Proceedings of the World Congress on Electrical Engineering and Computer Systems and Science (EECSS 2015)
Barcelona, Spain, July 13 - 14, 2015
Paper No. 307

The Biomechanical Consideration of a Comfortable Pillow

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Abstract- The present study aims to develop comfortable and ergonomic pillows that reflect anatomical differences between individuals. This paper describes a comfortable posture of the head and neck during sleeping. It is difficult to directly measure the shape of the back of the head and neck when the subject is lying on a pillow. We developed a new instrument which can measure the shape of the back of the head and neck in any standing position. Position and orientation of the head relative to the trunk are also measured using marker points attached to the subject's body in standing and supine postures. Using the information thus found on relative head-neck posture and orientation in standing positions, we estimated the relative posture of head and neck in a comfortable supine position on a pillow. The estimated result suggests there is an obvious difference between the most comfortable standing posture and the comfortable supine posture; contrary to the prevailing theory on this subject. This paper also discusses a relationship between pressure distribution in sleeping and subjects' individual shape of the back of the head and neck.

Keywords: Sleep, Posture, Supine, Natural standing, Pillow shape, Head shape

1 Introduction

Sleep is one of the most important issues in our daily life and crucial for maintaining good health and quality of life. It is said that the primary factors influencing the quality of sleep are temperature, sound, and light (Shirakawa 2014). Many researchers tried to clarify the effects of these factors on sleep from medical viewpoints (Haskell et al. 1981, Fvhri et al. 2010, and so on). However, none of these studies give definite conclusions on how to effectively induce sleep .

There are also several studies that look at the problem from a biomechanical perspective, analysing human posture during sleep. A comfortable hypnagogic posture positively influences the duration of sleep (Matsuura et al. 2005, Kogure et al. 2007). Based on the conclusions given by Matsuura et al., it is expected that a pillow plays an important role inducing and sustaining comfortable sleep. It is desirable to provide a suitable pillow for each individual. Height, hardness and material are listed as determining factors by Okuyama (2011). We expect that the posterior shape of the head and neck (from now on referred to as 'SBHN', Shape of the Back of the Head and Neck) has a strong influence on whether a subject perceives a pillow as comfortable. However, there are few quantitative discussions of these factors. A prevailing theory says that supine posture in comfortable sleeping is the same as the posture in natural standing. However, the mechanical support of the head is different in standing and supine positions, because of the changed direction of gravity relative to the body, as shown in Fig. 1. The possibility must be considered, that an individual's SBHN is changed by the gravity effect. There are no reports on this problem yet.

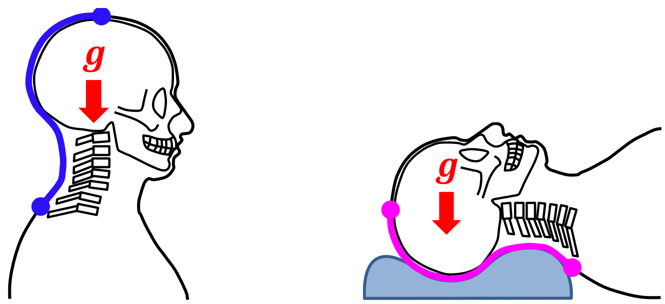


Fig. 1: Gravity direction against the body
The direction is different between standing and supine.

It is important to know posture in sleeping condition to validate the above prevailing theory. However, it is difficult to directly measure the posture of back head and neck in sleeping on a pillow. This paper reports on a new instrument which can measure SBHN in standing positions. The present study measures positions and orientations of head relative to trunk in standing and supine postures. From these data we estimate the SBHN in corresponding supine postures. The mechanical pressure distribution in supine positions are also discussed and linked to the subject's SBHN.

2 Methods

2.1 Measurement system for shape of back head and neck

We developed a new measurement system to obtain quantitative data on SBHN (Fig. 2). The basic principle is to measure the 3D surface of the posterior head and neck with an array of rods as shown in Fig. 3. When the measuring rods are pressed on against the subject, the terminal positions of the rods are recorded by two cameras. The positions of the rods in Cartesian coordinates are estimated by using digital image processing software developed specifically for this purpose. To lock the position of these rods after having pressed them against to the subject, a newly developed brake mechanism is embedded in this measurement system. Fig. 4 shows a measuring scene with the new device. The measurement error is ± 1.0 mm at the most. In practice, considering the scale of pillow deformations, this is sufficiently accurate.
In this paper, we focused on the SBHN in the median sagittal plane. Fig. 5 shows the area obtained by the measurement system. Region of interest is from the top of head to the 7th cervical vertebra. We extract the contour of the back head and neck in the sagittal plane as shown in Fig. 6.

2.2 Measurement system for shape of back head and neck

Human posture can take various 3D postures because of many degrees of freedom (DOF). The head and neck area also can take 3D postures. For the first step of this study, we deal with 2D motion assuming that the posture changes within the median sagittal plane. To estimate the SBHN in a supine condition, we measure relative positions of head and trunk in both standing and sleeping conditions. Then we estimate SBHN in supine posture from several SBHN and posture data in standing positions. Markers as shown in Fig. 7 are

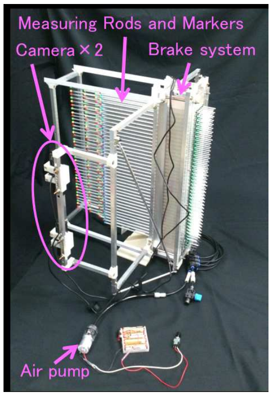


Fig. 2: Head shape measuring instrument

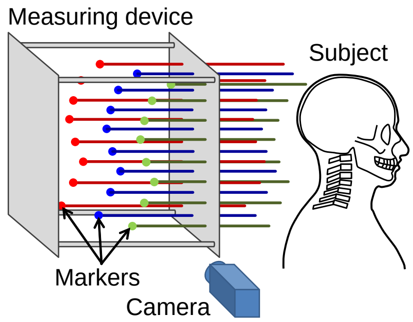


Fig. 3: Schematic of measurement

Fig. 4: Measuring scene in standing

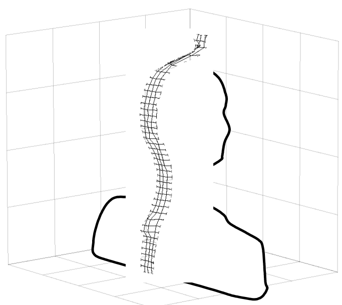


Fig. 5: Defined area of back head and neck

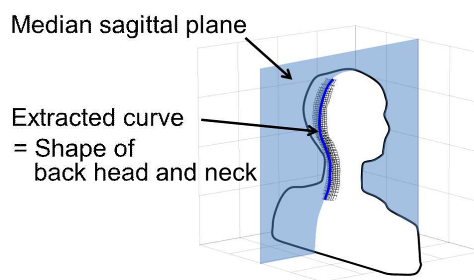


Fig. 6: Shape of back head and neck

used for measuring relative positions. They are attached to forehead and chest of a subject's body.

We measure marker positions of p_1, p_2, p_3, p_4, which are shown in Fig. 8 (Standing) and Fig. 9 (Supine). Posture change of head and neck is available from several relative positions of head $\overrightarrow{p_1p_2}$ to trunk $\overrightarrow{p_3p_4}$. They are necessary for estimation of the SBHN in a supine position. To detect the epithelial 7th cervical vertebrae in measured data $\boldsymbol{h}$, we attached a marker to the point p_5 as in Fig. 8. Although we do not see the position p_5 in a supine posture on a pillow, we can estimate p_5 because the relative positions of p_3, p_4, p_5 are almost constant as shown in Fig. 8. We set consider the relationship between the triangle $\triangle p_3p_4p_5$ (which has fixed dimensions for each subject) and vector $\overrightarrow{p_1p_2}$ and use this relationship to analyze posture change.

2.3 Estimation of shape of back head and neck in supine posture

The following steps explain how to estimate hidden SBHN in a supine posture.

Step 1: Detection of deformable part

Measured shape of back head and neck consists of an unchangeable bony segment (skull) and a deformable muscled segment (neck). To obtain information on the deformable part, we determine position p_5 using the geometrical relation between p_3, p_4, p_5, and a head vector $\overrightarrow{p_1p_2}$ in each standing posture. Then we extract the deformable part by subtracting the unchanging head segment for the each case.

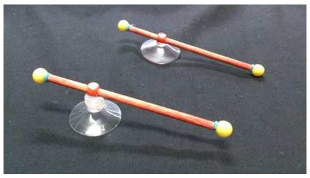


Fig. 7: Markers attached to the forehead and chest (L=126 mm)

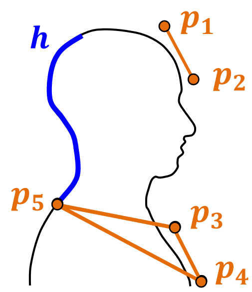


Fig. 8: Measure points and shape in standing

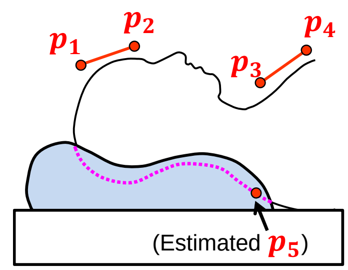


Fig. 9: Measure points in supine

Step 2: Expression of deformable part by formula

To estimate the SBHN in supine posture, we assume that neck segment changes its shape linearly within a small deformation as shown in Fig. 10. To apply the formula in change, we derive coefficients of a shape estimation formula by least-squares method using data obtained by step 1 in several standing conditions.

Step 3: Estimation of shape in supine posture

We obtain the deformable part in supine posture by the above formula substituting geometrical information. This information consists of the geometrical relationship between $\triangle p_3 p_4 p_5$ and the vector $\overrightarrow{p_1 p_2}$ in the supine condition.

We measure the relative positions of the subject between the head and trunk in supine position. Using the above mentioned formula, the SBHN can be estimated from the relative position in the supine posture.

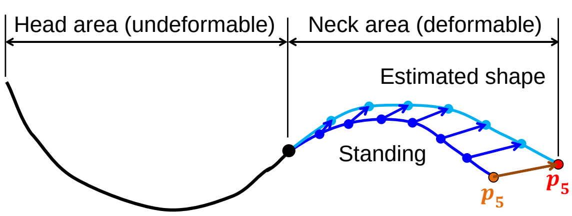


Fig. 10: Defined area of back head and neck

Fig. 11: Measuring scene in supine

2.4 Evaluation of comfortable pillow

To examine mechanical states in supine posture, we measured pressure distribution on the surface of pillow as shown in Fig. 11. We used the flexible sheet type pressure sensor X SENSOR PX100: 40.64.02 in this measurement. The spatial resolution is 12.7 mm.

This study tried to find a relationship between a pillow's comfort and an individual's SBHN. Fig. 12 shows one of the pillows used in this study. The height of its neck area can be changed independently from the height of its head area and vice versa. They are adjusted by the amount of filling in the pillow. Nine kinds of pillows were prepared for the test as in Table 1.

Correspondingly, we took markers' positions of a subject by a camera to estimate the SHBN by the previously mentioned method in section 2.3. Subjects were asked to compare the comfort provided by the different pillows, including the no-pillow case. The experiment was performed three times for each case.

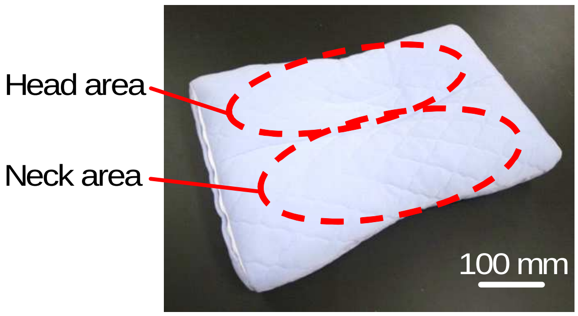


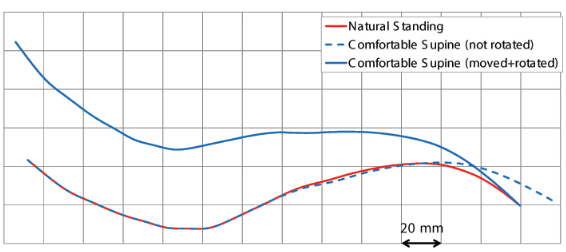
Fig. 12: Example of test pillow

Table 1: Specs of test pillow

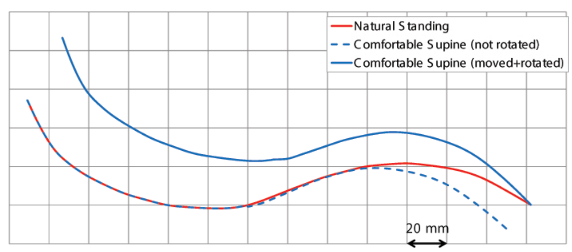
Pillow label	Height [mm]	
	Neck	Head
L1	50	25
L2	50	30
L3	50	35
M1	60	30
M2	60	35
M3	60	40
H1	65	35
H2	65	40
H3	65	45

3 Results and Discussion

Seven subjects participated in the experiment. All of them are healthy men between 22 to 27 years old (of either Japanese or Chinese nationality). Fig. 13 shows contours of SBHN measured in standing posture and estimated in supine posture for the pillow that the subject indicated as most comfortable.



(a) Subject A



(b) Subject B

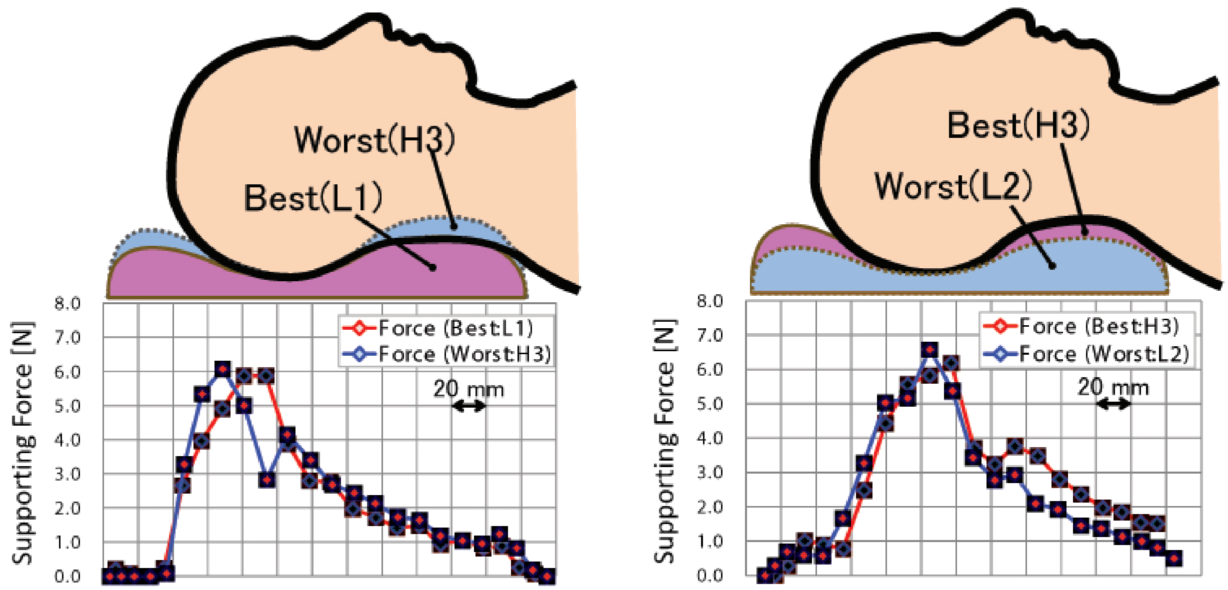
Fig. 13: Head shapes (measured or estimated)
The angle and depth of head shape are different between individuals.
Moreover, a difference between natural standing and comfortable supine position can be perceived.

There is a clear difference in SBHN between individuals. Subject A has low height neck; subject's B neck shows a much heavier curve. Subject A prefers the low neck height pillow L_1. Subject B prefers the high neck height pillow H_1. From the experimental results we found the following relation. A pillow with low neck height is preferred by subjects with shallow curved neck shape such as subject A. On the other hand, a high neck pillow is preferred by subjects with a deeply curved neck shape such as subject B. The shape difference indicates the difference of pillow preference between individuals.

These figures show clear angle difference between standing and supine postures, although the prevailing theory says they are the same. The red and blue solid curves in Fig. 13 show shapes of the subject's back head shape in natural standing and comfortable supine postures. We set their point of p_5 to the same position on a reference plane. Each reference plane is the horizontal plane in supine posture, and is the frontal plane in standing. Both planes include p_5. In Fig. 13, the frontal plane in standing is rotated to be corresponded with the horizontal plane in supine. The head shape angle is not the same for standing and supine posture.

We also found difference of the neck shape between standing and supine postures. The red solid and blue dotted curves shown in Fig. 13 represent change of the neck shape from standing to supine. These results indicate that the comfortable pillow shape is different from the SBHN in natural standing.

We compared supporting force distribution on the posterior head and neck, especially focusing on neck area. The forces on each point are calculated from the result of pressure distribution measurements. We assume the force peak of 3-point average is the same on the lowest point of the head area of estimated shape. Fig. 14 shows the experimental results of two subjects with different SBHN. The graph shows supporting force distribution when the each subject evaluated the best or the worst comfortable pillow. From the data, it seems that subjects with a shallow neck shape like Subject A prefer a weak force on using low neck pillow. On the other hand, subjects with a deeply curved neck shape like Subject B may prefer a strong neck support force on using high neck pillow. It means that a comfortable pillow supports users' neck moderately. This tendency is same for all subjects.



(a) Subject A (b) Subject B

Fig. 14: Supporting force distribution
Red lines are the results under using their best pillow. Each subject preferred the different supporting condition of neck area individually.

4 Conclusion

We compared SBHN (Shape of the Back of the Head and Neck) between natural standing and comfortable supine postures. To examine them, we developed a new measurement system for subject's SBHN. The results show that there is a clear shape difference between all subjects. SBHN in natural standing and comfortable supine are also different. This result suggests that comfortable pillows should be designed depending on each individual.

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