JESK
J Ergon Soc Korea 2017; 36(4): 281-292
http://dx.doi.org/10.5143/JESK.2017.36.4.281
http://jesk.or.kr eISSN:2093-8462

Ergonomic Design of Necklace Type Wearable Device

Jinsil Lee[1], Kimin Ban[1], Jaeho Choe[2], Eui S. Jung[1]

[1]Korea University, Department of Industrial Management Engineering, Seoul, 02841
[2]Daejin University, Department of Industrial and Management Engineering, Pocheon, 11159

Corresponding Author
Eui S. Jung
Korea University, Department of Industrial Management Engineering, Seoul, 02841
Phone : +82-2-3290-3391
Email : ejung@korea.ac.kr

Received : April 19, 2017
Revised : May 03, 2017
Accepted : May 29, 2017

Objective: This study aims to identify important physical design variables in designing a necklace type wearable device, and to present design guidelines to maximize comfort that a user feels upon wearing the device.

Background: Interests in fitness culture and personal health are on the rise recently. In such a situation, demand for necklace type wearable devices is projected to increase a lot, as the devices enable users to use their hands freely and to enjoy various contents through connection with mobile devices. However, the necklace type wearable device's comfort was assessed to have the lowest comfort in a running situation, where human body moves up and down and left and right more than other devices wearable on other human body parts. Therefore, the usability of a necklace type wearable device was low. In this regard, studies on identification of the variables affecting user comfort upon wearing a necklace type wearable device and on physical design direction maximizing comfort and usability are needed.

Method: A pretest and a main test were carried out to draw the direction of necklace type wearable device design. In the pretest, wearing evaluation on the diverse types of devices released in the market was conducted to draw physical design variables of the devices affecting comfort. Furthermore, variables significantly affecting the comfort of a device were selected through an analysis of variance (ANOVA). In the main test, anthropometry was performed, and information on anthropometric items corresponding to the design variables selected in the pretest was acquired. Based on the pretest results and the anthropometric information in the main test, the present study produced design guidelines maximizing the comfort of a necklace type wearable device with regard to major design variables upon dynamic tasks.

Results: According to the pretest results, the variables having effects on comfort were the angle of side points, width, and height. Due to interactions between variables, those need to be simultaneously considered upon designing a device. Upon dynamic tasks, the angle of side points and width of a device was designed to be smaller than mean angle of the trapezius muscle and neck width, and thus attachment to human body was high. As height was designed to be larger than mean neck front and rear point width, comfort was higher due to feeling of stability.

Conclusion: Because user sensitivity to comfort was high at human body's inflection points, a device needs to be designed for users not to feel high pressure on specific body parts with the device fitting human body shape well. A design considering user's situation is also required in further studies.

Keywords: Necklace wearable device, Ergonomic design, Comfort, Dynamic activity

1. Introduction & Literature Review

A wearable device refers to all human body-wearable computing devices. Starting with a study on attachment type wearable computing in the MIT Media Lab in the 1960s, various prototypes with input and output functions were made alongside further developed technology in the 1980s. As ubiquitous computing appeared and electronic devices became lighter in the 1990s, wearable devices became possible to be applied to industries in full swing (Kim and Jang, 2013). As mobile devices were activated since 2010, wearable devices have expanded to connected devices, and have been used in a real time information exchange fashion through M2M (machine to machine) communications. As interests in fitness culture and personal health increase recently, attention on wearable devices is on the rise. Especially, necklace type wearable devices have gained high recognition, because users can enjoy a variety of contents in exercises with connection with mobile devices such as smartphone. Various functions of necklace type wearable devices will be offered as infotainment, and users' demand will increase (Choi, 2016).

In the field of fashion, studies on enhancing comfort that humans feel in designing clothes humans wear have been conducted from the past, and an effort to reduce discomfort has been regarded as important in wearable devices. Domestic and international ergonomic and design experts have carried out diverse studies on the design and evaluation of wearable devices. It is necessary to design wearable devices by which users need to feel comfort and simultaneously not to feel the sense of difference and human's motions awkward through shape fitting human's body shape well (Kang, 2015; Hong, 2007; Knight et al., 2002; Gemperle et al., 1998).

Anthropometric information of a device to be designed varies enormously according to device or system, and anthropometry providing information on human body plays a pivotal role in designing devices or systems (Michod and Herron, 2006; Kroemer, 2006). Therefore many researchers conducted modelling of specific human body parts including the head and ear and let the models used in the relevant fields (Luximon et al., 2012; Zulkifli et al., 2014). In addition, there are various studies utilizing information on human body shapes for product design (Goonetilleke and Feizhou, 2001; Jung, 2016). It is required to reflect information on human shape acquired through anthropometry in designing wearable devices.

Although necklace type wearable devices are introduced in many studies as a form factor, due to a variety of biometrics that can be acquired from the neck, while they play a role of infotainment and gain high recognition as infotainment, users feel discomfort when they use them (Motti and Caine, 2014; Nagae and Suzuki, 2011; Rofouei et al., 2011). In dynamic tasks, necklace type wearable devices showed the lowest evaluation score on stability (Whether users are not tired and feel comfort despite wearing for a long time), attachment (Whether a device is designed not to move much on human body), and dynamic tasks (Whether the device is designed for human body to easily move), compared to the devices wearable on other human body parts including the head, wrist and chest. For this reason, studies on ergonomic design to improve such problems is needed (Kang, 2015). The neck-related anthropometric items of the Korean Agency for Technology and Standard are limited to the neck circumference of males and neck bottom circumferences of females utilized in designing garment, and thus, they are insufficient to be used for device design.

This study aimed to identify major design variables in designing necklace type wearable devices with low marketability due to discomfort in wearing them, despite high recognition of them, to acquire human body information required for device design, and to present design guidelines maximizing comfort in dynamic tasks.

This study carried out experiments by dividing it into a pretest and a main test. In the pretest, major design variables of necklace type wearable devices were identified. Based on this, standard per variable was defined through anthropometry to present design guidelines maximizing comfort, and the design guidelines were drawn via wearing evaluation. Previous studies revealed that the comfort of necklace type wearable devices in conducting dynamic tasks was evaluated to be the lowest, compared to the devises wearable on the other human parts, and that demand to people who enjoy fitness culture would increase. In this regard, this study allocated dynamic tasks performing walking and running as tasks so as to design suitable for user's wearing situation upon evaluation of wearing (Kang, 2015; Knight and Baber, 2005).

2. Pretest

The pretest attempted to identify major design variables in the design of a necklace type wearable device. Major design variables in necklace type wearable device design were drawn through previous study-based expert discussions. After wearing of the diverse necklace type wearable devices launched in the market were evaluated, major design variables significantly affecting comfort through repeated measures ANOVA were selected.

With ergonomic expert group discussions, major design variable candidates were drawn. Because comfort can be maximized, only when a wearable device is designed to fit human body shape, the characteristics of the organs, located at the neck and shoulder, where a necklace type wearable device is worn from the skeletal system, muscular system, nervous system, and cardiovascular system, were examined. Cervical vertebrae in the skeletal system, trapezius muscle and sternocleidomastoid in the muscular system, brachial plexus in the nervous system and carotid artery and jugular vein in the cardiovascular system were considered. Five ergonomic experts produced major design variables of necklace type wearable devices by wearing the various products launched in the market themselves. The produced design variable candidates were 1. Angle of the side points, 2. Height, 3. Width, 4. Width of lower part, 5. Angle of upper part, and 6. Circumference. Figure 1 shows them in the enumerated order.

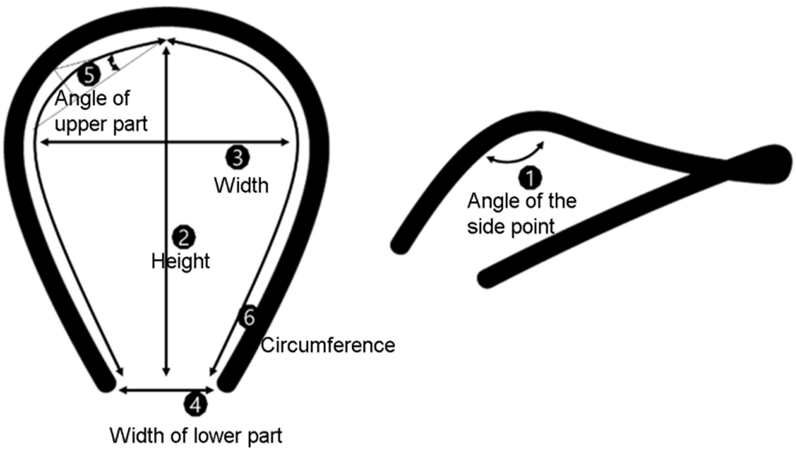

Figure 1. Design variables of necklace type wearable device

And then, major design variables affecting comfort were selected through wearing evaluation of those devices. Through wearing evaluation of 10 necklace type wearable devices (Figure 2), the variables significantly affecting comfort among the six design variables drawn by the ergonomic experts were selected as major design variables. The products, of which shape consists of free style due to being connected with string, were excluded from the evaluation subject. The brand-carved devises were controlled not to affect evaluation by attaching a tag to them.

Wearing evaluation was conducted in a lab, and sufficient spaces were prepared to carry out dynamic tasks. Evaluation was performed through three steps - evaluation preparation, evaluation practice, and wearing evaluation. In the first evaluation preparation step, the purpose of the experiment was explained. The definition of comfort, a dependent variable of the experiment, was explained to make the subjects sufficiently understand. Excluding visual design, evaluation was to be conducted on comfort felt with the sense of touch from the human body part where a device was worn. Also, each item of the 7-point bipolar numeric rating scale used in the experiment was explained (Pearson, 2009; Agarwal, 2006; Parent et al., 2000). For balanced sampling on neck

Figure 2. 10 Products launched in the market

size, male's neck circumference and female's bottom neck circumference, the representative anthropometric items related with the neck of the Korean Agency for Technology and Standard, were measured using a tape measure from Martin and recorded. In the second evaluation practice step, the subjects were to perceive that each device showed different shapes by wearing the 10 devices. An explanation on the 10 design variable candidates was offered, and interviews on the homogeneous group by variable were conducted so that the interview results can be used for ANOVA. The analysis was carried out by dividing into the groups with the highest frequency. Dynamic tasks were composed by referring to previous studies (Kang, 2015) (Table 1), and 60m walking and 80m running in which body is shaken up and down and left and right were allocated for dynamic tasks (Kang, 2015; Knight and Baber, 2005). In the third wearing evaluation step, the evaluation order was comprised according to Latin Square Randomization in order to control exogenous variables that may occur during the evaluation. The subjects wore the devices in line with order, and repeated 10 times of dynamic tasks and comfort evaluation. After evaluating three products, they took a rest for 3 to 5 minutes so as to precisely evaluate by blocking the slowdown of the sense of touch.

Table 1. Descriptions for dynamic task

Task	Descriptions
Dynamic task	Walking 60 meters per minute (=3.6km/h)
	Running 80 meters per 30 seconds (=9.6km/h)

Users from the middle of 20s and up to 30s with high interest in wearable devices and fitness health and higher intention to buy wearable devices in the future were selected as subjects (Kang, 2015). The subjects participated in the experiment were 25 Koreans in their 20s and 30s. Their mean age was 27.6 (SD=3.9), and the gender ratio was balanced with 13 males and 12 females. By choosing neck circumference (male) and bottom neck circumference (female) as representative anthropometric items, the subjects' neck size was balanced. Two males and two females belonged to 5%tile, two males and three females 25%tile, three males and three females 50%tile, three males and two females 75%tile, and three males and two females 95%tile.

To examine what design variables affect the comfort of necklace type wearable devices, repeated measures ANOVA was carried out using IBM SPSS Statics 24. At significance level of 0.05, the angle of side point, height, and width affected devices' comfort (Table 2).

Table 2. *F*-value and *p*-value of necklace type wearable device design variables

Variable	*F*-value	*p*-value
Angle of the side point	$F(1, 299)=8.611$	0.004**
Height	$F(1, 299)=9.154$	0.003**
Width	$F(2, 298)=3.344$	0.037*
Width of lower part	$F(1, 299)=1.415$	0.235
Angle of upper part	$F(1, 299)=2.563$	0.110
Circumference	$F(1, 299)=0.303$	0.582

$^{*}p<.05$, $^{**}p<.01$

3. Main Test

The main test attempted to produce design guidelines maximizing the comfort of necklace type wearable devices upon dynamic tasks. Prior to carrying out the main test, the standards of device's major design variables were defined through anthropometry, and wearing evaluation was conducted with the produced prototype in this study, and design guidelines maximizing the comfort of necklace type wearable devices were drawn. To design a device suitable for user's wearing situation upon evaluation, the subjects were instructed to carry out dynamic tasks, namely, walking and running (Kang, 2015; Knight and Baber, 2005).

In the anthropometric step, anthropometric items corresponding to devices' major design variables were defined through human body reference points, and measurements were undertaken using a 3D scanner.

As for the reference point, 1. Reck rear point (x1, y1, z1), 2. Neck front point (x2, y2, z2), 3. Neck right side point (x3, y3, z3), and 4. Neck left side point (x4, y4, z4), located on the neck and shoulder among the directly measured reference points of the Korean Agency for Technology and Standard, were referred to. And 5. Neck central point (x3+x4)/2, (y3+y4)/2, (z3+z4)/2), the central point between the neck side points was defined as a new reference point (Figure 3). A design variable, the angle of side point, corresponds to the angle of the trapezius muscle formed by neck rear point, neck central point between side points and neck front point. A design variable, height, corresponds to width between neck front and rear points. Width matches width between neck side points, which can be the distance between neck right side point and neck left side point. In an effort to enhance accuracy, anthropometry was performed using a 3D scanner, and from which information on the anthropometric items defined above was acquired.

The measurements were carried out in anthropometric sitting position, and a 3D scanner was used to enhance the accuracy by reducing measurement errors. Using 3D system' sense (spatial x/y resolution at 0.5m is 0.9mm and depth resolution at 0.5m is 1mm), anthropometric values suitable for the standard of ISO 15535 were produced (Figure 3). Using a tape measure, which can be Martin anthropometric meter, measurements were carried out simultaneously, and males' neck circumference and females' bottom neck circumference were measured for stratified sampling.

The subjects participated in the experiment were 30 Koreans in their 20s and 30s, and their mean age was 27.1 (SD=2.2). As seen in the pretest, the gender ratio was balance with 15 males and females, each. Through direct measurement, balancing on

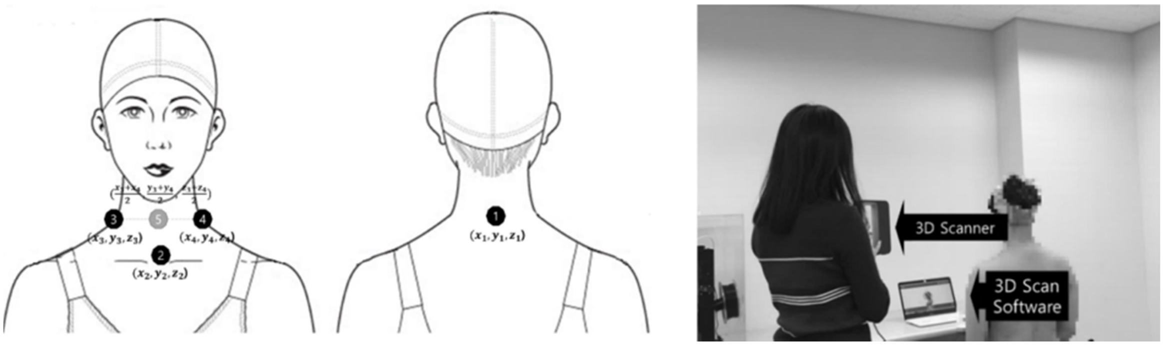

Figure 3. Reference points of neck measurements and the picture of 3D scanning

the neck size was conducted. Three males and three females belonged to 5%tile, three males and three females 25%tile, three male and three females 50%tile, three males and three females 75%tile, and three males and three females 95%tile.

3D scan data were analyzed through three steps. First, each reference point coordinate was acquired by calling 3d scan data with 3D Max. Second, coordinates were pasted to the Excel sheet. Lastly, numeric values on anthropometric items from the coordinates were acquired (Table 3).

Table 3. Information about the human neck (N=30)

Anthropometric item (unit)	M ± SD	5%ile	50%ile	95%ile
Angle of trapezius muscle (°)	157.7±11.4 (°)	139.4°	159.1°	179.5°
Width between neck front and rear point (mm)	135.4±8.9 (mm)	121.2mm	134.5mm	149.6mm
Width between neck side points (mm)	124.5±5.4 (mm)	115.7mm	124.2mm	134.8mm

Based on the devices' major design variables produced in the pretest, and also anthropometric information drawn through anthropometry, an experiment plan was carried out. Through full factor experimental design, design guidelines considering the relationship between variables were to be produced. Major design variables' levels were defined based on the anthropometric results. By selecting 140°, 160°, and 180°, which are 5%tile, 50%tile, and 95%tile of the trapezius muscle of the total subjects in terms of side points among the anthropometric items, three levels were set up. With regard to height, the levels were defined as 120mm, 135mm, and 150mm, which are respectively 5%tile, 50%tile, and 95%tile of the total subjects' neck front and rear points. Width's levels were defined as 115mm, 125mm, and 135mm, which are 5%tile, 50%tile, and 95%tile of the total subjects' neck circumference. Other design variables were controlled by No. 10 products' design specifications that gained the highest score in comfort in the pretest, and 27 prototypes in total were designed (Table 4).

When a prototype is produced, three steps were undergone. First, frame was made with elastic wire for a device to be realistically worn. Second, weight was controlled using wire made of lead wrapped on the frame with equal distance, and thus weight was made evenly distributed. Although weight is an important variable in product design, there is a limitation due to technical constraints to reduce below a certain weight. In the main test, the weight was controlled to the median weight, 36.4kg, through investigation of 10 various products launched in the market. Through this, the drawn guidelines in the main test were to be applied to actual

Table 4. Levels of necklace type wearable device design variables

Level	Angle of side point (°)	Height (mm)	Width (mm)
Low	140°	120mm	115mm
Middle	160°	135mm	125mm
High	180°	150mm	135mm

product's weight. Third, the experimental alternative shape was composed by attaching Amos I-clay with high friction force similar to the plastic material with low gloss used in the actual products (Jeong et al., 1999). The shape other than the major design variables was composed equal to the No. 10 product's shape, of which comfort was highest among the 10 wearing evaluation subjects in the first study, and thus exogenous variables were controlled (Figure 4).

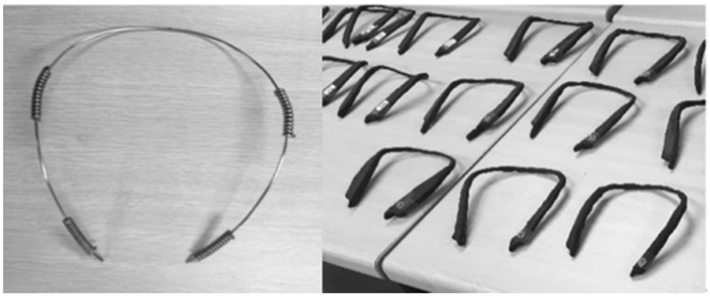

Figure 4. Frame of the prototype wrapped with a thin wire and clay having high friction force

The mode and venue for wearing evaluation was the same as in the pretest. To control exogenous variables that may occur during the evaluation, Latin Square Randomization was used. The subjects participating in the main test were 26 Koreans in their 20s and 30s, and their mean age was 28.5 (SD=4.3), and males were 14, and females were 12 people. Three males and two females belonged to 5%ile, three males and three females 25%tile, three males and three females 50%ile, three males and two females 75%ile, and two males and two females 95%tile.

4. Results

After examining the significance of design variables through ANOVA and a post-hoc analysis using Minitab 16, design guidelines maximizing comfort were produced. According to the post-hoc analysis results, this study drew relationships between comfort and major design variables through a regression analysis.

As a result of the analysis, main effects of the angle of side points, height, and width, and the second-phase interactions of width and height, and the third-phase interactions of the variables significantly affected the comfort of necklace type wearable devices at significance level of 0.05 (Table 5). Figure 5 shows the plot of each variable's comfort score and the interactions of neck side-point width and neck front width, where the second-phase interactions existed (Figure 5). The prototype with 140° in the angle of side points, 115mm in width, and 150mm in height acquired the highest comfort score.

By referring to the post-hoc analysis results, the initial stage regression model was built including second-order terms, first-order

Table 5. ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*p*
Angle of side point	2	134.283	134.283	67.141	131.75	0.000***
Height	2	16.094	16.094	8.047	15.79	0.000***
Width	2	60.84	60.84	30.42	59.69	0.000***
Angle of side point*Height	4	3.961	3.961	0.99	1.94	0.102
Angle of side point*Width	4	1.37	1.37	0.342	0.67	0.612
Height*Width	4	59.038	59.038	14.76	28.96	0.000***
Angle of side point*Height*Width	8	230.082	230.082	28.76	56.44	0.000***
Error	675	343.98	343.98	0.51		
Total	701	849.648				

*p<.05, **p<.01, ***p<.001

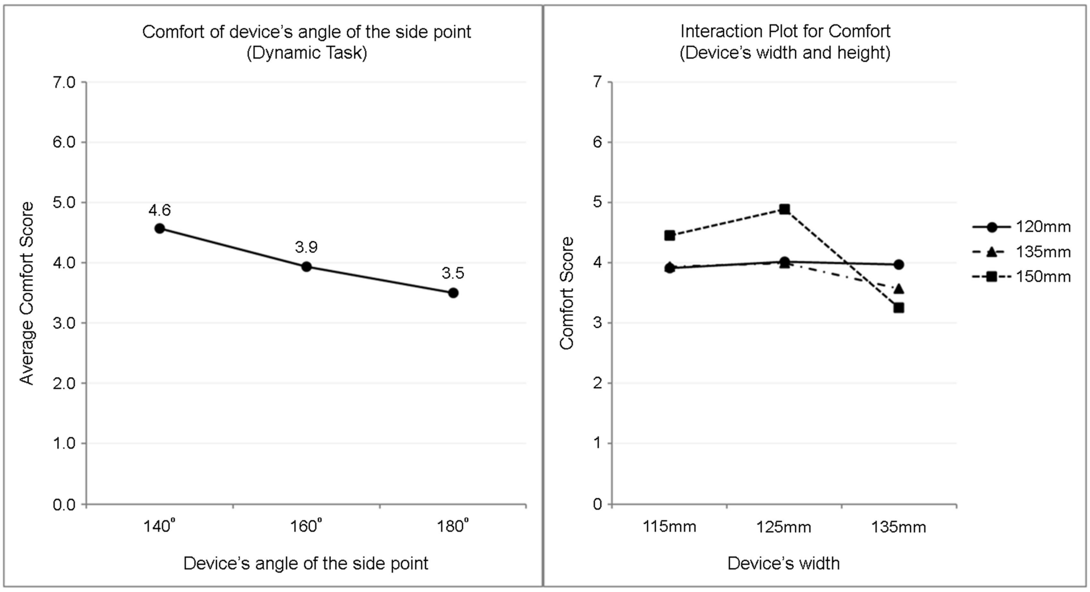

Figure 5. Average comfort score for device's angle of the side point in dynamic task and interaction plot for comfort of the device's width and height

term, and second-order interaction terms on three major design variables. The regression model with high explanation power and low Mellow's Cp value was selected as the final regression model of the present study. The relationship between comfort and major design variables can be expressed as shown in the following equation: All the coefficients were significant at the significance level of 0.05, and revised explanation power was 0.58.

$$\text{Comfort} = -0.005 \times \text{width}^2 + 0.001 \times \text{height}^2 - 0.002 \times \text{width} \times \text{height} - 0.031 \times \text{angle of side points} + 1.482 \times \text{width} - 83.578$$

5. Discussion and Conclusion

As demand of wearable devices is on the rise, studies on the devices having various form factors have been conducted. Although a necklace type wearable device has been introduced in various studies as one of the form factors, the relevant studies are insufficient, and information on human body that can be used for design has been lacking. In this regard, the pretest identified major device variables in designing a necklace type wearable device. The main test digitized anthropometric items corresponding to design variables to be used for design through human body measurements. With the produced prototypes, wearing evaluation was conducted to present optimum shape maximizing comfort upon dynamic tasks. In the Discussion & Conclusion, study results are summarized, and the things to consider in designing a necklace type wearable device are discussed, and conclusion is presented.

According to the pretest results, the design variables significantly affecting the comfort of necklace type wearable devices were angle of side points, height, and width. The design variables are the variables that can be explained through human body's measurable reference points existing on the neck and shoulder. It was found that users' sensitivity of comfort at human body's inflection points was high and that a necklace type wearable device needs to be designed not to make users feel high pressure on the specific body part by letting the device fit the human body shape well. The assertion of previous studies that ergonomic design needs to be decided by taking into account users' anthropometry and extra spaces is consistent with the results of this present study (Jung, 2016).

Dynamic task is defined as human's moving by walking or running and thus human physically moves or human body moves up and down and left and right. In such a situation, comfort tends to be high, when the angle of side points of a device are designed smaller than human body. With sufficiently small angle of side points, it was grasped that users feel comfort much, when a device is attached to human body (Kang, 2015; Kang and Kim, 2012; Chae et al., 2006).

Height and width, where the second-phase interactions existed should be considered. Comfort was higher, when width was suitable for average human body and when height was longer than human body. However, a result that comfort score rapidly fell was drawn, when height and width were both at high level. Through this, it was known that device's attachment to human body is very important upon dynamic tasks. When optimum design guidelines are produced due to the third-phase interactions existence between three major design variables, the three variables need to be simultaneously considered. When the angle of side points was smaller, height was longer, and width was shorter than anthropology, the comfort score was highest. The result is consistent with the regression analysis result. In device design, the angle of side points and width need to be smaller than mean angle of the trapezius muscle and neck width so that a device needs to be attached to human body sufficiently. Height needs to be designed longer than the width of mean neck front and rear point width to make users wear a device stably. In such a case, comfort was high. It was identified that devices' attachment to human body, sensitivity on comfort, and user situation should be simultaneously considered to make level of contact to human body by variable different.

This study quantitatively identified major design variables that need to be considered materially in designing a necklace type wearable device, and conducted anthropometry using a 3D scanner. Based on such information, this study presented design guidelines upon dynamic tasks. The information presented this study is expected to be used in various fields such as product design. In a previous study on use convenience by wearable health care device form factor type, necklace type wearable devices showed low score in stability that is defined as not feeling fatigue in dynamic tasks, and as the level of convenience (Kang, 2015). If a device is designed through the present study result, higher satisfaction is anticipated to be offered to users with enhanced comfort on devices.

However, the study's limitation can be that various design variables, such as device's weight, weight distribution, balance, and material that makes a user feel discomfort through the sense of touch, were not considered. Although the study controlled gender to set up user groups with males and females in their 20s and 30s who were projected to be main users, anthropometric variables related with design variables can be classified into different groups according to gender and age. A further study may draw optimum design by classifying groups in line with study purpose. In this study, dynamic tasks were allocated as walking and running to improve the comfort of necklace type wearable devices, when the subjects carry out for example running in which they move up and down and left and right, a further should take into account a task like ascending/descending stairs in which high level of change occurs for generalization of dynamic tasks. Lastly, not only comfort, but attachment by which a device is judged to be designed well not to move on human body and human body motions on whether human body can easily move are presented in various studies in wearable device design (Kang, 2015; Hong, 2007; Knight et al., 2002; Gemperle et al., 1998). A further study could meet human's multidimensional needs through evaluation based on multidimensional scale, if optimum design is carried out.

References

Agarwal, A., Volumetric Deformation: A New Objective Measure to Study Chair Comfort Using 3D Body Scanning Technology *[Honors Thesis]. Cornell University*, 2006, http://ecommons.cornell.edu/handle/1813/3130.

Chae, H., Hong, J., Cho, H., Lee, Y., Park, S., Han, K. and Lee, J., The Development of Usability Evaluation for Wearable Computer: An Investigation of Smart Clothing, *Korean Journal of the Science of Emotion & Sensibility*, 9(3), pp. 265-272, 2006.

Choi, J., How should we prepare for the super-connected society that is made by smart new people?, *42th KISTEP Forum*, http://www.ictconference.kr/sub/pdf/day2/004(%EC%B5%9C%EC%9E%AC%EB%B6%95).pdf (2016)

Gemperle, F., Kasabach, C., Stivoric, J., Bauer, M. and Martin, R., Design for Wearability, *Digest of Papers. Second International Symposium on Wearable Computers (Cat. No.98EX215), Pittsburgh, PA, USA*, pp. 116-122, 1998.

Goonetilleke, R.S. and Feizhou, S., A Methodology to Determine the Optimum Seat Depth, *International Journal of Industrial Ergonomics*, 27(4), pp. 207-217, 2001.

Hong, J.Y., Study on Requirement Investigation and Development of Usability Evaluation for Wearable Computers: Toward Smartwear, *Doctoral thesis of Yonsei University*, 94(24), 2007.

Jeong, Y.D., Hwang, S.H. and Lee, M.H., The Effects of Molding Conditions on the Surface Gloss of ABS Molding. *Journal of the Korean Society for Precision Engineering*, 16(4), 110-115, 1999.

Jung, H., An Ergonomic Vehicle Moving Handle Design and Evaluation Method for Grip Comfort, *Master's thesis of Pohang University of Science and Technology*, 2016.

Kang, D., (A) Study on Form Factor of Heart Rate Measurement Wearable Fitness Tracker in Human Factor Perspective, *Master's thesis of Kookmin University,* 2015.

Kang, S. and Kim, E., Design Process for Improving the Wearability of Wearable Computers: A Guideline based on the integration of HCI and Fashion Design, *the Conference on The HCI Society of Korea*, pp. 787-789, 2012.

Kim, D. and Jang, J., A Study on Pattern Development of Men's Slim-fit Dress Shirt: Focus on the 25-35 aged men, *Journal of the Korean Society of Clothing Industry*, 15(6), pp. 950-962, 2013.

Knight, J.F. and Baber, C., A Tool to Assess the Comfort of Wearable Computers, *Human Factors*, 47(1), pp. 77-91, 2005 Spring.

Knight, J.F., Baber, C., Schwirtz, A. and Bristow, H.W., The Comfort Assessment of Wearable Computers. Proceedings, *Sixth International Symposium on Wearable Computers*, pp. 65-72, 2002.

Kroemer, K.H.E., *Anthropometry*, International Encyclopedia of Ergonomics and Human Factors., Edited by Waldemar Karwowski, 2nd Edition, p. 242, 2006.

Luximon, Y., Ball, R. and Justice, L., The 3D Chinese Head and Face Modeling, *Computer-Aided Design*, 44(1), pp. 40-47, 2012.

Michod, R.E. and Herron, M.D., Cooperation and Conflict during Evolutionary Transitions in Individuality, *Journal of Evolutionary Biology*, 19(5), pp. 1406-1409, 2006.

Motti, V.G. and Caine, K., Human Factors Considerations in the Design of Wearable Devices, *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting*, pp. 1820-1824, 2014.

Nagae, M. and Suzuki, K., "A neck mounted interface for sensing the swallowing activity based on swallowing sound," *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Boston, MA, pp. 5224-5227, 2011.

Parent, F., Dansereau, J., Lacoste, M. and Aissaoui, R., Evaluation of the New Flexible Contour Backrest for Wheelchairs. *J Rehabil Res Dev*, 37, pp. 325-333, 2000.

Pearson, E.J., Comfort and its measurement - a literature review. *Disability and Rehabilitation: Assistive Technology*, 4(5), pp. 301-310, 2009.

Rofouei, M., Sinclairm, M., Bittner, R., Blank, T., Saw, N., DeJean, G. and Heffron, J., A Non-invasive Wearable Neck-Cuff System for Real-Time Sleep Monitoring, *2011 International Conference on Body Sensor Networks, Dallas, TX*, pp. 156-161, 2011.

Zulkifli, N., Yusof, F. and Rashid, R., Anthropometric Comparison of Cross-Sectional External Ear between Monozygotic Twin. *Ann Forensic Res Anal*, 1(2), pp. 1010-1015, 2014.

Author listings

Jinsil Lee: leejinsil52@korea.ac.kr
Highest degree: BA, Department of Industrial Management Engineering, Korea University
Position title: Master's Student, Department of Industrial Management Engineering, Korea University
Areas of interest: Product Development and UX Design

Kimin Ban: kmban@korea.ac.kr
Highest degree: MA, Department of Industrial Management Engineering, Korea University
Position title: Doctoral Student, Department of Industrial Management Engineering, Korea University
Areas of interest: Product Development and UX Design

Jaeho Choe: jhchoe@daejin.ac.kr
Highest degree: PhD, Department of Industrial Engineering, Pohang University of Science and Technology
Position title: Professor, Department of Industrial Management Engineering, Daejin University
Areas of interest: Product Development

Eui S. Jung: ejung@korea.ac.kr
Highest degree: PhD, Department of Industrial Engineering, Pennsylvania State University
Position title: Professor, Department of Industrial Management Engineering, Korea University
Areas of interest: Product Development