The Effects of Ear Dimensions and Product Attributes on the Wearing Comfort of Wireless Earphones

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Abstract: The purpose of this study was to evaluate the wearing comfort of wireless earphones. In order to test the effects of ear dimensions with the product characteristics on wearing comfort, first, a total of six ear dimensions were selected. In addition, each ear dimension was classified into two groups using K-means clustering analysis. Second, four major factors related to wearing comfort (pain, pressure, comfort, and fixation) with four sample products were investigated, considering the characteristics of the product (kernel-type/open-type), operation method (touch-input/button-press), and shape. Finally, a total of 38 participants (23 men and 15 women) participated in the experiments. The results show that pain in the ear canal was low to the participants who had a long length of the ear canal–incisura intertragica, and the fixation of the ear canal was high in the participants with a long incisura intertragica–antitragus cluster. Compared to open-type products, kernel-type products put more pressure on the ear canal area, so the participants felt less comfortable. In terms of operation methods, operating products in touch-input types caused less pain than operating products in button-press types did. Overall, the factors affecting user satisfaction and wearing comfort determined in this study will serve as a basis for the future design of wireless earphone products.

Keywords: wireless earphone; ear dimension; ear; wearing comfort; comfort

1. Introduction

The wireless earphone market has been showing rapid growth in recent years and was expected to reach 120 million units globally in 2019. The wireless earphone manufacturers, as well as global IT companies (e.g., Amazon and Microsoft) are expected to reach 230 million units in 2020, which is a 90% increase over 2019 [1]. Wireless earphones can provide a new user experience that traditional earphones cannot provide. Therefore, it is necessary to establish a factor of user satisfaction, among the various user satisfaction factors, wearing comfort could be the main factor affecting the experience of using wireless earphones. Wearable products such as wireless earphones require attention to anthropometric and product design characteristics [2]. In order to provide a comfortable fit through ergonomically designed products, it is important to measure relevant anthropometric parameters and design the products accordingly [3–6].

In order to investigate anthropometric factors affecting the comfort of wearing wireless earphones, it is necessary to consider the user behavior and weight of the product, as well as all contact areas in the ear for various factors related to the wearing comfort. However, previous studies have not fully evaluated user satisfaction or user experience in this aspect, with several limitations regarding the use of existing earphones. First, Jung and Jung (2003) [7] provided product design guidelines by comparing and analyzing ear sizes and ear-related product sizes. However, anthropometric variables related to
the use of earphones were limited to one ear canal area, and research on other ear dimensions related to the use of earphones was insufficient. Moreover, design dimensions were proposed by comparing the size of the ear with the size of the associated product, but no satisfaction with the actual user’s suitability to the proposed design dimensions was identified. Second, Liu (2008) [6] measured 200 ear dimensions and suggested the design dimensions of the earphones compared to the sample products, but the various human ear dimensions that affect wearing comfort were not considered by limiting the ear dimensions to the ear canal length. Third, Chiu et al. (2014) [8] conducted a study to evaluate the wearing comfort of Bluetooth earphones for 30 min in a given scenario. The difference in comfort, pain, and weight was investigated depending on the type of product, gender, ear, etc. In addition, the evaluation questionnaire provided detailed footage of ears and identified subjective pain in each area. Although this study evaluated overall comfort according to design characteristics, there is still a lack of research on pain and comfort in terms of ear dimensions and various other factors related to wearing comfort. Firth, Fu and Luximon (2020) [9] proposed universal criteria for ear-related products to represent human variability using 3D anthropometry, considering different demographic features of an external ear; however, they stated that direct scanning of the ear canal was still difficult. Therefore, it is necessary to explore 3D anthropometric applications in further research to overcome difficulties for practical use. In particular, it could not be applicable in scanning an internal ear for designing ear-related products such as kernel-type earphones. Fifth, Ji et al. (2018) [10] classified the different ear shapes in 24 groups in terms of the auricular concha, using data from 310 young Chinese people aged 18–28 years. However, participants made up a large percentage of only a small group. As a result, it was difficult to reach an agreement for universal design, providing only a limited number of individualities rather than securing design uniformity. Therefore, for the latest wireless earphones, the findings of the existing research could not be applied because they were obtained on wired earphones or less-used forms of Bluetooth earphones. In conclusion, the design, operation method, and wearing comfort of the latest wireless earphones should be considered.

In general, wireless earphones are heavy in weight because of internal components such as a battery, DAC (digital to analog converter), wireless communication modules, etc. For this reason, the wireless earphones are not fixed enough to ears, causing pain if worn for a long time. Therefore, it is important to identify design factors related to significant ear dimensions for developing well-fixed and comfortable wireless earphones. The purpose of this study is to evaluate the wearing comfort and design appropriateness of wireless earphones in relation to ear dimensions and product design factors. After reviewing existing research, we identified ear dimensions and evaluation items affecting the wearing comfort of wireless earphones with respect to the contact area. Consequently, we tried to identify the relationships between ear dimensions and the wearing comfort of products which were selected based on the market research on wireless earphones. Finally, we propose wireless earphone design guidelines, which can serve as a basis for their future design and universal application.

2. Methods

The overall process of this study is shown in Figure 1 and is divided into four stages. First, in the sample product selection stage, the product list was created based on market research about wireless earphones, and the wireless earphones for evaluation were selected through product selection criteria suitable for research. Second, in the ear dimension selection phase, the relevant ear dimensions were identified through the literature reviews on earphones and ear dimensions, and the area of the ear in contact with wireless earphones was identified to select the human dimension variables related to wireless earphones. Third, in the evaluation item selection phase, the wearing comfort and suitability of product design factors were selected for evaluation. Finally, the wearing comfort evaluation was conducted following an evaluation scenario, and the ear dimensions were measured before the evaluation.
2.1. Sample Products

In order to evaluate the user experience of the latest wireless earphones, we reviewed products currently on the market and selected suitable sample products. A total of 16 products currently on sale were identified through a search of a major internet shopping mall in South Korea (NAVER shopping; NAVER is South Korean online portal site). The products were classified by product characteristics (kernel-type/open-type), operation method (touch-input/button-press) and appearance of the product (main body of earphone), and a total of four sample products were finally selected with balanced product characteristics (Table 1).

| Overall shape | Sample Product 1 | Sample Product 2 | Sample Product 3 | Sample Product 4 |
|---------------|------------------|------------------|------------------|------------------|
| Name          | Samsung-Galaxy buds | Apple-Air pods 2 | Harman (JBL)-TUNE 120 | SABBAT-X12 PRO |
| Type          | Kernel           | Open             | Kernel           | Open             |
| Control       | Touch            | Touch            | Button           | Button           |
| Weight        | 5 g              | 4 g              | 7 g              | 5 g              |
| Size (cm)     | 1.7 × 1.7        | 1.7 × 4.0        | 2.7 × 1.9        | 2.2 × 2.5        |
| Ear canal area size (cm) | 0.6–0.8   | 0.8             | 0.9–1.2          | 0.8            |
| Concha area size (cm) | 1.7 × 1.7 | 1.7 × 1.7 | 1.7 × 1.7 | 2.2 × 2 |
| Depth (cm)    | 1.2              | 1                | 1.5              | 0.8              |

2.2. Selection of Ear Dimension Variables Related to Wireless Earphones

To select ear dimensions for wireless earphones, we collected key points and measurement variables for ear measurement based on the previous studies on ear measurement [11–17]. Prior to selecting the relevant ear size, four products selected as sample products were worn to identify the area of the ear in contact with the wireless earphone. The ear canal area and concha area were selected as the main measurement areas for this experiment. Based on the previous studies on ear dimension measurements [7], relevant dimensions were selected in consideration of the actual contact area of the wireless earphone, and finally, seven major points: anterior cymba concha, posterior concha, the upper
point of ear canal, the lower point of the ear canal, incisura intertragica, the horizontal endpoint of the ear canal, antitragus (Figure 2) and the six ear dimensions were selected (Table 2).

![Selected points for measuring ear dimensions.](image)

**Table 2.** Ear dimensions related to the use of wireless earphones.

| Ear Dimensions     | Definition                                                                 | Description |
|--------------------|-----------------------------------------------------------------------------|-------------|
| Concha length      | The length between the anterior cymba concha and the incisura intertragica was measured (point 1–3). This is the region that comes in contact with the main body of wireless earphones (operating part). | ![Image]    |
| Concha width       | The length between the incisura intertragica and the posterior concha was measured (point 2–3). This is the part that comes in contact with the main body of wireless earphones (operating part). | ![Image]    |
| Ear canal length   | The length between the superior ear canal and the inferior ear canal was measured (point 4–5). This region comes in contact with the ear tip of the wireless earphone. | ![Image]    |
Table 2. Cont.

| Ear Dimensions          | Definition                                                                 | Description |
|-------------------------|---------------------------------------------------------------------------|-------------|
| Ear canal width         | The horizontal length of the ear canal (the distance between the left and right point 6) was measured, and it is the part that comes in contact with the ear tip of the wireless earphone. | ![Image](image1.png) |
| Ear canal–incisura intertragica length | The length between the horizontal endpoint of the ear canal and the incisura intertragica was measured (point 3–6). This is the part of the product that comes in close contact with the inside of the ear. | ![Image](image2.png) |
| Incisura intertragica–antitragus length | The length between the incisura intertragica and the antitragus was measured (point 3–7). This is the area that contacts the base of the product. | ![Image](image3.png) |

2.3. Evaluation of the User Experience of Wireless Earphones and Determination of Factors Related to Wearing Comfort

We collected about 200 consumer reviews of wireless earphones in Korean internet shopping malls to identify factors that users consider important. Comfort, pain, pressure, and fixation were identified as factors affecting wearing comfort and were evaluated separately at the ear canal and concha (Table 3). Finally, the design characteristics of the product, including weight, size, material, and form, were determined, and a conformity survey was conducted (Table 4). The relevant dimensions were evaluated using a 7-point Likert scale.

Table 3. Evaluation questionnaires for wearing comfort.

| Category                | Questionnaire                                                                 |
|-------------------------|-------------------------------------------------------------------------------|
| Comfort                 | Is the concha area comfortable when you are wearing the product?               |
|                         | Is the ear canal area comfortable when you are wearing the product?           |
| Pain while wearing      | Did you feel pain in the concha area when you first used the product?         |
|                         | Did you feel pain in the ear canal area when you first used the product?      |
| Pain after usage        | Do you feel any pain in the concha area after using the product?              |
|                         | Do you feel any pain in the ear canal area after using the product?           |
| Pain while operating    | Do you feel pain in the concha area when you operate the product?             |
|                         | Do you feel pain in the ear canal area when you operate the product?          |
| Pressure                | Do you feel pressure in the concha area when you are wearing the product?    |
|                         | Do you feel pressure in the ear canal area when you are wearing the product?  |
| Fixation                | When wearing the product, does it come out of the concha area easily?         |
|                         | When wearing the product, does it come out of the ear canal area easily?      |
| Overall wearing comfort | Is the overall wearing comfort satisfactory?                                   |

7-point Likert scale
Table 4. Evaluation questionnaires for the appropriateness of the device design.

| Category | Questionnaires | Likert scale |
|----------|----------------|--------------|
| Size     | Is the size of the earphone touching the ear canal appropriate for use? Is the size of the head of the earphone (operating part) appropriate for use? | 7-point       |
| Texture  | Is the contact between the material of the earphone and the earhole appropriate? |              |
| Weight   | Is the weight of the earphones optimal for use? | 7-point Likert scale |
| Shape    | Do you think that the shape of the head of the earphone (the operating part) is appropriate for use? |              |

2.4. Experiment for Evaluating Comfort and Design Appropriateness

The participant’s ear dimensions were measured before the evaluation. The ear dimensions were measured using the Martin anthropometer, and the average value was recorded after measuring them three times (Figure 3). The wearing comfort of each sample product was evaluated according to premeditated scenarios such as walking or running in one place. In the evaluation of wearing comfort, a total of four wireless earphones were used, and the participants evaluated one earphone in 20 min with a one-minute break (Figure 3).

Figure 3. The evaluation process of the wearing comfort for wireless earphones.

2.5. Data Analysis

The SPSS 26.0 (IBM Corporation, Armonk, NY, USA) was used to analyze the collected data. All levels of statistical significance were set at 0.05. In order to identify the wearing comfort according to the human dimensions of the ear, the ear dimensions were clustered through a K-means clustering analysis, and independent t-tests were performed for comparisons between clusters. One-way analysis of variance (ANOVA) and Duncan post hoc tests were used to analyze the differences in wearing comfort and design appropriateness among products.
3. Results

3.1. Participants

In this study, 38 participants in their 20s (mean age = 25.92; SD = 2.99; male: 23 and female: 15) performed the user experience evaluation and measurement of ear dimensions. A total of 23 participants (60.5%) had regularly used their own wireless earphones, and the rest of the 15 participants (39.5%) had not. The average daily earphone usage time was 163 min (Min: 10; Max: 540; SD: 144.73), with the most time spent listening to music and talking on the phone (Tables 5 and 6).

Table 5. Demographics I—participant characteristics.

| Type                         | Min | Max | Mean  | SD   |
|------------------------------|-----|-----|-------|------|
| Age                         | 21  | 30  | 25.92 | 2.99 |
| Average usage time of        | 10  | 540 | 163.16| 144.73|
| wireless earphones per day (min) |     |     |       |      |

Table 6. Demographics II—participant classification by the status of earphone usage.

| Type                        | Classification | Frequency | Ratio (%) |
|-----------------------------|----------------|-----------|-----------|
| Sex (n = 38)                | Male           | 23        | 60.5      |
|                             | Female         | 15        | 39.5      |
| Wireless earphone possession (n = 38) | Possession    | 23        | 60.5      |
|                             | Non-possession | 15        | 39.5      |
| Major purpose of use (n = 38) | Listening to music | 23        | 61.6      |
|                             | Phone call     | 14        | 36.8      |
|                             | Other (Watching videos) | 1         | 2.6      |

3.2. Differences in Wearing Comfort and Design Appropriateness between Sample Products

ANOVA analysis was performed to identify differences between four sample products, and the results, showing significant differences between products, are presented in Figure 4. Overall, both sample product one and sample product two were scored highly. In terms of wearing comfort without pain in the ear canal area, sample product one scored the highest. On the contrary, both sample product three and sample product four had relatively low scores in wearing comfort. In particular, sample product three was found to have a high level of pain in the area of the ear canal, and sample product four had low levels of comfort for the concha area and overall fixation.

Figure 4. Results of ANOVA for wearing comfort by products (**: p < 0.01).

The results of the appropriateness of product design are shown in Figure 5. First, sample product one and sample product two received comparably higher scores than sample product three and sample
product four did. In particular, sample product three scored the lowest for its weight, shape, and size of area contacting the ear canal while sample product four showed low appropriateness scores for its size of operation part (head size) and overall size.

**Figure 5.** Results of ANOVA for appropriateness of product designs (**: p < 0.01).**

3.3. Classification of Ear Dimension (K-Means Clustering)

Six ear dimensions were selected and grouped into two clusters using K-means clustering analysis to test the effect of the difference in ear size (Table 7). The K-means clustering analysis is an algorithm that combines given data into K clusters and works in a way that minimizes the variance of the distance difference with each cluster. In this study, the size of the human body was divided into two groups of small and large, to more clearly identify how each of the relevant body dimensions relates to the wearing comfort of wireless earphones. The K-means algorithm was used to allow similar-sized human dimensions to be effectively grouped into one group. The center value of the first cluster was smaller than that of the second cluster for the following three dimensions: concha length, ear canal–incisura intertragica length, and incisura intertragica–antitragus length. On the other hand, the center value of the first cluster was greater than that of the second cluster for the following three dimensions: concha width, ear canal length, and ear canal width. Descriptive statistics (number of participants, mean, and SD) of measured ear dimensions for cluster one and cluster two (unit: cm) are presented in Table 7.

| Variables                                      | Cluster 1 |                  | Cluster 2 |                  |
|------------------------------------------------|-----------|------------------|-----------|------------------|
|                                                 | N  | Mean | SD | N  | Mean | SD |
| Concha length                                   | 23 | 2.59 | 0.11 | 15 | 3.00 | 0.09 |
| Concha width                                    | 22 | 2.08 | 0.17 | 16 | 1.58 | 0.15 |
| Ear canal length                                | 13 | 0.91 | 0.09 | 25 | 0.64 | 0.09 |
| Ear canal width                                 | 25 | 0.65 | 0.06 | 13 | 0.49 | 0.05 |
| Ear canal–incisura intertragica length          | 20 | 1.17 | 0.11 | 18 | 1.53 | 0.11 |
| Incisura intertragica–antitragus length         | 20 | 0.75 | 0.12 | 18 | 1.13 | 0.18 |

3.4. Relationship between Ear Size and Wearing Comfort

An independent t-test analysis was performed to determine the differences between the ear dimension clusters: length and width. Table 8 shows the results of the analysis for comfort, pain, pressure, and fixation in the area of the concha depending on the concha length. Table 9 shows the results of the analysis for comfort, pain, pressure, and fixation in the concha area, depending on the concha width. Although there was no statistically significant difference between the length and width with respect to comfort, participants with large conchas tended to evaluate high on comfort and fixation.
Table 8. Results of independent sample t-test for wearing comfort difference according to concha length clusters.

| Dependent Variable                  | Cluster | N  | Mean | SD   | t      | p     |
|-------------------------------------|---------|----|------|------|--------|-------|
| Comfort of concha area              | Small   | 92 | 4.74 | 1.60 | −0.75  | 0.45  |
|                                     | Large   | 60 | 4.93 | 1.48 |        |       |
| Pain of concha area while wearing   | Small   | 92 | 2.40 | 1.61 | −0.25  | 0.80  |
|                                     | Large   | 60 | 2.47 | 1.41 |        |       |
| Pain of concha area after usage     | Small   | 92 | 2.42 | 1.49 | −0.72  | 0.47  |
|                                     | Large   | 60 | 2.60 | 1.44 |        |       |
| Pain of concha area while operating | Small   | 92 | 2.60 | 1.50 | −0.74  | 0.46  |
|                                     | Large   | 60 | 2.78 | 1.54 |        |       |
| Pressure of concha area             | Small   | 92 | 3.15 | 1.64 | 0.99   | 0.32  |
|                                     | Large   | 60 | 2.88 | 1.62 |        |       |
| Fixation of concha area             | Small   | 92 | 4.37 | 1.71 | −0.46  | 0.65  |
|                                     | Large   | 60 | 4.50 | 1.72 |        |       |

Table 9. Results of independent sample t-test for wearing comfort difference according to concha width clusters.

| Dependent Variable                  | Cluster | N  | Mean | SD   | t      | p     |
|-------------------------------------|---------|----|------|------|--------|-------|
| Comfort of concha area              | Small   | 64 | 4.66 | 1.65 | 1.08   | 0.28  |
|                                     | Large   | 88 | 4.93 | 1.46 |        |       |
| Pain of concha area while wearing   | Small   | 64 | 2.45 | 1.63 | −0.18  | 0.86  |
|                                     | Large   | 88 | 2.41 | 1.46 |        |       |
| Pain of concha area after usage     | Small   | 64 | 2.64 | 1.47 | −1.05  | 0.29  |
|                                     | Large   | 88 | 2.39 | 1.47 |        |       |
| Pain of concha area while operating | Small   | 64 | 2.64 | 1.47 | 0.21   | 0.83  |
|                                     | Large   | 88 | 2.69 | 1.55 |        |       |
| Pressure of concha area             | Small   | 64 | 2.97 | 1.61 | 0.50   | 0.62  |
|                                     | Large   | 88 | 3.10 | 1.65 |        |       |
| Fixation of concha area             | Small   | 64 | 4.33 | 1.87 | 0.57   | 0.57  |
|                                     | Large   | 88 | 4.49 | 1.60 |        |       |

Table 10 shows the results of the analysis for comfort, pain, pressure, and fixation in the ear canal area depending on the clusters of ear canal length. Table 11 shows the results of the analysis for comfort, pain, pressure, and fixation in the ear canal area depending on the clusters of ear canal width. There was no significant difference between the ear canal length and width, as was in the case of the concha. However, in the case of a cluster with a longer ear canal, the comfort and fixation scores of the earhole area tended to be high.

Table 10. Results of independent sample t-test for wearing comfort difference according to ear canal length clusters.

| Dependent Variable                  | Cluster | N  | Mean | SD   | t      | p     |
|-------------------------------------|---------|----|------|------|--------|-------|
| Comfort of ear canal area           | Small   | 100| 4.49 | 1.69 | 1.97   | 0.06  |
|                                     | Large   | 52 | 5.04 | 1.51 |        |       |
| Pain of ear canal area while wearing| Small   | 100| 2.65 | 1.62 | −1.01  | 0.32  |
|                                     | Large   | 52 | 2.38 | 1.36 |        |       |
Table 10. Cont.

| Dependent Variable                  | Cluster | N   | Mean | SD  | t    | p   |
|-------------------------------------|---------|-----|------|-----|------|-----|
| Pain of ear canal area after usage  | Small   | 100 | 2.69 | 1.63| −1.59| 0.11|
|                                     | Large   | 52  | 2.27 | 1.36|      |     |
| Pain of ear canal area while operating | Small | 100 | 2.79 | 1.65| 0.32 | 0.75|
|                                     | Large   | 52  | 2.88 | 1.86|      |     |
| Pressure of ear canal area          | Small   | 100 | 3.43 | 1.84| −0.51| 0.61|
|                                     | Large   | 52  | 3.27 | 1.84|      |     |
| Fixation of ear canal area          | Small   | 100 | 4.43 | 1.83| 0.67 | 0.50|
|                                     | Large   | 52  | 4.63 | 1.69|      |     |

Table 11. Results of independent sample t-test for wearing comfort difference according to ear canal width clusters.

| Dependent Variable                  | Cluster | N   | Mean | SD  | t    | p   |
|-------------------------------------|---------|-----|------|-----|------|-----|
| Comfort of ear canal area           | Small   | 52  | 4.40 | 1.77| 1.48 | 0.14|
|                                     | Large   | 100 | 4.82 | 1.57|      |     |
| Pain of ear canal area while wearing | Small | 52  | 2.50 | 1.63| 0.34 | 0.73|
|                                     | Large   | 100 | 2.59 | 1.50|      |     |
| Pain of ear canal area after usage  | Small   | 52  | 2.52 | 1.65| 0.15 | 0.89|
|                                     | Large   | 100 | 2.56 | 1.51|      |     |
| Pain of ear canal area while operating | Small | 52  | 2.87 | 1.57| −0.22| 0.83|
|                                     | Large   | 100 | 2.80 | 1.80|      |     |
| Pressure of ear canal area          | Small   | 52  | 3.37 | 1.77| 0.05 | 0.96|
|                                     | Large   | 100 | 3.38 | 1.88|      |     |
| Fixation of ear canal area          | Small   | 52  | 4.25 | 1.80| 1.25 | 0.21|
|                                     | Large   | 100 | 4.63 | 1.76|      |     |

For the results of clustering on ear canal–incisura intertragica length and the incisura intertragica–antitragus length, an independent sample t-test was conducted to test the difference in comfort, pain, pressure, and fixation according to the size of ear canals and concha. There was a statistically significant difference between the clusters along the ear canal–incisura intertragica and incisura intertragica–antitragus. The participants in the cluster with longer ear canal–incisura intertragica showed lower levels of pain at the ear canal both “while wearing” and “after usage” (Table 12). Furthermore, clusters with longer incisura intertragica–antitragus showed a relatively higher score for fixation of the ear canal area (Table 13). In conclusion, only two among six ear dimensions (ear canal–incisura intertragica length and incisura intertragica–antitragus length) had significant differences between two clusters in terms of the pain of the ear canal area while wearing, the pain of the ear canal area after usage and fixation of the ear canal area.

Table 12. Results of independent sample t-test for wearing comfort difference according to ear canal–incisura intertragica length clusters.

| Dependent Variable                  | Cluster | N   | Mean | SD  | t    | p   |
|-------------------------------------|---------|-----|------|-----|------|-----|
| Comfort of concha area              | Small   | 80  | 4.71 | 1.52| −0.86| 0.39|
|                                     | Large   | 72  | 4.93 | 1.60|      |     |
| Comfort of ear canal area           | Small   | 80  | 4.64 | 1.67| −0.31| 0.75|
|                                     | Large   | 72  | 4.72 | 1.63|      |     |
| Pain of concha area while wearing   | Small   | 80  | 2.58 | 1.57| 1.26 | 0.21|
|                                     | Large   | 72  | 2.26 | 1.48|      |     |
Table 12. Cont.

| Dependent Variable | Cluster | N  | Mean  | SD  | t     | p   |
|--------------------|---------|----|-------|-----|-------|-----|
| Pain of ear canal area while wearing | Small | 80 | 2.80  | 1.61 | 2.06 * | 0.04|
|                    | Large  | 72 | 2.29  | 1.42 |       |     |
| Pain of concha after usage | Small | 80 | 2.63  | 1.49 | 1.17  | 0.25|
|                    | Large  | 72 | 2.35  | 1.45 |       |     |
| Pain of ear canal area after usage | Small | 80 | 2.98  | 1.70 | 3.74 *** | 0.00|
|                    | Large  | 72 | 2.07  | 1.21 |       |     |
| Pain of concha area while operating | Small | 80 | 2.69  | 1.45 | 0.14  | 0.89|
|                    | Large  | 72 | 2.65  | 1.59 |       |     |
| Pain of ear canal area while operating | Small | 80 | 2.91  | 1.70 | 0.68  | 0.50|
|                    | Large  | 72 | 2.72  | 1.75 |       |     |
| Pressure of concha area | Small | 80 | 3.20  | 1.69 | 1.23  | 0.22|
|                    | Large  | 72 | 2.88  | 1.56 |       |     |
| Pressure of ear canal area | Small | 80 | 3.50  | 1.83 | 0.88  | 0.38|
|                    | Large  | 72 | 3.24  | 1.85 |       |     |
| Fixation of concha area | Small | 80 | 4.35  | 1.65 | −0.54 | 0.59|
|                    | Large  | 72 | 4.50  | 1.78 |       |     |
| Fixation of ear canal area | Small | 80 | 4.40  | 1.78 | −0.73 | 0.47|
|                    | Large  | 72 | 4.61  | 1.79 |       |     |

Note. *: p < 0.05, ***: p < 0.001.

Table 13. Results of independent sample t-test for wearing comfort difference according to incisura intertragica–antitragus length clusters.

| Dependent Variable | Cluster | N  | Mean  | SD  | t     | p   |
|--------------------|---------|----|-------|-----|-------|-----|
| Comfort of concha area | Small | 80 | 4.71  | 1.50 | −0.86 | 0.39|
|                    | Large  | 72 | 4.93  | 1.61 |       |     |
| Comfort of ear canal area | Small | 80 | 4.44  | 1.69 | −1.91 | 0.06|
|                    | Large  | 72 | 4.94  | 1.56 |       |     |
| Pain of concha area while wearing | Small | 80 | 2.48  | 1.46 | 0.40  | 0.69|
|                    | Large  | 72 | 2.38  | 1.61 |       |     |
| Pain of ear canal area while wearing | Small | 80 | 2.69  | 1.53 | 1.08  | 0.28|
|                    | Large  | 72 | 2.42  | 1.55 |       |     |
| Pain of concha after usage | Small | 80 | 2.69  | 1.45 | 1.73  | 0.09|
|                    | Large  | 72 | 2.28  | 1.47 |       |     |
| Pain of ear canal area after usage | Small | 80 | 2.70  | 1.63 | 1.29  | 0.20|
|                    | Large  | 72 | 2.38  | 1.46 |       |     |
| Pain of concha area while operating | Small | 80 | 2.70  | 1.55 | 0.25  | 0.81|
|                    | Large  | 72 | 2.64  | 1.49 |       |     |
| Pain of ear canal area while operating | Small | 80 | 2.85  | 1.77 | 0.21  | 0.84|
|                    | Large  | 72 | 2.79  | 1.67 |       |     |
| Pressure of concha area | Small | 80 | 3.11  | 1.61 | 0.53  | 0.60|
|                    | Large  | 72 | 2.97  | 1.67 |       |     |
| Pressure of ear canal area | Small | 80 | 3.41  | 1.85 | 0.26  | 0.79|
|                    | Large  | 72 | 3.33  | 1.84 |       |     |
| Fixation of concha area | Small | 80 | 4.29  | 1.80 | −1.01 | 0.31|
|                    | Large  | 72 | 4.57  | 1.61 |       |     |
| Fixation of ear canal area | Small | 80 | 4.23  | 1.90 | −2.03 * | 0.04|
|                    | Large  | 72 | 4.81  | 1.59 |       |     |

Note. *: p < 0.05.
4. Discussion and Conclusions

Among the factors involved in the use of wireless earphones, the pain of the ear canal area was low in clusters with long ear canal–incisura intertragica lengths, which refers to the distance from the endpoint of the ear canal to the incisura intertragica. Moreover, this is related to the depth at which the product enters the ear, allowing it to fit tightly to the ear and fix in its proper position. The average length of the first cluster (the smallest cluster) for the ear canal–incisura intertragica was 1.17. On the other hand, the average length of the second cluster for that was 1.53. In addition, the depth of the sample products was ranged from 0.8 to 1.5 cm. Therefore, participants in clusters with long ear canal–incisura intertragica lengths can be more comfortable using a variety of products with different depths (lengths) than the participants in clusters with short ear canal–incisura intertragica lengths. Moreover, wearing the product in the correct position can reduce pain by reducing feelings of displacement in the ear area.

In terms of the sense of fixation to the ear canal, it was high in clusters with long incisura intertragica–antitragus length. The area between the incisura intertragica and the antitragus is the area in contact with the bottom of the earphone, and for clusters with relatively long areas, the lower part of the earphone was sufficiently supported so that the product could be worn in the correct position. Considering the length of the incisura intertragica–antitragus, the first group had an average length of 0.7 cm, and the second group had an average length of 1.1 cm, which is shorter than the length of the sample product (1.7 cm). However, when the actual product is worn, the lower part of the product can be supported because the product is placed inside the ear, and the lower support part of the earphone was wider in a cluster with a longer length. In addition, in the clusters with short and protruding antitragus, the product was held at the antitragus area, resulting in the product not being worn in its proper position of the inside of the ear canal. Therefore, clusters with long incisura intertragica–antitragus lengths can increase the fixation in the ear canal area by making it easier to wear and support the product.

Ear sizes vary by age and gender [17]. Moreover, these variations were noticed in diverse ethnic groups such as Italian, European, Caucasian, Turkish, Dutch-German, North American, and other countries [6,9,13,18,19]. In general, Koreans usually have larger ears [6], and Lee et al. (2018) [20] revealed that ear measurements in Korean were significantly larger and more varied than Caucasians in most ear dimensions. In this study, we divided 38 participants into two clusters by small and large ears (cluster one and two) and found that the cluster of small ears (cluster one) had more wearing discomfort and less fixation in the ear canal and incisura intertragica (related ear dimensions to earhole). Moreover, this study indicates that people with small ears tend to experience more discomfort in earholes because various ear dimensions are usually highly correlated with each other [7]. Hence, other ethnic groups that had relatively smaller ears than Koreans could also be more uncomfortable in wearing wireless earphones. Although participants with small ears (the cluster one) showed little dissatisfaction in this study, this could be a still problem because Westerners generally have smaller ears than Asians including our data from the 38 participants. Therefore, an appropriate solution should be suggested for designing smaller wireless earphones, considering earhole sizes.

In general, kernel-type products (sample product one and sample product three) had more pressure on the earhole than open-type products. Due to the characteristics of kernel-type products, the product contacts the inside of the ear canal, causing more pressure than open-type products that do not reach the inside of the ear canal. In addition, participants responded that they felt more pressure on the earhole area when the size of the earhole was large, even with the same kernel-type product. The average length of the participants' ear canal was 0.73 cm, and the average width of their ear canal was 0.59 cm, while sample product three had the largest size of 0.9–1.2 cm, which caused the highest pressure on the ear canal. According to responses to the adequacy of the design factors, there were many responses that the size of the earhole contact area was appropriate for products between 0.6 and 0.7 cm in size, and the larger the size, the lower the ratio. Therefore, when designing kernel-type
products, it is necessary to reduce the feeling of pressure by considering the size of the ear tip part that contacts the ear canal area.

The Kernel-type products, on the other hand, scored a high level of sense of fixation. Since kernel-type products are designed to reach the inside of the ear canal and are fixed to the ear canal, providing a strong sense of fixation. However, in the case of sample product three, the size of the ear tip (the part that contacts the ear canal) was designed to be larger than the size of the ear, so the ear tip could not properly be held to the inside of the ear canal. Thus, the sense of fixation was lowered even it was a kernel-type product.

The touch-type products (the sample product one and two) caused less pain to the participants. In general, the wireless earphone is operated by touching the product or pressing a button, causing pain due to pressure applied to the area where the earphone is worn. In the case of the button-type products (sample products three and four), the pressing force is stronger than that required for the touch-type products, which can cause more pain. In the case of sample product three, the pain in the earhole area was the highest because the product was in contact with the inside of the earhole, causing more pain in the earhole area while pressing the button. In the case of sample product four, the pain in the concha area was also high while operating because the button-type method was used to cover the concha area. Moreover, the pain in the area was caused by contacting the product while pressing the button.

The comfort of the ear canals was higher in the open-type products than the kernel-type products. In terms of the earhole, the open-type ones had a higher comfort rating than the kernel-type ones. These results indicate that the open-type ones were designed to be worn without contacting the inside of the earhole, providing a greater level of comfort in the earhole compared to the kernel-type products. Regarding the comfort in the concha area, however, there was a difference in the results between both open-type products. The comfort of the concha area was the highest in sample product two (concha area size: 1.7 cm × 1.7 cm) with the smallest main body of earphone (concha contact area), and it was lowest in sample product four (concha area size: 2.2 cm × 2 cm). The average width of the participants’ concha area was 1.8 cm, indicating that the main operation part size (head size) of sample product four is designed to be larger than the ear size. According to the evaluation on the appropriateness of earphone sizes, the larger the size of earphones, the less appropriate they are. This shows that although both products are the same as open-type, the level of comfort in the ears varies depending on the size of the product.

The earphones used in the experiment weighed between 4–7 g (g), and most participants responded that the lower the weight, the more appropriate. For example, they replied that the lightest weight of 4 g was the most appropriate, but the heaviest weight of 7 g was the least appropriate. Since the ear area is more sensitive than other body parts [21], the difference between weights can be accurately recognized [8]. As the use of wireless earphones increases in the future, the wearing time and usage are expected to increase, so designs that reduce the weight of earphones are required.

Most participants responded that touching the entire head of the earphone was the most appropriate to operate wireless earphones. Operating while wearing the wireless earphones is difficult because they could not see the operating part of the product. Therefore, in order to intuitively operate the product without visually identifying the operating part of the product, it is necessary to design a form that can be operated even when touching any part of the head.

This study investigated the effect of ear sizes and product design features on the wearing comfort of wireless earphones, however, the following limitations can be listed. First, as the number of sample products for the experiment was four, the product attributes of wireless earphones were limited to revealing all discomfort factors in a systematic approach. In other words, the effects of the specific characteristics of the product were not fully considered. By increasing the number of sample products, a clearer relationship between ear dimensions and characteristics of the product can be identified in further studies when products that have diverse characteristics are acquired. Second, wireless earphones generally have a longer wearing time in real life than in an experimental setting (20 min in this study), so they should be evaluated for a longer time in future studies. Third, this study examined
the impact of the size of ears on the wearing comfort of wireless earphones. Therefore, only two groups
(with small and large ears) were targeted to distinguish them by identifying very significant correlations
between ear dimensions and product attributes. However, we could not obtain various types of ear
measurement data because of the limited number of participants. In particular, the size of the ears
varies with age [22], and it tends to grow as the cartilage in the pinna hardens [7]. Since the participants
in this study were limited to those in their 20s, additional research considering other age groups should
be performed. Although we presented eight ear dimensions for the evaluation and derived the results
from the wearing comfort evaluation based on the four major characteristics (size, operating method,
weight, shape), this was not enough to suggest specific dimensions and forms for the wireless earphone
as universal design guidelines. Based on the results of this study, further studies should be conducted
on various attributes of ear size or shape for optimal design characteristics of comfortable wireless
earphones, and more participants should be tested with balanced demographic characteristics such as
age, gender, and race.

Compared to conventional earphones such as wired earphones and headphones, wireless earphones
are usually heavier because of the inclusion of various modules, and users can be more active while
wearing them. For these reasons, this study systematically evaluated the wearing comfort of the wireless
earphones and identified factors that had a great influence on the wearing comfort. In particular,
compared to previous studies, we identified differences in two groups of ear sizes considering specific
ear dimensions (e.g., ear canal–incisura intertragica and incisura intertragica–antitragus lengths) for
the wireless earphones. Therefore, in the future, it will be possible to design wireless earphones based
on the differences in the relevant ear dimensions from this study. In addition, the results of this study
can form a major basis for further investigating the correlation between the ear dimensions and features
of wireless earphones for improved wearing comfort.

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