# Earmuff Comfort Evaluation

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## ABSTRACT

The use of hearing protectors in high noise environments is indispensable, protecting the workers from suffering permanent hearing loss. In this regard, hearing protector comfort is of crucial importance. Consequently, the selection of the hearing protector used should be based on comfort rather than noise attenuation. In a previous paper (1), published by one of the authors of this article, a novel method was presented to evaluate the comfort of earmuffs by measuring the distribution of the contact pressure between the earmuff cushion and the human head surface. Also, in this previous paper a detailed literature review on earmuff comfort was presented. This literature review shows that a large number of papers published on hearing protector comfort cannot explain some results for subjective evaluations where a high degree of comfort is associated with earmuffs with high headband force rather than low headband force. Our previous paper explains these results which are due to the distribution of the contact pressure between the earmuff cushion and the human head. This paper is a continuation of that research, with two new contributions. Firstly, a new measurement system is used which is more robust and has permanent sensors fixed on a dummy head and a flat surface at the same time. Secondly, the comfort index is calculated employing a second equation for comparison.

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## 1. INTRODUCTION

When noise control at the source is not economically feasible in the short or medium term, hearing protectors are the only solution. Therefore, hearing protectors are the salvation of workers in noisy environments and should be given maximum attention in research and development to advance the technology required for high quality hearing protectors which satisfy the noise protection requirements of the users and also the relevant legislation. Hearing protectors should be used for 100% of the work shift, otherwise very little noise exposure attenuation is gained, and they should be accepted by the users, so that they will be worn consistently and correctly throughout the work shift. This means that the hearing protector must be comfortable. Most of the literature published on earmuff comfort appears to be based on the total force of the headband, or the average pressure (dividing total force by contact area), and evaluations based on the responses of a group of jurors who subjectively assess the comfort level. However, a large number of the studies published on hearing protectors show that there is often a lack of correlation between comfort and total headband force or average pressure. Some results previously published by one of the authors of this paper (1), even indicate the opposite situation, where a strong headband force is more comfortable than a weak headband force.

Although comfort may appear to be a secondary requirement at first glance, it should be noted that an uncomfortable hearing protector device (HPD) may become intolerable after prolonged wear times and is typically removed or refitted for comfort and not for best attenuation, leaving gaps for noise leakage. Pressure exerted by an HPD on the skin and underlying tissue and bone is probably one of the most common direct causes of discomfort. If the contact pressure is strong and continues for a relatively long period of time, the pain may become unbearable. Two factors are involved in this regard,

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the total force of the hearing protector against the skin and the distribution of the contact pressure. The pressure exerted by earmuffs varies proportionally with the force applied by means of their support. When the total force is well distributed over a large area, the resulting contact pressure is lower than when it is concentrated at a few contact points with small areas. In order to ensure a large area of contact with the skin, earmuff cushions should not only be of a size and shape compatible with the ear and head anatomy, but they should also be made of a compliant material. When the area of contact between the hearing protector and the skin is large, the total force acting on the skin must be limited to a value that permits proper circulation of the blood (2). In the case of earmuffs, a certain amount of pressure on the skin is necessary to hold the hearing protector in place and to provide sound attenuation. As the pressure diminishes the impedance of the skin decreases and the vibration of the hearing protector as a rigid body increases. With too little pressure, noise leakage may occur.

Beside the most important parameter, that is, the contact pressure distribution, other parameters of less importance can affect the comfort of an earmuff, such as (1):

1. Total force of the headband: Recommended to be below 14 Newtons. All earmuffs tested in this study had a total headband force of < 14 N. (5) recommend around 10.5 N
2. Weight of earmuff: Weight measurements for 69 earmuffs show values between 140 and 380 g, with an average of 220 g and standard deviation of 57 g. According to (6), earmuffs with less than 245 g are acceptable and comfort is weakly related to earmuff weight.
3. Contact area: For the same headband force, a larger contact area and a low pressure value result in better comfort. However, a large contact area can also result in leakage. Consequently, earmuffs should cover the smallest possible area of the head surface, while still accommodating the pinna, which conflicts with the need for homogeneous pressure distribution.
4. Noise attenuation: This is high for strong headband force, which may be less comfortable.
5. Temperature and humidity: Ambient temperature can affect both the acoustic performance and the comfort of an earmuff. In some cases, a moderate softening of the material at body temperature may improve the conformability, thus improving the seal and comfort.

This paper is a continuation of the aforementioned publication (1), which concentrates on the contact pressure distribution, with new contributions in relation to the measurements and calculation methodology. Firstly, the measurement system is more robust, with permanent sensors fixed on a dummy head and flat surface at the same time, unlike in the previous study where the sensors gave false signals due to curved areas on the dummy head. Secondly, the calculation of the comfort indices has been modified to cover a wider range with better resolution. Subjective evaluation is also carried out to confirm the measurement results. This study has also been discussed at ISO and ANSI work groups on hearing protectors aimed at establishing a guide for earmuff comfort.

## 2. MEASUREMENT SYSTEM

Highly sensitive conformable tactile sensors from PPS with thresholds down to pressures of less than 10 [Pa] were mounted on a measurement system (Figure 1).The sensor surface was 122 x 122 mm with 32x32 sensors; each sensor had an area of 3.8 x 3.8 mm. A fixture with variable width was constructed with a flat surface on one side and half human dummy head on the other, as shown in Figure 2. The half dummy head complies with the ANSI S3.36 standard (3). The open earmuff width was adjusted to 145±1 mm as recommended in ANSI S12.6-2008 (4) for the measurement of headband force.

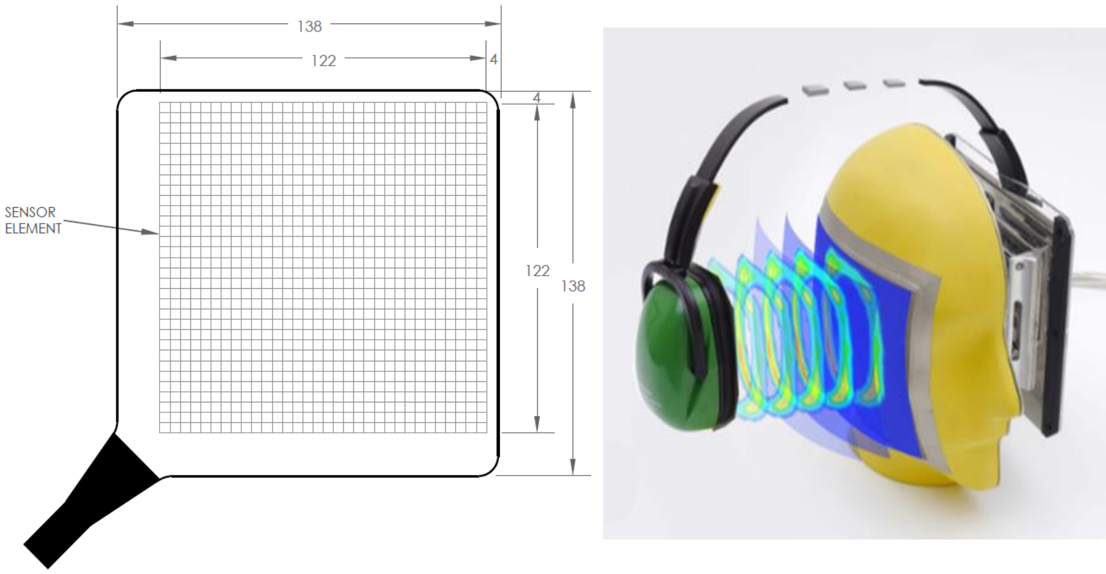


Figure 1 – Conformable tactile sensor element (from PPS Company), one on each side (see Figure2). Permanent fixed sensors. Each side has 1024 sensors with an area 3.8 x 3.8 mm

Figure 2 – Variable width measurement systems with flat surface on one side and half human dummy head on the other.

## 3. MEASUREMENTS OF CONTACT PRESSURE

Measurements were carried out for eight earmuffs (A, B, C, D, E, F, G and H). Three samples of each were measured in triplicate and the average results considered. Figure 3 shows the contact pressure map for the eight earmuffs. Some earmuffs show a more homogeneous contact pressure distribution than others. Also, some earmuffs show no contact at all in certain areas, where noise leakage may occur.

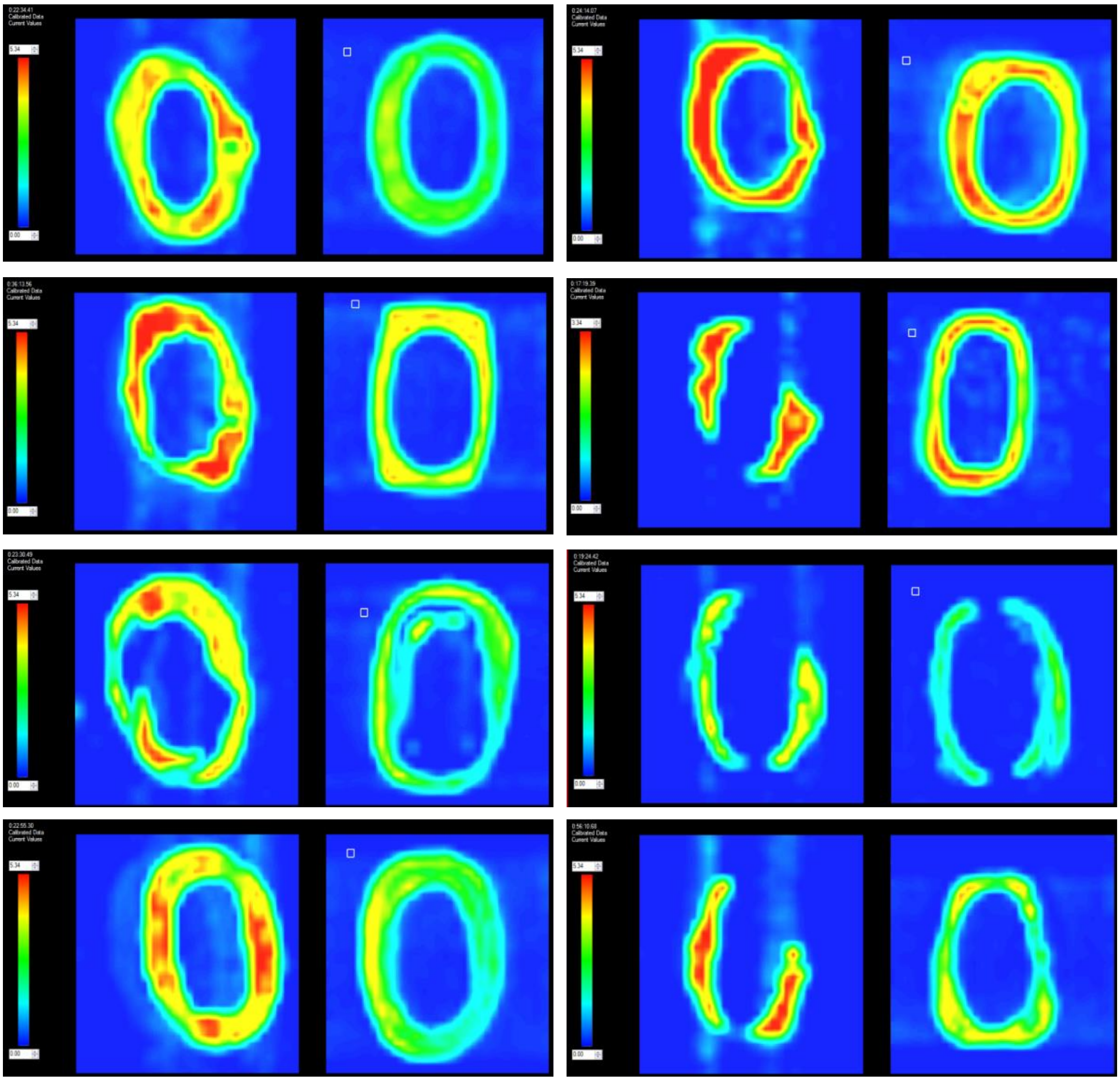

Figure 3 – Contact pressure between earmuff and human manikin (left) and flat surface (right) for the 8 earmuffs tested.

Two equations for the calculation of the comfort index where used:
Comfort index 1 (CI 1), which is used in (1), is given by;

$$CI1 = 100.\left[1 - \frac{\sum_{i=1}^{n}\left|P_i - \overline{P}\right|}{P_{Total} + (n-2).\overline{P}}\right]$$

where:

$P_i$ is the contact pressure at point i

$\overline{P}$ is the average pressure

$P_{Total}$ is the total pressure

n is the total number of contact points

This index varies between 100 and 0, indicating very comfortable muffs for 100 and highly concentrated contact pressure or a large standard deviation (very uncomfortable muffs) for 0. The values for the eight muffs obtained employing the CI 1 equation were very similar.

In the case of comfort index 2 (CI 2) the equation employed is a follows;

$$CI\,2 = 100.\left[1 - \frac{SD}{RMS}\right]$$

where:

$SD$ is the standard deviation

$RMS$ is the root mean square

These two equations are based on the standard deviation of the contact pressure distribution. The standard deviation shows the variation or dispersion in relation to the average pressure distribution. A low standard deviation indicates that the data points tend to be very close to the mean (comfortable muff), while a high standard deviation indicates that the data points are spread out over a large range of values (uncomfortable muff). Other equations were also investigated and gave very similar results.

It should be noted that the comfort indices are not calibrated and there is no reference value. The comfort indices obtained for the 8 earmuffs tested in this study are all relative to each other. Thus, the ranking of the values for the 8 comfort indices gives the relative comfort for the 8 earmuffs. Different equations for the calculation of the comfort index may give different absolute values, but the ranking should be the same.

Table 1 shows the results for the two sets of indices calculated using the two equations (CI 1 and CI 2), for the case of the dummy head and the flat surface for the 8 earmuffs considered. To obtain each value the mean ± standard deviation was calculated from the nine measurements (three samples each in triplicate) for each of the 8 earmuffs. Note that the comfort index for the flat surface is always higher than the corresponding value for the dummy head. This is because the dummy head has curved surfaces and the contact pressure variation is greater.

Table 1 – Comfort indices for the 8 muffs, for the dummy head and flat surface, calculated employing two equations: CI 1 (equation 1) and CI 2 (equation2)

| Model | CI 1 (equation 1) | | CI 2 (equation 2) | | NRRsf*, dB | Head Band Force, N | Weight, g |
|---|---|---|---|---|---|---|---|
| | Dummy head | Flat surface | Dummy head | Flat surface | | | |
| A | 53±2 | 60±4 | 78±2 | 82±2 | 24-26 | 8-12 | 233 |
| B | 27±4 | 35±7 | 57±6 | 64±7 | 19-21 | 18-20 | 247 |
| C | 27±6 | 41±9 | 56±7 | 69±9 | 14-19 | 9-11 | 215 |
| D | 35±3 | 51±5 | 64±3 | 77±5 | 22-28 | 11-13 | 299 |
| E | 41±5 | 52±4 | 67±5 | 77±3 | 18-21 | 11-14 | 254 |
| F | 44±6 | 46±5 | 73±4 | 74±4 | 19-21 | 16-19 | 265 |
| G | 28±13 | 25±11 | 53±16 | 52±15 | 10-21 | 7-13 | 211 |
| H | 38±9 | 42±10 | 65±8 | 69±9 | 11-15 | 13-16 | 187 |

* NRRsf is a single value for the noise attenuation measured according to ANSI S12.6-2008 (B – Subject fit) and it has a high variability. For the same samples tested in the same laboratory, repeated measurements may differ by up to 9 dB.

These two indices show low variation between the 8 earmuffs for both the dummy head and the flat surface), especially considering the standard deviation of each value. For the CI 1 index the variation ranges between only 82 and 52 and for the CI 2 index between 60 and 25.

## 4. SUBJECTIVE EVALUATION OF COMFORT

A subjective evaluation of the 8 earmuffs was carried out by twenty-three subjects (13 male and 10 female) randomly chosen from the students at the Federal University of Santa Catarina (UFSC), Brazil.

The subjects were asked to rank the 8 earmuffs from only the comfort point of view and each subject was permitted to attempt the assessment as many times as he/she wished. There was no time limit established. Each subject arranged the earmuffs on the table from worst to best in terms of comfort and was then asked to give them a grade from zero (worst) to 10 (best), using one-unit steps.

The age of the subjects was between 19 and 43 years (average 26 and standard deviation 6.2). The length of time which each subject spent on the experiment was between 8 to 25 min (average 12.6 min and standard deviation 4.7 min).

Figure 4 shows the measurement results compared with those of the subjective evaluation for the eight earmuffs.

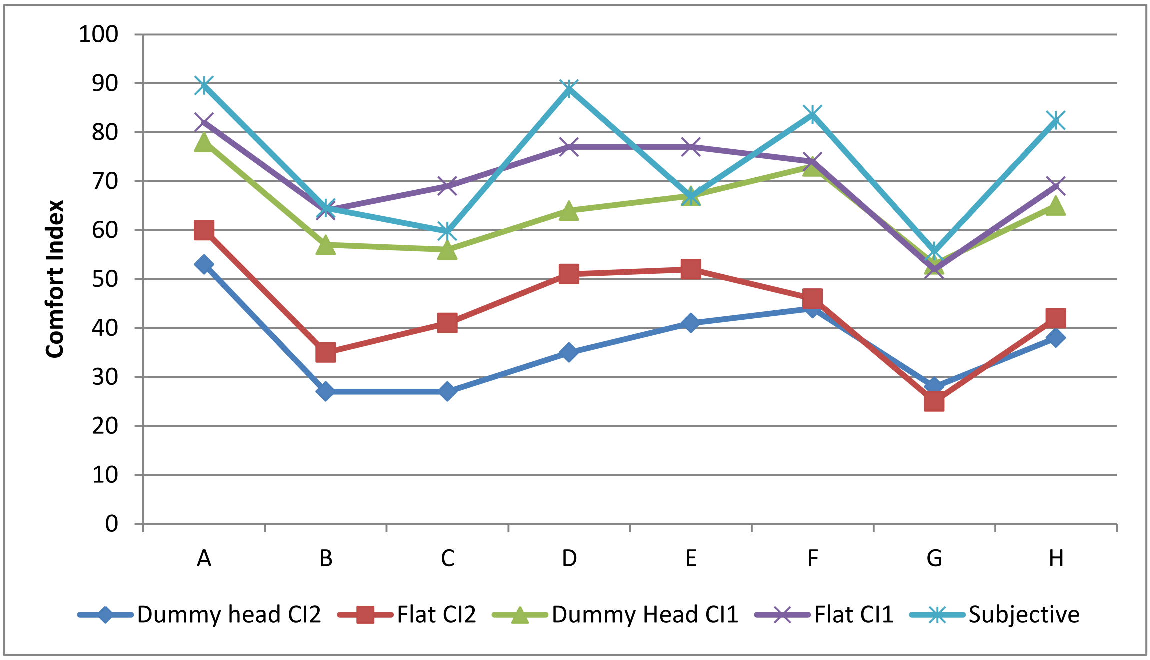


Figure 4 – Graphical representation of results in Table 1, adding subjective evaluation

The subjective results for the comfort indices are shown in Table 2 and Figure 4. Note that the comfort indices obtained from the subjective evaluation follow closely the measured indices (considering the standard deviation).

Table 2 – Subjective comfort index

| Earmuff | Subjective Comfort Index | Standard Deviation |
|---|---|---|
| A | 90 | 13 |
| B | 65 | 22 |
| C | 60 | 26 |
| D | 89 | 13 |
| E | 67 | 18 |
| F | 84 | 22 |
| G | 56 | 28 |
| H | 82 | 16 |

Therefore, a relative comfort evaluation of the different earmuffs can be carried out using either of these two equations or the dummy head or the flat measuring surface.

Using the Pearson (6) linear correlation, it can be shown that a stronger correlation is obtained between the subjective evaluation and the measured values (using CI 1 given by equation 1) with correlations of 82% for the dummy head and 75% for the flat surface. This means that the subjective evaluation was consistent with the measurements (correlation >75%).

Also, these results show that all of the curves for the comfort indices are close to parallel, which means that the comfort ranking for the eight earmuffs is similar using either of the two equations or either of the measurement surfaces (dummy head or flat surface).

## 5. CONCLUSIONS

Earmuff comfort was evaluated and the indices were calculated based on the measured distribution of the contact pressure between the earmuff cushion and surface (dummy normalized head and flat surface). Conformable tactile sensors (1024) of 3.8 x 3.8 mm each were permanently fixed onto a dummy head on one side and a flat surface on the other. The distance between the two sides was adjustable to 145±1 mm. Measurements were carried out for eight earmuffs of different brands. Three samples of each were used. Three measurements of each sample were carried out. The comfort indices (CI 1 from equation 1 and CI 2 from equation 2) were calculated from the average values of the 9 measurements. The comfort index is related to the standard deviation of the pressure distribution. The indices CI 1 and CI 2 varied between zero (low comfort) to one hundred (high comfort).

For the earmuffs F, G and H the values for the comfort indices were the same for the dummy head and the flat surface, which means that these earmuffs are not very sensitive to curved surfaces.

The results obtained applying this novel technique show that the distribution of the contact pressure between the earmuff cushions and dummy head or flat surface is directly related to comfort. A more uniformed distribution gives more comfort even for a higher total force. Therefore, the design of the headband point of attachment, type of headband arc and flexibility of the cushions are very important factors for earmuff design.

A comparison between the measure indices and subjective evaluations revealed a good correlation for all earmuffs (above 75%). The comfort index is not calibrated and does not have an absolute value, but is provides relative values for different brands (in this case A to H). Using either a flat surface or a dummy head, or using either equation 1 for CI 1 or equation 2 for CI 2, the results give almost parallel curves with the same comfort ranking.

Further research is needed for quantify the uncertainty of the measurements, since these data for the sensors used are not readily available from the manufacturer.

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