Ergonomic design of a pillow

Hideki OYAMA[1], Manami NOZAKI[2], Kageyu NORO[3]

[1] Graduate School of Biomedical Engineering, Tohoku University
2-1, Seiryo-cho, Aoba-ku, Sendai, Miyagi, 980-8575, Japan
[2] Faculty of Nursing, Toho University
4-16-20 Omorinishi, Ota-ku, Tokyo 143-0015, Japan
[3] Waseda University, ErgoSeating Co., Ltd.
4-40-2, Takadanobaba, Shinjuku-ku, Tokyo, 169-0075, Japan

Abstract. This research is aimed at promoting higher quality of sleep by developing pillows that will help improve breathing through realizing unhampered body movement, in particular head motion. A prototype model of cylindrical pillow was created based on a past finding that the extended positon of cervical part would lead to improved breathing than its flexed position. In addition, a supporting base was developed to put the cylinder on in a bid to secure head stability as well as to bring about more comfortable sleep and improved ventilation. Pressure distribution was measured resulting in an increase in contact area of the prototype model compared with that of a conventional flat type pillow. Investigation was made on how breathing characteristics were affected by differences in head position and pillow type to obtain a finding that the extended cervical position, compared with the flexed one, tends to have a significant effect of a decrease in breathing frequency while an increase in breathing amplitude. The aforementioned findings reasonably led to the presumption that prototype pillows could support the cervical extensive position with a wider contact area, enabling its user to breathe slower and deeper breathing.

Keywords. pillow, head position, breathing

1. Background and objectives

Nowadays not a few people are seen spending unpleasant nights while asleep to result in lack of deep sleep. The prerequisites for a desirable pillow include: 1) to provide easy roll-overs, 2) to secure an adequate respiratory passage, 3) to be hygienically designed or easily cleanable, and 4) to have superior heat-releasing performance. A pillow that satisfies these requirements would greatly contribute to improvement of sleeping quality. This research is aimed at promoting higher quality of sleep by developing an easy-to-breathe pillow that will not hinder body movement, in particular user's head motion, while also taking into consideration the aforementioned requirements 1), 3) and 4) in pillow design.

2. Method

From the initial stage of the pillow development, participatory ergonomic design was pursued with participation by ergonomists, otolaryngologists, medical professionals, designers, modelers and users. In the investigation phase in Figure 1, conducted were hearings from medical professionals, observation of head and neck areas through X-ray imaging, and surveys on marketed products. In the prototype development phase, the shape and size of a pillow along its material were examined, followed by development of a prototype and its improvement. In the measurement and evaluation, head motion, breathing, pressure distribution, and usability were investigated.

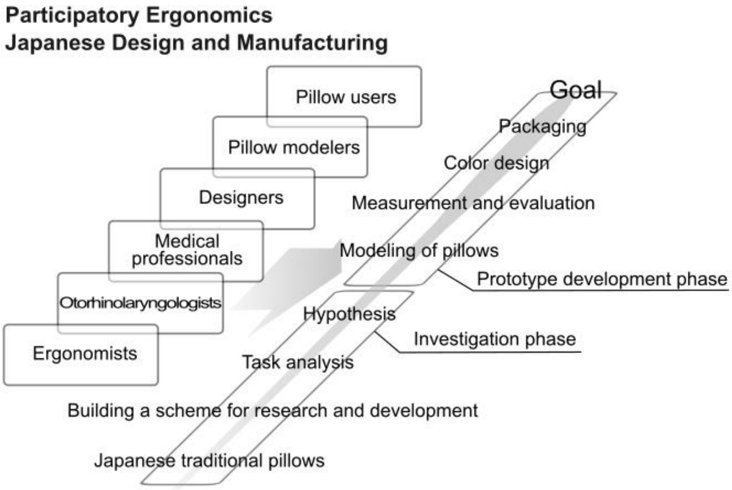

Figure 1. *Developmental stages.*

3. Development of easy-to-breathe pillows

The objectives to be achieved were realization of rotations of head — one lengthwise direction associated with up-and-down motion of chin position and the other widthwise one related to rolling-over motion of body — and supporting of head part. In view of these two objectives, the targeted pillow was optimally designed comprising two parts as described in the following.

3.1 Developmental policy

Our developmental policy was to develop a pillow that allows user's head to move as freely as possible. It is based on a report by Yanase et al (1972) that pointed out the necessity of adequate body motion for a high-quality sleep. Conventional flat pillows hinder head motion, which will lead to feelings of smothering. This is the reason why we developed a convex-type pillow that enables head to move in a large way.

3.2 Pillow structure and functions

Our prototype model of a concerned pillow has two-layer structure consisting of a roll-type main body of cylindrical form and its supporting base (Figure 2). The main body has two functions; one not to hinder head motion, and the other to promote nasal breathing. The reasons for selecting a convex-type shape are: 1) to observe a curved shape of neck and back of head area, and 2) to maintain the respiratory passage wide enough in a stable manner hinted by a suggestion from an otolaryngologist concerning the head position against a pillow. The supporting base has functions of shock absorption, improvement of stability, and prevention of adhesion between the main body and bedclothing for upgrading of heat-releasing performance.

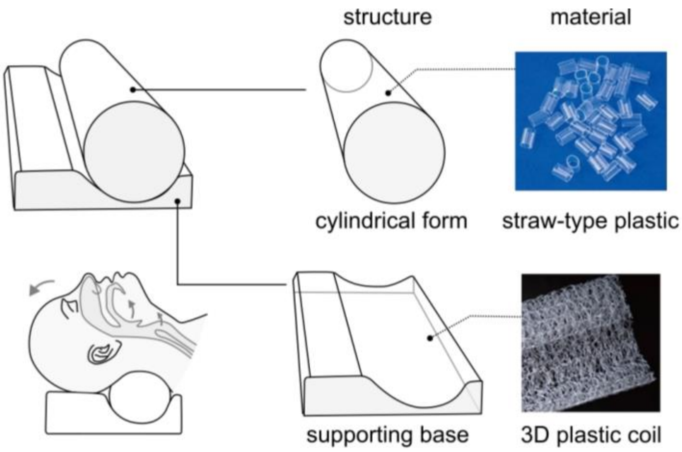

Figure 2. *Structure and functions of an easy-to-breathe pillow along with its material.*

3.3 Pillow materials

Compressed strain curves obtained from physical property tests were used for selection of two materials with different physical properties. Plastic straws were chosen for filling material of the main body of pillow, while 3-dimensional plastic coils were used for the supporting base. As long as the surveys by the authors are concerned, straws as filling material have physical property of weaker resilient force against the initial load with slower recovery speed, while still having a remarkably high maximum load capacity. It also was recognized that straws filled in bags would contribute to easier rolling-over through fluid feelings created by their moves caused by compression from outside. The straw material has another advantage of making pillow height adjustable by means of moderating filler content of straws in accordance with user's preference. Three dimensional plastic material is a molded plastic product created by fine polyethylene fibers entwined in the 3-dimensional manner. Its physical property is featured by repulsive force very close to the one provided by metal spring (Figure 3). The filling materials of the main body and supporting base are both washable polyethylene with the aspect of hygiene taken into consideration.

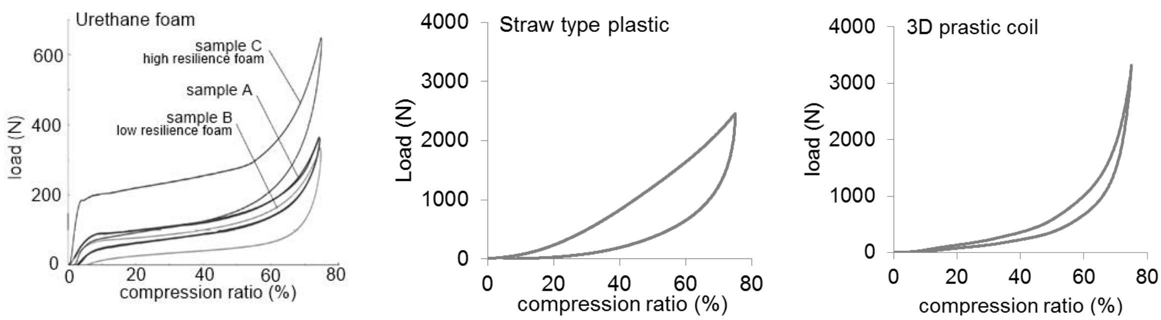

Figure 3. *Characteristic curves of compressive strain for each material*

4. Ergonomic evaluation

4.1 Measurement of breathing curves

Continuing from the investigation reported last year, a larger number of subjects participated this year to examine the effect of different combinations of head position and pillow on the neck angle and breathing characteristics. The neck angle was measured with 115 students from a nursing school serving as subjects, while 30 students participated in measurement of breathing. A conventional flat pillow and a roll-type prototype model were used as the measuring objects. For these two types of pillows, measurements were conducted under two conditions, one with the neck most extended (extension) and the other with the neck most flexed (flexion). A sleep evaluation device Sleep EYE GD700, DENSO, was used for measuring breathing in the supine position with breathing curves recorded for one minute. An analysis period of 40 seconds was set with breathing frequency and amplitude identified each from the breathing curve. The results were statistically processed with Two- way repeated measure ANOVA applied to neck angle, breathing frequency, and breathing amplitude with pillow type and head position. The difference between cervical extensive and flexed positions, which represents a range of neck motion, was evaluated with t-test used for comparison between a flat pillow and a roll-type model.

Figure 4 shows an example of breathing curves from a roll-type model. Higher breathing frequencies with smaller breathing amplitudes were taken from flexed neck position, which is considered to represent a shallower breathing. For the extended neck position, on the other hand, lower breathing frequencies with larger breathing amplitudes are seen associated with a deeper breathing.

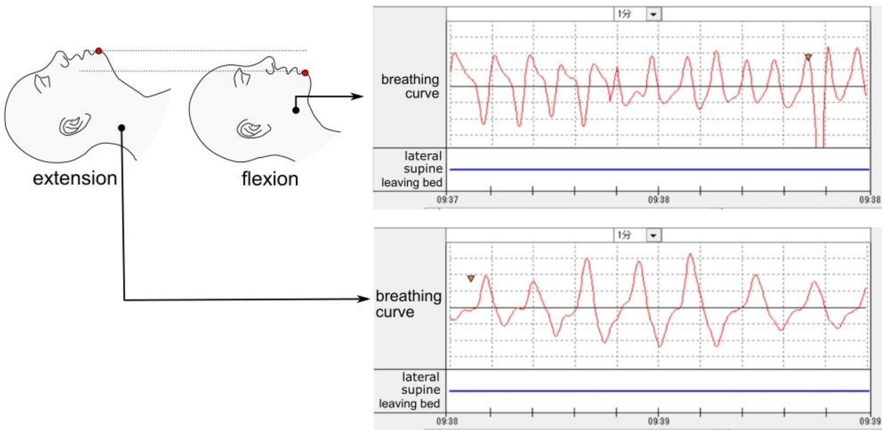

Figure 4. *An example of breathing curves corresponding to two different head positions.*

The results of the statistical analysis are summarized in Figure 5. With regard to neck angle, main effects of head position and pillow type were significant each ($p<0.01$), while also these two-factor interaction was significant ($p<0.01$). Cervical extensive position had greater neck angles than its flexed position, while cervical flexed position on roll-type pillows had smaller neck angles than on flat pillows. Significantly larger cervical motion ranges were seen on roll-type pillows than on flat pillows ($p<0.01$). With regard to breathing frequency, main effect of pillow type was significant ($p<0.05$), with smaller breathing frequencies seen on roll-type pillows than on flat pillows. Concerning breathing amplitude, roll-type pillows tended to give greater amplitudes on cervical extensive position than flat pillows.

Cervical extensive position, compared with its flexed position, tended to give significantly lower breathing frequencies with greater breathing amplitudes. A decrease in breathing frequency with an increase in breathing amplitude associated with roll-type pillows is considered to represent realization of a deeper breathing. It was concluded that encouraging the cervical part to extend in the supine position would expand the respiratory passage to promote a slower and deeper breathing. With possible shift of neck anticipated toward flexed position, appropriate attention should be paid to the fact that cervical flexed position could be linked to a shallower sleep.

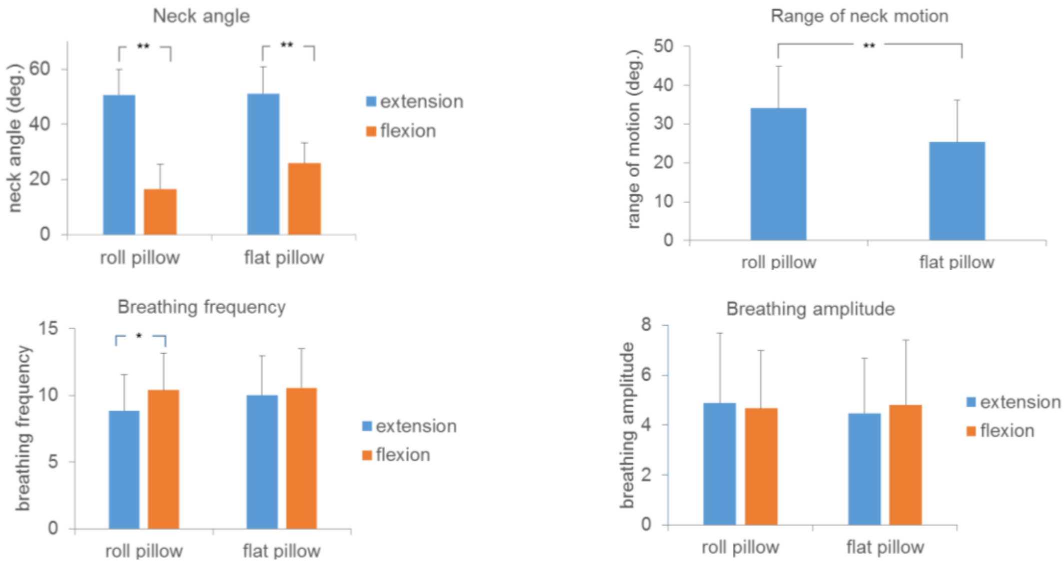

Figure 5. *Breathing characteristics for two types of pillows, flat type and prototype model.*

4.2 Measurement of pressure distribution

A pressure sensing device (X-sensor, XSENSOR Co.) was used for measuring the contact area on a conventional flat pillow and an initial version of a cylindrical prototype pillow (Figure 6). As a result, an increase of around 40% in contact area was seen for a prototype model compared with a flat pillow. It was concluded that a cylindrical prototype pillow with its wider contact area would contribute to keeping more stable head position and better sleeping comfort.

4.3 In-home usability test

Usability evaluation was conducted on prototype pillows by collecting users' opinions from 13 males and females in their 20s to 50s. They used those pillows

Conventional flat pillow (92cm^2) Prototype model (130.65cm^2)

Figure 6. *Comparison of pressure distribution between a flat pillow and a prototype model.*

when sleeping at their homes during an average period of one month. Positive views were obtained with regard to such characteristic features of prototype pillows as resilience, feelings of stability, and ease of rolling-over. Meanwhile, differences among individuals were recognized in terms of suitability of pillow height.

5. Conclusion

This paper described how pillows have so far been developed in Japan, structure and functions of easy-to-breathe pillows, and materials. Research results on relationships between head position and breathing, pressure distribution on pillows, and user experience were summarized as well. The aforementioned findings led to a conclusion that prototype pillows would facilitate cervical extensive position and support the wider area of back of head to neck, leading to an easier breathing. Based on research and prototyping, we have successfully developed convex-type pillows that have dual features of facilitating head motion and expanding supporting contact area (Figure 7). In the course of research and development of pillows, participatory ergonomics has actually been put to practical use in the design process.

Specifications		Base	Cylindrical form
			
Size(mm)	Pillowcase	W550×H240	W420×Φ170
	Inner	W350×D185×H(rear)50	W350×Φ90
Material	Pillowcase	Face side fabric /Cotton 100%, Padding /Polyester 100%	Face side fabric /Cotton 100%, Padding /Polyester 100%, Cord /Acrylic fiber100%
	Inner material	3D coil (Polyethylene resin 100%)	Mesh sack / Polyester 100%, Packing material/Polyethylene resin 100%
Color	Pillowcase	Navy & Off-White, Light-Green & Green, Off-White, Orange & Light-Yellow	

Figure 7. *Easy-to-breathe pillows.*

6. References

Oyama, H., Shibata, M., Noro, K. (2016) Design of pillows in view of breathing frequency and range of head motion, Proceedings of 62^{th} spring congress of GfA, A.4.13.

Yanase, T., Yamaguchi, M., Yamamoto, S., Hanaoka, T. (1972) A polygraphy-based study on natural sleep (5)- relationships between bed width and depth of sleep. Research Journal of Living Science 19 (1), 83-88. (in Japanese)

Acknowledgement. The authors thank Dr. Minori Shibata at University of Occupational and Environmental Health, Japan, for her valuable suggestions. They thank Dr. Goroh Fujimaki at Gifu Prefectural Research Institute for Human Life Technology for contribution in the physical property test of materials. They are indebted as well to students from Saitama Prefectural College of Nursing and Sakadotsurugashima Nursing School for their experimental co-operation. They also extend their thanks to DENSO CORPORATION for their contribution in the measurement of breathing.