

# FUNCTIONAL DISCOMFORT OF EARPLUGS AND ITS INFLUENCING VARIABLES

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## 1 Introduction

Earplugs are widely used to prevent noise-induced hearing loss. Their effectiveness depends on both attenuation and wearing time, which are affected among other factors by (dis)comfort aspects. Discomforts experienced by the wearer can make him/her deteriorate intentionally the fit quality or remove the protector which causes a drastic reduction in protection. The comfort is a multidimensional construct, and in the context of earplug use, four dimensions of earplug (dis)comfort have been proposed [1]. The ‘functional’ dimension of interest in this work, corresponds to the practical acceptability of earplugs and refers to the usability, efficiency and usefulness concepts. The (dis)comfort results from the complex interactions between the triad constituted of the person wearing the earplugs (wearer), his/her earplug, and his/her work environment. The triad components (wearer / earplug / environment) can be described by many physical and psychosocial characteristics which may have an impact on the (dis)comfort [2]. As examples, physical characteristics of the triad include person ear morphology and hand dominance, earplug shape and mechanical properties or work environment temperature. Psychosocial characteristics of the triad include for example the person gender and previous experience with earplugs, earplugs discreteness or aesthetic design and environment type of work or physical activity (e.g., body, head or jaw movements). A better knowledge of the characteristics of the triad promoting comfort, and thus effectiveness of the earplugs, could allow (i) manufacturers to design earplugs taking into physical and psychosocial characteristics and (ii) preventionists to propose to workers the most adapted earplugs fitting to their needs and characteristics, as well as to those of their work environment.

Following previous studies [3], the objective of this contribution is to identify the characteristics of the triad that significantly influence the general attribute of the functional comfort dimension and an attribute specifically related to earplugs “efficiency” (other attributes will be the subject of a future publication). The acoustic and psychological dimensions of comfort will be the subject of future publications.

## 2 Method

This study uses data of morphologic descriptions of the participants’ earcanals and field survey on earplug comfort app-

proved by the ethical committee of the École de Technologie Supérieure (ethics certificate H20171101).

### 2.1 Earplugs comfort assessment in the field

Nine earplug models among the most used in North America were tested as follows: three roll-down-foam four push-to-fit (one premolded and 3 push-to-fit-foam), and two custom earplugs. A total of 173 persons (84% of men) working in three different companies in Quebec (Canada) participated in this field study.

Participants first filled out the questionnaire “User Profile Questionnaire (UPQ)” and a custom earplugs manufacturer molded participants’ earcanals.

Over seven weeks, participants tested an earplug from each of the earplug’s families in their workplace. For both the roll-down foam and push-to-fit foam earplugs, the participant wore the same earplug model for one week, then wore it for another week, two weeks apart. A typical test week was as follows. At the beginning of the week, an individual training on earplugs insertion and use was offered to each participant by an audiologist. At the end of the individual training, if the earplug provided a safe attenuation for the participant, the test week could start. At the end of the week, participants completed the “Comfort of hearing protection devices – North America Questionnaire” (COPROD-NAQ) to express their opinion about the four dimensions of earplug comfort (i.e., physical, functional, acoustical and psychological).

To answer to the objective of this contribution, the functional dimension of comfort was evaluated with one general item (i.e., corresponding to the general attribute “functionality”) and one explanatory item “efficiency” (i.e., a specific attribute “efficiency”). Specifically, these two attributes were measured by the two questions “*Generally speaking, these earplugs are functional (efficiency, good fit, intuitive installation...)*” and “*These earplugs are useful considering: your work environment*” to which participants answered on a five points Likert scale ranging from 1 “Totally disagree” to 5 “Totally agree”.

### 2.2 Assessment of the triad characteristics

The triad characteristics considered in this study for the “person” component are the following: morphology of the external earcanal (girth and shape of 3 cross-sections, length and conicity), hearing loss, hand dominance, age, education and experience with HPD use. The characteristics of the work environment include the perception of exposition of high noise levels, possibility of changing departments, team work, work duration, shift and physical activity (body, head or jaw movements).

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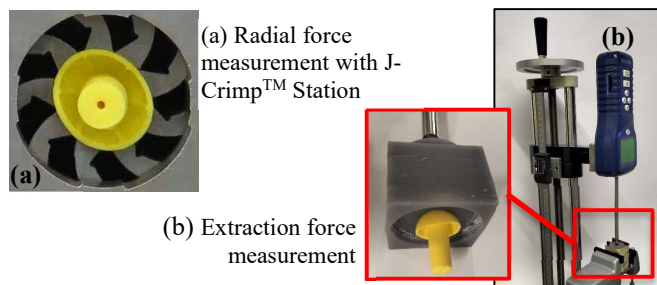
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The characteristics of the “earplug” component included the earplugs shapes which were described with a dichotomous variable to characterize earplugs conicity (conical/cylindrical) and the presence of a stem (yes/no). Earplugs masses were measured in grams on a scale and their diameter were assessed using a caliper placed at the position corresponding to the first bend of the earcanal.

The mechanical characteristics of the earplugs were assessed using two “comfort testers” described below. The J-Crimp™ Station (figure 1 (a)) enabled to measure the total radial force exerted by an earplug inserted in a rigid cylindrical earcanal, at different compression rates. The second comfort tester (see figure 1(b)) enabled to measure the force required to extract an earplug inserted inside a rigid cylinder of 9 mm diameter (the diameter was chosen based on earcanals morphologic data). The ratio between the extraction force and the radial force at 9 mm compression diameters was used to compute a static friction coefficient for each earplug.



**Figure 1:** Two comfort testers: (a) J-Crimp™ Station (©Blockwise, USA). (b) Extraction force measurement setup: the earplug is pushed out of the grey sample holder by a rigid rod connected to a Newtonmeter.

Linear mixed effect modeling was used to find relationships between triad characteristics and the two attributes of the functional comfort. Given the large number of variables characterizing the triad (around 50) in relation to the number of participants, an iterative procedure was carried out to sort out the variables of each component of the triad that influence significantly functional comfort (see more details about statistical analyses in [3]).

### 3 Results

The analyses mostly showed that the characteristics of the person influenced significantly the “Functionality”: being use to wear earplugs from the same family (roll-down foam, push-to-fit foam or premolded) as the one tested and having a small earcanal entrance make participants feel earplugs more functional. The influence of the size of the earcanal entrance on functional comfort is not easy to interpret, as the general element of functional comfort encompasses several different concepts linked, for example, to earplug maintaining in position or ease of insertion or removal. The fact that participants preferred (in term of functional comfort) the earplugs that they were used to wearing could be in line with the literature, which points out that habituation (or acclimatization) enhances comfort [4]. “Efficiency” was also influenced by the habits of the worker wearing the earplugs: being use

to wear earplugs from the same family as the one tested make participant feels earplugs more useful. Moreover, participants found their earplugs more useful if they didn’t interfere with their other work equipment (which are a characteristic of the triad that describes the work environment). This last finding underlines the importance of choosing earplugs that are adapted not only to the individual, but also to the working environment, which is characterized by the worker’s other protective equipment.

The functional comfort of earplugs encompasses several concepts related to the practical acceptability of earplugs such as usability, efficiency and usefulness. Evaluating all these concepts using a very limited number of items is not very conducive to finding the characteristics of the triad that influence earplugs comfort. Consequently, other explanatory items measuring other attributes of the functional comfort (e.g., stay in position, easy to use/to insert/to remove) will be used in an attempt to gain a more exhaustive view of the characteristics of the triad that influence the functional comfort of earplugs, and will be the subject of a future publication.

### 4 Conclusion

Functional comfort evaluated through its attributes “Functionality” and “Efficiency” is mainly governed by characteristics of the wearer: his/her previous experience with earplugs, his/her earcanal girth and a characteristic of the work environment: the interference of the earplug with other protective equipment. However, functional dimension of comfort refers to several other attributes and further analyses (which will be the subject of a future publication) are needed to better understand functional comfort influencing variables.

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### References

- [1] Doutres, O., Sgard, F., Terroir, J., Perrin, N., Jolly, C., Gauvin, C., & Negrini, A. (2019). A critical review of the literature on comfort of hearing protection devices: Definition of comfort and identification of its main attributes for earplug types. *International journal of audiology*, 58(12), 824-833.
- [2] Doutres, O., Terroir, J., Jolly, C., Gauvin, C., Martin, L., & Negrini, A. (2022). Towards a holistic model explaining hearing protection device use among workers. *International Journal of Environmental Research and Public Health*, 19(9), 5578.
- [3] Poissenot-Arrigoni, B., Negrini, A., Berbiche, D., Sgard, F. and Doutres, O. (2023). Analysis of the physical discomfort of earplugs experienced by a population of Canadian workers and identification of the influencing variables. Article under review in the *International journal of industrial ergonomics*.
- [4] Doutres, O., Sgard, F., Terroir, J., Perrin, N., Jolly, C., Gauvin, C., & Negrini, A. (2022). A critical review of the literature on comfort of hearing protection devices: Analysis of the comfort measurement variability. *International Journal of Occupational Safety and Ergonomics*, 28(1), 447-458.