of figure is available online.)

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