COMFORT FROM HEARING PROTECTORS

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ABSTRACT

Comfort is an important characteristic of hearing protectors, perhaps as important as sound attenuation. Different approaches were taken by researchers to study comfort: some did literature searches; others did lab studies, and some others did both: lab and field studies. In general, the lab studies were of short duration, which some researchers claim leads to the same results as those of long duration. When studying comfort of earmuffs, some focused on the force exerted against the head, while others were interested in the pressure. There are also studies regarding the influence of heat and humidity on comfort. Finally, some tried to put together sound attenuation and comfort. Almost all of them made use of questionnaires to quantify the weight of different factors of discomfort. This paper analyzes some of the relatively small number of studies on comfort done in the last 25 years. It is intended to serve as a background document for developing a procedure for ranking hearing protectors on the basis of their physical characteristics.

Key words: noise; hearing conservation; hearing protection; comfort

INTRODUCTION

Two properties are of utmost importance when dealing with hearing protectors. They are sound attenuation and comfort. Sound attenuation is defined as the difference between the sound levels of the open and the protected ear. The term is properly defined and different measuring methods are described in national and international standards (ANSI/ASA: 2008; ISO:1990).

There is no clear definition, however, on hearing protector comfort, nor are published standards for its measurement.

To examine the extent of research done regarding comfort as opposite to attenuation, a limited search was conducted on the popular Web of Science database. The search was by no means intended to be exhaustive, but just to get an indication of the relative number of papers being published on those two subjects. The result was that between the years 1970 and 2014, 208 papers were published dealing with attenuation, while only 22 papers were related to comfort.

Why has comfort not been studied more extensively? The literature shows that it is not because of a perceived lack of importance on the subject. As stated by Casali (1986), “even if a hearing protector device is sonically superb, if it is uncomfortable it may not be worn at all, or perhaps worn improperly, or even modified by the user”.

Therefore, there should be other reasons for the scientific community not to study comfort as extensively as the subject deserves it. One reason could be the lack of definition, due to the subjective nature of this sensation. Comfort is inherently subjective in nature and is also dependent on factors other than the protector itself, such as ambient temperature, humidity, and anatomical differences among wearers. A related concern is speech intelligibility, when reduced hearing (because of the protector) becomes a source
of discomfort.

This paper is the result of a bibliographic search of 10 papers published over the last 25 years on the subject of hearing protectors and comfort. They have been selected on the basis of how the authors have handled the subject including types of subjects, duration of the test, etc. The paper intends to serve as a basis for a future study, on ranking comfort experienced by their wearers on the basis of their physical properties. If, eventually, this objective is achieved, then, combined with the attenuation, the task of choosing a “perfect HPD” will be a relatively easy to perform for the individual responsible for selecting devices for use in the workplace.

COMFORT FACTORS

To define comfort is a simpler task, than the one of lack of. As an example, if we qualify a pair of shoes as “comfortable”, there is no need to explain why; it is implicit that the wearer of those shoes is at ease wearing them. This is not the case with the lack of comfort that requires explanations. In the example above, if the shoes are not comfortable, then one must define the quality or the qualities that make them feel as such and those can be numerous. The same concept can be applied to hearing protectors. As shown further below, there are many factors that can make them uncomfortable, and these factors need to be defined.

As a start, we shall propose that no Personal Protective Equipment (PPE) is comfortable. All PPEs present a certain degree of discomfort, probably related to the fact that they are not tools: a tool is used to perform a task, while the PPE is to protect the worker that most often considers that the harm “won’t happen to him”. Wearing uncomfortable protectors may even make harder the performance of the task.

It is a common experience that, with respect to comfort, respirators and hearing protectors are the worst offenders of all (Akbar-Khanzadeh et al., 1995). In general respirators tend to hinder breathing - they are also heavy and hot. Hearing protectors, in addition to comfort factors, interfere with hearing (and understanding) of speech, warning sounds and alarms (Lindeman, 2010; Wilkins, 1984). There is however, a fundamental difference on how each of those two types of devices is accepted. Respirators are perceived as (and they are) life-savers. Very little effort is needed to convince workers that they must be worn to avoid life-threatening consequences. The situation is different with hearing protectors. A much greater amount of effort and time is required to build awareness regarding noise as a hazard (“...ears don’t bleed”) and convince potential users of the benefit of their use.

It should be noted that some comfort factors are a function of the length of time HPDs are worn. Some devices appear comfortable when they are first donned. After some time, however, the user may start feeling the weight/pressure of the HPD, and find its use burdensome. This is the case with muffis, particularly if cap-mounted. Users of other types of hearing protectors, on the contrary, feel uncomfortable when they are first donned but after a period of time feel comfortable and the wearer may even forget that he has them on. This often happens with ear plugs.

Based on the above considerations, one would expect that, comfort studies should be performed over extended periods of time, or at least for the entire shift. Surprisingly, a study (Ivergård et al., 1976) came to the conclusion that properly designed, short-duration tests can provide comfort and user acceptance data equivalent to long-duration work experiences.

One negative effect often associated with earmuffs is the perspiration that results when the wearer is performing tasks in warm environments, either indoors or in the open (Davis et al., 2011). On the contrary, in the particular situation of cold weather, the protector may even be welcome.

Other factors are speech intelligibility (Candido Fernandes, 2003) and warning signals perception (Wilkins et al., 1987). It is a common experience that speech is perceived differently when hearing protectors are worn. This is due to the fact that the sound level is reduced and the frequency content of the signal is modified. The net effect is that workers often complain of not being able to hear well, something that they alleviate by lifting one cup of their muffis or doffing one plug to hear better. The net effect of this “hearing improvement” is a drastic reduction of the overall protection achieved by the HPD (CSA 94.2 – 14 - 2014).
In the case of earplugs, the occlusion effect (Stenfelt et al., 2007) is another discomfort factor. By emphasizing the low frequencies content of the signal, it changes the user’s perception of the harmonic content of the signal and increases forward masking.

**SUMMARY OF PAPERS**

This section will discuss selected publications from the last 25 years that have examined hearing protectors and attempted to rank comfort (see Table 1. Summary of papers).

Casali et al. (1987) conducted several tests using self-reported methodology, multidimensional rating scales and three HPD ranking criteria: comfort, ease of use and user preference. The methodology was applied to a variety of plugs, muffs and semi-inserts (canal caps). A group of 50 paid subjects wore earplugs once. Another group, also of 50 paid subjects, wore muffs and semi-inserts once. Subjects were required to answer questionnaires (9 for the plugs and 23 for the muffs and semi-inserts). Each question involved a 7 grade Likert scale (e.g. for plugs one was soft – hard or for muffs one was annoying – pleasing).

At the end of the session, each subject was asked to rank the protectors in terms of comfort. Experimenters found significant correlation between some of the descriptors and the ranking. Experimenters also found that the comfort did not correlate with the headband force of the muffs or the semi-inserts. The study ends up with four recommendations for further studies, consisting in a) taking into account previous experiences by the subjects, as well as the duration of the tests, b) focusing into ease of application (donning and doffing), comfort and preference, c) focusing into problematic attributes (e.g. clamping force) and d) standardized rating and ranking methodology.

Behar et al. (1987) presented a method for selection of hearing protectors for large groups of employees. The method makes use of the acoustical attenuation expressed as NRR and of a questionnaire especially developed to evaluate comfort. In developing the questionnaire it was assumed that the major factors that determine the likelihood that a hearing protector will be used are:

a) Comfort (both immediately after the donning and after the protector has been worn for the entire shift)

b) Ease of use

c) The perceived effectiveness of the protector

Comfort was assessed using a specially developed questionnaire that contained 16 questions, rewritten into a five-point Likert format. Workers were asked to answer five questions immediately after donning the protector. The remaining nine questions were answered after the workers had worn the protectors for the entire shift. It included ease of donning, comfort during the shift and ease of doffing.

Protectors were distributed to ten workers who were required to wear them during an entire shift. Results from evaluating 13 protectors (4 muffs, 6 cap-mounted muffs, one semi-insert and two plugs) were that those that ranked higher were the same products preferred by most workers on the floor.

Berger et al. (1989) examined the BS 6344, Part 1- Specifications for ear muffs, especially the calculation of the average pressure exerted by the cushions against the head. The calculation is based on the measurement of the force exerted by the headband and the area contacted by the cushion, called the “effective area”. This is an area that changes according to the type and cross-section of the muff as well as the force that changes the shape of the cushion. Using different techniques the authors found that the “true” pressure is not accurately measured. This is especially evident in the case of the foam-filled cushions. The authors further analyzed five studies done by different researchers in field situations. In all of the studies, researchers related the comfort reported by the subjects to the calculated average pressure. The authors concluded that no comfort estimate derived from physical measurements has been found and that further research is needed.

Park et al. (1991) conducted two mutually exclusive studies with 40 subjects each, testing a total of four hearing protection devices in both lab and field settings. Although they investigated a variety of factors, they specifically focused on the difference between lab and field environments when testing the perceived comfort of hearing protector devices.

In the lab setting, participants were non-users of HPs; conversely, the participants in the field study setup were daily users of HPs. The field study sample comprised of participants working in the industrial
sectors where hearing protection was mandatory.

The purpose of the lab testing was to “develop a repeatable protocol to investigate, under laboratory conditions, the effects of important in-field factors (HPD fitting procedure, worker activity movement, and HPD wearing time) on user comfort, and attenuation”. The lab setting involved four different hearing protection devices. The four independent variables investigated were the HP type; HP fitting procedure; activity movement; and HP wearing time.

The field research was aimed at “determining the actual comfort perceived by industrial workers wearing four different hearing protection devices while on the job”. Similar to the lab setting, the field study involved the variables of hearing protection device type, and fitting procedure; however, the field study also included the use of canal caps.

To test the perception of comfort of the users, the authors created a 14 seven-step bipolar scale. They went into detail as to which factors overall impacted the impression of the hearing protection device. A second questionnaire, similarly set up to the first, was administered to both the lab and field participants to collect data. The variables included: easy to apply; acceptable-unacceptable; good fit – poor fit; stable – unstable; unattractive – attractive; simple – complicated; easily loosens – doesn’t loosen; and inhibits head movement – doesn’t inhibit head movement.

Bhattacharya et al. (1993) designed a method to evaluate comfort of hearing protection devices, and evaluate the process of a comfort grading scale. Their study involved 30 college student subjects who did not have experience of being exposed to a noisy environment, nor did they have experience routinely wearing hearing protection devices. This test pool experimented with short-duration wear of hearing protection devices, and the results were measured using an acoustic chamber.

The study also involved 10 participants who worked in an environment where workers were exposed to high levels of noise on a daily basis; they trialed hearing protectors for a long-duration wear in their own work environment. Each subject tried each of the 7 hearing protection devices (two ear plugs and five models of ear muffs).

According to this study the following factors important for comfort are: oval-shaped cups which give a good fit around the pinna; more noise attenuation; larger space inside the cups to accommodate the pinna; foam cushions that conform to the head; and circumaural cushions which conform to the head to distribute the headband force.

Arezes et al. (2002) performed a study where 20 workers from four different workplaces were requested to wear four different types of protectors for a week. At the end, they filled the questionnaire, similar to the one used by Park et al. (1991).

When it came to calculating the Comfort Index, only the statistically significant values from the questionnaire were used; and the most important of all were the ratings for Comfortable vs. Uncomfortable. Further, a more meaningful measurement is the correlation between the Comfort Index, and the duration time of usage.

The conclusion of the study that “comfort, or a subjective feeling of comfort, while being a possible quantifying parameter, depends on a wide range of factors”.

Hsu et al. (2004) took a different approach to quantifying the perception of comfort, the contributing factors and their respective indices. The experimenters first designed a questionnaire to determine the contributing and defining factors for comfort perception when using hearing protectors. By taking an initial questionnaire approach, they were able to develop comfort indices before collecting data.

A randomly selected factory workers’ (total of 358 questionnaires distributed) feedback was used to design an ear muff as a “comfort tester”. The factors that the ear muff was designed to measure included: soundproofing (attenuation); air tightness; heat-sinking ability; texture; weight; headband force; adjustability; wearing convenience; and sweat absorbing ability. Recommendations for earmuff manufacturers are also included.

Williams (2007) focused on pressure distribution of the cushion of an earmuff and its correlation to comfort. The author found that a main component and driver of comfort perception of ear muffs is “the pressure on the area around the ears produced by the cushion mounted on the noise excluding cup of a
While Williams did not directly define comfort, he offered the variables he believes to comprise the perception of comfort, specifically, those of ear muff. The list by Williams included the overall cup mass (number of cup linings, number of external and inner caps, outer cap thickness, external cup volume, and cushion surface area), clamping force, and the pressure exerted on the user.

As an important component to this paper, Williams (2007) identified that “increasing the bulk of a hearing protector (volume, mass, and a number of cup elements) increases the attenuation but, as with clamping force, a limit is reached where increased bulk increases discomfort and wearing difficulty”.

Davis (2008) reviewed six studies completed by different researchers that dealt with testing of plugs and muffs in lab and field environments. Davis started with a quote by Nilsson and Lingend (1980) that “…the attenuation values are of secondary importance, so that the wearing comfort of the HP determines the degree of usage”, thus underlying the relative importance of comfort in that respect. He also stated that “no one may be able to adequately define comfort”.

The paper includes efforts by NIOSH in 2003, when a project was initiated looking into physical factors in HPD comfort. Then, in 2004 NIOSH contracted a study to develop a technique characterizing pressure of insert-type hearing protectors against the ear canal wall. Finally, a one-year-long longitudinal study of HP comfort was conducted in partnership with a major American auto manufacturer, starting in 2004. The goal of the study was to examine the acceptance of a custom earplug in a factory setting, and to measure the changes in comfort over the year of the study. The results indicated that the comfort did not change during the year and that the protectors were rated as less comfortable than neutral.

In a fundamental change in experimental technique, Gerges (2012) measured the pressure at different spots on the cushions of the muff. For this purpose, he used TEKSCAN I - Scan Lite Enhanced system, type 5101 with 1936 pressure resistive sensors. The sensors lined the cushions. With this method, Gerges was able not only to measure the total pressure, but also to precisely map the pressure at different spots on the muff. In such a way, he found exactly maximum and minimum pressure values and surfaces where they appear. As per the author “the results obtained in this break through study for the measurements of the contact pressure and force distribution between the earmuff cushions and circumaural flesh of the human head can explain the unexpected correlation between the measured total force and subjective evaluation…”.

The paper goes beyond that. After a review of 12 papers dealing with comfort of muffs, the author proposed a Single Associated Measured Index ‘SAMI’ calculated using seven Specific Associated Measurements (SAM 1 through SAM 7). Two of the SAMs are related to temperature, humidity and sound attenuation. The relation between the SAMs and the SAMI is simply sketched at this time.

Table 1 summarizes the papers reviewed here.

The first column, Type of protector, shows that the majority (6 out of 4) studies dealt with more than one type of protectors. The single protector studies were dedicated to muffs.

With respect to the characteristics being studied (second column), it can be seen that different objectives were researched, besides the comfort per se. Among them, ease of use and users’ preference were the most popular. The issue of ease of donning was considered as an inherent part to comfort.

Regarding muffs, all researchers agree that there is no relation between force, pressure and comfort. Two of the papers focused into the importance of pressure distribution and its measurement. Regarding test duration, there is wide variety: from short lab tests to fractions of a workday to several weeks. No conclusion regarding an optimum duration is shown. In one study, comparisons between results obtained from short lab tests and long field test arrived at different results, while in other, the results were similar. All that point to the difficulty in designing an optimum duration for a test.

There is a variety of approaches regarding subjects for the tests. Some studies have chosen to use volunteers especially for the lab tests. Field tests are mostly done with workers during their worktime (paid).

Finally, while some studies were basically literature reviews, most used questionnaires, something to be expected from a subjective test as the comfort is. The same questionnaires were used even when evaluating different types of protectors.
As pointed above, there are several factors involved in comfort from wearing hearing protectors. Many are particular to a particular type of device. For instance pressure on the head is particular to muffs, while pressure inside the ear canal is for plugs. Even within the same type, protectors differ in size, shape and material. As a result, simultaneous studies of different devices become quite a complex endeavor. This is especially valid for the subjects involved in the testing: assessing in the same session comfort from a muff, a semi-insert, a foam plug and a custom-molded ear plug is an almost impossible task. Also, if tests are conducted in different days, comparing their comfort will also be very difficult since the memory of previous tests will be lost.

RECOMMENDATION FOR FUTURE STUDIES

In view of the above, the main recommendation for future studies is to focus in one single type of protector at a time. The study should measure every single physical characteristic of the protector (e.g., stiffness, porosity, shape, etc.). Then, it should try to correlate results from those physical measurements with subjective evaluation by participants, using questionnaires. A correlation analysis of both could help determine the main physical characteristics that affect comfort. That could be for example the pressure in the ear canal due to the presence of the protector. Or the weight of the device in the case of the muff. The subjective evaluation could be initially for short duration, laboratory tests and then, to longer duration field tests. Such an approach may yield indices that could show a positive correlation to this elusive property that is comfort. It could then be used as a design tool for new devises. It could also be a useful mean for

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Type of protector</th>
<th>Subject of the study</th>
<th>Method</th>
<th>Basic observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casali (1987)</td>
<td>P, M, SI</td>
<td>Ease of use, users preference</td>
<td>50 + 50 paid volunteers, Q</td>
<td>Comfort ratings. No final conclusions</td>
</tr>
<tr>
<td>Behar (1987)</td>
<td>P, M, SI</td>
<td>Ease of use, perceived efficiency</td>
<td>Workers, Q</td>
<td>Questionnaire may not be valid for all protectors</td>
</tr>
<tr>
<td>Berger (1989)</td>
<td>M</td>
<td>Force, pressure</td>
<td>Literature survey</td>
<td>Force doesn't correlate to pressure</td>
</tr>
<tr>
<td>Park (1991)</td>
<td>P, M</td>
<td>Field versus lab test</td>
<td>40 + 40 subjects, 4 devices, Q</td>
<td>No correlation between lab and field results</td>
</tr>
<tr>
<td>Bhattacharya (1993)</td>
<td>P, M</td>
<td>comfort grading scale</td>
<td>30 college students + 10 workers, Q</td>
<td>Factors for improving muffs</td>
</tr>
<tr>
<td>Arezes (2002)</td>
<td>P, M</td>
<td>Evaluation of comfort</td>
<td>20 workers from 4 workplaces, Q</td>
<td>No significant difference in comfort between protectors of the same type</td>
</tr>
<tr>
<td>Williams (2007)</td>
<td>M</td>
<td>Pressure distribution and comfort</td>
<td>Literature search and 37 different earmuffs</td>
<td>Pressure and blood circulation</td>
</tr>
<tr>
<td>Davis (2008)</td>
<td>P, M, SI</td>
<td>Review of literature</td>
<td>Literature search</td>
<td>Comfort can be quantified on multiple psychological scales</td>
</tr>
<tr>
<td>Gerges (2012)</td>
<td>M</td>
<td>Phys. measurement of pressure</td>
<td>Contact meas. and subjects comfort</td>
<td>Creation of comfort indices</td>
</tr>
</tbody>
</table>

the selection of protectors in the workplace used along with the attenuation data supplied by the manufacturer.

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