CHALMERS

„Eco-design of ear-fitting headphones incorporating cellulose-based electronics"

M.Sc. Thesis in Industrial Design Engineering

PPUX05

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CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2017

Department of Product and Production Development

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Preface

"Eco-design of ear-fitting headphones incorporating cellulose-based electronics" is the master's thesis of Anna Zsófia Póka, it is part of the M.Sc. programme Industrial Design Engineering at Chalmers University of Technology. The project was carried out in cooperation with Innventia AB/ RISE Bioeconomy, a Stockholm based research institute and the transdisciplinary project Tech Mark Arena 2017. The project started in February 2017, ended in June 2017, it consisted of 30 ECTS.

First of all I would like to thank my wise grandmother Margaret, my dear, lovely, clever and beautiful mother, Susan and my brother, Robert for their continuous support throughout my Master studies.

I would also like to thank everybody at Innventia AB/ RISE Bioeconomy for a good collaboration, throughout the project. Special thanks to Hjalmar Granberg, who was the main supervisor of this thesis project, Marie-Claude Béland project leader of Tech Mark Arena 2017, Tatjana Karpenja Sustainability Manager at Innventia AB, Karl Håkansson Material Engineer, as well as Anton Hagman for their support during the project.

Special thanks goes to Henrik Pettersson, Kerstin Slettengren, Andreas Fall and Samuel Pendelgraph, who assisted my learning process and experimentations in Innventia Labs.

I would like to thank also Katja Tasala Gradin, responsible for "Eco-design" course at KTH Machine Design Institute, also Stefan Ståhlgren, responsible for "Product- and Service-design" courses at KTH Machine Design Institute for providing me with equipment and for giving me ideas to reflect upon, as well as useful insights.

Thank you to all, who spent their time to answer and send in answers to the survey.

Further, I want to thank Ulrike Rahe, my examiner at Chalmers.

Finally I would like to thank Beñat Garay and Eric Moragues Insa for being my opponents.

Stockholm, June 1rst 2017,
Anna Zsófia Póka

The author of this Master's thesis at the Eero Arnio exhibition at Kulturhuset in Stockholm, 2017.

Abstract

It is one of our society's biggest challenge, to keep up with rising energy demands, therefore it is a matter of necessity to develop materials capable of storing and managing huge amounts of electrical energy. RISE Bioeconomy is currently developing cellulose-based electronic materials, merging the production processes of papermaking with the functionalities of electronics.
ITE headphones account for more than half of all retail headphone revenue, the product category has underwent a lot of changes, due to technological and societal developments. In the upcoming decades more electronic devices will be used in a wireless mode, which allows a higher level of user experience, at the same time the products should be able to adapt and be updated corresponding with the user's lifestyle.
An ITE headphone product concept was developed, using active cellulose-based materials, from renewable resources. Eco-design principles were used during both the product concept development, as well as in the course of the laboratory work at Innventia. The project investigated the potential of cellulose-based materials within a circular economy context. Tech Mark Arena 2017 was a project led by Innventia, an interdisciplinary thesis school. Using a blend of user-centred approach, ergonomics and classic product engineering methods made it possible, to arrive to a final product concept, which widens the application possibilities of cellulose-based materials, at the same time applies them to the ITE headphone product in an optimal way. Eco-design principles were established according to the product category, focusing on the features, which enable the creation of an overall improved product experience :modularity. weight reduction, renewable materials and finally, pleasant haptic experience.

Keywords: ITE heaphones, ergonomics, cellulose-based materials, user experience

Abbreviations

ITE	*in-the-ear*
ITC	*in-the-canal*
CIC	*completely-in-canal*
IIC	*invisible-in-the-canal*
ANC	*active noise cancellation*
NFC	*nano-fibrillated cellulose*
MFC	*microfibrillated cellulose*
CNF	*cellulose nano-fibers*
MIEC	*mixed ionic electronic conductor*
PEDOT:PSS	*poly(3,4-ethylenedioxythiophene) polystyrene sulfonate*
NFC - PEDOT	*nano-fibrillated cellulose poly(3,4 -ethylenedioxythiophene)*
WiFi	*Wireless Local Area Networking*
A2DP	*Advanced Audio Distribution Profile*

Introduction

Theory

Current products

Methods

Analysis

Results

Final result

Discussion & Conclusion

1.1 Introduction

1.1.1 About Innventia AB/ Rise Bioeconomy

Innventia has been working to develop new biomaterials, based on forest raw materials. A significant proportion of their research operations is focused on finding new materials and products made from cellulose and other renewable raw materials, such as by-products from the forest industry or the food industry. Nanocellulose is an expanding area of their business where their pilot plant for production on a large scale is useful for showing the potential for commercialisation of various applications. From the pulp mill biorefinery, they can extract pure lignin as raw material for many new applications. Their key focus is, that these new materials should contribute to a sustainable society. RISE-Bioeconomy is currently developing cellulose-based electronic materials, merging the production processes of papermaking with the functionalities of electronics.

Fig. 1.1.1 Innventia AB (2017) *"Self-opening packaging"* [jpg]. Stockholm

1.1.2. About the project

This project was a master's thesis project within the Industrial Design Engineering Master of Science programme. The project was done by Anna Zsófia Póka.

1.1.3 Background

According to The United Nations, which has assembled a task force specifically to deal with the growing e-waste problem, said last year that electronic waste will have increased by a third by 2018. By then, it will weigh as much as eight of the great Egyptian pyramids.
Eco-design approaches for industrial designers means using lighter materials, less materials, less components, in turn for the recycling industry this results in a more challenging and less profitable recycling process. Valuable metals are being replaced by composites (alloys, laminates etc.), which require more energy to separate and restore to their original state.
Innventia AB has been working on projects on developing new materials that could replace and even optimize product experiences, which are in relation with consumer electronic products.
Materials, however are only partially contributing to moving society towards a more circular economy. Furthermore, from the product user's perspective emotional value is more important than physical value.
Since the humble beginnings of the audio technology, earphones have risen to fashion accessory status. Companies producing earphones and other audio equipment offer their customers earphones in every colour of the spectrum. Earphones have become part of everyday life and their consumption is driven by the constant need for the newest and most high-tech products. Therefore ear-fitting headphones contribute to the waste generated by consumer electronic products. Waste means that the item is not intended to be reused in any form.
Newly developed materials not only require adequate production processes, but the products, in which they are used should be adapted to a more circular life-cycle as well.

1.2 Purpose

The aim of the project is to develop an ear-fitting headphone product concept, which demonstrates the possibilities of designing electronic materials made of bio-based materials/ cellulose-based materials. The work will also investigate how to involve eco-design principles in the design process considering innovative materials.
Research questions

· (R.1) Eco-design of cellulose-based electronic materials – what are the best approaches?

· (R.2) How is it possible to introduce circular economy to cellulose-based materials?

· (R.3) How can principles of eco-design be used to show, via one or several material demonstrators, circular material flows?

1.3 Aim

Develop a prototype of an in-the-ear (ITE) headphone product concept, by incorporating materials under development at Innventia AB/ RISE Bioeconomy.

1.4 Limitations

The methodology has been defined according to the assignment :

- Designing a concept of ear-fitting (ITE) headphones using a user-centered approach (value for the student, and Innventia AB/ RISE Bioeconomy)
- Prototyping an in-the-ear (ITE) headphone product concept and investigating its feasibility on production scale (value for the student)
- Investigating properties and potential applications for the materials of interest (value for Innventia)

These three working areas have been defined to fulfill in parallel the goals defined for the different stakeholders: the student and her department at Chalmers University of Technology and Innventia AB/ RISE Bioeconomy.

The project focuses on in-the-ear (ITE) ear-fitting headphones used for communication and entertainment, used by users in Sweden, in 2017 regardless of age- and cultural background. The project is limited by available testing equipment, therefore the acoustics are not being evaluated within this stage of the project.
The project, including documentation work, was limited to 20 business weeks, equalling one university semester. There was a fix project budget, but however limited.

1.5 Partners

Collaboration with other TechMark Arena 2017 projects:
Joint activities with "Exploring biodegradable electronics" and "Textile-like Paper as Circular Material" for literature survey and material selection would be relevant.
This thesis project was a part of the interdisciplinary thesis school TechMark Arena led by Innventia during the spring semester of 2017. The common theme this year was 'Cellulose-based materials in a circular economy', and unite five thesis projects from different fields. This gave the participating students the opportunity to cooperate and exchange ideas, benefitting everyone involved.

Introduction

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2. Theory

One of the aim's of this thesis work is to design a product concept of an ear-fitting headphone product. As it's name suggests, ear-fitting headphones are products , which fulfill their's user's need for communication, entertainment or education by transferring electric signals into soundwaves audible to human ears, in which they are fitted into.
Even though human ears are as unique as our fingerprints, the headphones must respect the dimensions, spatial features and general proportions of this organ, as the product is used in close vicinity to it. Within the ear-fitting headphone product group the following subcategories can be found:

- in-the-ear (ITE),
- in-the-canal (ITC),
- completely-in-canal (CIC),
- invisible-in-the-canal (IIC).

ITE headphones are commonly used for communication, education and entertainment. ITC's are regularly used by professional musicians for the sake of their sound isolating properties. CIC and IIC solutions can be found in hearing aid applications. The thesis work will focus on the in-the-ear (ITE) subcategory of ear-fitting headphones.

Our ears have been formed during human evolution to a shape, that helps us gather information from the outside world. The first section of the Theory chapter will explain the ergonomics of the ears, the functionality of this organ. From the basic functionality of the human ears (See Fig. 2.1.1 *Functionality of the human ear*), the anatomy of the auricle is further discussed (See Fig. 2.1.2 *Photographs of human auricles. A- young male, B- young female, C-middle-aged male*; Fig. 2.1.3 *The external ear*, followed by a short introduction to describe:

- What are ear-fitting headphones?
- What type of headphone technologies exist today?

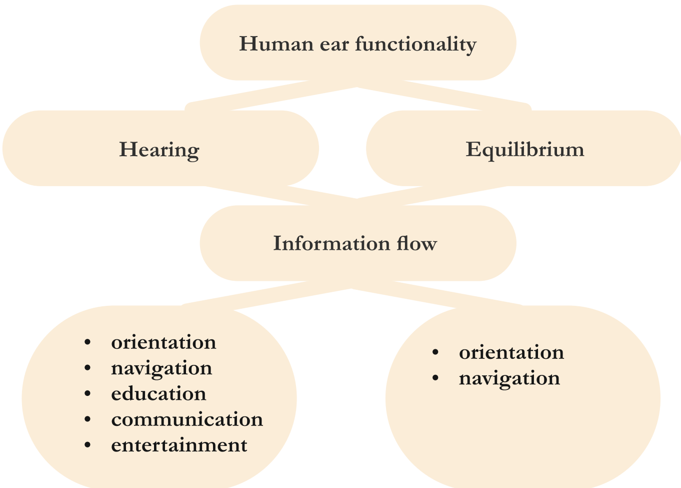


Fig. 2.1.1 Anna Póka (2017) *Functionality of the human ear* [png] Stockholm

2.1 Human ear

Our ears are sensorial organs, with an operating mechanism as complicated as the nervous system in our body. The main functionality of our ears are:

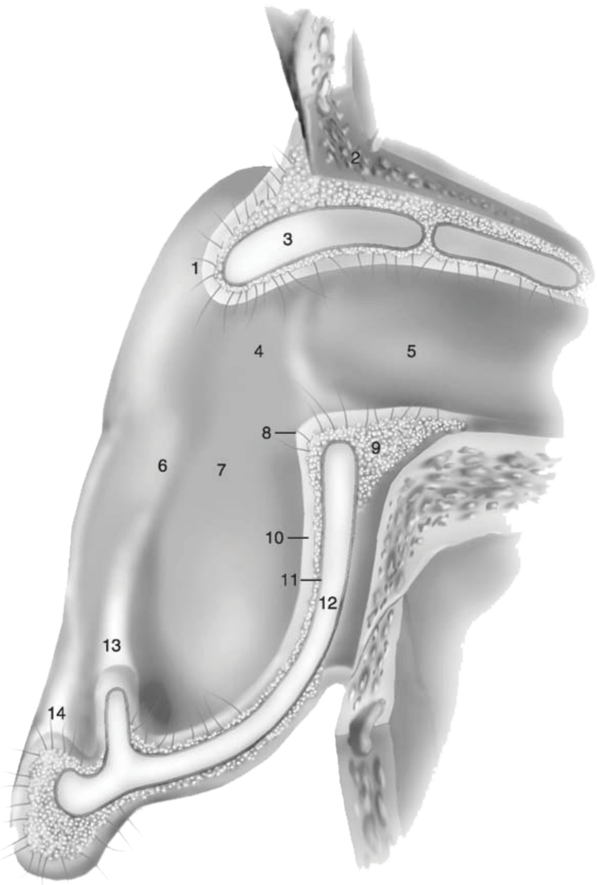
- hearing
- and equilibrium.

Both of these main functions are owed to a very small confined area, which is a membrane-bound space containing fluid. Signals are generated by the vibration of the atmospheric air or positure changes, these are picked up by specialized receptors and transmitted towards our brains for processing. The external ears are situated on both sides of our heads, presenting a variety of shapes, sizes, angles etc. They are formed explicitly to be able to capture sound waves and to transmit the latter towards the middle-ear, with the tympanic membrane and the combination of the smallest bone structures in the human body, that pass on the sound vibration to the inner-ear, with the cochlea and the hair receptors, arranged in order to be able to detect frequencies between 20 Hz and 20 kHz.

The external ear can be characterized by various bumps and cavities, the boundary of the auricle is called the helix. The second elevation is the antihelix, starting with two stems, crura anthelicis, above the external acoustic pore. The anterior bulge in front of the pore (tragus) is opposite another convexity in the lower part of the antihelix, known as the antitragus. In between the tragus and antitragus is the intertragic incisure, a gap directing towards the soft, cartilage-free earlobe (lobulus auricularis). The groove between the helix and antihelix is called scaphoid fossa, whereas the space defined by the crura anthelicis is known as the fossa triangularis. The cavum conchae inside the pinna is the deepest cavity, whereas the area delineated by the crus of helix is known as the cymba conchae. The soundscape is the component of the acoustic environment that can be perceived by humans.

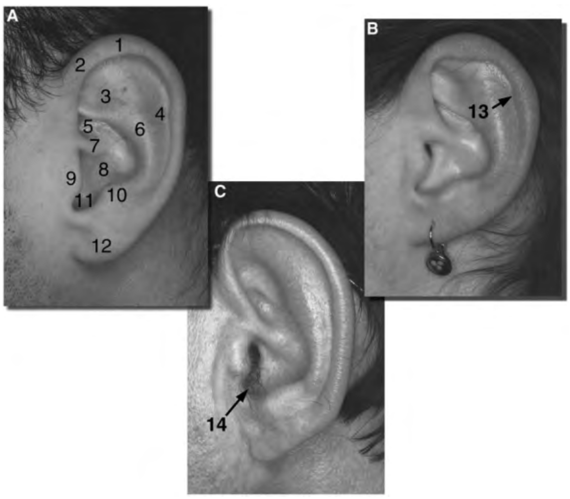
2.1.1 Ergonomics of the human ear

Ears are unique in shape, size and contours of various features, they are used for identification by forensic experts. The length of our ears changes throughout life, as a result of the lengthening of the earlobe. The thickness of the earlobe alters on a daily basis due to postural changes. (Verel, 1955). The auricles are covered with skin, serving as a protective barrier of the human body. Size changes of the ear canal can occur as well, especially in the outer one-third to one-half of the canal, wherein the canal walls are cartilaginous.
(Roebuck, Jr. J (2011) Re-inventing anthropometry for design of ear-mounted or ear-coupled products. In: The Human Factors and Ergonomics Society 55th Annual Meeting [online]
City: Santa Monica, California, pages. Available at :http://journals.sagepub.com.proxy.lib.chalmers.se/doi/abs/10.1177/1071181311551344 [Accessed 31.03.2017].
Scientific studies as well as real-life observations support the statement, that older people are inclined to have bigger ears. This is contributed to the ears being among those body structures, which don't cease to grow after the completion of skeletal maturity. Sex influences all distances and areas (all measurements larger in men than in women of corresponding age), while no significant variation were found for the angles, the ratios and the symmetry indices. Distinct age-related patterns can be observed in men and women, with notable sex x age interactions.
(C.Forza et al. (2009) Age- and sex related changes in the normal human ear. Forensic Science International [online] Volume 187 110e1-110e7 Available at: http://search.proquest.com.proxy.lib.chalmers.se/docview/1034456626/fulltextPDF/BA382C06062B4B8FPQ/1?accountid=10041 [Accessed 31.03.2017]



1. Tragus
2. Osseous part of meatus
3. Cartilagineous part of meatus
4. External acoustic pore
5. External acoustic meatus
6. Antitragus
7. Auricle
8. Auricular hair (tragi)
9. Subcutaneous fat
10. Skin
11. Perichondrium
12. Auricular cartilage
13. Antihelix
14. Helix

Fig. 2.1.3 András Csillag (2005) *The external ear* [png]



1. Helix
2. Crura anthelicis
3. Triangular fossa
4. Scaphoid fossa
5. Cymba conchae
6. Antihelix
7. Crus helicis
8. Cavum conchae
9. Tragus
10. Antitragus
11. Intertragic notch (incisura intertragica)
12. Earlobe
13. Tuberculum apicale
14. Coarse hairs (tragi) surrounding the external acoustic pore

Fig.2.1.2 András Csillag (2005) „ *Photographs of human auricles. A - young male; B - young female; C - middle-aged male. Note the individual differences in the shape and size of the earlobe.”* [png]

2.2 In-the-ear (ITE) headphones

In-the-ear (ITE) headphones are electroacoustic transducers, which convert an electrical signal to a corresponding sound in the user's ear. Headphones are designed to allow a single user to listen to an audio source privately. Earphones are very small headphones that are fitted directly in the outer ear, facing but not inserted in the ear canal. Earphones are portable and convenient, but many people consider them to be uncomfortable. (Ha, P. (2010) TIME Magazine [online]. Available at: http://content.time.com/time/magazine/article/0,9171,1982314,00.html [Accessed 31.03.2017].

Fig. 2.2.1 *Who made that earbud?* Jens Mortensen for The New York Times 16.05.2014 [png] Available at: https://mobile.nytimes.com/2014/05/18/magazine/who-made-that-earbud.html[Accessed 16.04.2017].

They provide hardly any acoustic isolation and leave room for ambient noise to seep in; users may turn up the volume dangerously high to compensate, at the risk of causing hearing loss. On the other hand, they let the user be better aware of their surroundings. Since the early days of the transistor radio, earphones have commonly been bundled with personal music devices. They are sold at times with foam pads for comfort.

Engber,D. (2014). 'Who Made That Earbud?' The New York Times Magazine. [online]. Available at: https://mobile.nytimes.com/2014/05/18/magazine/who-made-that-earbud.html [Accessed 31.03.2017].

2.2.1 Audio transparency

Audio transparency means the amount of audio sounds coming from the outside, when actively using earbuds.

2.2.1.1 Noise cancellation

Technology inside the headphones decreasing ambient sounds.

2.2.1.2 Active noise cancellation

Active noise cancellation requires energy, this type of noise cancellation method means more components inside the headphones.

2.2.1.3 Passive noise cancellation

Compared to ANC, passive noise cancellation does not require additional power, it exploits the soundproofing properties of certain materials, in order to reduce ambient sounds.

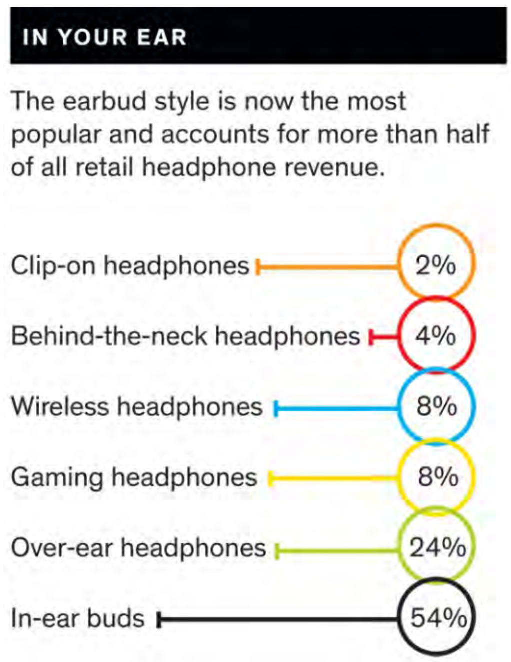


Fig. 2.2.2 *In your ear* [png] Available at: https://mobile.nytimes.com/2014/05/18/magazine/who-made-that-earbud.html [Accessed 16.04.2017].

2.2.2 Evolution of ear-fitting headphone technologies

If we study the form of earbuds available on the market today, we could discover resembling features of a device that couldn't have a less entertaining application in comparison to those of ear-fitting headphones nowadays, this device is : the stethoscope. The shape and size of the latter has changed little since it's invention in 1850's, the headphones have evolved much since then with the help of technological, as well as societal development.

Transducer's are essential components of headphones. In order to evaluate how eco-design and circularity of headphone products could be improved , several transducer technologies were studied. However it is to be noted that the design of the internal signal processing of the headphones is out-of-scope for the current thesis work, with regards to academic goals as well as time limitations. The type of technology chosen for the in-the-ear headphone product concept determines it's design process, as well as further work and production potential.
Mapping out the components, which unfortunately at the moment are well beyond the scope for cellulose-based material research is a more efficient eco-design overture.
Understanding seemingly more complex components is for the benefit of the overall in-the-ear headphone product concept, which is constructed from multiple parts.

2.2.3 Transducer technology

Different types of transducers are used to convert electric signals into audio signals, sound.

2.2.3.1 Moving coil

The most commonly used transducer in headphones. A static magnetic field is created by a fixed stationary magnet, a voice coil is suspended in this attached to the diaphragm. A varying magnetic field against the static magnetic field causes the diaphragm to vibrate back and forth.

2.2.3.2 Electrostatic

The diaphragm is suspended between two perforated metal electrodes, which create an electrical field. Electrical signal drives the membrane, while the air is forced through the perforations, which creates the soundwave.

2.2.3.3 Orthodynamic

The membrane is suspended between two sets of permanent, oppositely-aligned magnets. Movement in the membrane makes the sound waves, when current is passed through the wires, which are embedded in the membrane, the magnetic field produced by the current reacts with the field caused by the permanent magnets.

2.2.3.4 Thermoacoustic technology

Sound is created by the audio frequency Joule heating of the conductor.

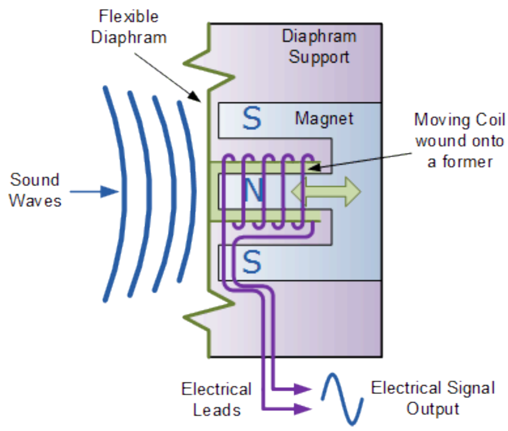


Fig.2.2.2.1 *Dynamic Moving-coil Microphone Sound Transducer*
Available at: http://www.electronics-tutorials.ws/io/io45.gif?x98918
[Accessed 16.04.2017].

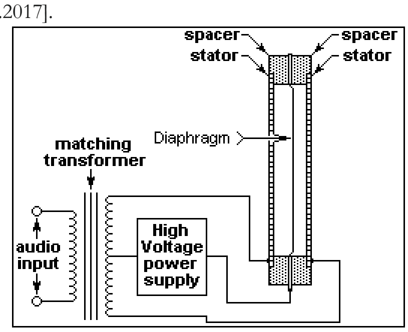


Fig. 2.2.2.2 *Electrostatics* [online]
Available at: http://www.soundimage.dk/Different-col/Electro.htm
[Accessed 16.04.2017]

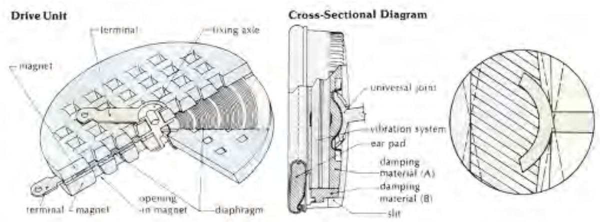


Fig. 2.2.2.3 (2013) *"Orthodynamic transducer"* [online] hifiheadphones Available at: http://www.hifiheadphones.co.uk/reviews/what-are-orthodynamic-headphones/ [Accessed 16.04.2017].

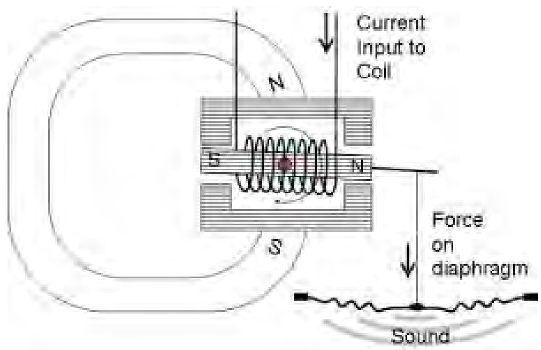


Fig. 2.2.2.5 *"Balanced armature driver"* (2012) [online] Jerry Harvey Audio. Available at: https://jhaudioblog.wordpress.com/2012/09/26/what-is-a-balanced-armature-driver/ [Accessed 16.04.2017].

2.2.3.5 Balanced armature

Moving magnetic armature is pivoted so it can move in the field of the permanent magnet. Electric current magnetizes the armature one way or the other, causing it to rotate slightly one way or the other about the pivot thus moving the diaphragm to make sound.

2.2.3.6 Air Motion Transfer technology

Moves air in an augmented, semi-perpendicular motion using a folded sheet, structured around a series of aluminum struts positioned in a high-intensity magnetic field.

2.2.3.7 Piezoelectric film

An electric charge induced by a flow of electrons when pressure is applied at the ends of a polar axis of a crystal which lacks a centre of symmetry and which has different crystal forms at opposite ends.
(Allaby, M. (2013) The Oxford Dictionary of Geology & Earth Sciences, Oxford University Press)

Ear-fitting headphones, wireless and wired alike contain electronics. Electronic materials are used for cables, wires for signal processing, driver units translate these electrical signals to soundwaves, which we could hear. Both wired and wireless ear-fitting headphones require a power source, batteries are used to store energy in case a device is being operated in a wireless mode. In the next section conductivity is briefly explained 2.3 *Electrical conductivity,* further on properties of cellulose-based materials are disclosed (See Fig. 2.4.1 *MFC gel*; Fig. 2.4.2 *Aerogel after freeze-drying);* active materials are explained in section 2.4.3 *Mixed ionic electronic conductor (MIEC)*, 2.4.4 *PEDOT:PSS,* 2.4.8 *NFC-PEDOT paper.* Production techniques of cellulose-based materials, as well as those of active materials are shortly outlined (See 2.5 *Production techniques)*

2.3 Electrical conductivity

The ease with which an electrical current will pass through a material, in units of siemens or reciprocal ohms (ohms) per metre. In materials which are assumed to be isotropic, conductivity is equal to the inverse of resistivity (ϱ), therefore $\sigma = 1/\varrho$. (Allaby, M. (2016) Dictionary of Geology and Earth Sciences, Oxford University Press)

Resistance of conductors with uniform cross-section defined as:

$$\rho = R \cdot \frac{A}{l}$$

where,

R is the electrical resistance of a uniform specimen of the material;
L is the length of the piece of material;
A is the cross-sectional area of the specimen.

Every material has its own characteristic resistivity. For example, rubber has a far larger resistivity than copper. The above equation can be transposed to get Pouillet's law (named after Claude Pouillet):

$$R = \rho \cdot \frac{l}{A}$$

The resistance of a given material increases with length, but decreases with increasing cross-sectional area. From the above equations, resistivity has the SI unit "ohm metre" (Ω·m).

Conductivity, σ, is defined as the inverse of resistivity:

$$\sigma = \frac{1}{\rho}$$

Conductivity has SI units of "siemens per metre" (S/m).
The electrical resistivity, ϱ, is defined as the ratio of the electric field to the density of the current it creates:

$$\rho = \frac{E}{J}$$

where

ϱ is the resistivity of the conductor material,
E is the magnitude of the electric field,
J is the magnitude of the current density,
in which E and J are inside the conductor.
Conductivity is the inverse:

$$\sigma = \frac{1}{\rho} = \frac{J}{E}$$

2.4 Materials

2.4.1 Nanocellulose

Nanocellulose is a completely renewable material derived from wood fibres, which could be used to produce high-strength, durable materials. Recent studies had found that the energy efficiency of it’s production process could be improved, which translates into a more applicable commercialized production. It is composed of nanosized cellulose fibrils, typical fibril widths are 5-10 nanometers with a wide range of lengths, typically several micrometers. *NFC* is a short abbreviation of the word nano-fibrillated cellulose. *CNF* (cellulose nanofibers) or *MFC* (microfibrillated cellulose) are also used to describe the material. (Innventia, (2011). “Nanocellulose”.)

Fig. 2.4.1 Innventia (2011) *„MFC gel"* [png] Available at: http://innventia.com/en/Our-Expertise/New-materials/Nanocellulose/ [Accessed 16.04.2017].

Fig. 2.4.2 Anna Póka (2017) *„Aerogel after freeze-drying"*[png]

2.4.2 Aerogels

Their application area is wide, due to the series of outstanding properties, such as low thermal conductivity, and low propagating speed of sound. (Hüsing , N., Schubert, U. , Angew. Chem. Int. Ed.1998 , 37 , 22.); (Pierre,A. , Pajonk, G. , Chem. Rev.2002 , 102 , 4243.) Thanks to organic carbon nanotube (Bryning, M. B., Milkie, D. E., Islam, M. F., Hough, L. A., Kikkawa, J. M., Yodh, A. G., Adv. Mater. 2007 , 19 , 661 .) graphene, (Hu, H. , Zhao, Z. , Wan, W. , Gogotsi, Y. , Qiu, J. , Adv. Mater. 2013 , 25 , 2219.); Sun, H. , Xu, Z. , Gao, C. , Adv. Mater. 2013 , 25 , 2554 .) nanocellulose, (Hamedi, M., Karabulut, E. ,Marais, A. ,Herland, A., Nyström, G. , Wågberg, L. , Angew. Chem. Int. Ed. 2013 , 52 , 12038.); (Kobayashi, Y. , Saito, Isogai, T., Angew. Chem. Int. Ed. 2014 , 53 , 10394.) conductivity and heat insulation properties in combination with extreme mechanical flexibility are achievable. The above listed characteristics designate aerogels towards energy storage applications, where these distinctive properties could be exploited. Aerogel beads could be produced with new technological methods.

2.4.3 Mixed ionic electronic conductor (MIEC)

It is one of our society's biggest challenge, to keep up with rising energy demands, therefore it is a matter of necessity to develop materials capable of storing and managing huge amounts of electrical energy.
This process is being barred by the lack of bulk materials with both a high electronic - ionic conduction, i.e., mixed ionic electronic conductor (MIEC) bulk systems. The aforementioned systems should preferably be produced out of sustainable, lightweight, abundant materials, the manufacturing process of which could be scaled up with ease. The MIEC's would facilitate the appropriation of supercapacitors, they may be further functionalized with catalysts for fuel cells (Winther-Jensen, B. , Winther-Jensen, O. ,Forsyth, M. , MacFarlane, D. R. , Science 2008 , 321 , 671 .) or with additional redox species for batteries. (Milczarek, G. ,Inganäs, O. , Science 2012 , 335 ,
1468.) The field of high power electronics, as well as ultra-low noise bioelectronic sensors could be pursued, due to these technological innovations. Rivnay, J. , Leleux, P. , Hama, A. , Ramuz, M., Huerta, M. , Malliaras, G.G. , Owens, R.M. , Sci. Rep. 2015 , 5 , 11613.)
MIEC's are part of two separate families:

- ceramics
- conducting polymers.

The latter are potential candidates for mass production, moreover implementation on larger scales, owing to their low temperature processability (relative to ceramics) and their easily scalable wet synthesis. (Forrest, S.R. , Nature 2004 , 428 , 911.)
High electronic conductivity (1000 to 4000 S cm−1O. (Bubnova , Khan, Z. U. , Wang, H. , Braun, S. , Evans, D. R. , Fabretto, M. , Hojati-Talemi, P. , Dagnelund, D. , Arlin, J. B. , Geerts, Y. H. , Desbief, S. , Breiby, D. W. , Andreasen, J. W. , Lazzaroni, R. , Chen, W. M. , Zozoulenko, I. , Fahlman, M. , Murphy, P. J. , Berggren, M. , Crispin, X. ,Nat. Mater. 2014 , 13 , 190.); (Kim, N. , Kang, H. , Lee, J. - H. , Kee, S. , Lee, S. H. , Lee, K. , Adv. Mater.2015 , 27 , 2317.) has been achieved in organic thin films (10 nm to 10 μm) and in functional fibers and fibrils . (Kim, F. S. , Ren, G. , Jenekhe, S. A. , Chem. Mater. 2010 , 23 , 682.); (Long, Y. - Z. , Li, M. -M. , Gu, C. , Wan, M., Duvail, J. - L. , Liu, Z. , Fan, Z. , Prog. Polym. Sci. 2011 , 36 , 1415.); (Persano, L. , Camposeo, A. , Pisignano, D. , Prog. Polym. Sci. 2015 , 43 ,48.)

2.4.4 PEDOT:PSS

PEDOT:PSS or poly(3,4-ethylenedioxythiophene) polystyrene sulfonate is a polymer mixture of two ionomers. The charged macromolecules add up to a macromolecular salt. It could be utilized in various applications as a transparent, conductive polymer with high ductility. PEDOT is a conjugated polymer, based on polythiophene, which carries positive charges.
The other component in this mixture is made up of sodium polystyrene sulfonate, which is a sulfonated polystyrene. Part of the sulfonyl groups are deprotonated, along with carrying a negative charge.

2.4.5 Cellulose-based materials

Cellulose is an organic compound with the formula (C6H10O5)n, a polysaccharide consisting of a linear chain of several hundred to many thousands of linked D-glucose units. Cellulose is an important structural component of the primary cell wall of green plants, many forms of algae and the oomycetes. Some species of bacteria secrete it to form biofilms. Cellulose is the most abundant organic polymer on Earth. The cellulose content of cotton fiber is 90%, that of wood is 40–50% , that of dried hemp is approximately 57%.
Cellulose: „The most abundant polymer used in nature by nature." (Lucisano M., Cellulose-based society)

2.4.6 NFC-PEDOT paper

NFC-PEDOT paper, is a composite material created using solvent-casting method; it blends high electronic and ionic conductivity with ease of production, mechanical properties compatible with paper-making machines.
NFC is a nanofiber frame system with " remarkably high toughness with a large strain-to-failure." (Henriksson, M. , Berglund, L. A. , Isaksson, P. , Lindström, T. , Nishino, T. ,Biomacromolecules 2008 , 9 , 1579.)
NFC is here utilized as a 3D-scaffold to improve the PEDOT:PSS's micro/mesoscopic organization in 3D
(i.e., it acts as a tertiary dopant to favor high conductivity also in bulky dimensions).
NFC-PEDOT is therefore a composite material combining the beneficial properties of cellulose and conducting polymers. The NFC-PEDOT paper may be folded (even creased) repeatedly, while retaining its mechanical and electrical properties. Figure 2.4.6.1(b) shows NFC-PEDOT folded into an origami swan, a treatment which is impossible to apply to a thick PEDOT:PSS film, because of its brittleness.
The NFC-PEDOT can be used as an electrical conductor, which supplies current to an (opto)electronic device. It is a mechanically resilient composite material. Structural integrity is imperative for the implementation of bulk electrochemical devices. Studies have shown that PEDOT:PSS forms a homogeneous coating around entangled cellulose nanofibrils. (Abdellah Malti, Jesper Edberg, Hjalmar Granberg, Zia Ullah Khan, Jens W. Andreasen, Xianjie Liu, Dan Zhao, Hao Zhang, Yulong Yao, Joseph W. Brill, Isak Engquist, Mats Fahlman, Lars Wågberg, Xavier Crispin and Magnus Berggren (2015) An Organic Mixed Ion-Electron Conductor for Power Electronics. Advanced Science. [online] Volume 3, Issue 2, February 2016, Available at:
http://onlinelibrary.wiley.com/doi/10.1002/advs.201500305/epdf [31.03.2017]

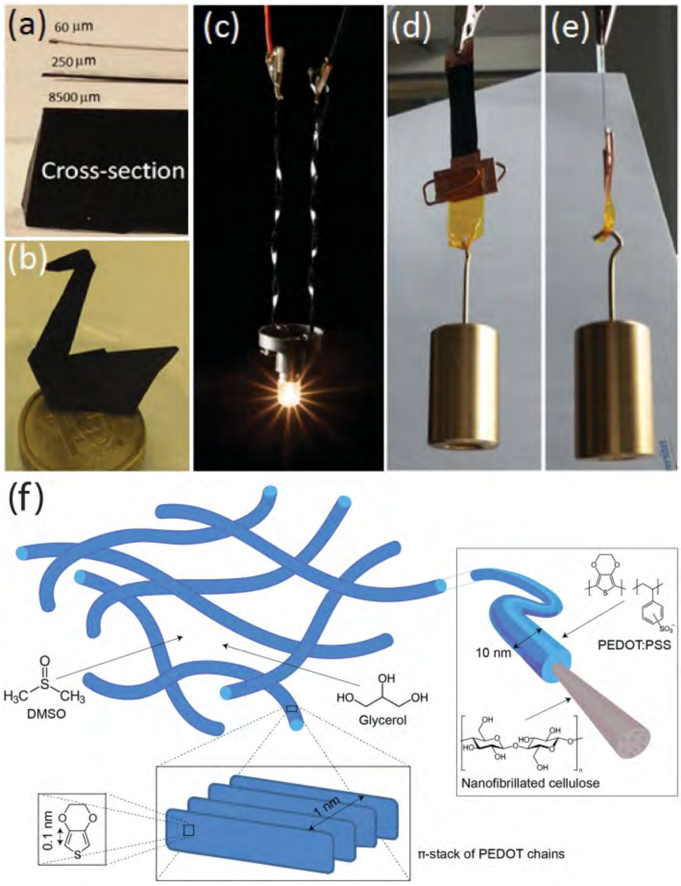


Fig.2.4.6.1 (2016)
a) *Cross section showing a wide range of thicknesses for the NFC-PEDOT nanocomposite,*
b) *NFC-PEDOT origami structure,*
c) *NFC-PEDOT ribbons connected to a LED,*
d,e) *122 µm thick NFC-PEDOT stripe subjected to a weight of 100 g.*
f) *Proposed multiscale model for the morphology and self-organization in the NFC-PEDOT composite.* The chemical structures of each of the component are indicated.[png]
Available at:
http://onlinelibrary.wiley.com/doi/10.1002/advs.201500305/epdf [31.03.2017]

2.7 Production techniques

2.7.1 Solvent-casting

A process of pouring a solvent into a mould in liquid state, after which the solvent forms a film in the mould in the course of air-drying for a certain time period.

2.7.2 Freeze-drying

This technique involves placing solutions in a specific mould inside a freezer for a certain time period. After removing the frozen solution, the water is removed by placing the frozen material in various solvents in a predefined sequence.

2.8 Eco-design

Ecological design. This particular approach to designing the object takes into account the harmful effects of the object on the environment, reducing and eliminating them, and striving for a more favorable boundary by exploiting the technical, technological, social, economic, political and cultural opportunities. This approach is realized by holistic product and company philosophy. Ecodesign applies the technical possibilities in combination with social and cultural sensitivity. It strives to focus its attention towards self-restraint opposite to over styling, and artificially generated needs and towards the product's basic function, the importance of its qualitative originality. Ecodesign is the result of an ecologically committed design method that creates an organic product.

Eco-design's design approach can be registered in three main points:

- Cycle approach:

Artificial materials could be recycled into production as new raw material, when the product is worn out.

- Dematerialisation:

The aim is the minimisation of raw material use, when creating the product.

- "Caring for things":

Longer life-cycles and maintenance of the product is value, it's efficiency becomes a basic design requirement.

Today eco-design's basic requirements could be listed as such: durability, long life-cycle, protection of the environment and health, biological degradability, renewability, low energy-use.

2.8.1 Eco-materials

Eco-materials are a group of materials, which have the least harmful impact on the human and natural environment.
From design point-of-view eco-materials have to comply to the following three basic demands:

- *Classic material properties:*

Physical, solidity, chemical properties and aspects.

- *Environmental compatibility:*

By using eco-materials the environmental impact is reduced to minimal throughout the entire product life-cycle, during the processing, the shipping and the disposal.

- *Condition of pleasantness:*

The new material must have in regards to physiological and psychological aspects a pleasant effect on the human sensorial system in its appearance, feel.

Main research- and development directions for eco-materials:
Expands the human possibilities with the help of new materials and new technologies. By complementing the traditional material development with new viewpoints, new physical, aesthetical, functional and biological properties could appear in our environment. Harmonic relationship is formed in the eco-sphere between the artificial human environment and nature. The most important aspect is developing processes enabling sustainability. Establishing an optimal technology and infrastructure, creating the conditions of a healthy life.
(Zalavári,J. (2008) "A forma tervezése - Designökológia. Designökológiai kislexikonnal". Budapest: Scolar)

2.9 Connectivity

2.9.1 Bluetooth technology

A wireless technology designed to replace cables between cell phones, laptops, and other devices. Bluetooth wireless technology works within a 1-, 10-, or 100-metre range and uses the 2.4 GHz band, which is unlicensed and can be used by many other types of devices such as cordless phones, and baby monitors. See also WiFi. (Butterfield, A and Ekembe Ngondi, G.. (2016) Oxford Dictionary of Computer Science, Oxford University Press)

2.9.1.1 Advanced Audio Distribution Profile (A2DP)

This profile defines the requirements for Bluetooth® devices necessary for support of the high quality audio distribution.
(The Bluetooth SIG Board of Directors (2012). ADVANCED AUDIO DISTRIBUTION PROFILE SPECIFICATION. [pdf] Available at: file:///C:/Users/Felhaszn%C3%A1l%C3%B3/Downloads/A2DP_SPEC_V13.pdf [Accessed 29.04.2017].

Introduction
Theory
Current products
Methods
Analysis
Results
Final result
Discussion & Conclusion

3. Current products

Given the popularity of the in-the-ear (ITE) headphones there is a wide variety of this product available on the market today. (See Fig.2.2.2 *In your ear*). Some products within the in-the-ear (ITE) subcategory of the earbuds were reviewed.

The following ITE products all feature appealing answers to the issues in relation to this product category :

- usage
- storage
- product experience
- circular economy
- energy-efficiency

From this thesis project's perspective, it was beneficial to study these solutions in detail, as the product is undergoing another iterative phase with the increased importance of wireless technology. The evolution of the human body is slower than that of technology, under normal circumstances people will continue to have two ears, each positioned on both sides of the head to fulfill the hearing and balancer functionality for a very long time in the future (See Fig.2.1.1 *Human ear funcionality*).
Bone conductive technology is used in some products, albeit the sound quality of these products cannot yet be compared to that of ITE headphones using conventional transducer technology (*See 2.2.3 Transducer technology, p.21*). The examined products have been studied for the sake of examining the listed aspects, additionally how these are integrated into the product experiences, the brand and pricing of the articles are not being regarded as representative evaluative criterions.

3.1 Sumpan

This in-the-ear headphone has lots of smart solutions, for example the cable-hoop, which enables the user to hook the left- and right-side earbuds onto each other, forming a loop around the user's neck. It also has tangle-free cords, the wiring of the headphones are covered in textile-like material. The CableLoop allows the user to store the product in a more organized way, the cords can be fastened together due to the slightly longer plug, made from flexible silicone material. According to the product's reviews, some users find it too large and uncomfortable after a certain usage period, also it tends to fall out of their ears, while chewing or eating.

Headphone type: In ear
Compatible with: All devices
Weight: 20 grams
CableLoop: Yes
L-plug: Yes
Connection: 3,5mm plug
Audio size: 13.6 mm dynamic drivers
Frequency response: 20Hz-20kHz
Impedance: 39Ω
Sensitivity: 101dB
Max input power: 50mW

Fig. 3.1.1 UrbanEars. (2016). *"Sumpan ear-fitting headphones - Hook construction"*. [png] Available at: https://www.urbanears.com/ue_se_en/sumpan [Accessed 29.03.2017].

Fig. 3.1.2 UrbanEars. (2016). *"Sumpan ear-fitting headphones."* [png] Available at: https://www.urbanears.com/ue_se_en/sumpan [Accessed 29.03.2017].

love it! but...
Gabriël March 3, 2017 I love these and often use them when I am traveling or working out. perfect fit for this, but would like to see as well that I can buy those earphones silicones. Easily fall off and I would honestly pay just to buy some extra silicones. they are soft and noce on the ears rather the bold and hurting inside.
Size matters
Rolja February 25, 2017 I like this earbuds a lot. The design and sound are great, but the size not so much. This earbuds seem to be designed for folks with large ears. I can't spend more than an hour with them on. And it hurts when I take them off. Next time make them smaller, ethnic folks with small ears will appreciate it. Thanks!
Earbud Solution
Alex January 16, 2017 Had the same problem with the earbuds. But just put a tiny drop of super glue around the edge of the bud and put the silicone ear piece on problem solved.
Great, but not for everyone
Vic November 29, 2016 Great design, great sound and great price.

The remote has round edges and doesn't catch on your clothing.

Fitment on the other hand is very poor for those with small ears. I am physically unable to wear the earbuds. If I smile or chew gum, they fall out instantly.

I would love to be able to choose from different ear pieces to allow for the anatomy of different listeners.
Great Sound but Have Problem in Ear Sleeves
MusafiArif November 28, 2016 Love it, the sound is great but same with other people my earphone have problem with lost ear sleeves, i think this earphone must make ear sleeves patching well.

Fig. 3.1.3 UrbanEars (2016)*Sumpan user reviews* [png] Available at: https://www.urbanears.com/ue_se_en/reimers [Accessed 29.03.2017].

3.2 Reimers

These ITE headphones have been designed for physical activities, the "EarClick solution" fixes the headphones in the user's ears, while doing sports etc. It also has reflective material integrated in the cable sleeves, which provides more visibility for the user while doing sports during the night or early in the morning. According to the users reviews they prefer this product's sound quality over "Medis", which is another UrbanEars product in the same category. Some are missing the 3.5 mm plug and some complained that the earpieces could be easily lost.

Headphone type: In ear
Weight: 20 grams
Volume control: Yes
L-plug: Yes
Connection: 3,5mm plug
Audio size: 13.6 mm dynamic drivers
Impedance: 32Ω
Sensitivity: 101dB
Max input power: 50mW

Fig. 3.2.1 UrbanEars (2016) *"Reimers ear-fitting headphones Hero 900"* [png] Available at: https://www.urbanears.com/ue_se_en/reimers [Accessed 29.03.2017].

Olle December 30, 2016 The sound is really good and the fit my ears perfectly. The remote+mic is very handy. The only thing that's "bad" is that there is no L-shaped 3,5mm plug like the medis have. Overall I think it's a better version of a pair of medis.
Liz April 6, 2017 These were great for the first few weeks, but then the right earpiece cover starting falling off when I would take them out of my ear. After a few drops, I finally lost it for good. Looking into getting replacement covers because these are the only earbuds that stay in my ear. I just wish the earpiece didn't separate from the base so easily....
Loulou February 23, 2017 Love it!! Just one thing to know before order: not compatible with anything else than Apple products for control buttons. Perfect for everyday life and for running.

Fig. 3.2.2 UrbanEars (2016) *"Reimers user reviews"* [png] Available at: https://www.urbanears.com/ue_se_en/reimers [Accessed 29.03.2017].

3.3 Kransen

Kransen headphones feature a snap construction, similar to the interlocking mechanism of a LEGO brick, users can form a loop around their neck, when they are passively using the product. Kransen also has "CableLoop" technology for easier storage. According to the reviews published on UrbanEars website, users really like using this product.

Headphone type: In ear
Compatibility: All devices
Weight: 20 gr
Snapconstruction: Yes
Cableloop: Yes
L-plug: Yes
14 hrs playback: Yes
Connection: 3,5 mm plug
Audio size: 10 mm hand-made drivers
Impedance: 16 Ω

Fig. 3.3 UrbanEars (2015) *"Kransen ear-fitting headphones"* [png] Available at:https://www.urbanears.com/ue_se_en/kransen [Accessed 29.03.2017].

3.4 Medis

These ITE headphones have an "EarClick" solution, which fix the headphones in the user's ears while conducting physical activity. It has also the built-in "CableLoop" for easier storing. The cables are covered in a textile-like material for making them less prone to tangling.
In comparison to the previous UrbanEars product from the same category the reviews seemed to be more extensive and detailed on this product. Many users wrote, that the part that is fixing them in their ears is easy to lose, without any back-up service after they lose a part they cannot enjoy the same level of product experience as before.

Headphone type: In ear
Compatible with: All devices
Weight: 20 grams
CableLoop: No
EarClick: Yes
Connection: 3,5mm plug
Audio size: 15.4 mm handmade drivers
Impedance: 32Ω
Sensitivity: 115dB
Max input power: 5mW

Fig. 3.4.1 UrbanEars (2015) *"Medis ear-fitting headphones - Earclick solution"*. [png] Available at: https://www.urbanears.com/ue_se_en/medis [Accessed 29.03.2017].

Magnus March 14, 2017 Great earbuds not least for running. Only complaint is the pads easily get lost

Hidas February 16, 2017 I have just one thing to complain: I have lost one of the ear pads three times and found it just twice. You should sell spare pads. :(

Henkhenk December 5, 2016 Great sound, fit and looks. However, the cable quality is terrifying bad, within 6months mine were done

Anna November 29, 2016 OUTSTANDING product. Great sound, cute colors, cableloop is genius. I wish i could get them as bluetooth wireless.

Borka September 29, 2016 Fits my ears. I cannot use those you plug into the ears. The only bad thing is that the blunt ends of the "controller" constantly hooks into my clothes.

CampGrizzly January 22, 2016 These headphones are awesome, they last a long time and are super comfortable! I accidentally put these headphones through the wash and three months later they're still the same quality as I bought them! I just wish I could buy replacement ear click parts, I lost the size I usually wore and now it's either too big and a bit painful after a while or too small and they get tugged out easily. If these ever bust I'll for sure buy the same ones, they're pretty great overall.

HavocFactory December 28, 2015 The sound is decent (sounds about as good as my old V-modas), and the design is great for running safely (allows ambient sound in without interfering with your listening). Durability is the weak link... I've had problems both with the buds themselves falling apart (the speaker part detaching from the outer disc where the cord inserts), as well as with the little rubber tabs breaking apart (and thus no longer holding the buds in the ear). The first problem is fairly easily fixed with some super glue, but the second is particularly annoying. IMO, the Medis should ship with a dozen or so of the little rubber tabs if you want them to last more than a year or so, or UE should at least make these available in replacement packs.

The only reason I didn't give them five stars is that the fitting pieces are non-replaceable. I was told by a customer service rep months ago that they would be available for purchase, but I haven't seen any sign of this. As a result, having lost one of the fittings, they are much less excellent.

Fig. 3.4.2 UrbanEars (2015) *"Medis user reviews"*[png]
Available at: https://www.urbanears.com/ue_se_en/medis [Accessed 29.03.2017].

3.5 Stitch

ITE headphones part of the Molami brand. This Zound Industries brand focuses on creating audio products as high-end fashion accessories. It is available in matte black and gold or matte white and copper. As all Molami headphones, Stitch comes with a twisted fabric cable sleeve complete with a microphone and remote. No user reviews are available about this product on the company's website.

Driver: 9mm dynamic
Sensitivity: 100mV @ 1kHz = 98dB SPL
Impedance: 32 ohm
Frequency Range: 20Hz - 20kHz
Weight: 17 g / 0.59 oz

Fig. 3.5 Molami (2011) *"Stitch ear-fitting headphones".* [jpg] Available at: https://www.molami.com/mo_se_en/stitch-black-gold [Accessed 29.03.2017].

3.6 Coloud No. 4

This product features a magnetic snap built-in the earbuds to make their passive usage and storage easier. They also have a "ZoundLasso", which is a longer plug, made from flexible silicone material, which could be wrapped around the wiring, making it easier to store the product. The cabling is flat, which makes them more tangle-free. The reviews were mostly positive about the product, only some were concerned about the product's durability.

Material
I have no sayings about the sound quality of coloud no. 4 but I'm not sure about the earbuds, it's not rubber coated. I don't care about the style, i care about on the durability of your product. But all in all I'll rate it 4 over 5

Fig. 3.6.1 Coloud (2015) *"No. 4 user reviews."* [png]
Available at: https://www.coloud.com/co_se_en/no-4/ [Accessed 29.03.2017].

Fig. 3.6.2 Coloud (2015) *"No. 4 ear-fitting headphones".* [png]
Available at: https://www.coloud.com/co_se_en/no-4/ [Accessed 29.03.2017].

3.7 The Hoop

This product is Coloud brand's answer to the demands of an urban, active person. It has "sweat-resistant" earbuds with front and back vents, reflective cabling for more visibility, also "AnchorLoop" for finding the best fit for the users. It has flat cabling and "ZoundLasso" built-in for making the storage easier. The user reviews were mostly positive about this product, some were concerned about the rubber tips coming off easily or not having instructions or illustrations included in the packaging.

Driver: 13.6mm dynamic
Sensitivity: 100mV @ 1kHz = 101dB SPL
Impendance: 32 ohm
Frequency Range: 20Hz - 20kHz
Weight: 20g /0.70 oz

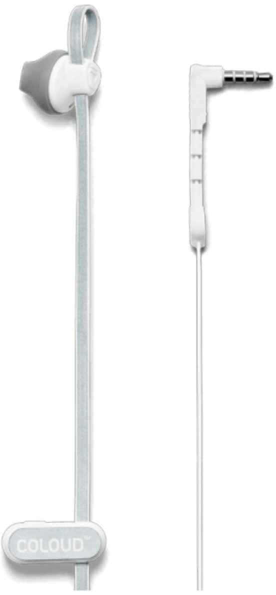


Fig. 3.7 Coloud (2015) *"The Hoop ear-fitting headphones".* [png]
Available at: https://www.coloud.com/co_se_en/hoop/ [Accessed 29.03.2017].

3.8 BUTTONS

The familiar shape of vinyl records has influenced the product's circular design, which has been crafted from machined metal, paired with a woven fabric cable. This allows wearers to seamlessly integrate the device into their everyday wardrobe. The fashion-forward headphones don't compromise on technology, they include a 30-foot bluetooth range and a built-in remote and microphone. The devices are compatible with iphone, ipad, apple watch, and android platforms.
(Azzarello,N. (2016) "interview with will.i.am on the debut of i.am+ BUTTONS bluetooth earphones". Designboom [online] Available at: http://www.designboom.com/technology/will-i-am-interview-buttons-i-am-bluetooth-earphones-11-02-2016/ [Accessed 03.04.2017])

Color: Black, Grey, Rose, Gold
Bluetooth: Bluetooth 3.0 + EDR
Features: Magnetic Discs, Microphone, Nylon Cable, Siri Activation
Size: Small/Medium/Large interchangeable earpads
Connection: Micro USB cable for charging
Driver: 11mm
Power Source: Rechargeable Lithium-ion Battery
Active Battery Life: 6+ Hours
Talk Time: 6+ Hours
Standby Time: 120+ Hours

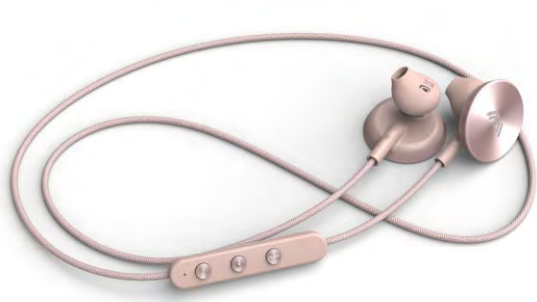


Fig. 3.8 i.am+ (2016) *"BUTTONS wireless ear-fitting headphones".* [jpg]
Available at: https://iamplus.com/buttons/ [Accessed 29.03.2017].

3.9 Stadion

Cable-free ITE headphones, designed for active use. Remote control at the back of the set, with control buttons for adjusting sound volume and a button for answering incoming calls. The "EarClick Solution" ensures the fixture of the headphones in the external ear. The stretchy coils enable the headphones to fit different head sizes, also reflective cables provide higher personal safety for conditions without sufficient lighting conditions.

Headphone type: In ear
Compatible with: All devices
Microphone & Remote: Yes
Connection: Bluetooth 4.0
Max SPL: 115 dB
THD: < 2% at 200 Hz and 100 db SPL
Playtime: Up to 7 hours

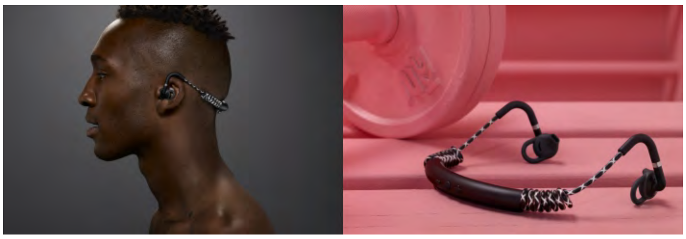


Fig. 3.9 UrbanEars (2017) *"Stadion ear-fitting headphones".* [jpg]
Available at:https://www.urbanears.com/ue_se_en/stadion [Accessed 29.04.2017].

3.10 Dash

Wireless earphones with bilateral balanced armature speakers (*See 2.2.3.5 Balanced armature*). Battery life up to 3 hrs with 5 additional charges using the charging case. It can store up to 4GB of audio files, it is water resistant to 1m depth. It has a touch interface, it can be used in a passive noise isolation mode (mutes surrounding ambient noises), as well as audio transparency (when you can hear the environment around you).
(Bragi , (2016). Compare Bragi products. [online] Available at: https://www.bragi.com/comparison/ [Accessed 29.03.2017].

Fig. 3.10 Bragi (2016) *„The Dash wireless ear-fitting headphones.*" [png] Available at: https://www.bragi.com/thedash/ [Accessed 29.03.2017].

3.11 SHURE SE846

ITE headphones featuring ten precision-welded stainless-steel plates inside the driver, as well as detachable cable reinforced with Durable Kevlar™ allowing easy replacement or customization. The cable is available with two different lengths (45" and 60") for flexible wearing options.

Speaker type: Quad High-Definition Microdrivers
Sensitivity (1 kHz): 114 dB SPL/mW
Impedance: 9 Ω
Frequency range: 15 Hz - 20 kHz
Cable length: 162 & 116 cm
Color: Clear, black

Fig. 3.11 SHURE (2016) *„SHURE Se846 ear-fitting headphones."* [png] Available at: http://www.shure.eu/products/earphones/se846 [Accessed 29.03.2017].

3.12 Monster iSport Bluetooth Wireless Sport Headphones

Wireless ITE headphones with a 30 foot range. Provides 5+ hours of play time, it comes with USB charging cable and carry pouch. It is characterized by an angled ear tip, serving to provide a better fit for the ears.

Fig. 3.12 Monster (2016) *„iSport Bluetooth wireless ear-fitting headphones.*" [png] Available at: http://www.monsterproducts.com/collections/headphones/isport-wireless [Accessed 29.03.2017].

A product' s success amongst the customers depends on a lot of aspects, the reviews illustrate the importance of the user experience, during the active and passive usage phase. (See Fig.3.1.3 *Sumpan user reviews,* Fig. 3.4.2 *'Medis user reviews").* Beyond great sound quality user's appreciate the added design value in product's, which makes active and passive usage easier for them. Creating cables, which are less likely to tangle up or manufacturing a flexible plug joint (See Fig. 3.1.2 *Sumpan ear-fitting headphones,* Fig. 3.3 *Kransen ear-fitting headphones).* Adjustable cable lengths, providing detachable cable designs (See Fig.3.7 *The Hoop ear-fitting headphones,* Fig. 3.11 *Shure Se846 ear-fitting headphones)* serve the purpose of increasing the quality of the user experience, simultaneously these features add up to contributing to a more circular economy of the ITE headphone category.
With wireless technology being forecasted to take over the market of audio products, user's will continue to purchase products, that are adaptable to their lifestyle, while learning how to use these products in a more energy-efficient way. Ultimately this leads to the creation of a society, that is aware of which choices are more eco-friendly, thus have the possibility of tilting the life-cycle of the ITE headphone products on a micro-level, the environment on a macro-level to the sustainable side.

Methods

4. Methods - *Data collection*

4.1 Observations

The subject of this thesis project is a product, which is used by almost everybody for different purposes regardless of age-, cultural background..etc. , therefore the author of this thesis project observed people, while they were using ITE headphones or similar products. Real-time observation was a careful observation of scenarios taking place in the metro system of Stockholm, Sweden. In 2013, the metro carried approximately 898,630 riders per day.
(SL (2006)AB StorStockholms Lokaltrafik Annual Report 2006 , R19 Strategisk Kommunikation).
The accumulated observation time was cca. 136 hrs, the author of the thesis used the metro system at least twice daily during the designated working weeks. The subjects of this observation were the other passengers, active and passive in-the-ear (ITE) headphone consumers, using the metro system, while they were commuting between their home and workplace or other locations.

4.2 Laboratory work

The following techniques were studied in Innventia AB laboratories: (See Appendix D - Laboratory work)

- Solution-casting production technique - Films
- Freeze-linking production technique - Aerogels
- Functionalized aerogels
- CNF aerogel beads

4.3 Stakeholder interviews

Interviews are an important building block, when it comes to human-centered design. Asking open-ended questions, then encouraging interviewees to tell stories and to deeply describe how they live, think and act enables knowledge to emerge of what they need. This leads to insights and inspirations to the ideation phase.

Subjects of the unstructured interviews, listed below:

Hjalmar Granberg
Hjalmar Granberg was the main supervisor of this thesis project, regular meetings were held throughout the semester, where the actual and upcoming challenges of the project were discussed.

Katja Tasala Gradin
Responsible for the Eco Design course at The Machine Design Institute at KTH, eco-design approaches, issues of sustainability, renewable resources and biodegradability were discussed during the interview.

Steffan Ståhlgren
Responsible for "Product- and Service-design" courses at KTH Machine Design Institute.

Tatjana Karpenja
Project leader at Innventia was interviewed on issues of circular economy and sustainability.

Emma Dahlgren
Fellow Master's student in the interdisciplinary TechMark Arena 2017, working on thesis project:
" Exploring biodegradable electronics". Challenges and issues of the production and life-cycle of the active materials were discussed throughout the semester.

Archana Archok
Fellow Master's student in the interdisciplinary TechMark Arena 2017, working on thesis project:
"Textile-like Paper as Circular Material". Views about the circularity of materials, prototyping demonstrators were exchanged during the semester.

Kerstin Slettengren
Laboratory Engineer at Innventia AB production techniques of active materials and aerogels were examined during planned laboratory sessions.

Henrik Pettersson
Laboratory Engineer at Innventia AB additive manufacturing techniques were discussed, as well as using cellulose-based materials for 3D printing. Also Sense scanning tool was studied for prototyping purposes.

Andreas Fall
Laboratory Engineer at Innventia AB, aerogels and possibilities of producing functional materials were discussed.

Samuel Pendergraph
Laboratory Engineer at Innventia AB, material properties and production techniques of PEDOT:PSS were talked over.

Conrad Luttrop
Professor at KTH Machine Design Institute, eco-design expert. Eco-design and e-waste management issues.

4.4 Survey

A survey containing 18 questions was created using the following website:
(SurveyGizmo, (2017). SurveyGizmo. [online] Available at: https://www.surveygizmo.com/ [Accessed 13.03.2017].)
The survey was distributed online in Swedish and English language and a poster was created for distribution purposes on information boards, whiteboards etc. at the company location, (Innventia AB, Drottning Kristinas väg 61, 114 28 Stockholm), as well as different locations throughout Stockholm. 20 copies of the poster were distributed to the fellow students and their supervisors at the half-time presentation of the interdisciplinary TechMark Arena 2017, an additional 10 copies of the poster was distributed to the researchers after the project presentations at the study visit to Acreo ICT in Norrköping. The author of the thesis asked the participants of both presentations to place the posters at their local bus-, tram-, underground- etc. stop. Also the survey was published on the company's internal website "Innsidan". QR codes were used for the poster to facilitate the survey's accessibility. Most people using public transport carry a mobile device, which could read the QR code with the help of an application. Both the English- and the Swedish-language survey were posted on social media of the fellow students at the TechMark Arena 2017, as well as the author's .

4.5 TechMark Arena

As the project is a part of the interdisciplinary thesis school TechMark Arena, the project members had regular meetings with the other TechMark students and their supervisors. Five planned seminars that were held over the course of the semester, as well as additional workshop activities in connection with the following thesis projects:

- „Exploring biodegradable electronics"
- „Textile-like paper in a circular economy"

4.6 Study trips

- ArkDes - „Designed to last" exhibition:

The exhibition Designed to Last seeks to address some of the most important issues in the furniture design industry today: durability, quality and sustainable production. It showcases some of the leading designers now working in Sweden and is a collaboration between ArkDes and Residence.

Fig.4.5.2 Anna Póka (2017) *"Survey poster placed in Högdalen busstop"* [jpg]. Stockholm

- Norrköping Acreo ICT:

The „clean room" area was visited, where the following machines were examined:

- - impedancespectrometer (0,1Hz - 1 Mhz) - electrochemical characteristics
- - ultrasonic mixer
  - SMU - source measure unit
- battery measurement:- constant current
- - apply/ meaure current
- - cryogenic vacuum-chamber
- - evaporaor machines - electronic functionality
- - spin-coating
- - Printed Electronics Arena

- Manufacturing company

Challenges of designing headphones were discussed, as well as exchange of ideas on renewable materials, biodegradability, sustainability and adaptability to circular economy.

Methods - Data analysis

4.7 Ergonomic analysis

Ergonomic analysis of the external ears was executed as an evaluation of the ear-fitting headphone concepts or environments currently in use to suggest improvements through corrective measures such as adaptations, adjustment, or equipment replacement, or to inspire redesign. It was conducted as a predesign analysis, through the evaluation of comparable products or utilizing human studies, iterature, and standards, to establish ergonomic criteria for new design. (See Appendix C - Ergonomic analysis). Five interrelated criteria commonly used in ergonomic analysis:

- Size

Anthropometry is the systematic measurement of people, used in the evaluation of existing tools for size appropriateness, and for designing new tools and systems according to human scale.

- Strength

The amount of manual force needed for effective use of products and systems encompasses the range of human criteria from finger strength in trigger-based actions, to hand strength for gripping and force requirements, and limb, torso, and body strength for tasks such as lifting.

- Reach

At a micro level, reach refers to the span of the hand, measured as the distance between touch points in tool and equipment design, establishing grip requirements. At a macro level, reach is used to establish and evaluate effective body positions, for the user to safely, effectively access operator controls, or components of a workstation, appliance, or architectural feature in the environment. Reach thresholds are typically established for the fifth percentile of females, assuming that if the smallest user can grip or access, most users will be accommodated. (Martin, B; Hanington, B. (2012).
Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions. Beverly, MA: Rockport Publishers, p.72.)

4.7.1 Anthropometry

Taking relevant measurements is especially important in case of the design of ear-related products due to the complexity of this organ. Ear landmarks were marked with a black-coloured marker on the 3D printed ears. A tripod was used to take photographs with the same lens settings of the 3D printed ears, which were analyzed using vector graphic software.
The variation between the following ear landmarks was studied:

Fig.4.7.1 Anna Póka (2017) *"Variation between ear landmarks"* [jpg]. Stockholm

ADULTDATA - The handbook of adult anthropometric and strength measurements - Data for Design Safety was used to study head-related measurements: p.12-20

- head length
- head breadth
- head diameter
- head height
- coronal arc
- sagittal arc
- back of head height

Ear related anthropometric data (p. 21-25)

- ear length
- ear breadth
- ear height (tragion, standing)
- ear height (tragion, sitting)
- ear to back of head
- ear to top of head

Face related anthropometric data(p.27)

- face length
- face breadth

Neck related anthropometric data (p. 47-52)

- neck breadth (just below level of Adam's apple)
- neck circumference (just below level of Adam's apple)
- neck circumference (around the base of the neck)
- height of prominent neck vertebrae (standing)
- height of prominent neck vertebrae (sitting)
- nape of neck height (sitting)

4.8 Eco-audit

An in-the-ear (ITE) headphone was dissassembled, the components were studied, based on the following questions:

- What type of materials are used for the particular product?
- How are they manufactured?
- How many raw materials are used in the manufacturing of the individual components?
- What type of fixtures and joints are used?
- Which components could be made from cellulose-based materials?
- Which are the components that have more impact on improving the entire product life-cycle?

There is an oversupply of the in-the-ear (ITE) headphone product type, so a complete life-cyle analysis is not the goal of this thesis work. Furthermore companies are creating new user groups, by targetting eg. classic music listeners or fans of rock music. These musical genres require finely tuned acoustic technology, which fulfills the users needs.
As previously mentioned there is an abundance of this product category on the market today, so picking out one in-the-ear product would not help in getting a better overview of how circularity could be introduced, as well as how recently developed, or materials under development at Innventia AB/RISE Bioeconomy could be applied to this particular product category. „Ecodesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development" and „EcoDesign Roadmap" by Conrad Luttropp, as well as „Eternally yours: Time in Design: Product Value Sustenance by Ed van Hinte was used to establish requirements for an in-the-ear (ITE) headphone product concept.

4.9 SWOT analysis

S.W.O.T. is an acronym, wherein „S" stand for strengths, „W" is short for weaknesses, „O" is for opportunities and „T" meaning threats. It is used to understand the characteristics of a product or service better. Strengths are those aspects of the project,which create an advantage, on the other hand weaknesses are those characteristics, that might create a disadvantage for it. Opportunities are indicators to attaining advantage over other products, while threats are factors, which could hinder the project. It provides decision-makers with a clear view, on whether or not an objective is attainable within certain circumstances.

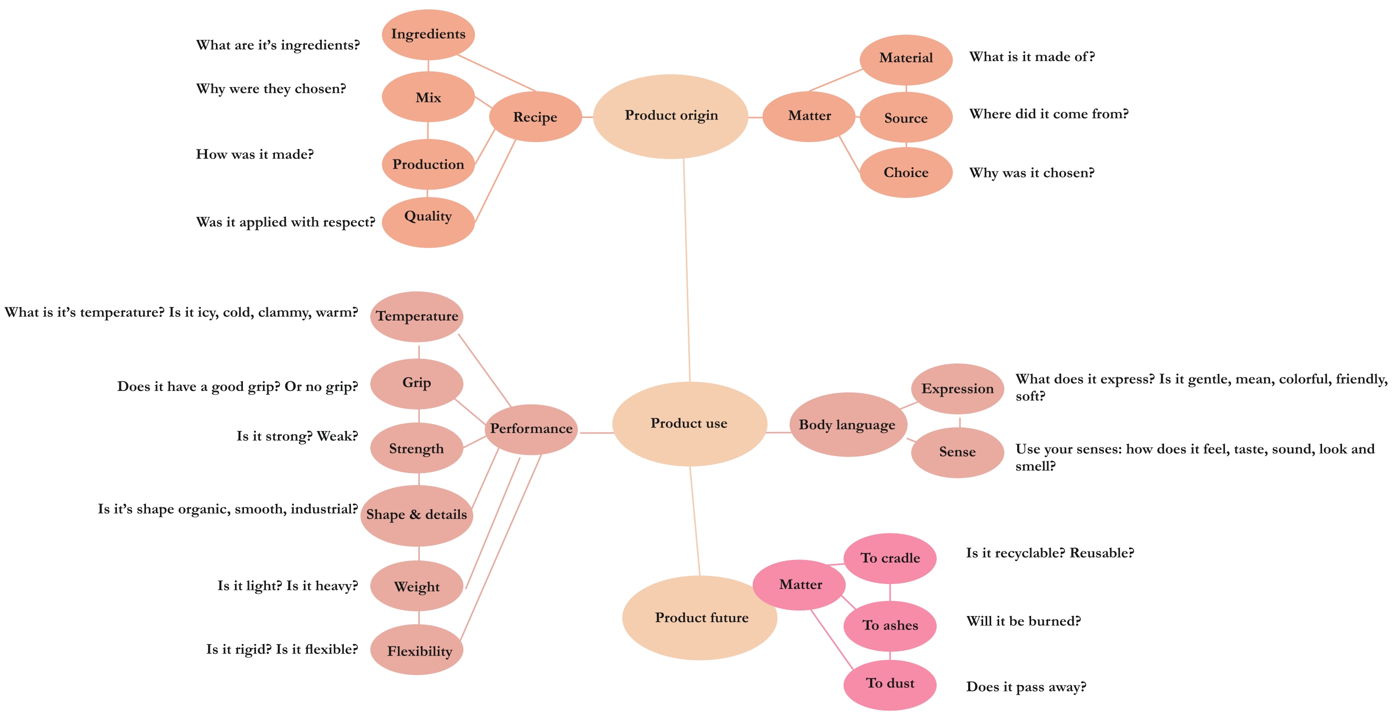


Fig.5.9 Van Hinte, E. (2004) *Eternally yours: Time in Design: Product Value Sustenance* p.276-277 [png] Stockholm

Methods - Visualisation/ Ideation

4.12 Moodboard

Colour photographs and sketches made by the author were used throughout the project to understand the product's context and the users, who are actively using these products, as well as those within the same product category. The moodboards therefore served the project by visualizing certain aspects of it, also generating insightful discussion between the author and those visiting her office.

4.13 Sketching

Typically a design problem is not only one problem with one correct solution, more often it is a set of multiple problems, which could have more than one solution. Designing in the corporate world is a group activity, in order to make a design process run more efficiently people involved in this activity need to evaluate thoughts, ideas and eventually test them. Sketching and prototyping serve as tools for argumentation during this process. They also serve to document the process, to be able to evolve it and create the foundation for further developments in the future. Many design students fall into the mistake of getting fixed on an idea, because „it looks better". By all means, to be able to produce ideas one has to have a picture in their head. The design profession itself is undergoing changes nowadays, as new tools are being introduced to us, the mere definition of who is a designer is getting blurrier and harder to outline than before. It is misleading ourselves and our environment that we would reduce our knowledge to one skill only, when the problems that we are expected to attend to cannot be reduced to a single problem.

„Sketching is not about drawing. Rather it is about design. Primarily, it is:
- a fundamental tool that helps designers express, develop and communicate design ideas;
- a critical part of a process that begins with idea generation, to design elaboration, to design choices, and ultimately to engineering."
(Buxton, B (2012) Sketching user experiences)

4.14 CAD

Autodesk Inventor was used to create the mold tools and the components of the final product concept.

3DS Max was worked with in order to refine the 3D ear models as well as refining the product concepts.

4.15 Additive manufacturing technology

Ultimaker 3D printer was used to print 1:1 models of n=8 ears modeled from eight different people, with different ear shapes and sizes. The ears were printed using PLA plastic material. The 3D printed ears were used to evaluate the differences between the ergonomic landmarks of the human ears, also to test and evaluate the fitting of the mock-ups. The 3D printed ears taken from eight different subjects made it easier to understand the variations between the ear landmarks.
I find that 3D printing is a good complementary tool for a designer, as it allows the construction of parts that otherwise would be hard to make using other technologies. The only drawback for the moment is that for bigger models it takes a lot of time and often designers cannot afford to print a part for a whole day or more if they work under strict time constraints. Making quick physical mock-ups from foam or other materials could be as useful as 3D printing in communicating the shape/geometry/surface of a product concept. For the moment additive manufacturing allows for a much more iterative approach to manufacturing and enables the user of the product to influence its performance and aesthetics within certain boundaries. Compared to most conventional manufacturing methods, all these additive processes produce little or no waste, enable mass-customization from individual part to part, and offer one-step process for putting together of many complex parts made from different materials. The evolution of additive manufacturing will result in a feasible method for producing many consumer products, especially those that offer certain amount of customization and design adaptation, but the slower speed compared to other manufacturing processes e.g.:injection molding will likely to place it as a more bespoke, higher-end way of creating products. The accessibility of the technology creates an opportunity for individual inventors/makers to perfect it, so it might become an even more popular way of making things.

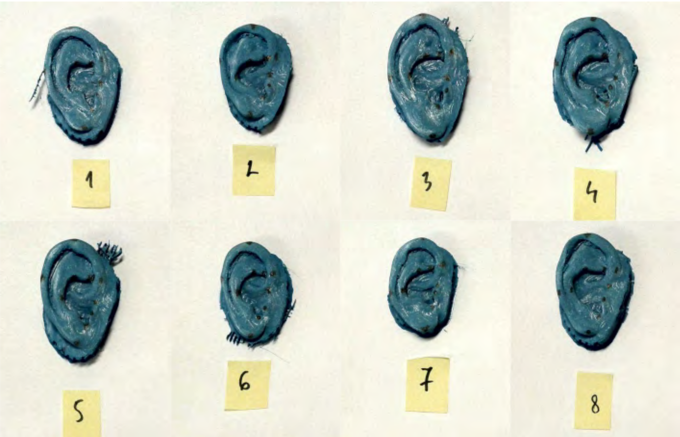


Fig.4.10.1 Anna Póka (2017) *"3D printed ears with ear landmarks"* [jpg]. Stockholm

Handheld scanner was used to create 3D model of the author's head, focusing on the area of the ears.

4.16 Mock-up

Cardboard (Physical volume) Sketch model

Cardboard mock-ups were made to test the length of the cords of a headphone concept idea. Two versions were created using cut-out cardboard to model the flexibility of cords made up by several modules. One of the mock-ups was made with 5 cm long modules, the other with 8 cm long modules.
Textile material was used to test the fitting of headphones, made from soft material filled with granular material or other filler material, which allows movement, enabling the headphones shape to take up the shape of subject's ear shape. Couscous was used for the mock-up granular material.

4.17 Prototyping

Prototyping is practiced in many forms from architects building mock-ups of their first ideas to car companies working on clay models of cars over years. The time span is quite extreme ranging from about 15 minutes to more than a year, in the era of digitalization why can't companies simply replace these age-old techniques by 3-D computer modeling or virtual reality?
Prototyping becomes a convenient mediator between the designer and the designer's impressions, as well as the individual and the group. Although the degree to which a prototype is detailed has to depend on the current stage of the overall design process.
Active materials were used for demonstrating their conductivity by adding them to an electrical circuit. Ultimaker 2+ was used to 3D print the final in-the-ear (ITE) headphone product concept design, in order to showcase the fitting, the volume and the design assembly of the major components.

Fig.4.16.1 Anna Póka (2017) *"Cardboard mock-ups"* [jpg]. Stockholm

Fig.4.16.2-5 Anna Póka (2017) *"Usability testing of the mock-ups by two different subjects"* [jpg]. Stockholm

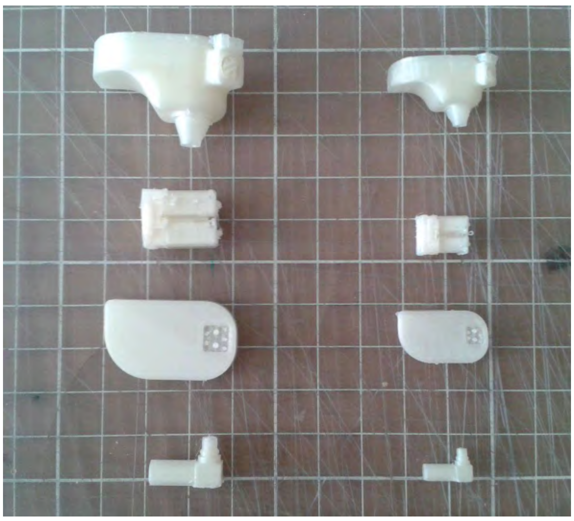


Fig.4.17.1 Anna Póka (2017) *"3D printed parts of the headphone product concept"* [jpg]. Stockholm

Fig.4.16.7 Anna Póka (2017) *"Textile mock-ups with couscous"* [jpg]. Stockholm

Introduction
Theory
Current products
Methods
Analysis
Results
Final result
Discussion & Conclusion

5. Analysis

5.1 Ear-fitting headphone products

According to basic functionality one could differentiate three different types of ITE headphones:

- ITE headphones with cables
- Wireless ITE headphones with cables
- Wireless ITE headphones without cables

5.1.1 ITE headphones with cables

The most popular type of headphones, the amount of energy used by the product depends on it's impedance, which in general is between 9-39 Ω. (See 3. Current products p.27-31). Depending on the individual habits of the user, this type of ITE headphone product uses between 1-10 mW energy. They are like small loudspeakers, which can be fixed into the user's external ears, facing the ear canal. Some users choose to wear them leaving the headphone cords hanging vertically from the earphone casing, the other channels the fixture from the top of the ear and the cords are directed between the user's head and the root of the ears. Most common material used for the fixtures is plastic, with the ear-hooks and other fitting components made from silicone rubber.

5.1.1.1 Active product use

This type of ITE headphones provide the user with limited mobility within an unconstrained area, as they can switch easily between the power sources for actively using the product. Limitations could be found in the type of plug used. The manufacturing companies are producing thinner smartphones, which require alternative solutions for the plug connections. Many devices are no longer compatible with e.g. 3.5 mm plugs, these trends directly affect headphone manufacturers, indirectly of course the users as well.

5.1.1.2 Passive product use

The product storage presents a challenge, because the headphone cables could get tangled up, depending on their geometry and material quality. Companies are tackling these issues by using solutions like UrbanEars "ZoundLasso", which enables the cords to be stored in a more organized way. Also companies are using textile or textile-like materials as cable sleeves, which prevents them from sticking together like many cables made from thermoplastic materials. Some products are being designed with rectangular-shaped wire sleeves or with a larger diameter.

5.1.2 Wireless ITE headphones with cables

5.1.2.1 Active use

These allow the users upto 6 hrs of talking time, upto 120 hrs of standby time. The cables serve a more practical and decorative purpose.

5.1.2.2 Passive use

When the headphones are not being used the users could form a hoop around their necks to store the device, the cords also serve the purpose of making the product easier to handle, like in the case of other face- and ear-related products e.g.: dust-filter, glasses etc.

5.1.3 Wireless ITE headphones without cables

5.1.3.1 Active use

Between 4 to 6 hrs of battery life with 2 hrs of charging time. The wireless ITE headphones offer the user unlimited mobility within a constrained area, the headphones come with different sized sleeve fits, which are made out of silicone. The casing of the devices is made from thermoplastic material. Some are water resistant to 1m depth.

5.1.3.2 Passive use

The device in itself doesn't take up a lot of space, as it should be able to fit into the user's ears. However the casing, which serves as the battery charger could provide up to 5 full charges of the device.

5.2 Survey

A survey containing 18 questions was distributed in English- and Swedish-language in Stockholm area and on social media. The English-language survey was filled out by n=24 participants, with n=12 female and n=12 male participants. The Swedish-language survey was filled out by n=48 participants, with n=28 female, n=19 male and n=1 participant, who preferred not to disclose their gender.
Overall 55% n=40 female , 43% n=31 male and ~1.4 % n=1 preferred not to disclose their gender.
Fig.5.2.1 shows the focus areas of the survey, „user responsibility" and „passive product use" were the focus areas found to be the „grey zones" for this particular product category, also individual habits determine eg. „active product usage", so in order to improve issues regarding „user responsibility" and „passive product usage", more questions were asked in the survey to have a better overall understanding of these areas. The age distribution of the participants was fairly even. More than half of the respondents is actively using ear-fitting headphones, which supports and strengthens the previous research about the type of headphones people are using. (See. 2.2 *Ear-fitting headphones*). Most of the respondents usually purchase their headphones at specialized stores.
When asked about how much they like devices that can be operated in a wireless mode, the majority likes them a lot.
The participants were asked to rank product attributes before purchase and post-purchase.
Their choices are price-driven at the point of purchase and they also ranked Brand and Longevity at a similar rate, whilst post-purchase the majority ranked Longevity as the most important product attribute, the importance of price decreased at the same time the Material of the product became twice as important for them.
As anticipated, the most common electronic devices, used by most people in wireless mode are laptops and telephones. We can see a growing trend, when it comes to using headphone products in a wireless system.
Most respondents charge their electronic devices on a daily basis, which suggests that they are trying to fit this activity into their natural biorhythm. Survey respondents were asked to describe, where they typically charge their wireless devices, also for how long they do so. The most frequent answers was at their home, at the workplace was the second most frequent answer. Charging their devices seems to mean a stationary activity for most of the participants, this might raise the question, whether or not people should be able to charge their wireless electronic devices, while on-the-go in their urban environment.
30% of the survey contributors charges their wireless devices overnight, 19% answered 1-2 hrs of charging time, which is followed by 15 % saying they charge for 3-8 hrs. These answers are supported by the answers to the following question, where they were asked what other activities they do, while charging.
Here, 40% replied sleeping or sleeping in combination with other activities. Question nr. 14 was also designed to be a

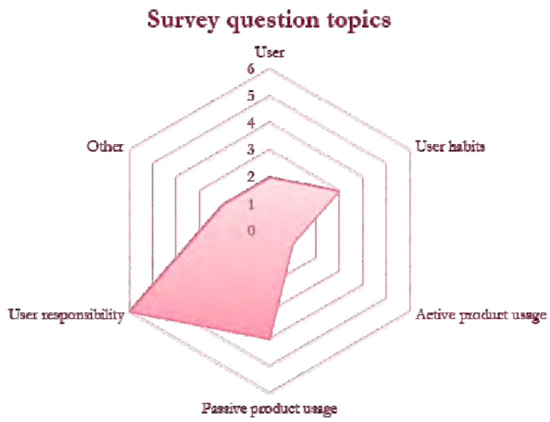


Fig.5.2.1 Anna Póka (2017) Survey question topics [png] Stockholm

descriptive type of answer. The most commonly used words, for „why did you want to have wireless headphones/ other wireless devices":

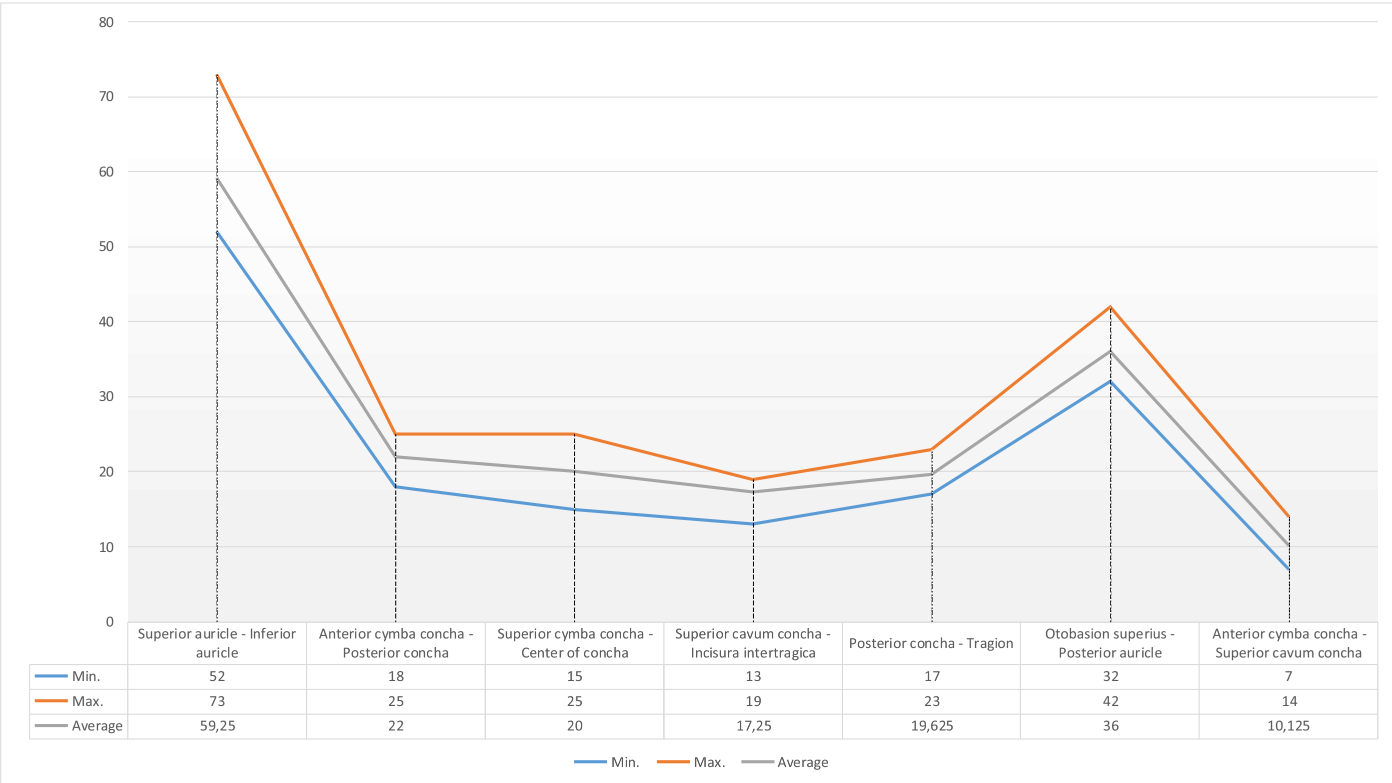
- freedom
- easy
- comfort & convenience.

Questions nr. 13, 15 & 16 were asked to find out more, how the users relate to their headphones, do they try to maintain them for as long as possible, or do they dispose of them in a responsible way. Most of them replied, that they use them for more than 2 yrs or until they cannot be used anymore, when asked where they dispose of their headphones, 95% of the respondents chose the specialised container for electronic devices.
These answers show that there is an increased awareness about handling electronic waste in Sweden.

(See Appendix B - *Survey questions & answers*).

5.3 Ergonomic analysis

Variation between minimum-maximum & average distances of the ear landmarks (mm)



	Superior auricle - Inferior auricle	Anterior cymba concha - Posterior concha	Superior cymba concha - Center of concha	Superior cavum concha - Incisura intertragica	Posterior concha - Tragion	Otobasion superius - Posterior auricle	Anterior cymba concha - Superior cavum concha
Min.	52	18	15	13	17	32	7
Max.	73	25	25	19	23	42	14
Average	59,25	22	20	17,25	19,625	36	10,125

The following ear landmark distances were measured:

(1) superior auricle - inferior auricle
(2) anterior cymba concha - posterior concha
(3) superior cymba concha - center of concha
(4) superior cavum concha - incisura intertragica
(5) posterior concha - tragion
(6) otobasion superius - posterior auricle
(7) anterior cymba concha - superior cavum concha

The two variants, which show the biggest alteration, between their corresponding minimum and maximum values are the following ear landmark distances: (2) and (6). The superior auricle - inferior (mm) auricle distance, represents the length of the ears. The otobasion superius - posterior auricle (mm) distance implies the width of the ears. The measurements are taken from the 3D printed ears, which were modeled after eight different persons. The distances can be different on the other side of the head, as the ear moulds were taken from one side only. These values support the information obtained during the literature review (See. 2.1.2 *Ergonomics of the human ear*). Values (2) and (5) are the most crucial, when it comes to determining adjustment ranges for eartips, (4) and (7) could show extreme variation individually, however based on the 3D printed ears the least deviation is between these extremeties. (3) is the value, which is the most challenging in terms of being able to define on a 2D plane. This value only makes sense in 3D, even though this could be true for all of the ear landmarks. However, as the project didn't dispose of magnetic resonance imaging the measurements were carried out by optical measurement. The product category suggests that anthropometric data of the human ears should be explored, however for obtaining a higher level of functional quality, data regarding the head and neck was considered besides ear-related measurements. (See Appendix C - *Ergonomic analysis p.90 - 100*)

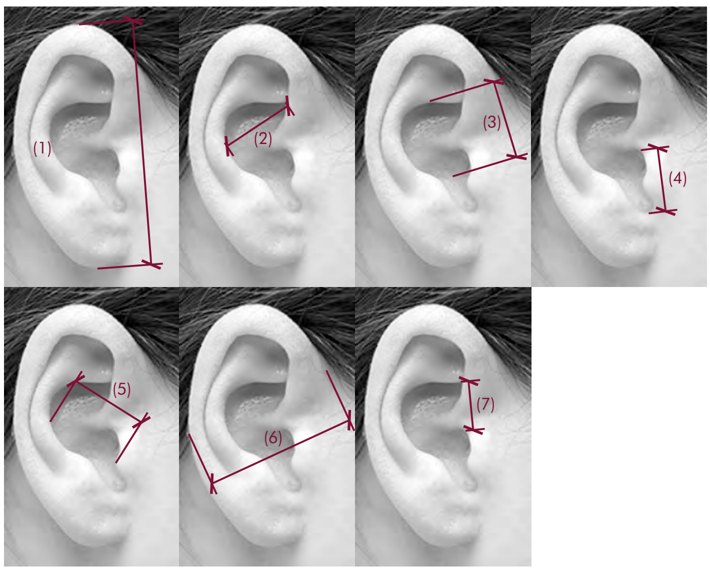


Fig.5.3.1 Anna Póka (2017) *Measured ear landmark distances* [png] Stockholm

In *Fig.5.5.2* the current state of recyclability potential is illustrated, comparing ITE wireless headphone components to ITE headphones with cables. The figure reflects on traditional electronics, that are being used currently in the manufacturing of these devices. It is not representative of every single product within the ITE category, it aims to show that both wireless and wired products have a similar ratio of components, that could be recycled. This figure would certainly change, if it were to depict the recyclability potential of ITE headphones incorporating cellulose-based materials. However, one must note, that it's not only the material, that defines recyclability potential, moreso how it is used in a product.
„There is no such thing as good materials, there is only a bad or better way to treat them" - Conrad Luttropp, Professor at KTH Machine Design Insitute, Eco-design specialist.

5.4 Electronic waste material flow chart (Sweden, 2017)

The life-cycle of an ITE headphone, being an electronic product starts with consumption in Sweden, in 2017. There could be several loops in the network of users with a variety of second-hand distribution channels, online and offline alike. If the product is disposed of in a correct way, meaning by putting in one of El-Kretsen's waste containers designated for electronic devices. Upon arrival at their sorting plant, the devices are examined optically, then they are categorized into five categories, based on functionality.

- Item fully reusable in current condition
- Slight repair required, but generally in good condition
- Parts missing, but item is reusable with slight/moderate repair
- Item requires major repair work
- Not reusable

The articles, which fall under the last category are taken to landfill or the incinerator. Therefore this system provides an almost closed loop for all electronic devices, that are being imported to Sweden from another country. Reasonable doubt is necessary to be able to understand, why illegal waste could be found or how much of illegal electronic waste is sent to developing countries as articles categorized under reusable products. Usually these products contain hazardous materials as well, which present a serious risk for the environment without adequate waste handling and management infrastructure.
By outsourcing the manufacturing of these audio products to other countries, Swedish companies and the designers and engineers working for them have the responsibility of influencing:

- How these products are assembled?
- What materials could be used for manufacturing them?
- If they contain components made from non-renewable sources, how could these be reused or recycled?
- Which material is used for packaging?
- Establishing adequate service- and maintenance system

Consumers of audio products in Sweden, should influence the companies to incorporate more renewable materials into their products, if this is not fully attainable they should push them towards the creation of a service system, which enables the smaller loops to be more closed.
Fig. 5.4.1 shows the simplified flow of the electronic waste material in Swedish context today. With regards to ITE headphones, many of the components contain materials e.g.copper, neodymium, alumina that are extracted in foreign countries, the raw materials have to be processed in order to be sent to a manufacturing company, for Swedish audio electronics companies this means, that the manufacturing is taking place in foreign countries as well. Of course, these suppliers have to meet regulations and standards, but it's challenging to refine these processes. From the point-of-purchase it's the user's responsibility to make sure, that the device is used, reused and disposed of in the most environmentally-friendly way possible. Finally, El-Kretsen manages the EOL of the electronic waste, by collecting it, sorting it, evaluating their functionality, last but not least deciding, which of these is sent to landfill or incinerator.

Ear-fitting headphones with cables vs.
Wireless ear-fitting headphones

Wireless headphones do not automatically mean less components and less materials. If the technology of :

- Energy storage
- Energy harvesting

is improved in the future it could mean the same level of energy-efficiency as ear-fitting headphones with cables. Wireless products must be charged from time to time, therefore they are less energy-efficient at the moment. Products with cables do not require charging, on the other hand the device, in which they are plugged into is probably in need of charging. It must be noted here that the energy efficiency of the product is directly related to the user's energy consumption habits as well. These two different product categories mean different energy-consumption patterns on a user-level. Furthermore they indicate distinctive environmental impact on a socio-economical level. The flow chart demonstrates, that the users in Sweden are well-aware of the potential environmental impact of e-waste. By creating networks, which enable recycling or reuse they contribute to decreasing the latter. On a product level, the ITE headphones could contribute to this effort, creating designs which make disassembly or reuse easier. Applying cellulose-based materials to certain components could decrease the environmental footprint of the product. Cellulose-based materials could be sourced and manufactured in Sweden in the future, this would decrease the need for extracting certain raw materials, which need to be imported into the country. Recycling systems capable of handling such materials should be developed in parallel in the future.

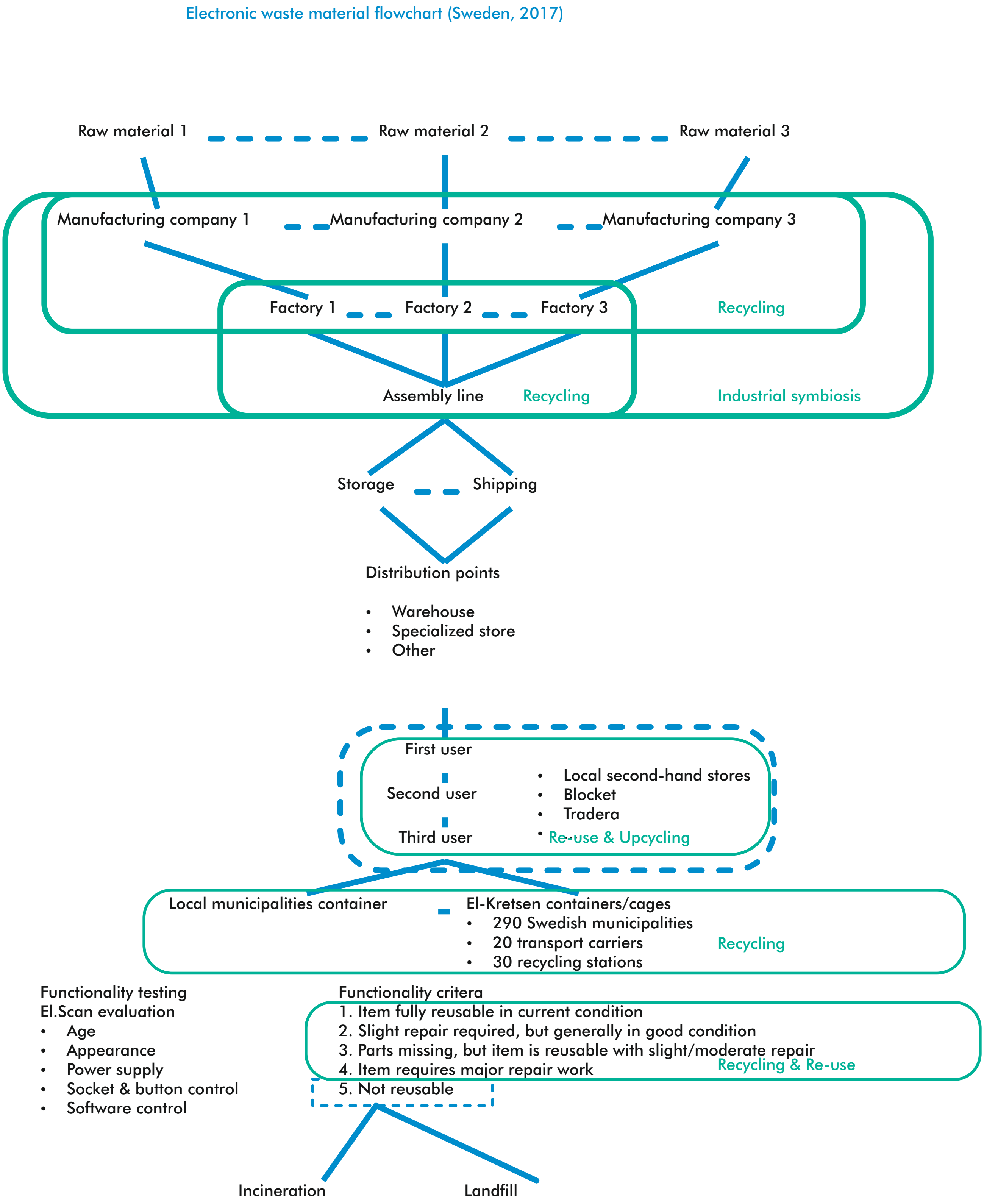


Fig.5.4.1 Anna Póka (2017) *Electronic devices material flow chart in a Swedish context* [png] Stockholm

5.5 Eco-audit of ITE headphones

ITE headphones are made of several components, each of these have their own role in forming the user experience, sound quality, energy efficiency etc. The parts usually come from different sources, they are manufactured differently according to the headphone technology involved (See. 2.2.2 *Transducer technology),* or the desired user experience (See 3. *Current products*).
In the following section each part is examined according to their origin, environmental aspects of their extraction, social sustainability aspects of their extraction and manufacturing, also if their production is energy efficient at the moment.

ITE headphone components:

Cables

The way cables are designed, makes them a problematic component, in regards to environmental aspects today. The wiring is made from copper, the production of which is not eco-friendly. It has to be treated with sulphuric acid, in order to become an oxygen-free electrolysis wire. Several long-term health effects have been registered in workers, who are exposed to these procedures. These are the main steps for copper:

- mining
- concentrating
- smelting
- refining
- casting
- drawing process

is used to create the required diameter of the copper wires.

The other component of the wiring is the cable sleeves, made from plastic materials. Most companies produce these from thermoplastic materials, from which PVC is the most harmful from an environmental perspective. Kevlar reinforcement is also used by some companies, the production of the aforementioned requires a lot of energy.

Housing

Typically made from plastics materials used for injection-molding. For example: ABS. Production of many polymer materials is based on crude oil, which is not a renewable resource.

Drivers

There are several types of transducer technology, depending on what sort of sound quality a company is aiming for.

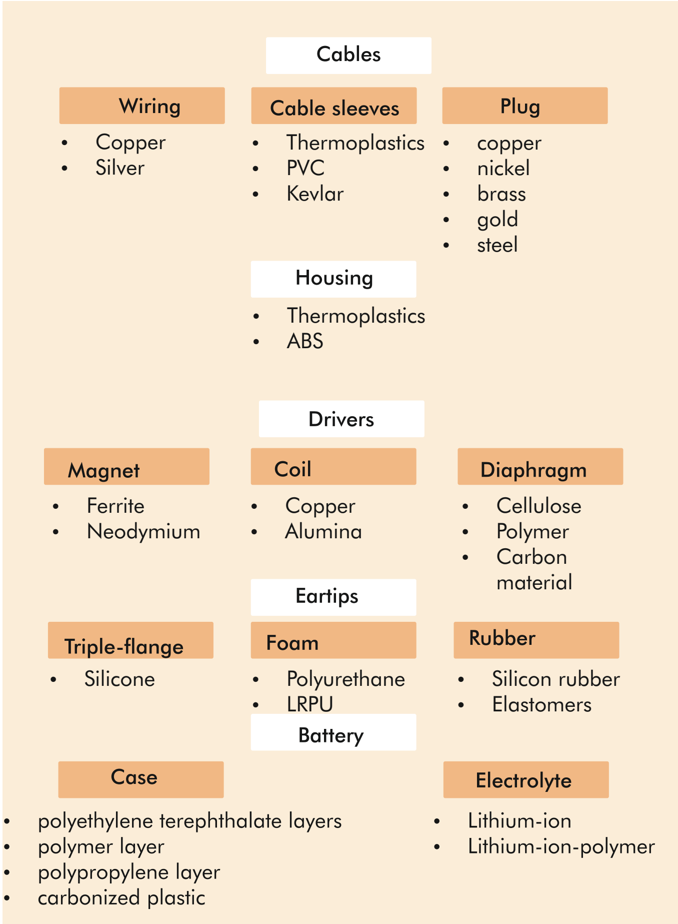


Fig.5.4.1 Anna Póka (2017) *Earbud materials by components* [png] Stockholm

The most frequently used, however is moving coil type (*See 2.2.3.1 Moving coil*). This is made of three elements:

- magnet
- coil
- diaphragm

Magnet

The magnet is usually made from ferrite, or neodymium. Neodymium extraction contributes to environmental pollution and may cause severe health problems, for those who are exposed to it. Ferrites are composed of rare earth metals and their production involves a lot of high-temperature processing and sintering, both of which are energy-intensive industrial procedures.

Coil
Is made from copper wire or alumina, the latter is made from bauxite ore, which is not renewable and the extraction and production requires same amount of energy as copper wiring.

Diaphragm

One of the most delicate components. Often made from cellulose, which is a renewable material. It could be produced from polymers or carbon material, which are not taken from renewable sources.

Ear-tips

Triple-flange

This type of eartip has an easily recognizable shape, it is made out of silicone rubber. Polysiloxane or polydimethylsiloxane, it is manufactured by injection moulding.

Foam

Most commonly made from polyurethane or LRPU, the production is harmful for the environment.

Rubber

This type of eartip is from elastomers.

Battery

Lithium-ion-polymer batteries make it possible for designers to create e.g. thinner smartphones, because better energy-storing capacity could be acheived by these technologies. However, their production is harmful for the environment and often criticized to cause health issues for factory workers. Planned obsolesence is also a known problem in these products.

Packaging

Headphone packaging could be plastics or paper pulp material, which could be fully recycled depending on the purity of the material e.g. PET plastic...

Distribution

Transportation from the manufacturer to various distribution points requires fossil fuels.

Disposal

Swedish company El-Kretsen provides separate containers for electronic waste, covering all 290 municipalities in Sweden.

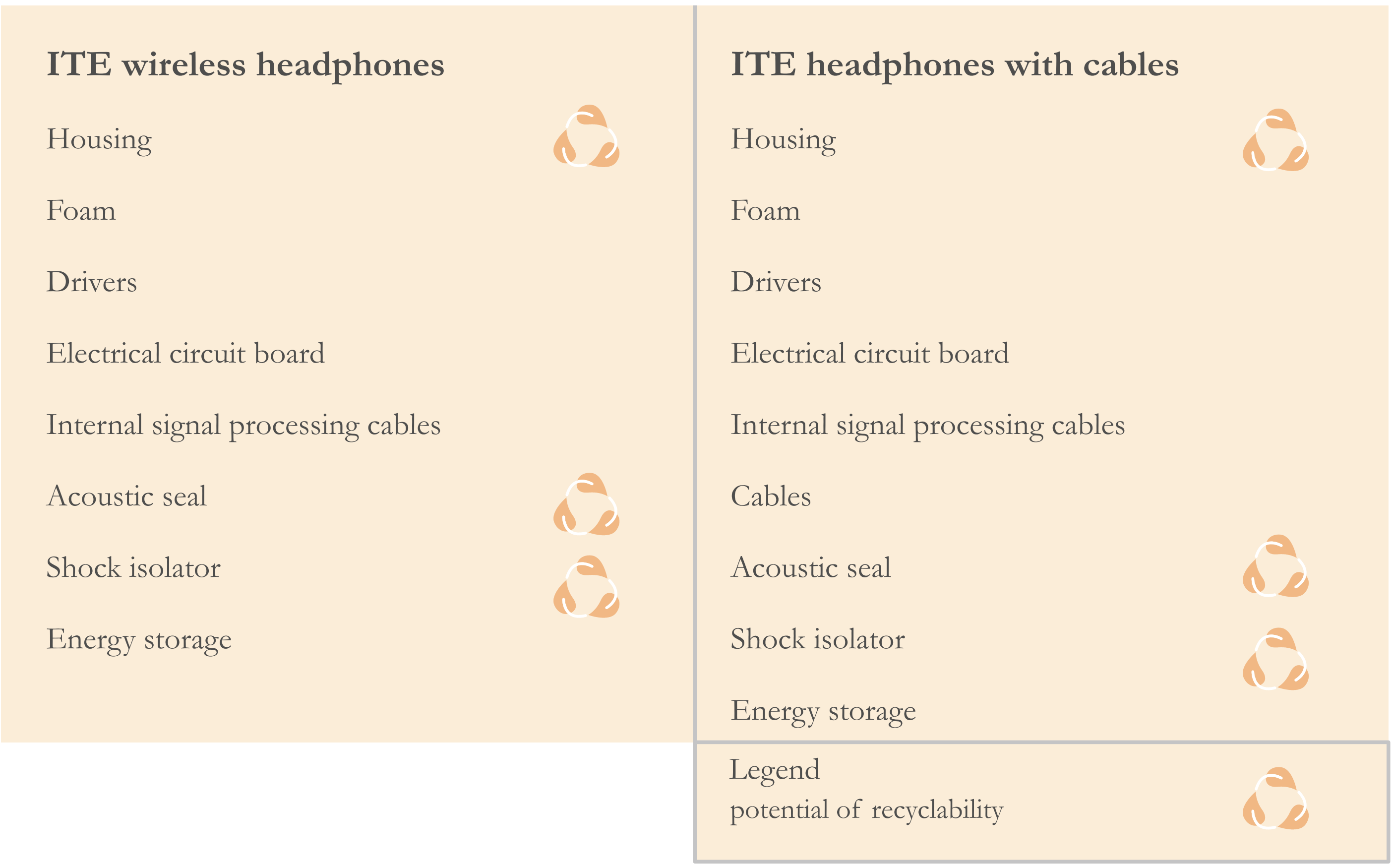


Fig.5.5.2 Anna Póka (2017) *Earbud material's potential of recyclability* [png] Stockholm

5.6 SWOT analysis

5.6.1 SWOT analysis of wireless ITE headphones using conventional materials

Wireless ITE headphone products have several pro's over contra's. They offer increased mobility, hands-free communication, which has a direct positive impact on the personal security. E.g. if we can use our hands to grip a handrail on the subway, there is less chance of injuries etc.
The wirelessness could result in a more problematic storage of the product, the cables not only have a decorational purpose in this case, they support the storage functionality. Wireless ITE headphones are easier to lose, if they do not enjoy cords holding them together.
The sound quality could become compromised depending on the quality of the wireless connection technology, the distance between the headphones and the device, that are connected with via Bluetooth.
In case of wireless ITE gear without cables, the components serving wireless connectivity should be easy to dissassemble, reuse or safe to dispose of.

Fig.5.6.1 Anna Póka (2017) *SWOT chart - wireless headphones* [png] Stockholm

5.6.2 SWOT analysis of ITE headphones with cables using conventional materials

Earbuds with cables are still the most popular ITE headphone product. They require a constant power source, although there are existing examples of products with the possibility to switch between wired/ wireless mode. Cable management presents a weakness compared to wireless products. However, they also make the product experience better, in terms of functionality. Cables allow easier storage during passive usage phase, while they could be harder to manage for storage phase. The plastic cable sleeves are usually melted, before the copper wiring could be evaluated for recyclability. If used properly they have a certain level of natural audio transparency, compared to other headphone products, although they might not offer hands-free communication for instance, when weighed against wireless ITE products.
The product experience does not push companies towards taking the service systems around this product more seriously. Especially if it's a product without detachable cables, people accept to purchase this product more frequently, without trying to repair it or reuse some parts of it, the rest goes to landfill or the incinerator. Producer and user responsibility could be improved likewise.

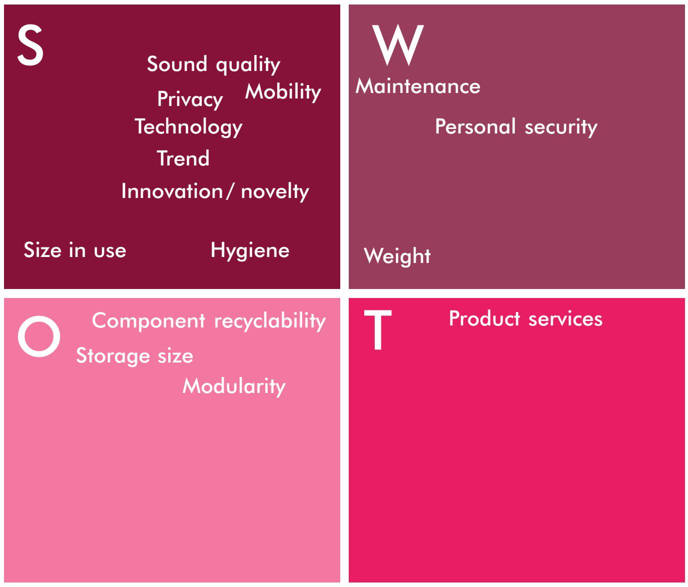


Fig.5.6.2 Anna Póka (2017) *SWOT chart - headphones with cables* [png] Stockholm

5.6.3 SWOT analysis of ITE headphones using conventional electronics

ITE headphones using conventional electronics was analyzed, with the current technology-readiness level of recycling certain components e.g. cables, drivers it is clear, that their is room for improvement for these components. Cables are not entirely useless though, they add functionality value to the overall product, some of it's components e.g. eartips are manufactured in huge volumes, with the purpose of producing profit for the respective companies. The eartips could be improved in terms of hygiene, maintenance and product services (See 3.*Current products*).

Fig.5.6.3 Anna Póka (2017) *SWOT chart - ITE headphones using conventional electronics* [png] Stockholm

5.6.4 SWOT analysis of ITE headphones using cellulose-based electronics

The following paragraph is based on theory (See *2.4 Materials*). Active materials have been produced by researchers at Innventia, many of them are intrigued by cellulose-based materials, because of their beneficial properties (See *2.4.1 Nanocellulose*, *2.4.2 Aerogels*, *2.4.3 Mixed ionic electronic conductor (MIEC)*, *2.4.8 NFC-PEDOT paper*). These could be classified as composite materials, when applied to electronics, with that said in parallel to improving functionality features of these materials e.g. tensile strength, conductivity, heat & sound isolation, strategies must be developed on how to recycle, re-use or dispose of these materials appropriately. The cellulose-based materials have many opportunities with regards to ITE headphones products, they may reduce the overall weight of the product, they could improve the modularity of the product, most importantly in a Swedish context they could be extracted from renewable resources, they may replace partially or eventually entirely the need to import components, which contain non-renewable ingredients. Furthermore, they may present as less harmful for the environment, but this implies that correct service system is developed in parallel with research activities. At the moment composite materials present a lot of innovative solutions, when studied on a macro-level, for the Swedish electronic waste management system this imposes a new or maybe the next step. How could these cellulose-based materials be recycled properly? How could their processing be rendered energy-efficient?

Fig.5.6.4 Anna Póka (2017) *SWOT chart - ITE headphones using cellulose-based electronics* [png] Stockholm

After conducting a research of materials at Innventia AB, (*See 2.4 Materials, p.22-24*) it was decided that the point-of-value, with regards to the product development process of ITE headphone, would be to experiment with cellulose-based materials that could be used for energy-storage. *(See 2.4.3 Mixed ionic electronic conductor (MIEC), p.23).* Research conducted at Innventia AB/RISE Bioeconomy has confirmed, that it is possible to produce cellulose-based films and fibrils with a high ductility with the help of additional materials. *(See 2.4.4 PEDOT:PSS, p. 23; 2.4.6 NFC-PEDOT paper, p. 24).* The aim of the experiments was to find out how different geometries might influence the structure of the energy-storing material, also adding to the knowledge-base of functionalized aerogels. The produced samples were tested at Innventia AB laboratories on bulk resistance, as a result their conductivity could be estimated.
In the future more light-weight and sustainable bulk materials will be necessary for energy-storing purposes. These experiments were made with the intention of building knowledge of these new materials. It is to be noted that the thesis project had certain limitations, with regards to having access to databases of how much raw materials are used for ITE headphones containing conventional electronics. Stakeholder interviews confirmed, the assumptions drawn from the research, that in case of the ITE headphones, their energy storing options could be developed by incorporating cellulose-based materials. Due to the size and proportions of the external ears (*See Appendix C - Ergonomic analysis, p. 91- 96*) we can observe, that the difference of using cellulose-based materials for components, such as the housing (*See 5.5 Eco-audit of ITE headphones, p.45-46*) or eartips would not be significant, even though the number of headphones/headsets sold worldwide has increased from 236 million in 2013 to an estimate of 334 million in 2016.
(The Statistics Portal, (2017).Global sales of headphones/headsets 2013-2016. [online] Available at: https://www.statista.com/statistics/327000/worldwide-sales-headphones-headsets/ [Accessed 29.06. 2017]. If we use an average weight of 20 gr/ headphone (*See 3. Current products, p.27-31*) we would get cca. 6680 t of headphones/headsets.
In comparison the Burj Khalifa , the tallest man-made structure in the world at the moment contains 4000 t of structural steel.

5.7 About cellulose-based electronic materials

Three batches of NFC-PEDOT aerogels were made at the Innventia laboratories. The solutions were prepared based on previous experiments made by Samuel Pendergraph. The experiments haven't been made before, using this set up. Eight different size- and shaped moulds were printed out with Ultimaker 2+ 3D printer. The material used for the moulds was PLA plastic. The experiment allows the widening of the knowledge about functionalized aerogels. It hasn't been studied before how different geometries affect the NFC's structure formation, or how they may affect the mass, density and conductivity properties of the functionalized aerogels.

First experiment

The following geometries were used for freeze-drying the solution:

- (a) 12 x 12 x 55 (mm) rectangular
- (b) 24 x 24 x 55 (mm) rectangular
- (c) Ø 12 x 55 (mm) cylindrical
- (d) a=13,343 x 55 (mm) hexagon
- (e) a=13,343 x 55(mm) oktagon
- (f) 5 x 5 x 300 (mm)

The first batch was processed according to protocol (See Appendix D - Laboratory work / Freeze-drying)
The thinner geomteries (a; c; f) had thawed in a way, that their upper part had become tapered, this was probably due to their weight and the DI water, which diluted the solution. After the samples were dried under fume-hood, uniform pieces were cut off with a box cutter. These pieces were measured with a digital scale, then their mass and density was calculated.
Aerogel structure was achieved during the first experiment, also conductivity was measured. The samples were easy to cut after drying, their size was reduced after the thawing process:

- (a) 9 x 9 x 55 (mm) rectangular
- (b) 16 x 16 x 16 (mm) rectangular
- (c) Ø 9 x 55 (mm) cylindrical
- (d) a=13,343 x 55 (mm) hexagon
- (e) a=13,343 x 55(mm) oktagon
- (f) 2 x 4 x 220 (mm)

Second experiment

The following geometries were applied during the freeze-drying procedure:

- (a) 12 x 12 x 55 (mm) rectangular
- (b) 24 x 24 x 55 (mm) rectangular
- (c) Ø 12 x 55 (mm) cylindrical
- (d) a=13,343 x 55 (mm) hexagon
- (e) a=13,343 x 55(mm) oktagon
- (f) a=13 x 55 (mm) triangular cylinder

The second batch was processed according to protocol (See Appendix D - Laboratory work / Freeze-drying). After the freeze-drying this batch was water-thawed after being taken out of the freezer. More size reduction could be observed after the thawing, the edges of the gels were sharper compared to the first batch. The gels were slightly harder to cut uniformily after drying.

- (a) 8 x 8 x 55 (mm) rectangular
- (b) 14 x 14 x 55 (mm) rectangular
- (c) Ø 7 x 55 (mm) cylindrical
- (d) a =11 x 55 (mm) hexagon
- (e) a =11 x 55(mm) oktagon
- (f) a = 13 x 55 (mm) triangular cylinder

Third experiment

Third batch was prepared without the dilution of the concentrated PEDOT:PSS (2%). Higher conductivity was observed in the samples, which were water-thawed, their water content was removed following the standard procedure (See Appendix D - Laboratory work / Freeze-linking).
Functionalized aerogels could be used for energy storage in the future, their large specific surface area [1] makes them a potential alternative for energy storage. The energy density of PEDOT:PSS is around 1 Wh/kg.

„In the research I'm doing I have been able to increase the energy density eightfold by introducing certain redox-active molecules into PEDOT." - Jesper Edberg, Researcher, Acreo ICT, Norrköping. Fellow thesis working student Emma Dahlgren's research found that PEDOT:PSS has increased conductivity, when subjected to accelerated aging. „The composite with the highest tensile strength is the composite with 48 % glycerol after being aged in the climate chamber for 72 hours." - Emma Dahlgren, LIU.
The 3D scaffold, which creates the nanostructure is made from renewable resources, which makes it a less environmentally harmful energy storage application for the future. Their definite potential lies in their weight, which is significantly lower than any other existing energy storage application. The structure remains cross-linked even after being re-wetted. In their wetted state the aerogel becomes easier to compress, which increases their volumetric efficiency.

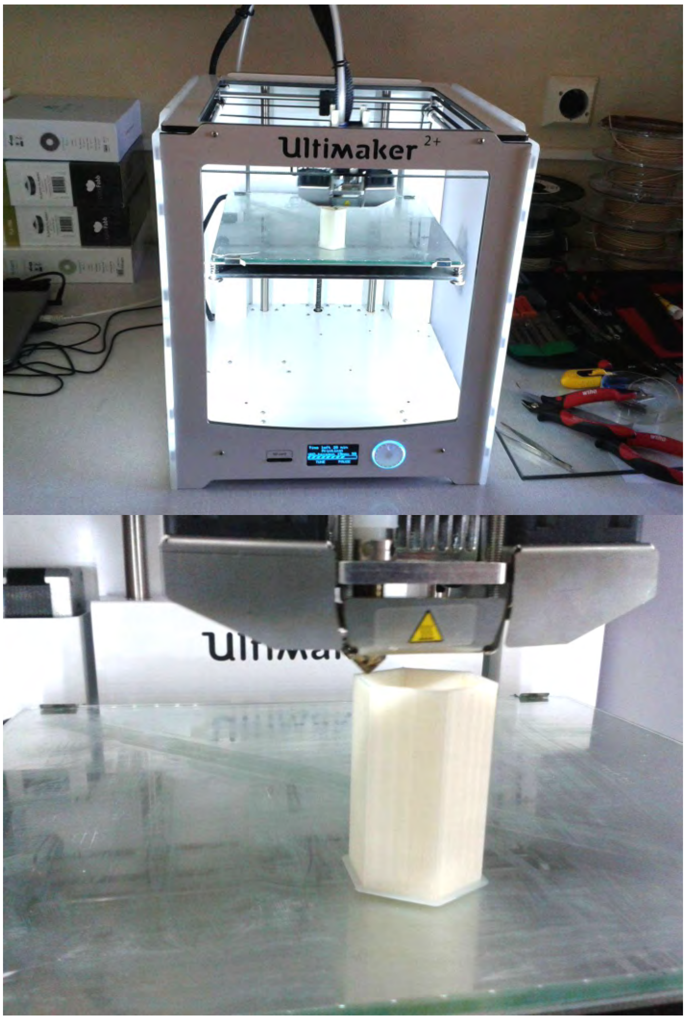


Fig.5.7.3-4 Anna Póka (2017) *Ultimaker 2+ printing mold tools* [png] Stockholm

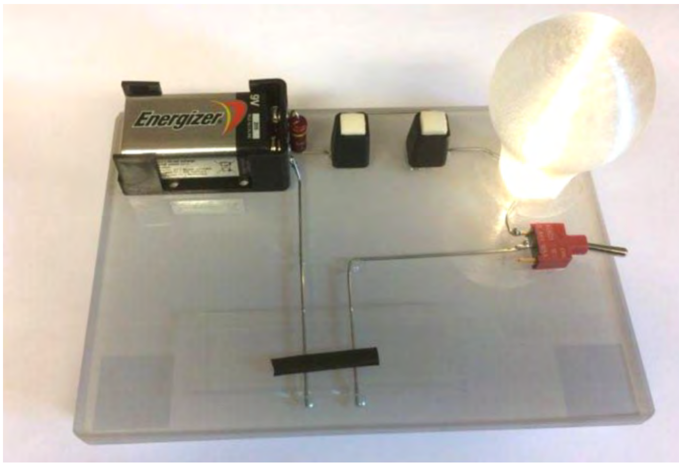


Fig.5.7.5 Emma Dahlgren (2017) *Demonstrator built using active materials* [png] Stockholm

specific surface area [1] - A measure of the total surface area of a solid per unit mass or volume.

5.8 Requirement list of ITE headphones

A list of requirements was developed based on the research, survey, stakeholder interviews and the analysis.

Group	Name	Requirement	Specification	Motivation
Pleasantness/ Pleasant haptic experience	P1	Provide pleasant haptic experience	The parts in direct skin-contact, may not cause any short-term, or long-term injury	Users will not use a product for a long time, which gives them an unpleasant user experience.
	P2	Ergonomic fitting	The fitting must take into account anthropometric data relating to the ear-, the neck & the head.	Ear canal size is dynamic, fitting must be optimal to avoid pain by pressure, also losing parts.
	P3	Easy to use	The use of the product should be clear.	It must be clear to users, how to use the product in a correct way.
Eco-design	E1	Using materials from renewable resources	Minimalize the use of materials from non-renewable resources.	Mass produced products, must take into account environmental impact.
	E2	Components should be easy to disassemble	Recyclability & reuse should be facilitated by the design construction.	Converge towards a more circular life-cycle for the product.
	E3	Reduce weight	Minimalize the weight/ components. <20 gr.	Weight increases energy requirement, during transportation.
	E4	Adaptable to energy-consumption patterns	Allow users to switch between plug-and-play mode to wireless mode.	Increases quality of product experience.
	E5	Modularity	Components design construction should strive for increased modularity.	Modular parts make disassembly or repair service easier.
Hygiene	H1	Easy to maintain	Parts should be easy to replace, repair & update.	The product is used on a daily basis, within different user environments, it has to be easy to clean, change parts.
	H2	Parts in direct skin-contact should be easy to clean	Antibacterial material surface should be used for parts in direct skin contact.	Material in direct skin-contact should not cause health problems, as the ears are sensitive to infections etc.
Personal safety	S1	Allows hands-free communication	Adapt to user-scenario.	The product is used in a wide range of environments, the functionality should support the user's context.
	S2	Allows audio transparency	Allow user to enable audio transparency, when the user environment requires it.	Avoid injuries by not being able to hear surrounding environment.
Energy-efficiency	Ee1	Allows adaptation to individual energy-consumption patterns	Wireless mode requires easy & adaptive chargability.	Saves energy for the user & the environment as well, if both modes are being supported by the product.
	Ee2	Nudges users towards a less environmentally harmful EC- behaviour	Influence user behaviour, to save energy.	User could plan their user scenarios, by doing this they learn more about using electronic devices energy-efficiently.

5.9 Ideation

Ideation process

The ideation development of this thesis work took a non-linear, iterative course. From the initial broad overview of the topic, the results were shaped by the knowledge gained from the research about the ergonomics of the external ears (*See 2.1.1 Ergonomics of the human ear, p.19*), which was followed up with studies of 3D printed ears (*See 5.3 Ergonomic analysis, p.42, Appendix C - Ergonomic analysis p.90 - 100*).
Innventia AB/ RISE Bioeconomy being the commissioner of the present thesis project cellulose-based materials were studied (*See 2.4 Materials, p.22-24*), as a result experiments were carried out at the companies laboratories, with the aim to widen the knowledge base of functionalized aerogel materials (*See 5.7 About cellulose-based electronic materials, p.49-50*). The exact formula of the cellulose-based material to be incorporated into an ITE headphone was not defined in the beginning of the project, narrowing the materials to functionalized aerogels could have been conducted in the course of a separate thesis work.
Eco-design was considered during the process (*See 2.8 Eco-design, p.25; 4.8 Eco- audit, p.36; 5.4 Electronic waste material flow chart, p.43-44; 5.5 Eco-audit of ITE headphones, p.45-46*).
ITE headphones featuring innovative solutions were reviewed (*See 3. Current products, p. 26-29*), which underlined the assessments of the stakeholder interviews (*See Appendix A - Interviews, p. 72-84*) and the survey (*See 5.2 Survey, p. 41; Appendix B - Survey questions & answers, p. 86-90).*
In the beginning of the project it was not defined, whether the ear-fitting headphone should be a wired or wireless type of product. The interviews, the survey results and the observations made it clear that there is an increased interest for wireless electronic products in an urban context, which mean different energy-consumption habits on a user-level.
The initial questions that came up were:
Should the development focus on a wired ITE headphone product? Or should it focus on a flexible product, which could be used both in wired and wireless modes? To what extent should eco-design principles be applied to the product?
Using personal observations on the Stockholm metro system as an initial inspiration, an idea of a modular ITE headphone was made, which was followed up by the experimentation made in shapes of different geometries (*See 5.7 About cellulose-based electronic materials, p. 49-50*). There were several underlying ideas connected to this, such as influencing energy-consumption habits by having interconnected energy-storing modules, which would contain cellulose-based energy-storing materials, also the modules would have a functional and decorational purpose. Different sized and shaped modules would contain a certain amount of energy, so the user would style the ITE headphone according to their needs eg. if they are taking a short walk with their dog or making a several hour long commute to their workplace. Both are real life scenarios, which would mean different amounts of energy-consumption.

Ear canal size is dynamic in terms of:
- age
- sex
- BMI
- open/ closed jaw position
- body posture

Even without all of these factors, there is a wide variety of shapes-, sizes in external ears. Perfect fitting could be achieved by taking individual ear impressions, as in the development of hearing aids. In that case an optimal fitting could be created, the advantage becomes immediately a disadvantage, in case of this optimalized fitting. On one hand the user will not need to increase the volume, to filter out unwanted sounds; on the other their personal safety becomes compromised. Simply due to the fact, that the optimal fitting blocks out soundwaves from the user's surrounding environment, so they must rely on their other senses (visual-, olfactory-...) if they would like to adapt to their user context.

Several fittings were tested using small physical mock-ups. During the ideation there was an analogy found between Bean Bag, an iconic design, which was developed in 1969 by the Italian company Zanotta. These pieces of furniture became very popular with users, as it allows multiple lounging positions, thanks to the small pellets, that mold the individual sitter's shape. Couscous was tested with the ear models for the particle size, after which the ideal particle size was found to be around 2 - 3 mm for having an optimal spread in the complex shape of the auricle. Most companies make the housing of the earbuds, from hard thermoplastic materials e.g. ABS. Subjective pain points were studied in a survey, which aimed to measure the comfort perception of Bluetooth earphones. Three zones were studied separately in this survey:

- Area A

The zone between the tragus to the antihelix, which was the contact area between the earplug and the ear.

- Area B

The zone between the antihelix to the helix.

- Area C

The dorsal zone of ear.

Both Area B and Area C were contact areas between the earhook and the ear.

5.9.1 Anna Póka (2017) Idea sketch - Wireless ITE headphone
[jpg] Stockholm

5.9.3 Anna Póka (2017) Idea sketch - Wireless ITE headphone
with interconnected energy-storing modules
[jpg] Stockholm

5.9.2 Anna Póka (2017) Idea sketch - ITE headphone with
detachable cables
[jpg] Stockholm

Fig.5.9.4 Anna Póka (2017) *Various physical mock-ups used for ideation* [png]
Stockholm

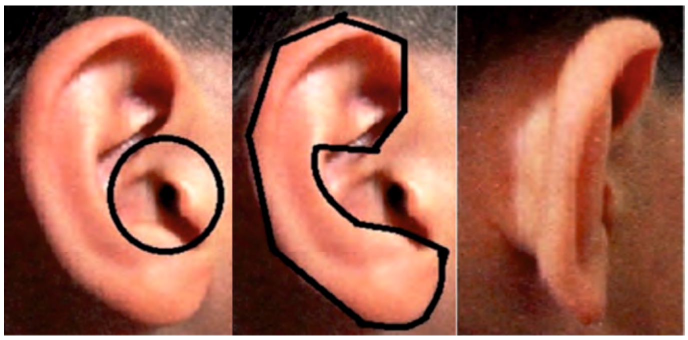


Fig.5.9.5 Chiu, Hsiao-Ping et Al. ; (2014) *Area A; Area B; Area C - showing survey participant's pain point percentile (%)* p. 238 [png]

Examining user's lifestyles

Moodboards were created to understand the target user's lifestlye, what kind of environment they live in, what type of materials could be present in their living spaces. Since the ITE headphones are used regardless of age-, sex- and cultural background. Three different contexts were visualized with the help of image collages. The first two represent a student lifestyle in a Swedish context, the third aspires to picture the lifestyle of an urban working person in a Swedish context. The following word associations were made of the moodboards:

- light, ethereal, cheeky, vibrant
- eclectic, adventorous, vintage, denim
- casual, curious, modern, patina.

All of the studied contexts showed the importance of modularity for people living in an urban context. Products should be able to reflect and adapt to alternating user scenarios, while providing a high quality user experience.

Fig.5.9.6 Anna Póka (2017) *Moodboard urban student A* [png] Stockholm

Fig.5.9.7Anna Póka (2017) *Moodboard urban student B* [png] Stockholm *next page on top*

Fig.5.9.8 Anna Póka (2017) *Moodboard urban working person C* [png] Stockholm *next page at the bottom*

B

C

Introduction
Theory
Current products
Methods
Analysis
Results
Final result
Conclusion
Discussion

6. Results

The try-and-error tests made during the ideation, lead up to important insights for the concept development phase. Physical properties of the materials were tested with the 3D printed ears, as well as volunteering co-workers.

6.2 Synthesis

Research and ideation phase established some guidelines for further concept development.

Modularity from user perspective (E5)

The product and it's accessories should be as modular as possible. Not only for the sake of easier disassembly, but also for allowing user's to change quickly between user scenarios:

- plug-and-play mode coupled with laptop for commuting
- wireless mode for physical activity

Weight (E3)

The individual component's weight should be minimalized.

Eartips

Three differently shaped eartips are available with ITE headphones on the market. The triple-flange and the rubber eartips are made from silicone rubber usually. The triple-flange blocks out sounds the most efficiently, but it is not good for personal safety. (S2) All of the eartips are made from plastics, which could become uncomfortable to wear for a longer period of time. The target user's could be using ITE headphones for over 8 hrs daily. Plastics are not breathable materials, in moist high-temperature conditions, the surface of the materials in direct skin-contact with the auricle should be healthy and comfortable to wear for these extended usage periods. (P1, H2) Users have experienced pain points in their ears, even with the application of these eartips. One of the possible reasons for this is that, the users ear canal moves in sync with the jaws, so eventually even the most comfortable eartip becomes uncomfortable, due to the pressure build-up on the walls of the ear canal or in the studied areas. (P2) (*See 5.9 Ideation*)
This pressure is distributed unevenly along the points of contact, which in this case is the skin of the ear canal and the zone between the tragus and the antihelix. The pressure is caused by multiple factors:

- elasticity of the material (Young-modulus)
- the shape of the eartips
- how the eartips are connected to the housing unit
- the individual shape of the wearer's ears
- temperature

The following illustrations demonstrate the positioning of the eartips in the auricles and how this affects the pressure on the ear canal walls, ultimately the users subjective pain points.

Fig.6.3.1 Anna Póka (2017) *Subjective pain points in user's ears* [png] Stockholm

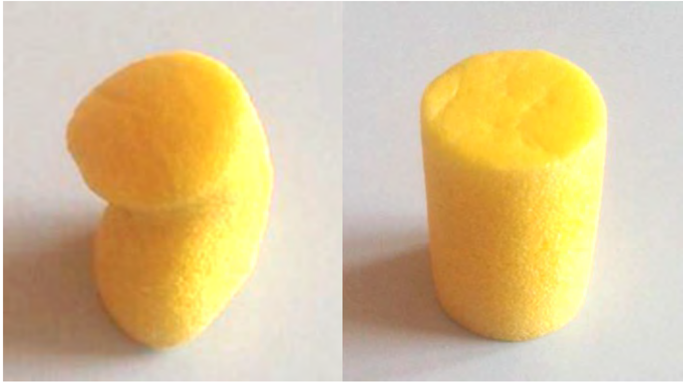


Fig.6.3.2 Anna Póka ; (2017) *Deformed foam eartip, deformation free foam eartip* [png] Stockholm

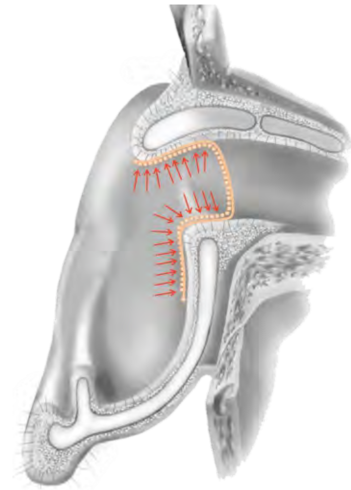


Fig.6.3.3 Anna Póka (2017) *Pressure distribution in user's ear with granular material* [png] Stockholm

6.3 Concepts

1) Adaptable textile buds with beads

Research showed that the available ear-fittings are more like a quick-fix in terms of design, instead of approaching the problem by understanding the ergonomics of the ears, most companies provide three different types of eartips in three different sizes, which are pre-packed with the product.

In a collaboration between Innventia and KTH researchers have developed a procedure, that enables the creation of CNF aerogel beads, with a 3 mm diameter. Aerogel beads were created by dropping the aerogel solution on a superhydrophobic surface. The elasticity and the weight of these beads means, that they could be used in a product to achieve a better fitting. The current technological development of this process, means that it is very time-consuming. In the future production could be scaled up using e.g. larger perforated metallic plates, which would allow many droplets to be pressed on to a superhydrophobic surface, where the spherical aerogel beads could be formed. Or the solution could be drawed out to a certain degree, then sliced in small segments, which would drop on a superhydrophobic surface, where they could organize into a spherical shape.

2) Adaptable earbuds with textile-like eartips

Different types of textile materials were used to make further mock-ups for testing the fitting of the ITE headphone product. Softer textile materials allow more movement for the particles placed inside, they enable a better fitting, however the ease of movement of the particles could ultimately cause the earbuds to fall out of place. Thicker textile materials are less flexible, their fitting is not affected by particles placed inside them, they are soft enough to take up the shape of the ears, without falling out of the shape. This makes them interesting for creating a different haptic experience of the eartips. (P1)
Different patterns were used to create prototypes of these textile eartips, these allow different shapes to be created. A bulkier trapezoid shape and a pointier conic shape was made by hand-stitching.

Fig.6.3.5 Anna Póka (2017) *Hand-stitched eartip mock-up made with soft textile material* [jpg] Stockholm

Fig.6.3.1 Erlandsson, J. ; López Durán, V. et al.(2016) *Aerogel beads* [png] Stockholm
Fig.6.3.2 Anna Póka (2017) *Water droplet on a plate with superhydrophobic coating* [jpg] Stockholm

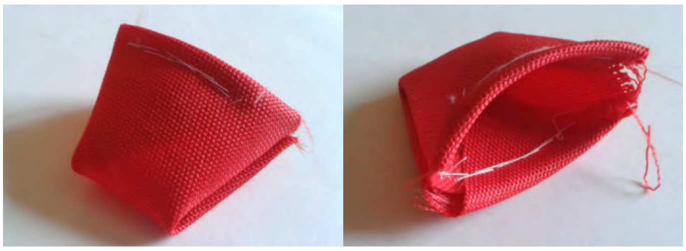


Fig.6.3.3 Anna Póka (2017) *Hand-stitched eartip mock-up* [jpg] Stockholm

Fig.6.3.4 Anna Póka (2017) *Hand-stitched eartip mock-up* [jpg] Stockholm

Fig.6.3.6-7 Anna Póka (2017) *Hand-stitched eartip mock-up made with soft textile material* [jpg] Stockholm
Fig.6.3.8-9 Anna Póka (2017) *Hand-stitched eartip mock-up made with soft textile material turned upside down*[jpg] Stockholm

Scaled up ear models were used for these tests, the size of the mock-up ear-tips were scaled up as well (1:7), to be able to evaluate their fitting. The eartip patterns support different assembly arrangements for the housing, holding the driver unit and other components. The angle of the ear-canal is different individually, actually it is probably different in the left-side ear and the right-side ear in each person. This means that the product would benefit from having an easily adjustable nozzle. The nozzle is the component, which directs the soundwave coming from the drivers towards the ear-canal. (P3)

Modularity for personalization & recyclability

The shape and fitting properties of the earbuds depend on the type of transducer technology used inside the driver unit. Most commonly used transducers are the moving coil, dynamic drivers, these come in different sizes (*See 2.2.3 Transducer technology*):
-9 mm, -16 mm. These take up more space compared to other transducers. With regards to energy-efficiency the

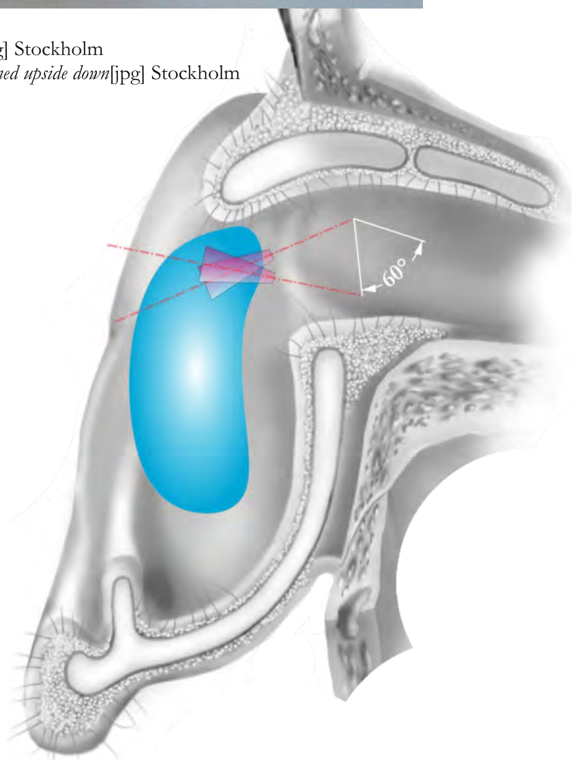


Fig.6.3.10 Anna Póka (2017) *Illustration of necessary adjustment range of earbuds* [jpg] Stockholm

balanced armature driver consumes the same amount of energy in a week, in comparison to the daily energy-usage of a dynamic driver. (E2, E3, E4, E5) Most wireless ITE, as well as OTE headphones are designed with multiple balanced armature drivers, multiple drivers are fixed inside the housing, in order to render low- and high-range signals in a higher quality. The unit introduced to convert the low-range signals is called the woofer, the unit for the high-range audio signals is named tweeter. Paper mockups were created to understand the proportions of the driver unit, also how it can be arranged inside the housing unit of the ITE headphones. These drivers contain materials, that are originating from non-renewable resources, but their energy consumption is considerably lower related to the other driver technologies. They are constructed in such a way, that the valuable materials could be sorted for recycling, re-use.

Design sprint

A short sketching session was done at Innventia to search for a potential design for the earbuds, that could represent the institute's core values:

- research
- innovation
- sustainability

Three designs were selected and developed using vector-graphic software, the designs were created using monochrome colours to avoid making biased decisions based on colour preferences.

6.4 Evaluation

The left-most design was found to be the form, which could be the most emblematic of the institute's efforts, as well as being a subtle shape. Representing research with a transformative shape, innovation in the dynamics of the overall form, as well as sustainability by avoiding unnecessary form elements. The earbud could be developed in order to fit the target user groups, being a simple shape it could adapt easily to the user.

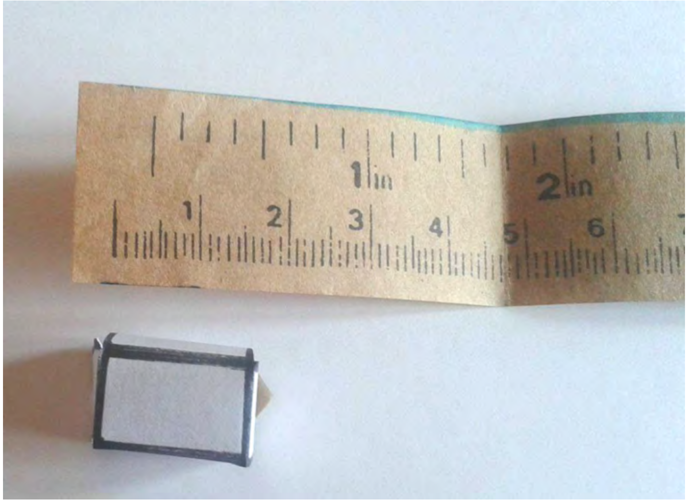


Fig.6.3.11 Anna Póka (2017) *Paper mock-up of a driver unit* [jpg] Stockholm

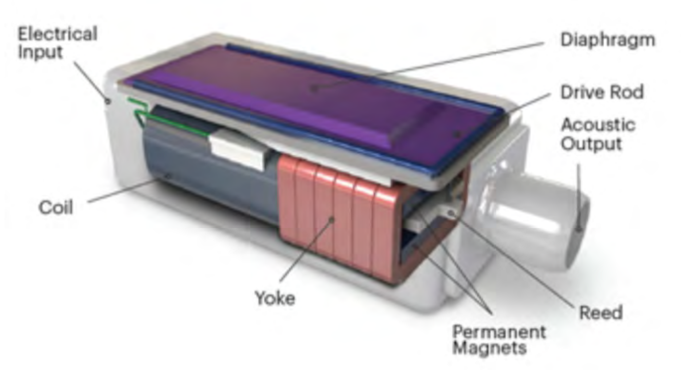


Fig.6.3.11 (2017) *Balanced armature driver unit section view* [jpg] Available at:http://www.knowles.com/eng/premiumsound/Resource-center [Accessed 03.05.2017].

Fig.6.3.12 Anna Póka (2017) *Design sprint* [jpg] Stockholm

6.5 Development

3D CAD models were developed using Autodesk Inventor software. The housing of the components is a complex shape, which is manufactured by injection molding.
Internal ribs were added to reduce shocks and vibrations, that could affect the sound quality negatively. The overall dimensions of the housing unit A are : 23 x 12 x 16 mm.
The energy storage material could be placed on the left side of the unit.

Fig.6.5.1 Anna Póka (2017) *Earbud housing unit A* [jpg] Stockholm

Battery design

It should be noted here, that further development would be necessary in order to be able to use the functionalized aerogel materials inside the ITE headphone, as well as in an external energy-storage unit. It is out-of-scope for the present thesis project to develop a battery design, which could be manufactured at the moment, due to professional, as well as time limitations. However as the assessments created following the research and experiments at Innventia AB/ RISE Bioeconomy demonstrate, that in the future there is a big potential in utilizing aerogel materials in energy-storage applications for consumer electronic products. In the Swedish context, they represent an alternative solution using renewable materials, instead of having to extract non-renewable materials in foreign countries eg. lithium (*See 5.5 Eco - audit of ITE headphones, p.45-46*).

6.6 Technical development

The housing unit is manufactured using injection molding technology, it is composed of two parts:
Housing unit A
Housing unit B

The parts are joined together with a lip-fit, which holds the components together, as well as being easy to disassembly, if an individual component needs to be repaired, replaced etc. (E2). The part, which is visible from the side of the head is unit B. Unit B follows the contour of unit A, it has an angular split line dividing its plane. The two planes form a concave shape from this unit. The split line also serves the purpose of guiding the user, between the different functionalities of the two planes. In the uppermost picture of Fig.6.5.2 the left side of the unit holds Innventia's logo, which is an aesthetic covering of the battery charging unit, that is below this component. The right side of unit B holds the LED lamp indicator, showing if the product is in standby mode or charging, above the indicator lamp is the clearly visible sign, demonstrating the side of the head, that the earbud should be fitted into. (P3). Ideally this side of unit B should be treated with colouring material to provide a darker surface, which gives better contrast for the LED lamp, also for the „L" - left side symbol, additionally other features could be added, by incorporating specialized sensors e.g. accelerometers into the ITE headphones.

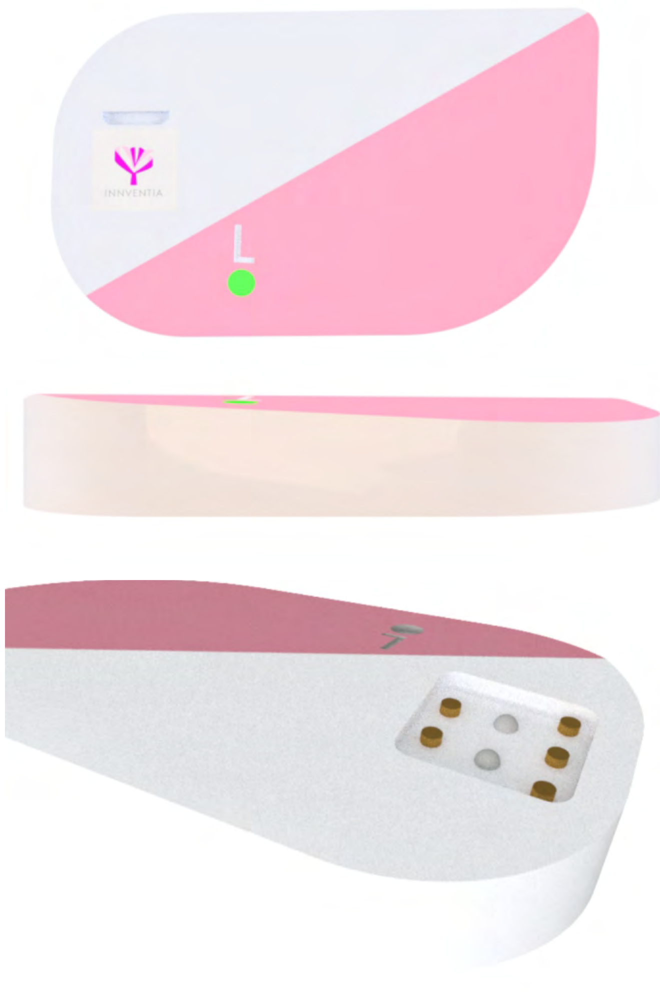


Fig.6.6.1-3 Anna Póka (2017) *Earbud housing unit B* [jpg] Stockholm

In Fig. 6.6.4 the assembly of a cable made with cellulose-based active material is shown. Active material is doped with glycerol to render it more flexible, as a result more suitable for this application area.

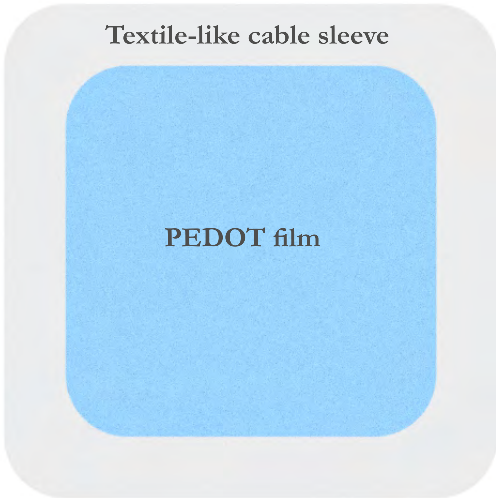


Fig.6.6.4 Anna Póka (2017) *Cable assembl*y model [jpg] Stockholm

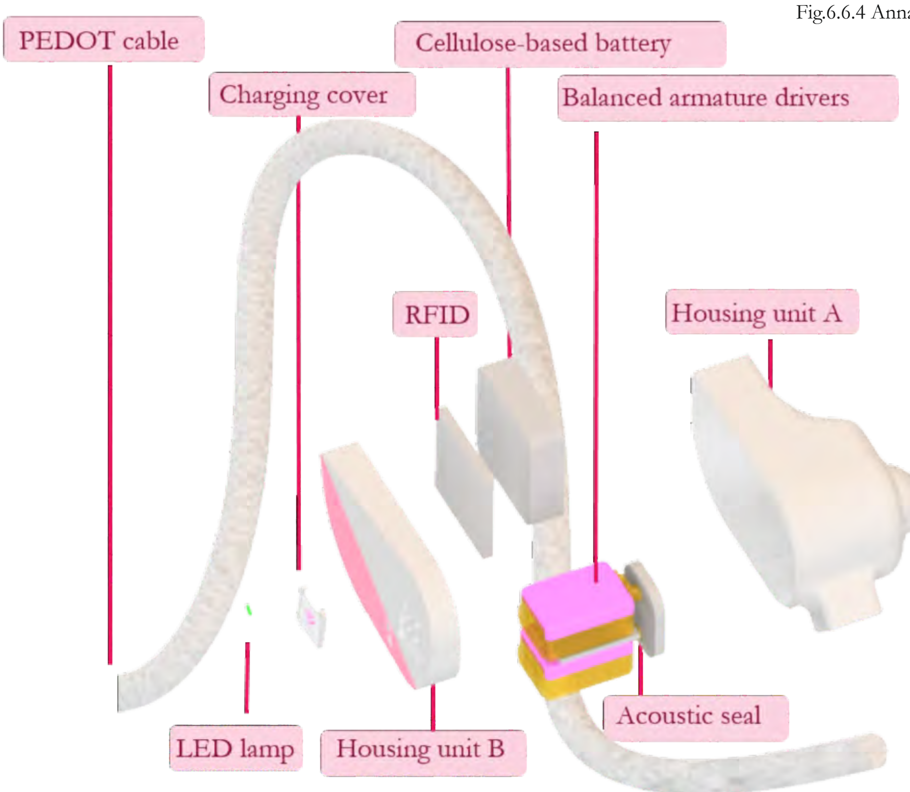


Fig.6.6.4 Anna Póka (2017) *Earbud Left-side assembly model* [jpg] Stockholm

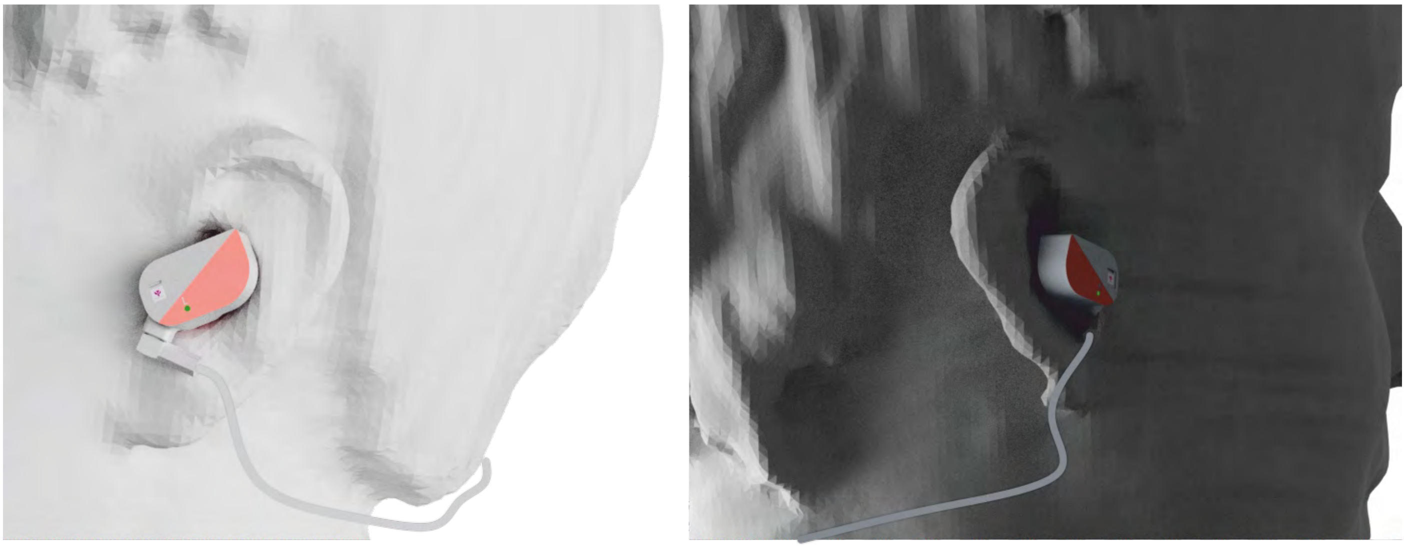


Fig.6.6.5 Anna Póka (2017) *Earbud Left & Right side assembly model* fitted into the scanned head model [png] Stockholm

7. Final result

7.1 Design specification

The final product concept proposes the option of using the ITE headphone product in wireless mode, or by attaching a longer cable in plug-and-play mode, requiring the coupled device to provide it with power. The product should be sold with different cable lengths, so users could fit it to their individual parameters. The eartips are made of a thicker hydrophobic textile-like material, they make sure that the user has a pleasant haptic experience by having even pressure distribution along the ear-canal walls. The eartips could be joined to the housing unit in an easily detachable way, via small plastic connectors, which are attached to a platic frame attached to the lower part of the eartips. This makes the product adaptive to personal needs and updateable.

7.2 Ideas not included in the design specification

The internal signal processing of the device is not included in the design specification, as well as the technical specifications of the internal or external battery unit this requires further development .

7.3 Manufacturing

The housing unit containing the internal components of the earbuds, is made using injection molding, which is a manufacturing technique that allows the rapid production of complex shapes, it also allows the creation of parts, which could be precisely fit.
The active cellulose-based materials could be manufactured using techniques such as freeze-drying or solvent-casting, in case of the PEDOT films for the cables.

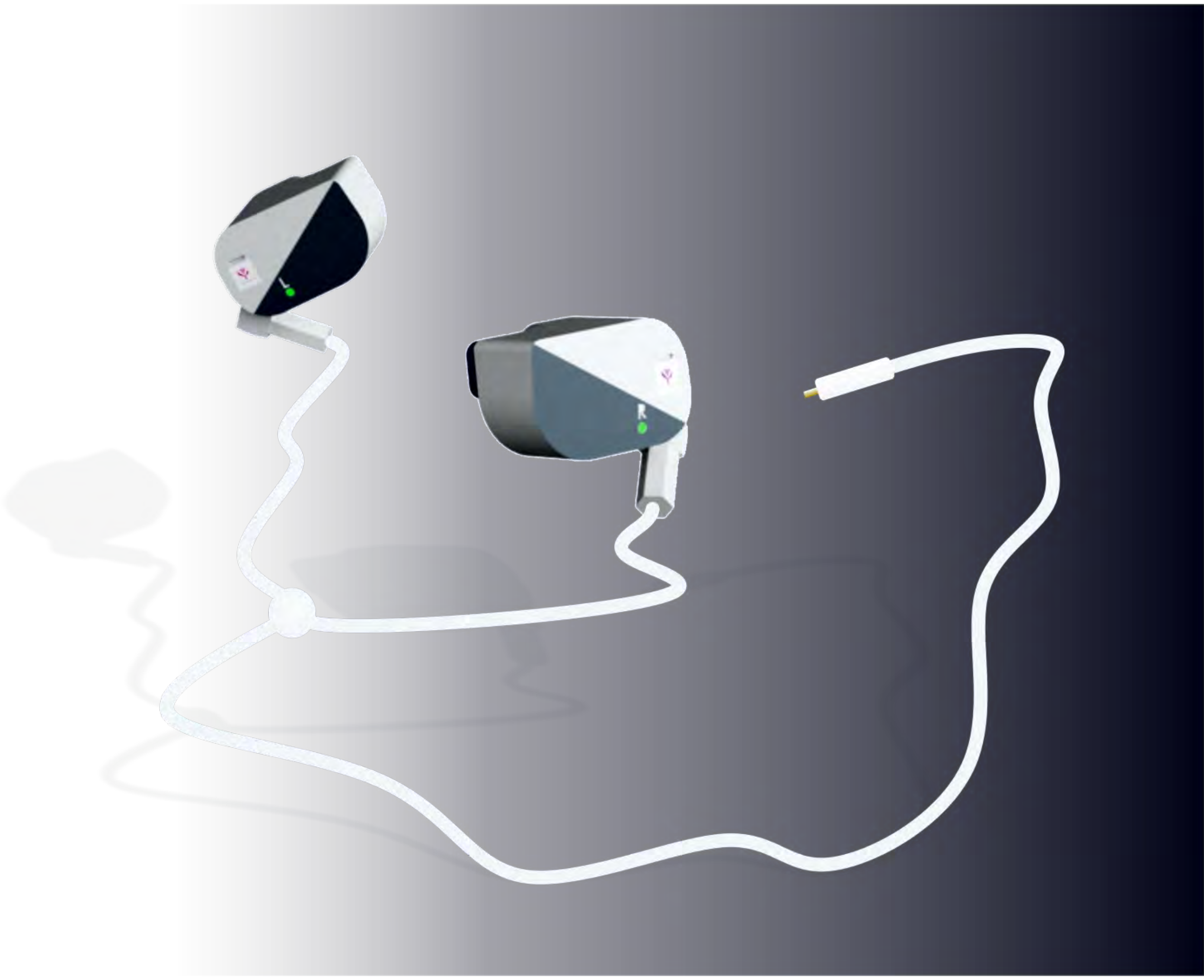


Fig.7.1.1 Anna Póka (2017) Innventia earbuds[jpg] Stockholm

Fig.7.1.2 Anna Póka (2017) Innventia earbuds wireless with reflective cable material [jpg] Stockholm

Introduction
Theory
Current products
Methods
Analysis
Results
Final result
Discussion & conclusion

8. Discussion and conclusion

8.1 The product

Innventia earbuds product concept offers an iteration to the abundant selection of ITE headphone products. It uses cellulose-based active materials, for the purpose of electrical conductivity for the detachable cables, energy storage for the battery and portable charger. The cellulose-based active materials provide a solution to energy storage, which originates from renewable sources. The further components e.g.housing unit, textile eartips could be created from cellulose-based plastic materials in the future. Manufacturing techniques could be altered to fit the material properties of cellulose-based plastic materials. The earbuds represent the core values of Innventia:

- research
- innovation
- sustainability.

8.2 The process

Using a blend of user-centred approach, ergonomics and classic product engineering methods made it possible, to arrive to a final product, which widens the application possibilities of cellulose-based materials, at the same time applies them to the ITE headphone product in an optimal way, not bypassing the MAYA-point for users.
Eco-design principles were established according to the product category, focusing on the features, which enable the creation of an overall improved product experience:

- modularity
- weight reduction
- renewable materials
- finally, pleasant haptic experience.

Tech Mark Arena 2017 produced a platform for the participating Master's students, which allowed them to exchange ideas and learn how issues of sustainability, moreso circular economy could be implemented within product development projects, with distint focus areas e.g. reusing old furniture, exploring biodegradability of MIEC's (See 2.4.3 *Mixed ionic-electronic conductors*), developing paper bags from post-consumer waste (dustfibers), or improving corrugated boards.

8.3 Sustainability

Parts, that define energy-consumption have been made from innovative materials, developed at Innventia, which provide alternative solutions for energy storage, as well as electrical conductivity. These offer an optimal solution, within the current Swedish context, as they could be produced from material, which are available locally. The Innventia earbuds enrich the user experience, with a more pleasant haptic experience, which is beneficial for extended usage time. By making the product adapted to user's urban lifestyle. It is used for longer by users, by having maximum modularity of the individual components of the ITE headphones, it becomes a product, which can be re-used or updated efficiently. In parallel to material research of cellulose-based plastics and active materials, Swedish recycling industry must learn how to recycle, re-use cellulose-based materials in the most environmentally-friendly way possible.

Conclusion

R.1) Eco-design of cellulose-based electronic materials – what are the best approaches?

The application area of the electronic materials needs to be explored first and foremost, in order to be able to align their production, life-cycle to circular economy. Eco-design in itself is a holistic approach, to be able to name electronic materials one must carefully balance the amount of ingredients that could be derived from renewable resources, also those that originate from non-renewable resources. If one would have to answer the first research question in a simple fashion, „best approach" does not exist, if we don't count having an open mindset as such. In this case, open mindset is meant for striving to understand what could be gained or lost by using cellulose-based electronic materials. The short answer would be, the best approach is to be able to make a compromise. Most importantly for electronic devices or ear-fitting headphones the user context needs to be mapped out in detail. Then the device needs to undergo an eco-audit. It has to be disassembled and the individual components need to be examined one by one:

- What are they made out of?
- How are they manufactured?
- Is the manufacturing in another country?
- If yes, how are the worker health & safety regulations applied? (Social sustainability)
- How much energy is used during the manufacturing of the individual components?
- How is the device used?
- For how long is it used on an average?
- Which components could be reused?
- Which components could be recycled?
- Does the company have a well-developed product service system?
- Is the device updateable?

(R.2) How is it possible to introduce circular economy to cellulose-based materials?

In case of active cellulose-based materials, further research is needed to define optimal energy density, charging cycles for energy storage applications. Furthermore recycling technologies need to be developed to sustain a large amount of cellulose-based MIEC's, in the future there is a potential for making organic polymers from bacteria, which provides

possibility for engineering the biodegradability of MIEC's.
A product, which is adapted to circular economy is conciously constructed, it is aware of it's life-cycle, knows, which are the parts that could be recycled, upcycled, reused or subject to industrial symbiosis. The quality of the demostrators/ prototypes lies in recognizing the circular economy aspects within each part, that makes the whole electronic device.

· (R.3) How can principles of eco-design be used to show, via one or several material demonstrators, circular material flows?

Cycle approach

Various components may have different life-cycles, companies must develop a strategy for supporting the life-cycle of each part, otherwise the product could only operate with decreased functionality.

Dematerialisation

This principle is the easiest to explain, material or matter must not be applied in a component, if it's not necessary. Wall thicknesses should respect the produceability aspects.

„Caring for things"

The above principle is used to define the service system of a product, using durable materials for the demonstrators or prototypes is a good way to show, that they have an extended life-cycle, on the other hand it is challenging to forecast an EOL strategy for cellulose-based electronic materials, as these materials are under development. Functionalized films and aerogels must be handled adequately, so the ingredients, which are less harmful or more harmful for the environment can be isolated. For energy storage applications charging cycles must be defined with regards to the product context. Are we storing enough energy to make a wireless ear-fitting headphone work for 4hrs or 10hrs? Different storing methods must be used on an industrial scale in comparison to a personal scale.

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Images

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a) *Cross section showing a wide range of thicknesses for the NFC-PEDOT nanocomposite,*
b) *NFC-PEDOT origami structure,*
c) *NFC-PEDOT ribbons connected to a LED,*
d,e) *122 µm thick NFC-PEDOT stripe subjected to a weight of 100 g.*
f) *Proposed multiscale model for the morphology and self-organization in the NFC-PEDOT composite.* The chemical structures of each of the component are indicated.[png]
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Fig. 3.3 UrbanEars (2015) “Kransen ear-fitting headphones” [png]
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Fig. 3.7 Coloud (2015) “The Hoop ear-fitting headphones”. [png]
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Fig. 3.9 UrbanEars (2017) “Stadion ear-fitting headphones”. [jpg]
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Fig.5.9.2 Chiu, Hsiao-Ping et Al. ; (2014) *Area A; Area B; Area C - showing survey participant's pain point percentile (%)* p. 238 [png]

Fig.5.9.2 Anna Póka (2017) *Moodboard urban student A* [png] Stockholm
Available at: Feather in vase:
https://s-media-cache-ak0.pinimg.com/564x/66/a0/f8/66a0f8c9aa665bc1af218d850f761d90.jpg
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Fig.5.9.3 Anna Póka (2017) *Moodboard urban student B* [png] Stockholm
Available at: https://s-media-cache-ak0.pinimg.com/564x/70/99/ed/7099edae906a48ab8bf0ab06aee271fd.jpg
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Fig.5.9.3 Anna Póka (2017) *Moodboard urban working person C* [png] Stockholm
Available at:Cork saddle:
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Fig.6.3.11 Anna Póka (2017) *Balanced armature driver unit section view* [jpg] Stockholm
Available at: http://www.shure.eu/products/earphones/se846 [Accessed 29.03.2017].

Appendix A - Interviews

Study visit to Acreo ICT Norrköping - 27.03.2017

Discussion summary, points discussed:

- PEDOT and graphene aging and biodegradability
- Biocompatibility of PEDOT
- Energy density properties of PEDOT
- Further application areas

Study visit to headphone manufacturing company - 03.04.2017

Discussion summary, points discussed:

- Sustainability & impact
- Cables
- Wifi
- Biodegradability
- How they work with materials
- Biobenign materials preferred
- Challenges of designing ear-related products
- Defining user groups

Interview questions
Materials

What kind of materials are you currently using in your products?

Are you using any biodegradable materials in any of your products for your in-house brands currently?
If yes, could you describe these?
If not, why not?

How do you choose the materials for your products?

What are the standard requirements that you follow, when making material choices during the different product development phases?

What is your follow-up strategy if you are forced in any way to alter a previously made material choice? How? When? Why?

Product development

All of your in-house brands feature ear-fitting headphone products, for which brand would you think that you would implement more eco-friendly materials?

How do you implement eco-design to your product development processes at your in-house brands?

Would it be possible to visit one of your design teams to talk about eco-design in practice?

Could we use your labs to test the acoustic properties of the materials we are developing?

Do you consider electronics as materials during your product development?

How do you test the usability of your products?

Could you talk about the methods you typically use while developing a new product?

Sustainability - Manufacturing phase

How are the different components in your products being recycled at the moment?

Do you have any recycled waste content in your product components?

Do you have different waste categories at the production facilities for the different product components?

How are you implementing circular economy to your production process/ product lifecycle?

Sustainability - In-use phase

How much of your products end up being recycled?

Could you tell us about your strategy for products lifecycles` sustainability?

How much of your production process would you consider part of circular economy?

Sustainability - End-of-life phase

How do you work in fulfilling the producer responsibility requirement from the EU?

What is the rate of recycling of the different product components at their EOL?

How do you incorporate this responsibility, when working on the US market?

Katja Tasala Gradin - Interview 12.04.2017

AP: What is your opinion about the tools and methods that were developed for designers to improve their product's eco-efficiency?

KTG: There are certainly a lot of tools, also designer tools that have eco-design built-in and there are some methods and tools that are attached to some design processes. So there are both, qualitative and quantitative methods as well. There is really a lot of methods and tools. That`s my view of it, I don't know, I couldn't say what is the best.

AP: Too much maybe, or abundance?

KTG: I think some of the reasons for this abundance is that many companies want to have a special method or tool for their product. So usually they want to have it adapted specially for their product. I think that could be the reason.

AP: What is your experience with electronic devices or headphones?

KTG: I could just briefly tell you about the eco-design course. There's a project, usually four students get a product for example headphones or radio or water kettle. And what they do is they disassemble it, they identify the materials and parts, usually it could be pcb card, usually we don`t identify all the materials and then with the simplified LCA, usually an eco-audit, to see where the environmental impacts are. The manufacturing, use or stock also and then they can make suggestions, how to make this product more environmentally beneficial or less environmentally harmful. So that is what we basically do and we always include products with some kind of electronics and plastics.

AP: I did some sketching about the evolution of headphones and what I found was that, the ear-fitting headphones originated from stethoscopes, which was invented by a French doctor in the beginning of the 18-th century. He felt uncomfortable, when he was examining the female patients, he didn't want to place his ear directly on their chest, so he made a cylindrical device, which is not longer than a whiteboard marker. This was a "proto-stethoscope", then it developed into the product as we know it today. It has the same shape and size as the one developed in the 18th century. Only the part that is in direct contact with the patient changed in terms, of new materials and technology being developed and it became more ergonomic. And then in between the beginning of the 18th century until 1990 or 2000 there was a lot of iteration in the shape, the distribution, the technology, also the materials that they were using, but it all went back to (when it comes to ear-fitting headphones) the shape, that can be derived back to the stethoscope.

The starting point for my thesis is that, there is a huge amount of electronic waste, that goes to landfill or incineration, which is not beneficial environmentally. There are certain components inside the headphones, which require special materials, which could be also so-called "conflict-minerals". Depending on the required audio quality, the headphones could have one or more drivers, containing magnets. The manufacturing company starts by designing the sound, before they actually design the product. What type of sound quality does that specific target user listen to. But also they said that the people that are the most demanding in terms of added functionality, materials and finishing is the people that might have the most hearing problems. Because even middle-aged or depending on their environment younger people could also develop some serious hearing problems. But they are the most demanding users. There is a lot of core issues, that I have found during my research.

KTG: Are you going to look at it from sustainability point of view?

AP: My thesis project is part of TechMark Arena 2017, there are a group of Master students working on different thesis projects and the main theme for the TechMark Arena this year is circular economy. So all the projects look at that how their project could contribute to going towards a circular economy.

KTG: Well so circular economy. I would say that is, if you think about sustainability you have included the environmental and the financial aspect of sustainability. But right now, I'm pretty much looking into the three pillars of sustainability, so as you said with hearing losses. That is a very serious social issue, and it feels like it should not be excluded. What is your mission?

AP: I would really like to have a prototype in the end that demonstrates that there is a possibility to use these materials for ear-fitting headphones, so I'm also working with cellulose-based materials. So it is also a question is biodegradable good in the end? It could also be not good and also when I spoke of core issues is how people relate to owning stuff and typically headphones (maybe not ear-fitting headphones, because most people use it for 1-2 years) depending on the quality and how you use it. But then people just throw it away. For example I did this survey about using wireless stuff. Most of these materials are in such a phase, that it is not yet evaluated how and when they start disintegrating, it is maybe also something that could be triggered by engineering, that is also an ongoing discussion.

KTG: But could it be also that it is not the material, that is the weak-link of headphones? It feels like the sound quality is the most vulnerable, because the devices with cords could easily get damaged, which could affect the sound quality.

AP: Definitely, when we went to the manufacturing company, they said that everything is going wireless now, because all of these parts like: sensors, bluetooth it doesn't take up much space, when we speak about volume, but it's also relatively cheap as a material. Lunch-box philosophy, if I look at people commuting in Stockholm, sometimes they don`t know how to hold on, when the train is moving, because they are holding onto their phones. On the other hand if we look at the more extreme hazards of using headphones, like somebody steps off the pavement without looking around and they could get hit by a car. But this is more connected to maybe social sustainability.

KTG: Yes, but also I'm thinking, I just had a thought there, if you have wireless headphones, if you have smart cars they could send a warning signal maybe to your headphones. Like "Look up, I`m coming behind you!". It shouldn't be too hard.

AP: Yes, it sounds like this should be feasible by now.

KTG: And also that could elevate the security of the human-beings using headphones.

AP: You mean as an added functionality, not only for entertainment, but if you are walking around with them, then you know that you have a device in your pocket or in your bag that gives signals to you.

KTG: Yes, because also you could have a hearing disability or problems with your eye-sight, so that could be an added feature maybe. But maybe we are just going off-track here.

AP: The EU and WEEE directives is already there, but they sometimes "fake-check" companies and give them fines for small things, but they don't really go in-depth.

KTG: Do you mean that the regulations are not keeping up with?

AP: I wouldn't say the regulations are not keeping up, but the volume of all of these products is less understood.

KTG: Yes, there is a lot of waste management, but I think there is a lot of issues with electronics, because the shear amount that end up in waste management. Also there are a lot of products that are not thrown away, because they are damaged or nonfunctional, but it also could be that they are dirty, out-of-fashion or you have bought something new, it is not possible to update anymore. So there are a lot of reasons besides "it doesn't work anymore".
For example the Iphone, you have endless updates, until the phone is full, then you have to buy a new one. I would say that is one kind of planned obsolescence. So there are a lot of issues with electronics, but for example with a phone, you could replace parts, instead of throwing the whole device away. Like have modular phones, I think that are some tests with phones having parts, that you could change.

AP: Yes, when you speak of modularity I got a lot of idea from the people commuting in Stockholm. If they are using devices with cords they try to make them tangle-free. Wires are also a type of waste, you could question if those are necessary or not? In case you have a wireless device you have to charge the device, you it becomes also the relationship with energy consumption.

KTG: You need additional materials, also maybe more specialized materials, like the wire is quite simple its some kind of PVC , copper compared to a wireless device that is so much more material.

AP: I saw a photograph of a woman, who was sleeping with wireless headphones on an airplane, somehow the headphones started burning, as a consequence she had burn marks on her face, neck also the carpet in the middle of the airplane was starting to melt, before the stewardess put out the fire. The wireless headphones had LiIon batteries. This is also something that could be replaced maybe by other options.

KTG: So then you can have maybe a shorter charging time, lifetime and so on.
There is always some kind of compromise.
If you look at manufacturing usually they have so many sub-suppliers , the sub-suppliers have sub-suppliers, so on. So usually it is very hard for a company to keep track of them. They could have quite good control over the first level, but the second and third could be really hard.

AP: Out-of-scope maybe?

KTG: Yes, maybe the influence. But also, they maybe make supply materials for the products. That is one of the problems maybe, that where does the scope begins and ends.

AP: For the company?

KTG: Yes, because I believe that if you look at a product then, you should look at the whole lifecycle of materials until EOL. I guess many companies look at the manufacturing, what they can control, other things or are more or less out of their control maybe. Companies are very short-sighted, because they look at how much money they earned during one year or a quarter, so that is very short-sighted. That is not sustainable, sustainable is, are you familiar with "The natural step"?

AP: No, I haven't heard of it yet.

KTG: It is very interesting, because they look at a longer scope, how can this business evolve towards being sustainable, because our resources are diminishing. Those, who don't adapt will disappear, there will not be anything for not sustainable companies.

for not sustainable companies. Not only because, there won't be enough resources and so on, but there won't be any business way.

AP: Can I ask you a question, with headphones it seems like it's, because of the people, who felt like they need this extra in their life. Like smartphones, in the 90`s and 2000`s it was about, who has the best smartphones and then maybe this trend infiltrated all the other electronic products.

KTG: Well, I would say that is like the “hen and the egg” , what came first? The company, that said to the consumer you would like it? Or was it the desire that came first? People always wanted to flaunt their status and companies know this, that they can sell that. But also people are moldable, are you familiar with nudging?

AP: Yes.

KTG: So in the same way, that you could make people buy more stuff, you can also guide them towards good decisions, towards environmental decisions. Yes, I`m thinking it`s not only the consumer or not only the producer, it`s all of us, that must learn to make the good choices. Of course, this is really hard. But there are also really easy answers too, like : Consume less!. That is an easy answer, but it`s not accepted, not very popular.

AP: Because consuming is also a status in itself. When we speak of longevity for ear-fitting devices, it`s interesting, because the ears are one of those human organs, that don`t stop growing or changing after our body has reached skeletal maturity. That`s why people, who are fortunate enough to reach an older age, have actually larger ears. Different sex- and age-related patterns on how the ears grow and how the hearing is affected. So if you buy a product at let`s say 40, then you might not have the same fit for the same product, when you're in your 60`s and so on, because your ears are changing. If that product has that span of longevity, the question is do we need that?

KTG: In circular economy they also discover other possibilities, you don't have to buy the product, you can lease it, you can borrow it or it could be a service, so in a situation, when I discover that these headphones don't fit me anymore. I can change it, because I pay a little fee each month and then I can get clean ones, or larger/smaller ones.

AP: I don't think that people would be comfortable with borrowing ear-fitting headphones, since it is a product that has direct contact on their skin.

KTG: Of course, it would be a new product, but otherwise it would be it`s kind of a re-use of parts of the product.

AP: I don't think that they even have a take-back system for headphones, how would it be sustainable for a company, that we are providing this service to you, that when you “grow out” of your headphones or you just want to upgrade, then you have the service of , but now in practice if you are an “Eco-conscious” customer you take your nonfunctional/unwanted/etc. Devices to the container for electronic devices, if you`re not one of these, you just throw them in the general waste container and then they buy the new product. Then I don't know how they select and categorize the waste that is inside the electronic waste containers.

KTG: If it's of a certain size, they take it apart, or if there is a precious metal in it like: gold, platinum, silver etc. Otherwise everything is incinerated. It is very inefficient.

AP: So then it`s more sustainable for the companies to have take-back systems..

KTG: But then the product needs to be modular, it has to be adapted for that, because now it is adapted for a throw-away product, disposable. It`s not that expensive and it's almost impossible to take materials apart, so it`s not adapted for the take-back. It`s not like some of the power tools, many companies they want their products back, because there are a lot of parts and materials that they could re-use, because they are modular. So for it to be circular, the product has to be adapted to it, otherwise it's just green-washing. It is quite sad actually , that there is so much talk about how important it is and yet it is moving so slowly. But I think it's, because of the short-sightedness, they want to make money now, they are not looking into the future.

AP: There is definitely a degree to how much money is needed, and what is the ultimate benefit in 10 or 15 years, that is something that is forgotten by some stakeholders.

KTG: Yes, for many companies sustainability is an add-on, they don't have a strategy for it. I agree, like sustainability is not a department, it should be the company. But IKEA a well-known producer of furniture, actually has been working a lot more with sustainability. Their focusing towards more durable materials, more durable furniture and so on. They are changing their business plan from cheap-end

(Co-worker enters the room, she is using over-ear headphones at her desk, she joins in the conversation. She said, that she has been using them for three years and is thinking about where to go from here? She is considering buying wireless headphones, but for the over-ear headphones the sound quality is not the same. Also she doesn`t take her old headphones anywhere, because of the cords. She only uses it at her office desk.)
KTG: Interesting point..

Karl Håkansson - Interview 21.04.2017

Internal structure of aerogels, how can it be modified, when is it modified? What are the consequences?

Nanofibrils are randomly scattered. After freeze-linking ice crystals are formed, made of water.
Freeze-linking is the process used to make the nano-fibrils attach to each other. Then you thaw it and remove the water and you get an aerogel, because if you just let the water evaporate, there will be a film formed in the bottom. And if you freeze it and then do the same thing you get the aerogel. So what happens when you freeze it? Ice crystals will grow and these crystals are big (micron-size), and if you freeze them from one-direction they will form tubes and then they will have thin walls, that will consist of these fibrils.
After the aerogel is made it can be re-wetted, it becomes a gel again

Samuel Pendergraph - Interview 26.04.2017

AP: When is it better to apply PEDOT:PSS to any colloid suspension containing nanocellulose? Would you recommend trying both ways, like you have PEDOT:PSS already mixed into the suspension then you freeze-cast/freeze-dry it or you would recommend to apply PEDOT:PSS as a post-treatment?

SP: I can't give any comprehensive outline on what is better, I haven't systematically evaluated the features. From my experience I have done this freeze method, (it's not freeze-drying, where you are reducing the pressure and you are driving the sublimation) it's a newer technique, where you oxidize the cellulose and then you freeze it, put it in the freezer and then you solvent exchange the structure. Now in that case I always think it is better to stably disperse PEDOT:PSS, to mix it in solution. Because you have a greater chance of mixing it more effectively and having a more even distribution, than if you were to force a solution through a porous structure. It's very difficult to say how that mixture is, where you can be pretty certain that by mechanically stirring you are going to mix the polymer more effectively with the cellulose. I would assume that is better than freezing a porous structure, which then you have to apply a lot of force to force through with fluid and you are not certain how the solution is changing as the polymers is absorbing to the cellulose itself. Also if there is any sort of salt-interaction, you have a more concentrated solution, when you are forcing PEDOT:PSS than when you are mixing it with a cellulose gel. In one case you have cellulose and water and in the other PEDOT:PSS and water, but if I dry the cellulose for example I have removed all that water, so you are going to have a more concentrated solution in that sense. It is not certain how the driving force to remove ions and to promote absorption is going to change with those aspects. You also don't have the same driving force, because the mixing is more difficult in that situation, in terms of removing the ions.

AP: How does oxidizing the cellulose before any freezing process affect the cellulose structure?

SP: The mechanism of the chemical oxidization is a very well-established, it's an old chemistry technique. You take sodium-periodate ($NaIO4$) and it specifically oxidizes the vicinal diol ones, in the glucose residue or the repeat unit, the two alcohols that sit next to each other. They oxidize from the alcohols and aldehydes, I'm not an expert on the final structure on what chemically happens with the final structure is, what happens when the system drys. I think that is being progressively studied at the moment, so I don't think it's 100% understood, with these CNF and I'm speaking specifically about CNF.
What it does allow though, is the mild freezing procedure, where I can take this oxidized cellulose, so I take cellulose gel and I mix in this periodate and I leave it for a couple of hours, then I can put it in the freezer, let it freeze all the water and then I can gently solvent exchange out the water and I'm left with a porous structure. So that is one advantage that you have is that it's actually a water-stable gel, which is nice, because then you are able to avoid doing modifications that are not compatible with how people want to manufacture things. So that is one advantage I would say to this procedure of oxidizing.
You do change the mechanical properties, those can be altered if you do more chemistry, but I think in my mind the biggest advantage that you gain is the processability, alternative process.

AP: What about the material itself PEDOT:PSS, it has a good record on conducting electricity?

SP: Yes, I would say the standard polymer material, not necessarily because it's the best, but it has relatively very good conductive properties and is commercially available and could be scaled up. And it is well-studied and established.

AP: Is it well-studied in regards to its production or do you mean it for it's EOL as well?

SP: Yes biodegradability is less studied, because if you look at the polymer structurally there is not an inherent functional group in the polymer that says, yes this is really easily biodegradable. I would think that's why it hasn't been studied in that sense. Polystyrene is very difficult to break down and a lot of the polymer is that and then your PEDOT is also not easy to break down, because it's a conjugated aromatic structure.

AP: If we look at headphones with cords containing metallic wires, in what way would the electrical conductivity be different if we were using PEDOT:PSS to replace metallic wires?

SP: Well I think one advantage you always gain, when you have polymers versus metals is weight. It will always reduce weight, because you use organic carbon-based polymers, and carbon is a much less dense atom than transitional metals, so you definitely gain that. A lot of metals that are melted to electronics are toxic and not particularly environmentally-friendly. I'm not going to advocate that PEDOT:PSS is particularly environmentally-friendly, but it may have a lower impact, if you had disposal issues for example versus heavy metals. The other advantage that you gain is that, when you have the ability to make organic molecules, polymers you open up opportunities that you can use renewable resources, now it may not be the most "green-method" and it may not be the most environmentally-friendly even.

AP: But these procedures could be improved in the future..

SP: They could be improved and also it just opens up the possibility. If you don't have copper sitting in the ground in your country, you can't mine it, you can't get it out, you have to import it from another country. But if we have trees, and we learn how to refine molecules into simple organic molecules that can be then refined, that opens up the possibility of sourcing it in a different way. That you wouldn't be able to do with metals.

AP: What about the energy storing features of PEDOT:PSS?

SP: I'm not a 100% up-to-date on the core literature on that, that is something that you could ask someone else about. I don't want to throw out misleading facts.

AP: Let's talk about how the properties of the PEDOT:PSS could be modified..

SP: The required material quality is entirely dependant on your application. Cellulose and nanocellulose have a very high-strength, especially when you consider their weight. That's one of the biggest drawers to nanocellulose for researchers, that these materials approach the strength of metals, but their density is significantly lower. Which means your strength to weight ratio is very high, which is ideal for a number of applications.
But you have to consider what type of strains, deformations, these things that you put on your application, because if you strain your material too much it is probably a very poor choice, because usually materials that strain a lot want it to deform a lot, it means that it doesn't need to be super strong, it needs to be able to move substantially.
One way would be to get around issues like that, is to modify the geometry, so for example, when something bends. The bending energy is proportional to the thickness of the third power, so that means that if I change my thickness by factor 2, the bending energy changes by factor 8. It's a very substantial difference. Bending strain is directly proportional to thickness, so these are factors that you can look at, what kind of demands do we need.
You can make something thinner, so that it bends easier, I mean metals can't strain substantially yet if you have a thin piece of aluminium foil that can bend pretty well, why? Because it's very, very thin. So it's not just an issue of the materials, it is also how you design the geometry also and understand the mechanics. And knowing whether or not cellulose/ nanocellulose is appropriate is really having a deep, fundamental understanding of what is your product, what are the demands and what are you demanding out of your product? What can it handle? And considering nanocellulose under these design parameters, my geometry and what I need to get out of it, in terms of deformation is satisfactory. Or whether I should seek another material, because the cord doesn't stretch enough, so nanocellulose is probably a poor choice, because it can't strain substantially. But maybe you don't want it to strain, most cords don't strain very much, because they do have metals inside them.Ok, so then it doesn't matter, then it's a very ideal choice, because let's say it holds the same amount of force, but now it's three times lighter. Because it's made out of carbon atoms and oxygen atoms, not copper atoms.

AP: Aerogels contain a lot of air as well, which is good for insulation

SP: It's good for insulation, but you have to remember a more porous structure means a more thicker structure and that makes it harder to bend. These are things that you need to weigh out. It definitely has the advantage of insulation properties, in terms of having a porous structure. It is a very good idea, but you also have to remember that, if you are making a porous structure you are making something that has high volume and not so much weight, low density. That may have repurcussions on other characteristics, that you may need to have.

AP: According to some papers PEDOT:PSS films have an average of 0.6 (GPa) Young modulus..

SP: This only means that they could take that much energy per unit of volume. You always have to put the numbers into context. What is your application? What are you trying to do with it in trying to understand whether it is a good material or a bad one? And that goes for any material. Hard, soft, whatever. Just having a modulus number, all it says is, that it can take this much force per area, or energy per volume to deform the material.

AP: So on the whiteboard there is picture of an ear-fitting headphone produced by Shure, their answer to having a more environmentally-friendly cable, is to manufacture the headphone cables as detachable parts

SP: So what you are saying is that, they have compartmentalized part of the cord, so if one part fails, you can buy a replacement rather than buying the whole product.
That's certainly a practical, I mean it's a nice idea towards yes you are just simply consuming less material..

AP: So I would consider that a step in the right direction, but also I think it's feasible to work on the modularity of this part, which could also be interesting with regards to the energy-storing feature of the product.
For the ear-fitting companies use three most common types of eartips: triple flange, foam and rubber. Some of them sell all three options with their products, so the user can choose, which is the best fit for their ears. In most cases the part that is in direct contact with your ears is made out of plastic, which is still not the most natural thing, that you could put in your ear canal.

SP: I would make a comment on the natural versus artificial. Just because something is natural, doesn't mean it's more environmentally-friendly. If I take cellulose, which comes from trees, which sequesters CO2, which requires a lot of water. Water has a high heat capacity versus many organic solvents, that process will require a lot of energy versus a synthetic process, which may not require as much energy.

AP: But when you dispose of it doesn't disintegrate or interact with the environment in the same way as..

SP: Depends in what sense. I got into an interesting conversation with somebody that worked at a recycling plant. I told him, that I'm going to work with cellulose, so I'm working with something that is environmentally-friendly. The first thing he said to me, is that cellulose isn't recyclable, but your PET bottle is 100% recyclable. If I would just throw it in a bath of acids, then cook it, I will get what I exactly got out of it. So my thinking is that, one has to be careful on wanting something, because it's more natural. You have to understand why you want something to be natural. Of course it is ideal to derive your material from a source, that can be regenerated within a lifetime versus something that gets depleted very rapidly. But you also have to understand the whole process, in terms of CO2 emissions, what kind of energy it takes to process it. Is it recyclable versus biodegradable? What is the biodegradability? These are all factors that are not apparently clear. I enjoy working with cellulose myself, for the reason that it's natural. But it's extremely important to be cognizant why something is environmentally-friendly. What is environmentally-friendly, in what context is something more environmentally-friendly? It is easy for people to extrapolate circumstances that happen, that paint a broad picture of being environmentally-friendly. For instance if there is an oil-spill, that is very environmentally-unfriendly, however if the situation was handled properly is it an impact? See it under normal manufacturing circumstances, is this more ideal plastic material or anything? Because a lot of times, it's marketing..

AP: Green-washing you mean?

SP: Yes

AP: Yes people need to be more aware on what is less harmful in their own context..

SP: Yes, they also need to be able to assume, how something is disposed. If I throw my plastic headphones in the ocean that is not good, but you need a proper method to dispose of your material. If I throw this cellulose composite-based 6 ring holder on sailboats, would that not create problems for birds, etc. It's not clear how long it takes to biodegrade. Just because it's made of cellulose, it's not going to have the impact. Then you also have to weigh out, if I make something, I'm trying to make something to be lasting and durable, but I'm also engineering this property that inherently breaks down those compete directly with each other.
So if I make a material, that degrades in the ground, but if I'm buying the headphones at five times the pace that I bought the other headphones, then it's not necessarily more "green".

AP: So we can speak about the durability of the material, a lot of companies are trying to apply more durable materials to their products, in case of the headphones, some companies are using metals for the casing instead of injection-molded plastics. What do you think of durability of PEDOT:PSS, what is the ideal durability of PEDOT:PSS?

SP: What type of durability, do you mean electrical, longevity, do you mean mechanical durability?

AP: All

SP: One problem that you face with organics, also for metals, is that they are subject to be attacked by oxygen. So in terms of electrical conductivity it's a little unclear how much better or worse it might get. In terms of mechanics, it really depends on what you are subjecting your materials to in terms of deformation. Your geometry I think it has more of an effect over that. One thing that you have to consider with PEDOT:PSS is that it can also potentially be an irritant, because it is acidic. It could cause irritation as well. I heavily doubt that the product would put you into direct exposure to the metals, it would compromise the longevity of the material, in terms of the conductivity.

AP: I have made a material flow chart based on the information available on the internet for the Swedish context of audio electronic products..

SP: What you need for the input is just a rate of accumulation, what are we bringing in, then what is going out, if you want to know how it is circular. If it is circular everything has to conserve, like what you put in, has to be what goes out

AP: In the circular economy, the value of the material/product/service etc. has to also be the same..

SP: I don't know, but if we look at the Swedish context, if the product is not manufactured in Sweden. Then it starts with consumption here, then it has to be balanced how do you dispose, recycle, recover that original material that came into the country from the manufacturer.

AP: El-Kretsen has containers and cages and also the Swedish municipalities have containers designated for electronic waste and according to the company's website they have this five criteria for evaluating the functionality of the waste. Companies like to develop their own ecological rating, this was developed by a German company, they have a rating scale from A to D, A being the "Particularly relevant ecological problem"

SP: Can I ask why NFC and cellulose-based materials have the same ecological problems?

AP: Aerogel with graphene, Aerogel with carbon nanotubes or aerogels treated with PEDOT:PSS, we can say that all of these are cellulose-based materials? Then it's also maybe a too big category

SP: The problem is that you are not isolating what the actual ecological problem is, it's not the cellulose-based material, but the additional materials used the achieve a particular functionality, which cellulose or NFC in itself does not have. It would be better for each material to have a stand-alone category.

AP: I searched literature on the toxicity levels of these materials, how they disintegrate etc. at the moment there isn't much literature on this. But these materials as composites have a different EOL strategy than NFC or cellulose

SP: I understand that companies usually use these broader terms when they speak about the materials they use in their products, because they would like to protect the recipes, so they use these broader terms like polyester or polyamides to note that this is a class of polymers that we are currently using in our products and they suffer from these issues.

Steffan Ståhlgren - Interview 09.05.2017

SS: I have bought those 4 pairs of those shoes, they cost 4000 SEK each. They are quite expensive, but if you spread it over 19 years, it's not much. The comparison is, that you buy a new pair every year, which are fashionable, but the environmental impact is much bigger. So what I'm saying is, if you (and I understand the aspect of fashion everything like that, but you also have to weigh in, if you can have a product, that you can have a product, that you can have for a very long time..

AP: I'm weighing that in, but also I'm trying to weigh in, that if I'm targeting an age-group of twenty-somethings, then they might not think like that, all the time.

SS: But that's also, I'm not saying that there is something wrong with that or if it's bad. Isn't that also something that we as humans or as individuals have to re-think? It's a bit like, we can't both have the cake and the same time not eat it, we have to make a choice. Yes we want to be environmental, we can't have everything new all the time and the same time be environmental. Like for instance, I speak to my students about how do we in the design or in the appearance, try to highlight that when you look at the product, you have a feeling, that this is a product, that you should have for a long time. It's not a short-lived, something that I have for six months and then I throw it away type of product. I worked before at Fjällräven as a product developer there and so that's a totally different area, but the clothing they make is considered very hip. To have a Fjällräven jacket, that your grandmother had thirty years ago, but they still use more or less the same pattern, same material. So what you're doing, you're building in a story to the material, where I'm not saying it will work from this, but interesting thought, when you take this jacket that your grandmother had, when she was younger. You are taking over heritage and the material itself becomes cool, because it's old. It's not uncool, because it's old.

APK: That's one of the ideas, that I'm trying to build-in with the modularity. The main reason to have it this way, is to have continuity in the product, it could be called an added "cool-factor". Because if you don't have parts of the product, that offer the possibility of being updated, it stays the same, but you can't expect "the user" or all "the users" to continue using it.

SS: What I feel sometimes, a problem we had about two weeks ago, we had a polymer seminar here and that industry. The polymer, plastics industry talked about recycling and so on. The problem is today, that today there is very few examples of any company, being able to take their product, recycling it and then being able to make the same product after recycling. It always goes into something that is 10% or 20%. So we have to be careful, when we use the word "recycling". Instead be honest and say, we haven't got the technique yet. So when companies say they recycle, it's mostly out of the pure material they had before production, when we cut away to pure material, we can still recycle that, because it's still pure. Whereas when they do this (shows pink highlighter pen) different coloured materials, textures, finishing etc. You can't recycle it. So I'm thinking that in your case, when we're looking at different materials, try to see what needs to be done, but also what happens with the materials afterwards. Swedish waste from the home for example is so clean they have to add plastic to it, when they burn it. I'm speaking of general household waste, that goes to incineration is so clean, that they have to add about 30% plastic from the plastic recycling, because otherwise it's not efficient. The temperature will go up, but you won't get rid of the poisonous stuff, so they have to add plastic to high temperature so the incinerator consumes everything. So when using these things, we have sometimes I feel a tendency to be a bit too happy about all the ideas about recycling. You have to call it what it is.

AP: I did a material waste flow chart, from the information, that I have found on the internet. El-Kretsen is responsible for collecting electronic waste in Sweden. They tested how good are people at deciding, when to dispose of their electronic devices. They found based on the random picking of 2t of waste from all of the cca. 400 t waste being generated, that people are fairly good at estimating, when to dispose of their electronic devices. They have a scale from 1 to 5 testing the product's functionality, nr. 5 meaning landfill or incineration. Ear-fitting headphones there is a problem, with the cables tangling up and becoming hard to manage. One solution they use to avoid this is producing the cable with a larger diameter or with a flat or rectangular cross-section. Some of them also use a textile-like material as cable sleeves to make them less sticky, therefore less prone for tangling up. When it comes to circularity the cables are designed for disposal, if the headphones are not designed with detachable cables, then if something happens to the cables you have to buy a new product, because you can't use the product anymore. So do I need a cable or do I not need a cable, which is better? What is your opinion?

SS: It depends, out of functionality I would say no, you don't need cables…

AP: I compared the ear-fitting headphones with cables and the wireless ones and I found that the wireless ones offer "the user" unlimited mobility within a constrained area, but the ones with cables gives you limited mobility within an unconstrained area, you can plug them into a device anywhere, of course ultimately these devices need a power source as well.

SS: So yes out of functionality wireless is better, but if you consider environmental aspects, what type of additional parts do you need for a wireless device and how does that affect the environment? What is the environmental impact of having bluetooth inside? Is that OK? What's the difference in terms of environment?

AP: I think if we put them on a virtual balance, they are equal in terms of environmental impact. Because you can't say that the ones with the cables are more environmentally-friendly, due to the copper they use inside and that is not renewable.

SS: I haven't done the maths on this one, I don't know.

AP: I haven't either, because not all data is available.

SS: It will depend, which way you want to go on your work? Is it towards more the functionality or is it the environmental?

AP: Both.

SS: Then to see, what is their impact, are they the same, or are they different in terms of impact? You have to be able to sort different components from one another.

AP: Sorting, take-back system all of these services mean additional work from companies..
The technology-readiness level recycling the materials under development could be higher, if we look at the analogy of how we consume energy and in some African countries they skipped the part, which was called industrial revolution in Europe and North-America and they just went from pitch dark to using renewable energy sources and in Sweden we are going towards having more renewable energy, there is a big potential for that in Europe.

SS: This debate has been going on since I went to university, back then the discussion was to construct product components as pure as possible, so when the moment arrives during the product lifecycle to recycle them, they could be easily disassembled. As you say the copper should be taken out, plastic should be plastic and wood should be wood and metal should be metal and that's something that has been going on for thirty years. This should be the basis of being able to recycle things.

AP: When customers go into a store to buy headphones, they are sort of forced to choose between wireless products and products with cables, or they can buy both. It's very interesting is there something in-between? At the moment there isn't..

SS: Have you seen the camera that could be used once and then you throw it away and develop the film, so they designed the product in a way, that made it easy to disassemble the housing and the lenses, so you could use it up to 3 or 6 times, they did tests on the material. So they took out the used films and cleaned the housing, so depending on the state of the lens you could reuse it.

AP: Interesting, for the headphones they actually produce them based on musical genre, because every genre has its own preferences, when it comes to acoustics and that is being defined heavily by what type of driver is used inside the headphones.

SS: I understand that, but I think that people are not that much connoisseurs anymore. I think they are more inclined to fall for a physical aesthetic change, that would fit them, than is the sound quality prepped towards house, opera etc. I don't think they notice the difference and if you have a person, who listens to opera that person, won't listen to hip-hop. But if the design is towards somebody, who is a typical opera listener, that would be more interesting. So it becomes more interesting from consumer perspective, if you design something that you know you could use over a long time period, not just a couple of months and then you throw it away, because it's out of fashion all of a sudden. In there is a challenge, when it comes to design, to make something updateable, being able to live for a long time and that the quality in this product should be on that level, that it doesn't break down. You know the problem of planned obsolescence?

AP:Yes.

SS: That is a problem, that companies who make the products will use this, it's really bad.

AP: I have been doing some experiments with aerogels, one of the principles of eco-design is to design products, which have a lower weight. At the moment the ear-fitting headphones are about 20gr, so it might not seem like a big deal, but this could be lowered as well. I have been thinking about the idea of having a modular cable, technically it seems feasible, when you google "modular cables" you get images of ethernet cables. What do you think? I made these mock-ups to test the length and the flexibility of the cables.

SS: It would be interesting to see a prototype, to see if it's functionally correct, does it work? Or is it something that I would use, or it's just a gimmick? I would need something to physically relate to, to be able to form an opinion. But the idea is interesting, but that's just based on what you have communicated to me, my ideas of what that could be.

AP: I made an 8 cm and a 5 cm long module mock-up ear-fitting headphone with modular cables and I tested it on coworkers and they said they like the 5 cm better, because it felt more natural, it is more flexible than the one with longer modules

SS: There have been attempts, but I haven't seen anything real, hasn't been anything that maybe incorporating it, or give it maybe the physical form of jewelry. This is something that you wear, so why does it have to express what it is?

Could it be something else? Could it express something else? Could it be part of my jacket? Or could it be jewelry? Or could it be more camouflaged? I think it would be interesting to see, how far you can go on that, because you could make earpieces, that are actually non-earpieces. Some products are so focused on being earpieces, why do they have to be that? It is a stereotype that both male and female designers fall into, this is the way that you should do it. Female designers have a easier or are better at not falling into this mistake. So I would say that is something to..

AP: Avoid?

SS: Definitely avoid, but if you take also the aspect of gender-equality into your design?

AP: My aim would not be to produce something that answers all questions and is perfect, it's enough to have at least 80% of perfectness, but it would be really good.

SS: When it comes to your work, it depends towards who you would like to go? Is it gender specific?

AP: My target "user" would be somebody, who is living in an urban context and is aware of environmental issues. I spoke with Tatjana at Innventia and she made a comment to me about how people could get confused about appearances, that seem to look "natural" and "eco" or environmentally-friendly. These products are associated with brownish, earth-tone colours, but those are not necessarily appearances that people would like to wear every day of the week. So the outlines of "the user" are neutral, not gender-specific, urban context and aware about environmental issues.

SS: Maybe try to make moodboards, who is "the user" , where do they live, what are the materials present in their environment, make a moodboard which expresses how these people are not as persons, but how they live, what cars they drive, things that interest them, so you get a picture. Then you could make another with colours and materials, if you communicate how this group lives, which materials they like and what shapes they appreciate and then you could communicate, what are their preferences. I can have a clear vision, but my customers they could be engineers, businessmen they have a hard time understanding, but if you show them a picture it makes it easier for me to communicate my vision to them, by showing them, making a model, which just a volume model out of foam, that could make them go A-HA! As opposed to having a nice sketch in 2D, which is flat. If you make a volume sketch with foam they understand the dimensions and proportions better, because its 3D.

Siv Lindberg - Interview 12.05.2017

AP: What is your opinion of creating demonstrators/ prototypes, which don't have an "eco" appearance?

SL: In general there are a number of things, that spring to my mind. First of all I was interested by the natural appearance of things, because I think that is interesting. We have done a number of research and asked people about materials, and how they perceive materials. We asked them to rate aspects like: naturalness, quality and exclusivity showing them different materials. They seem to have a very strong opinion, when we showed them a material sample with a brownish colour, if it had a rough, fibrous surface, then they perceived it as being natural. They rate everything like that, natural. They may not rate it, as having high quality. It could be quite opposite actually. Even young people, when we asked young people, they think that it should be brownish, beige, rough, not glossy, warm, these kinds of things. Pretty much an image of wood in people's head. But these opinions do not necessarily reflect their willingness to buy or if they are going to like it. I think now we are very caught up in the bioeconomy and making things in a sustainable way, I mean we cannot go on making everything brown forever. I think it is a learning aspect in the community, that you will have to learn eventually, that sustainable products, materials could have a nice colour, nice surface. Red colour could be achieved in a sustainable way maybe. That's why it's interesting, because what people perceive as natural also signals low-quality. Then you have another aspect of course, if you wish to be part of a community, to represent your social sensitivity and your an eco-friendly person, who cares about the environment. In that case, you might want to wear "signs", that shows that you are. So that could be brown headphones, I don't know.

AP: I made two mood boards representing two potential user groups, one of them is a student living in an urban environment, the other one is a working person living in an urban surroundings. I wanted to be more broad, because the product I'm designing is being used by people regardless their age or cultural background..

SL: These pictures that you showed, reminded me of an article I read about a mother "hacking" her small son's hearing aid, with action figures like Batman, Spiderman, to make it look cooler. Because it's not fun having a hearing impairment, when you're a child in a sensitive age. So she redesigned the hearing aid, to make it look "cooler". And of course, it could be restyled, because you might not want to wear an action figure on your hearing aid, when you're 35 years old for example. So in this situation I think the way of thinking is very interesting. In my case I don't use earbuds a lot, certainly I can't use the ones that are flat, because it creates pressure against your ears after a certain amount of time. I don't know, there is something with the size of my inner ear that the ear-fitting headphones don't fit them very well. They fall out, I haven't found any that fits really nicely actually. So for me I was thinking, if I could have ear-fitting headphones that are hanging from the top of the ears and then I can maybe stick them in my ears and they won't fall out. I really, really hate the cables on the headphones.

AP: I'm working on having modularity to certain degree in the product. So it could have a detachable cable, if you wish to use your headphones in a wireless mode. If you are commuting then you can attach the cable again and use it in a plug-and-play mode. This way the product would become more circular, if something goes wrong with the cables, you don't have to buy the whole product again.

SL: Yes, that's the part that breaks the most easily, due to the friction and the wear.

AP: Back to the mood boards…

SL: Pulp PLA would be a part of this concept?

AP: The structure holding together the rest of the components, definitely. The accessories for the product will be made of that as well. With the whole product experience in mind.

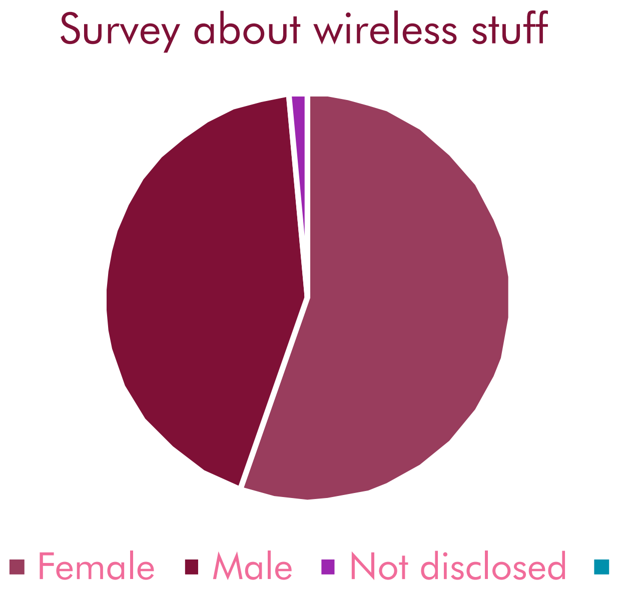
SL: Are they packing these up in Asia? Where are they manufacturing them?

AP: In China,

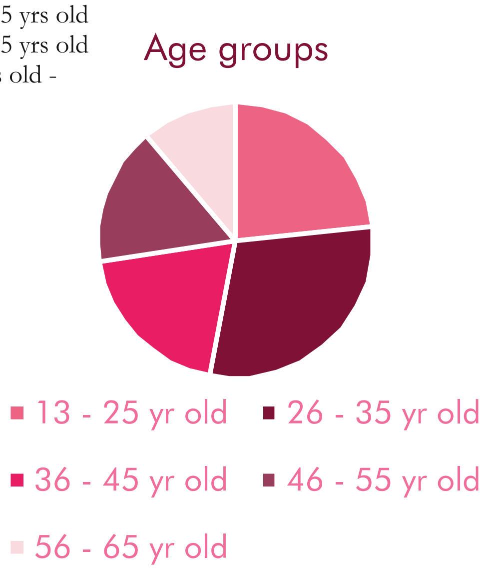
SL: For companies that enter the stock-market, that changes a lot, because they need comply to the regulations regarding manufacturing, packaging, disposal etc.

Appendix B - Survey

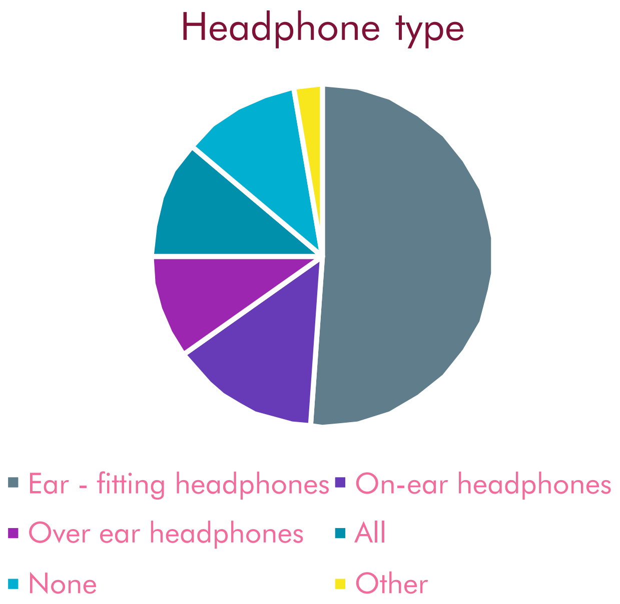
1. Please choose your gender by selecting one of the options:
Female
Male
Prefer not to disclose
Trans*



2. Please select your age group:
0 - 12yrs old
13 - 25 yrs old
26 - 35 yrs old
36 - 45 yrs old
46 - 55 yrs old
56 - 65 yrs old
66 - 75 yrs old
76 - 85 yrs old
86 yrs old -

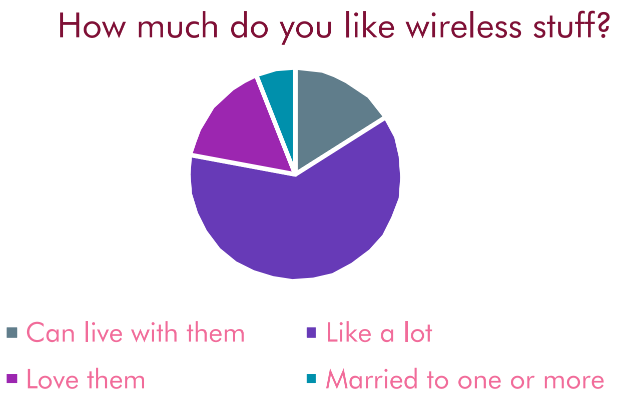


3. Please choose what type of headphones are you using?
Ear-fitting headphones/ Earbuds
On-ear headphones
Over-ear headphones
All
None
I am using another type of headphones



4. Where do you purchase your electronic devices usually?
Online
Warehouse
Specialised store
Most of the time I get them as a gift
All
Other

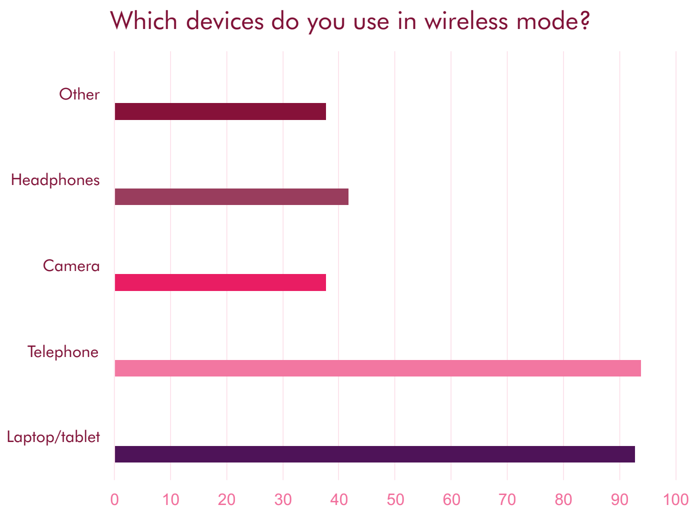
5. How much do you like wireless stuff/ electronic devices?
I hate them.
I can live with them.
I like them a lot.
I love them.
I am married to one or more currently.

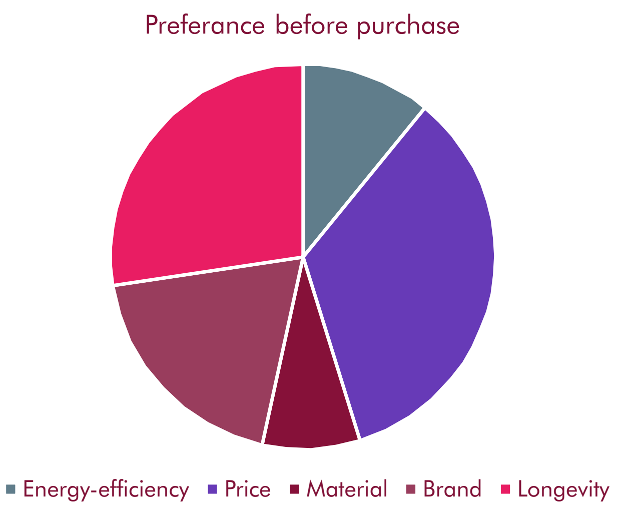


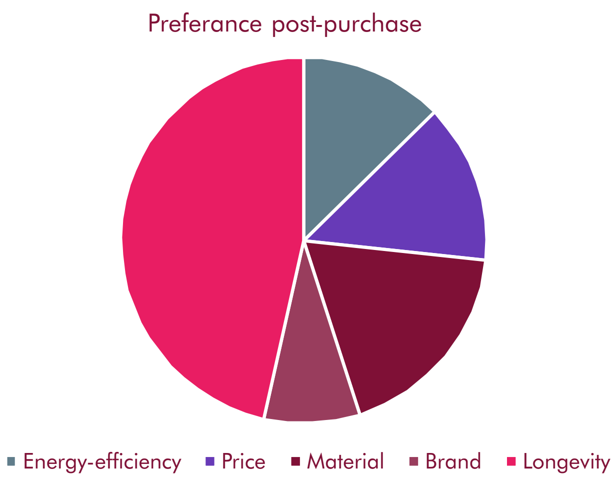
6. Select which product characteristic is the most important for you before you buy the product!
Energy-efficiency
Price
Material
Brand
Longevity

7. Select which product characteristic is the most important for you after you have purchased the product!
Energy-efficiency
Price
Material
Brand
Longevity

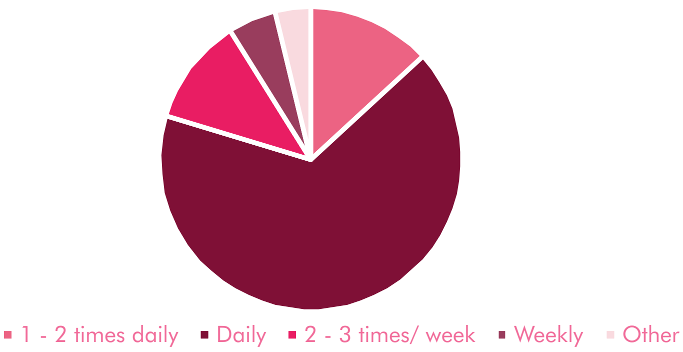
8. Please select which type of electronic devices that you have can be used in wireless mode!
Laptop/ tablet
Phone
Camera
Headphones
Other electronic wireless device



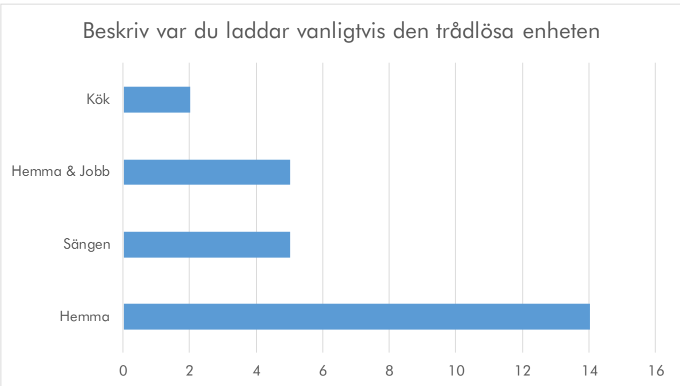


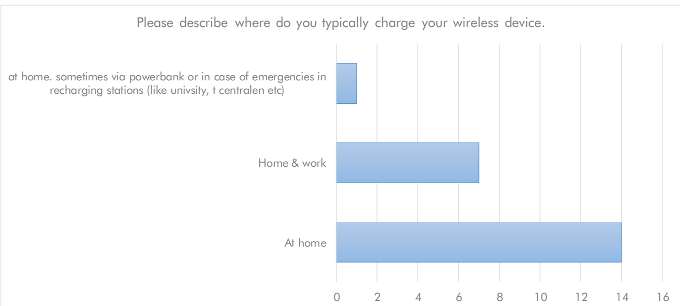


9. How often do you have to charge your wireless device?
1 - 2 times daily
Daily
2 - 3 times/week
Weekly
Other

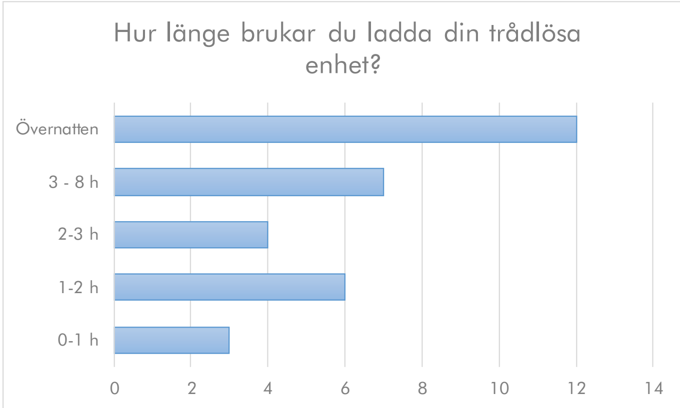


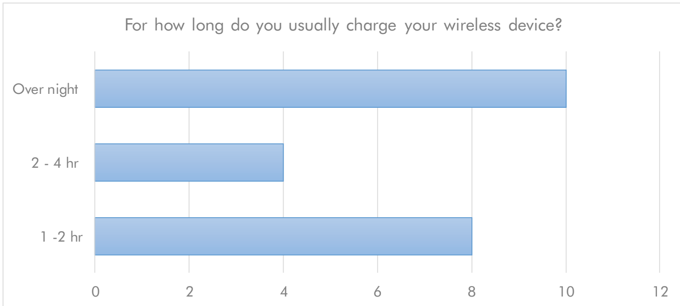
10. Please describe where do you typically charge your wireless device!



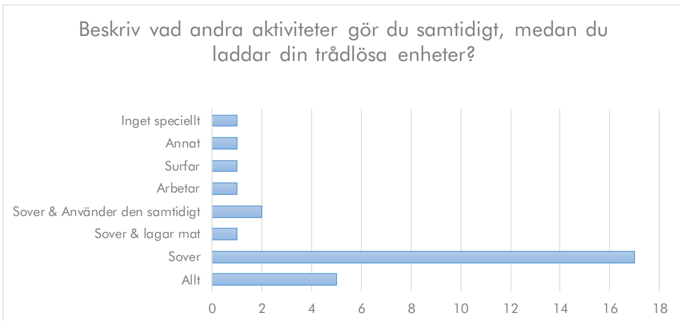


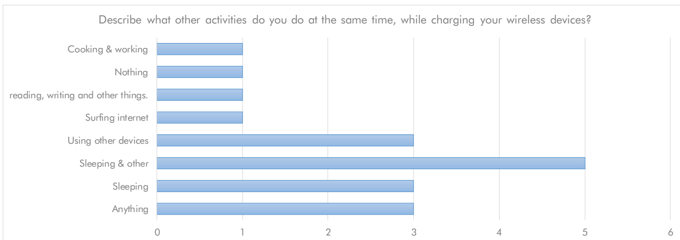
11. For how long do you usually charge your wireless device?



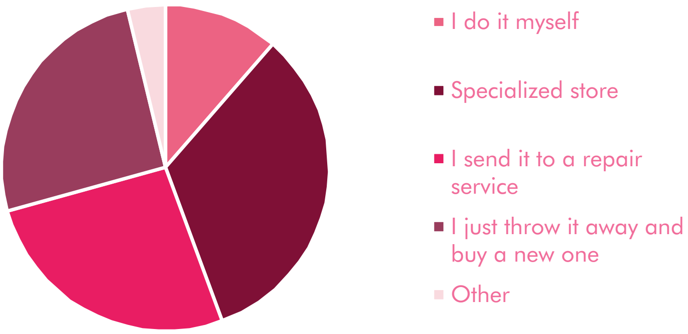


12. Describe what other activities do you do at the same time, while you are charging your wireless device!

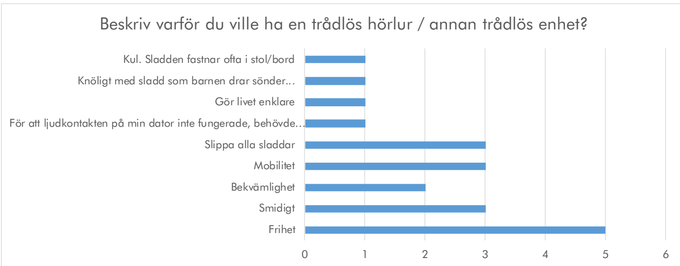


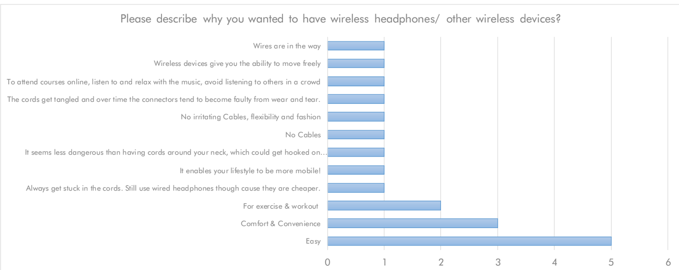


13. When your device is broken, where do you take it for repairing?
I do it myself.
Specialized store.
I send it to the repair service.
I just throw it away and buy a new one.
Other.

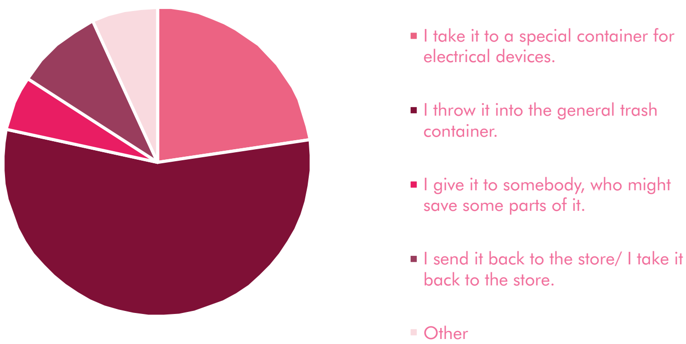


14. Please describe why you wanted to have wireless headphones/ other wireless devices?

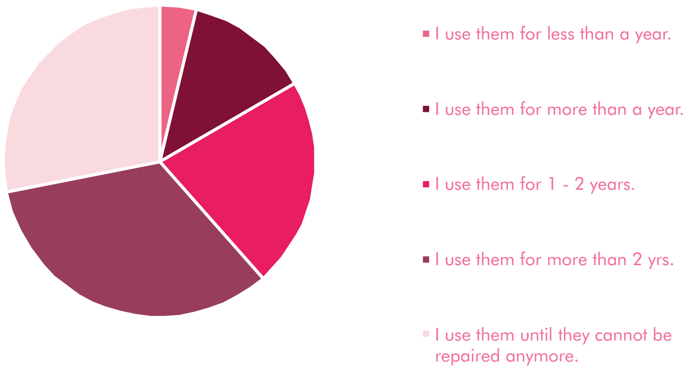




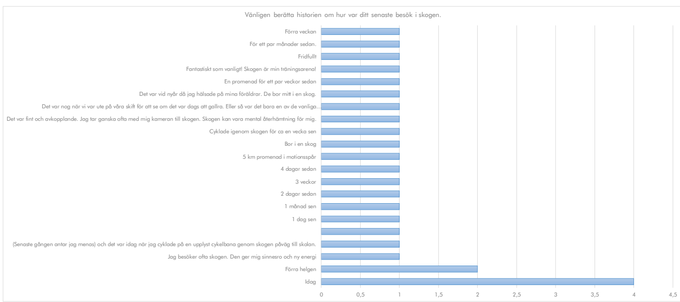
15. Where do you typically dispose of your wireless headphones/ other electronic wireless devices?
Throw it out of the window.
I take it to a special container for electrical devices.
I throw it into the general trash container.
I give it to somebody, who might save some parts of it.
I send it back to the store/ I take it back to the store.
Other.

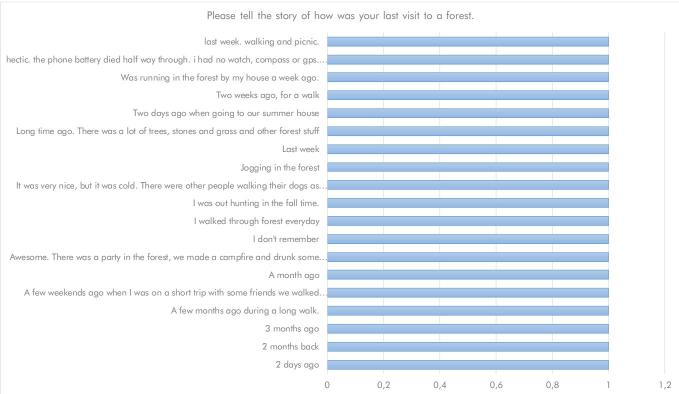


16. For how long do you use your wireless headphones/ other wireless electronic devices?
I use them for a couple of months.
I use them for less than a year.
I use them for more than a year.
I use them for 1 - 2 years.
I use them for 2 yrs or longer.
I used them until they cannot be repaired anymore.

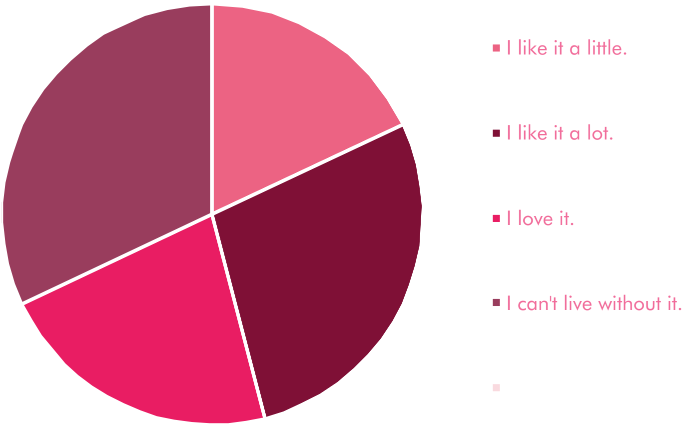


17. Please tell the story of how was your last visit to the forest!



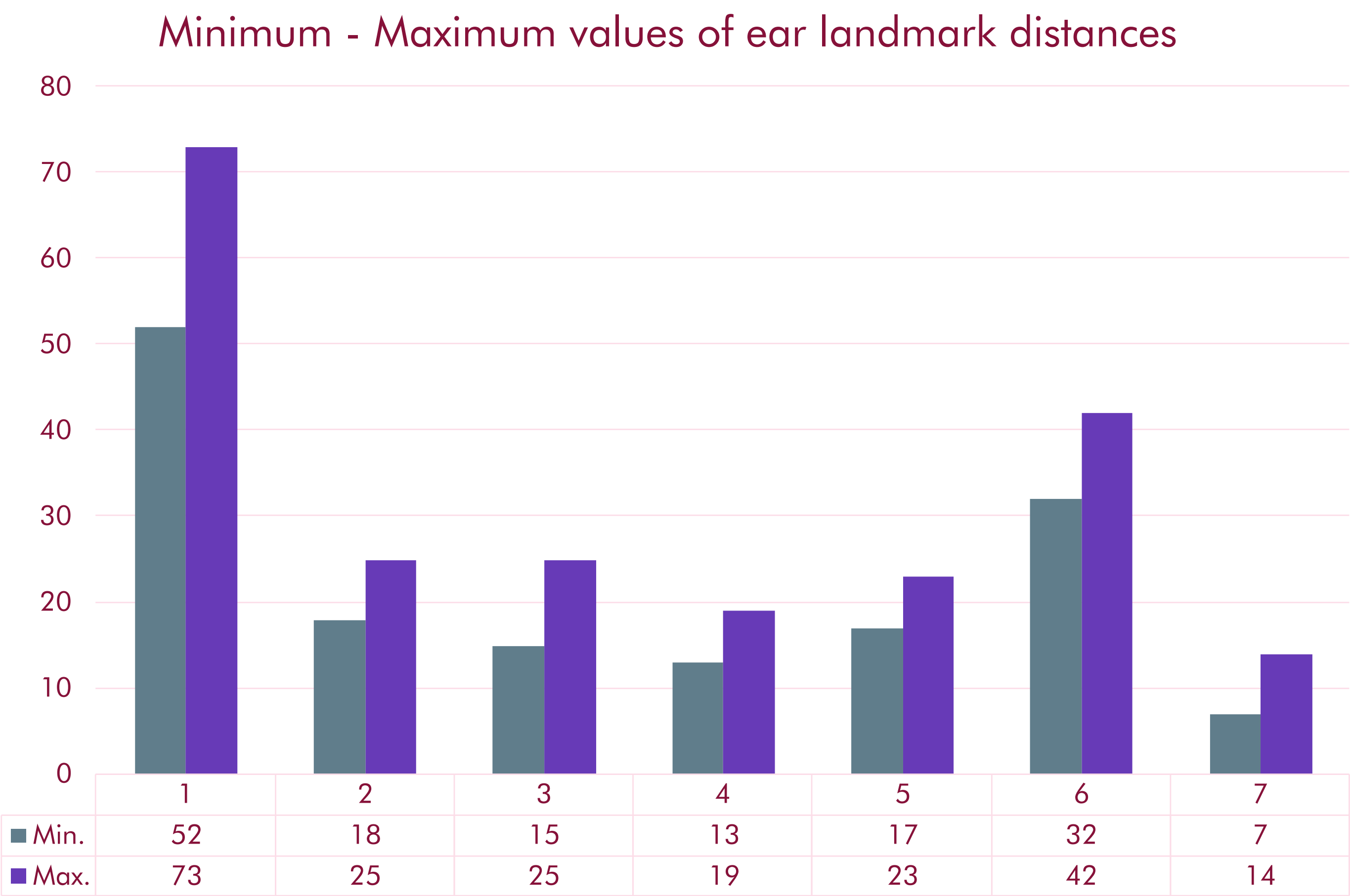


18. How much do you like the forest?
I hate it.
I like it a little.
I like it a lot.
I love it.
I cannot live without it.



Appendix C - Ergonomic analysis

Ear landmark distances (mm)	1	2	3	4	5	6	7	8	Min.
Superior auricle - Inferior auricle	55	52	71	73	59	54	53	57	52
Anterior cymba concha - Posterior concha	23	20	21	24	22	18	25	23	18
Superior cymba concha - Center of concha	22	17	22	23	25	18	15	18	15
Superior cavum concha - Incisura intertragica	18	15	19	19	17	18	13	19	13
Posterior concha - Tragion	17	21	23	22	19	18	18	19	17
Otobasion superius - Posterior auricle	33	34	42	38	36	32	37	36	32
Anterior cymba concha - Superior cavum concha	10	7	12	14	13	9	8	8	7



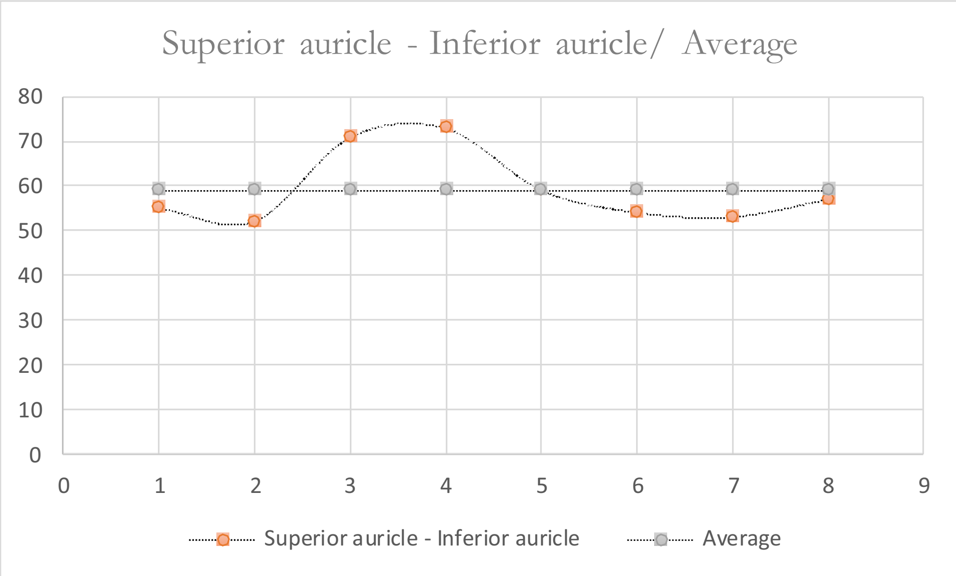


Fig. Superior auricle - Inferior auricle comparison to average distance (mm)

Ear landmark distances (mm)	1	2	3	4	5	6	7	8
Superior auricle - Inferior auricle	55	52	71	73	59	54	53	57
Average	59,25	59,25	59,25	59,25	59,25	59,25	59,25	59,25

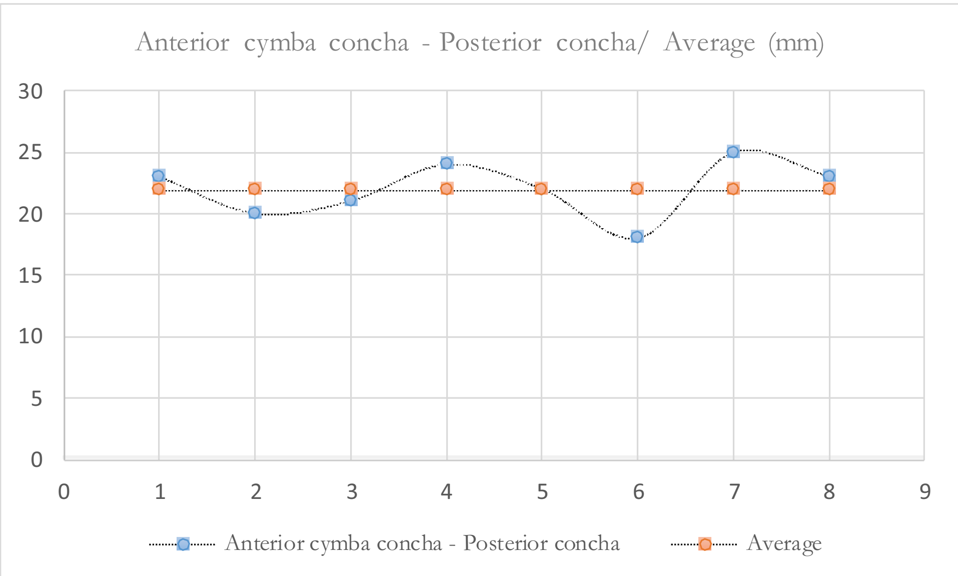
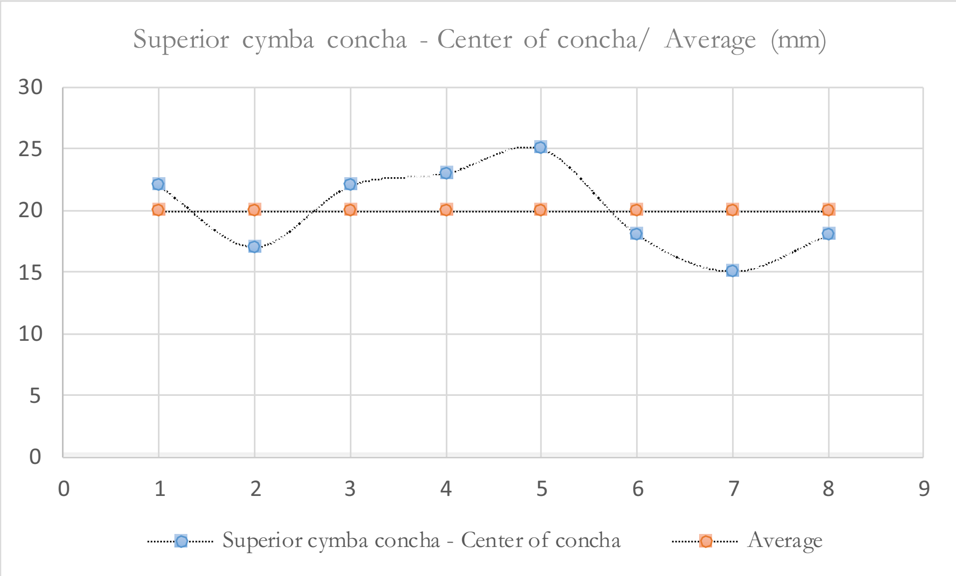


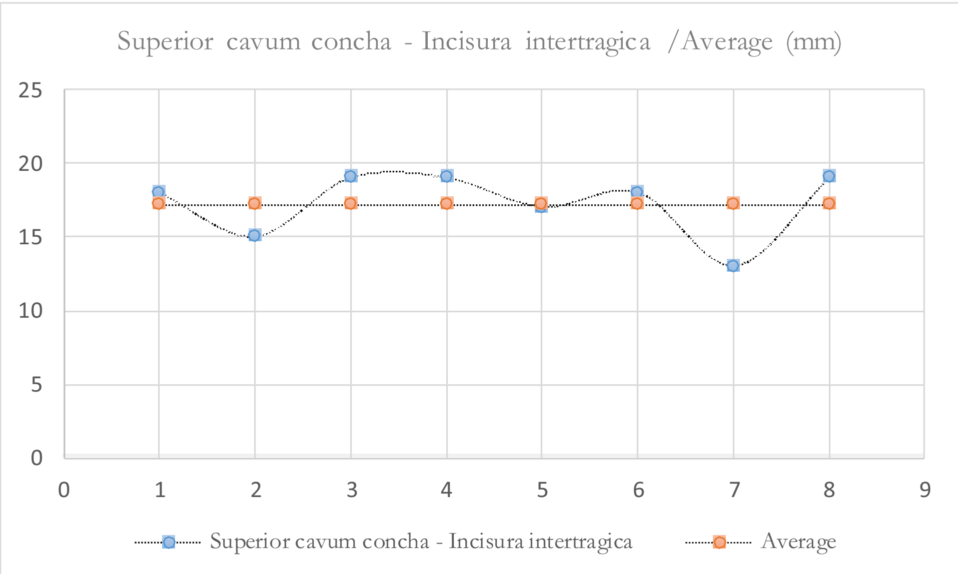
Fig. Anterior cymba concha - Posterior concha comparison to average distance

Ear landmark distances (mm)	1	2	3	4	5	6	7	8
Anterior cymba concha - Posterior concha	23	20	21	24	22	18	25	23
Average	22	22	22	22	22	22	22	22



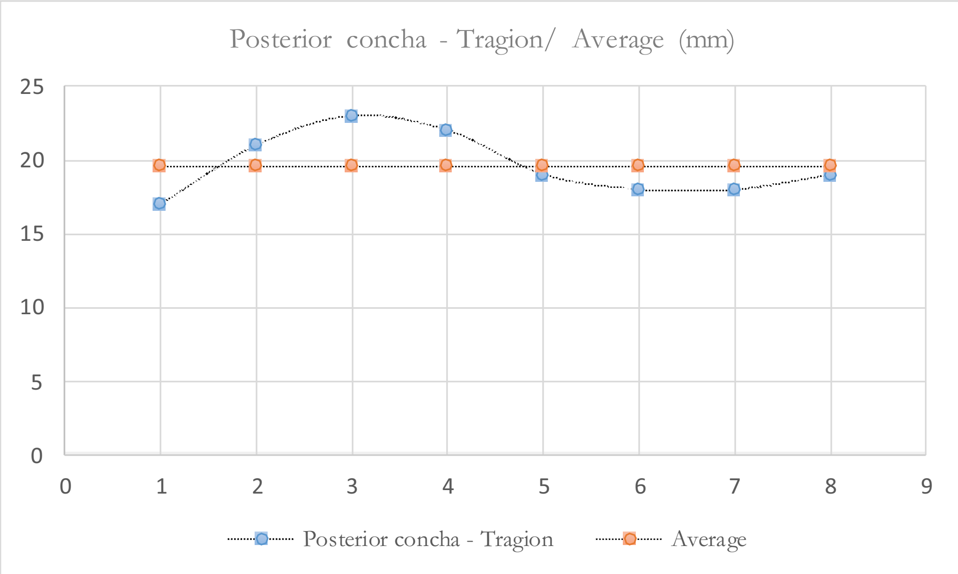
Ear landmark distances (mm)	1	2	3	4	5	6	7	8
Superior cymba concha - Center of concha	22	17	22	23	25	18	15	18
Average	20	20	20	20	20	20	20	20

Fig. Superior cymba concha - center of concha comparison to average distance (mm)



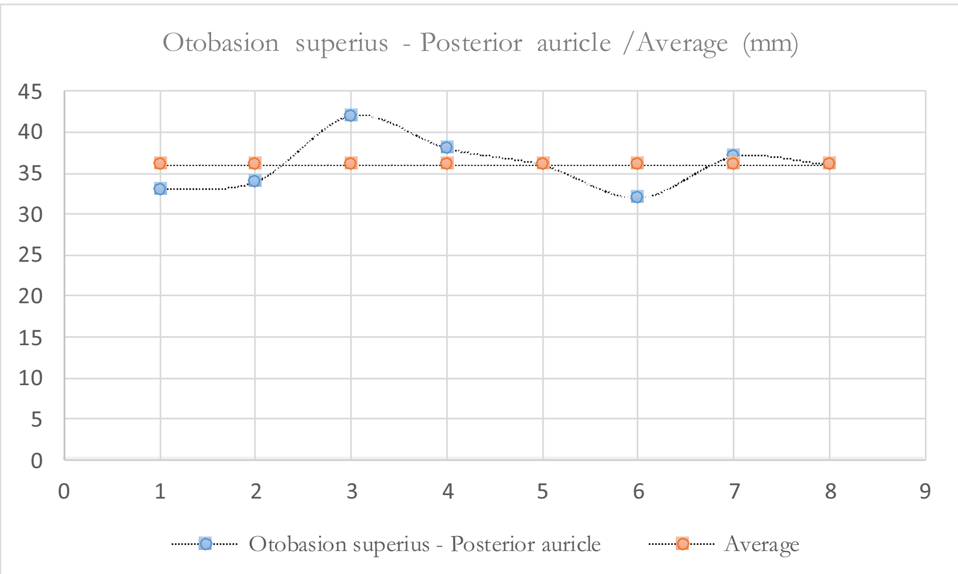
Ear landmark distances (mm)	1	2	3	4	5	6	7	8
Superior cavum concha - Incisura intertragica	18	15	19	19	17	18	13	19
Average	17,25	17,25	17,25	17,25	17,25	17,25	17,25	17,25

Fig. Superior cavum concha - Incisura intertragica comparison to average distance (mm)



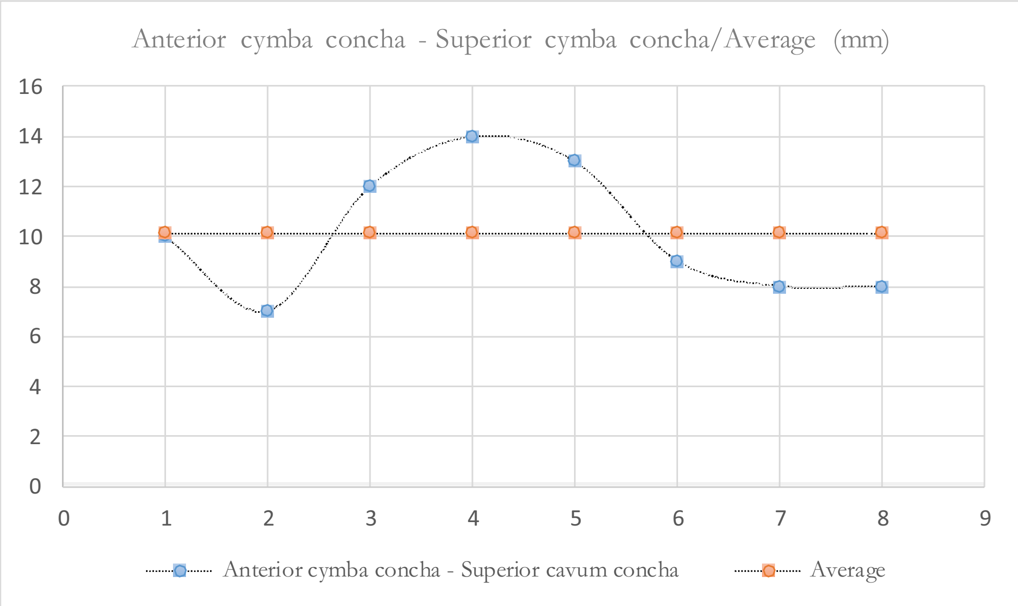
Ear landmark distances (mm)	1	2	3	4	5	6	7	8
Posterior concha - Tragion	17	21	23	22	19	18	18	19
Average	19,63	19,63	19,63	19,63	19,63	19,63	19,63	19,6

Fig. Posterior concha - Tragion comparison to average distance (mm)



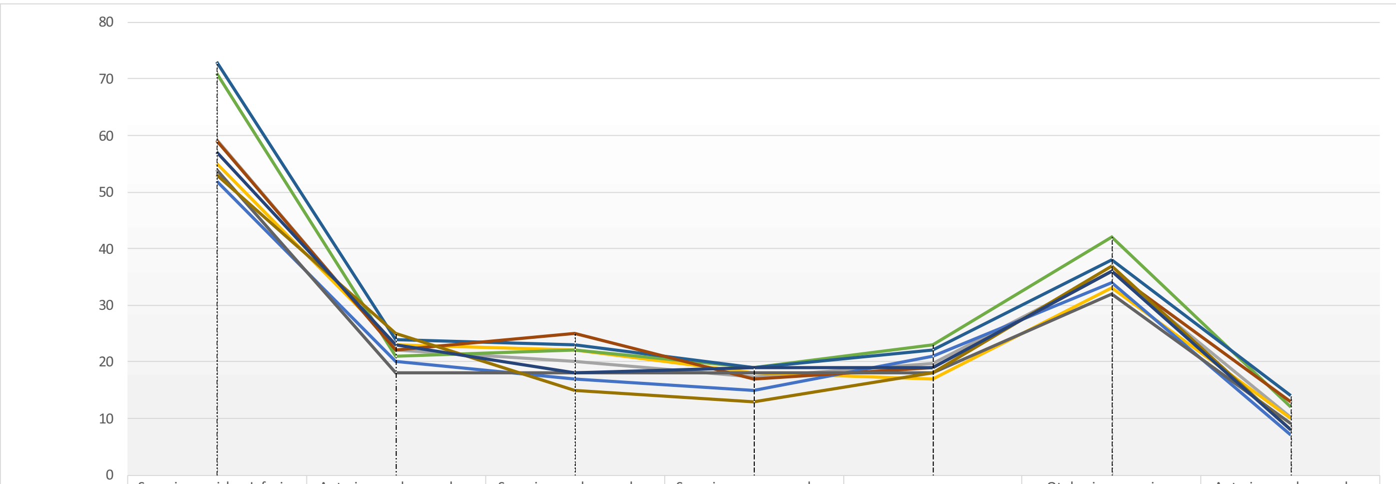
Ear landmark distances (mm)	1	2	3	4	5	6	7	8
Otobasion superius - Posterior auricle	33	34	42	38	36	32	37	36
Average	36	36	36	36	36	36	36	36

Fig. Otobasion superius - Posterior auricle to average distance (mm)



Ear landmark distances (mm)	1	2	3	4	5	6	7	8
Anterior cymba concha - Superior cavum concha	10	7	12	14	13	9	8	8
Average	10,13	10,13	10,13	10,13	10,13	10,13	10,13	10,13

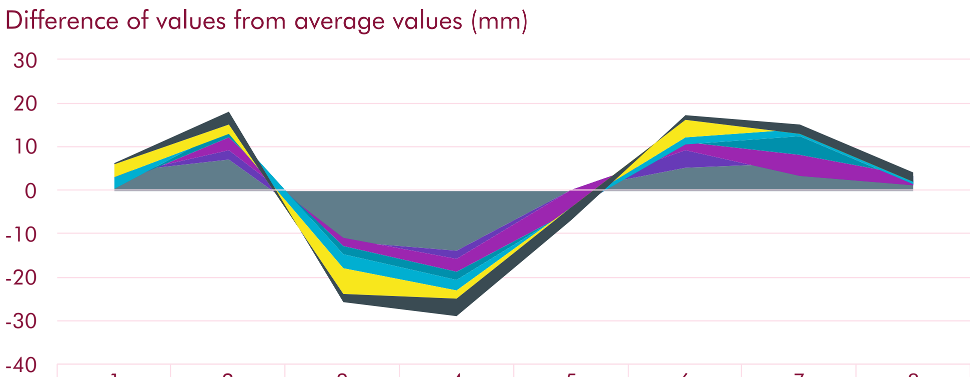
Fig. Anterior cymba concha - Superior cavum concha comparison to average distance (mm)



	Superior auricle - Inferior auricle	Anterior cymba concha - Posterior concha	Superior cymba concha - Center of concha	Superior cavum concha - Incisura intertragica	Posterior concha - Tragion	Otobasion superius - Posterior auricle	Anterior cymba concha - Superior cavum concha
Average	59,25	22	20	17,25	19,625	36	10,125
1	55	23	22	18	17	33	10
2	52	20	17	15	21	34	7
3	71	21	22	19	23	42	12
4	73	24	23	19	22	38	14
5	59	22	25	17	19	36	13
6	54	18	18	18	18	32	9
7	53	25	15	13	18	37	8
8	57	23	18	19	19	36	8

Average 1 2 3 4 5 6 7 8

Fig. Comparative chart - Ear landmark distances /Average/Min./Max.



	1	2	3	4	5	6	7	8
Anterior cymba concha - Superior cavum concha	0,125	3,125	-1,875	-3,875	-2,875	1,125	2,125	2,125
Otobasion superius - Posterior auricle	3	2	-6	-2	0	4	-1	0
Posterior concha - Tragion	2,625	-1,375	-3,375	-2,375	0,625	1,625	1,625	0,625
Superior cavum concha - Incisura intertragica	-0,75	2,25	-1,75	-1,75	0,25	-0,75	4,25	-1,75
Superior cymba concha - Center of concha	-2	3	-2	-3	-5	2	5	2
Anterior cymba concha - Posterior concha	-1	2	1	-2	0	4	-3	-1
Superior auricle - Inferior auricle	4,25	7,25	-11,75	-13,75	0,25	5,25	6,25	2,25

HEAD BREADTH 13

maximum above and behind ears

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	156.0	6.6	145.1	166.8	PeopleSize 1998
	f	147.4	6.3	137.1	157.7	PeopleSize 1998
Brazil	m	150	6	140	160	Pheasant 1996
China	m	157.9	7.0	146.4	169.4	PeopleSize 1998
	f	153.7	7.3	141.7	165.6	PeopleSize 1998
France	m	150	6	140	160	Pheasant 1996
	f	140	5	130	150	Pheasant 1996
Germany	m	156		146	167	DIN 1986
	f	149		138	159	DIN 1986
Italy	m	155		146	165	Masali et al. 1992
	f	148		138	158	Masali et al. 1992
Japan	m	158.0	6.7	147.0	169.0	PeopleSize 1998
	f	153.2	6.2	143.0	163.4	PeopleSize 1998
Poland	m			148	167	PKN 1988
	f			143	162	PKN 1988
Sri Lanka	m	143	11.66	130	153	Abeysekera & Shahnavaz 1987
	f	137	17.32	124	146	Abeysekera & Shahnavaz 1987
Sweden	m	155	6	145	165	Pheasant 1996
	f	145	6	135	155	Pheasant 1996
Netherlands	m	160	6	150	170	Pheasant 1996
	f	150	6	140	160	Pheasant 1996
USA	m	156.4	6.7	145.4	167.5	PeopleSize 1998
	f	148.0	6.8	136.8	159.2	PeopleSize 1998

Definition

Measured horizontally across the head, above and behind the ears, where the head is broadest. Hair is compressed.

Data Sheet 14

HEAD BREADTH 14

just in front of ears

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	143.8	6.3	133.4	154.1	PeopleSize 1998
	f	128.6	6.0	118.8	138.5	PeopleSize 1998
Japan	m	152.8	6.6	142.0	163.6	PeopleSize 1998
	f	143.7	6.1	133.8	153.7	PeopleSize 1998
Sri Lanka	m	130	20.18	118	140	Abeysekera & Shahnavaz 1987
	f	122	12.68	110	131	Abeysekera & Shahnavaz 1987
USA	m	144.2	6.4	133.7	154.7	PeopleSize 1998
	f	129.2	6.5	118.5	139.9	PeopleSize 1998

Definition

Measured horizontally between the tragia (just above the small projection of cartilage, or tragus, which is found just in front of the external opening of the ear).

HEAD CIRCUMFERENCE 15

just above brow ridges

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	575.0	16.8	547.3	602.7	PeopleSize 1998
	f	547.4	15.6	521.7	573.0	PeopleSize 1998
China	m	565.2	17.9	535.7	594.7	PeopleSize 1998
	f	549.5	16.2	522.8	576.3	PeopleSize 1998
Germany	m	573		548	599	DIN 1986
	f	544		520	572	DIN 1986
Japan	m	552.8	16.6	525.5	580.1	PeopleSize 1998
	f	543.8	13.7	521.2	566.4	PeopleSize 1998
Sri Lanka	m	543	18.42	515	570	Abeysekera & Shahnavaz 1987
	f	523	14.61	500	550	Abeysekera & Shahnavaz 1987
USA	m	576.8	17.1	548.6	604.9	PeopleSize 1998
	f	549.7	17.0	521.7	577.6	PeopleSize 1998

Definition

Measured around the maximum circumference of the head, just above the eyebrows at the front and the most protruding portion of the back of the head (the occiput). The hair should be compressed.

HEAD DIAMETER 16

maximum from chin

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	257.2	8.0	244.1	270.3	PeopleSize 1998
	f	236.5	7.3	224.5	248.4	PeopleSize 1998
Sri Lanka	m	239	10.37	222	253	Abeysekera & Shahnavaz 1987
	f	227	14.79	214	241	Abeysekera & Shahnavaz 1987
USA	m	258.0	8.1	244.7	271.3	PeopleSize 1998
	f	237.4	7.9	224.4	250.5	PeopleSize 1998

Definition

Measured obliquely from the bony point of the chin to the crown (vertex) of the head.

Data Sheet 17

HEAD HEIGHT 17

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	228.5	11.3	209.9	247.1	PeopleSize 1998
	f	196.6	11.5	177.7	215.5	PeopleSize 1998
China	m	236.1	14.9	211.5	260.6	PeopleSize 1998
	f	220.6	9.8	204.4	236.8	PeopleSize 1998
Germany	m	228		213	244	DIN 1986
	f	219		195	240	DIN 1986
Japan	f	224.2	8.2	210.7	237.6	PeopleSize 1998
USA	m	229.2	11.5	210.3	248.1	PeopleSize 1998
	f	197.4	12.5	176.8	218.0	PeopleSize 1998

Definition

Measured vertically from the bony tip of the chin to the top of the head.

CORONAL ARC 18

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	350	15	325	375	Pheasant 1990
	f	340	15	315	365	Pheasant 1990
Germany	m	352		328	374	DIN 1986
	f	343		316	362	DIN 1986
Sri Lanka	m	343	23.68	320	370	Abeysekera & Shahnavaz 1987
	f	327	23.50	300	355	Abeysekera & Shahnavaz 1987

Definition

Measured from ear to ear across the crown of the head.

SAGITTAL ARC 19

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	380	18	350	410	Pheasant 1990
	f	350	15	325	375	Pheasant 1990
Germany	m	337		312	356	DIN 1986
	f	332		301	359	DIN 1986

Definition

Measured from the glabella (a point on the forehead between the two brow ridges) to the occiput (back of head) across the crown of the head.

BACK OF HEAD HEIGHT 20

(occiput), sitting

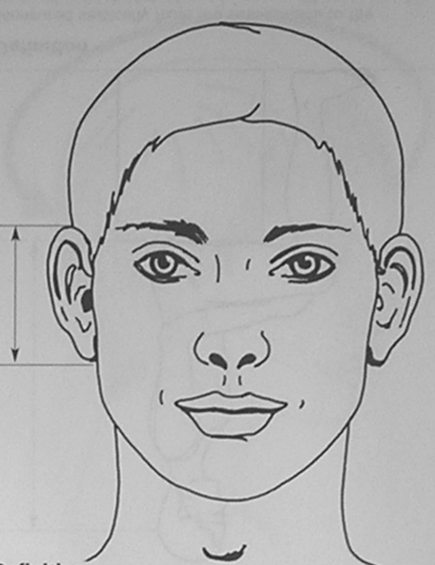
Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	838.2	33.8	782.6	893.8	PeopleSize 1998
	f	766.7	34.3	710.4	823.1	PeopleSize 1998
USA	m	840.7	34.3	784.3	897.2	PeopleSize 1998
	f	769.9	37.3	708.5	831.3	PeopleSize 1998

Definition

Measured vertically from the seat surface to the protruding back of the head (occiput). The person sits erect, looking straight ahead, hands in lap and with the feet either unsupported or supported at a level that ensures the thighs are horizontal.

EAR LENGTH 21

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	63.9	4.5	56.6	71.3	PeopleSize 1998
	f	57.4	3.6	51.4	63.3	PeopleSize 1998
Japan	m	64	3.3	53.5	73	Hoshi & Kouchi 1978
	f	61	3.3	51.5	71.5	Hoshi et al. 1980
Sri Lanka	m	59	0.24	52	67	Abeysekera & Shahnavaz 1987
	f	55	5.38	47	62	Abeysekera & Shahnavaz 1987
USA	m	64.1	4.5	56.7	71.6	PeopleSize 1998
	f	57.6	4.0	51.1	64.1	PeopleSize 1998



Definition

Measured from the upper border of the ear to the lower border of the lobe of the ear. The measurement is maximal.

EAR BREADTH 22

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	33.3	2.0	30.0	36.6	PeopleSize 1998
	f	30.7	1.9	27.6	33.8	PeopleSize 1998
Japan	m	36	2.1	31.5	41	Hoshi & Kouchi 1978
	f	34.5	1.9	29	40	Hoshi et al. 1980
Sri Lanka	m	29	3.16	25	34	Abeysekera & Shahnavaz 1987
	f	28	3.79	23	32	Abeysekera & Shahnavaz 1987
USA	m	33.4	2.0	30.1	36.7	PeopleSize 1998
	f	30.9	2.0	27.5	34.2	PeopleSize 1998

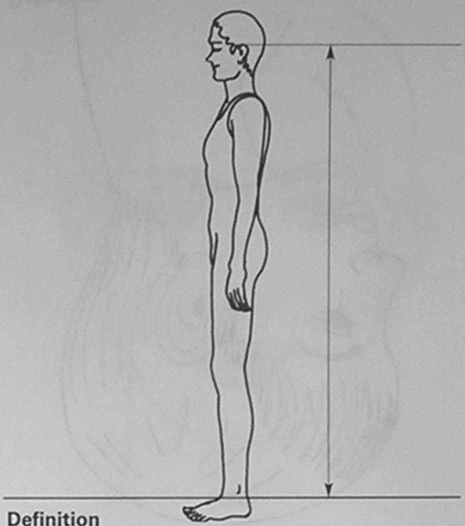
Definition

Measured across the ear from just above the small projection of cartilage (tragus), found in front of the external opening of the ear, to the rearmost point.

EAR HEIGHT 23

(tragion), standing

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	1631.7	66.6	1522.2	1741.2	PeopleSize 1998
	f	1496.3	63.5	1391.8	1600.7	PeopleSize 1998
Japan	m	1568.2	54.8	1478.0	1658.3	PeopleSize 1998
	f	1438.9	50.2	1356.4	1521.4	PeopleSize 1998
Sri Lanka	m	1507	60.46	1412	1607	Abeysekera & Shahnavaz 1987
	f	1397	57.69	1304	1490	Abeysekera & Shahnavaz 1987
USA	m	1636.6	67.6	1525.4	1747.8	PeopleSize 1998
	f	1502.4	69.2	1388.6	1616.2	PeopleSize 1998



Definition

Measured vertically from the floor to just above the small projection of cartilage (tragus), found just in front of the external opening of the ear. The person stands erect, arms hanging loosely at the side.

EAR HEIGHT 24

(tragion), sitting

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	790.5	35.9	731.5	849.5	PeopleSize 1998
	f	732.2	32.7	678.5	785.9	PeopleSize 1998
Japan	m	774.6	29.5	726.0	823.2	PeopleSize 1998
	f	721.2	25.8	678.7	763.6	PeopleSize 1998
USA	m	792.9	36.5	732.9	852.8	PeopleSize 1998
	f	735.2	35.6	676.7	793.7	PeopleSize 1998

Definition

Measured vertically from the seat surface to just above the small projection of cartilage (tragus), found just in front of the external opening of the ear.
The person sits erect, looking straight ahead, hands in lap and thighs horizontal.

EAR TO BACK OF HEAD 25

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	98.5	7.6	86.0	111.0	PeopleSize 1998
	f	97.0	8.5	83.0	111.0	PeopleSize 1998
Sri Lanka	m	97	13.91	77	118	Abeysekera & Shahnavaz 1987
	f	94	13.41	74	117	Abeysekera & Shahnavaz 1987
USA	m	98.8	7.7	86.1	111.5	PeopleSize 1998
	f	97.4	9.3	82.2	112.6	PeopleSize 1998

Definition

Measured horizontally from just above the small projection of cartilage (tragus), found just in front of the external opening of the ear, to the most protruding part of the back of the head (the occiput).

EAR TO TOP OF HEAD 26

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	130.4	8.5	116.5	144.4	PeopleSize 1998
	f	121.3	7.5	108.9	133.6	PeopleSize 1998
Sri Lanka	m	134	21.52	113	153	Abeysekera & Shahnavaz 1987
	f	127	13.99	106	146	Abeysekera & Shahnavaz 1987
USA	m	130.8	8.6	116.6	145.0	PeopleSize 1998
	f	121.8	8.2	108.3	135.2	PeopleSize 1998

Definition

Measured vertically from the tragion (just above the small projection of cartilage, or tragus, which is found just in front of the external opening of the ear) to the top of the head.

FACE LENGTH 27

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	118.8	7.9	105.9	131.7	PeopleSize 1998
	f	105.9	6.4	95.3	116.5	PeopleSize 1998
China	m	115.0	7.0	103.6	126.5	PeopleSize 1998
	f	110.3	5.9	100.6	120.0	PeopleSize 1998
Japan	m	122.5	7.1	110.8	134.2	PeopleSize 1998
	f	112.8	5.6	103.6	122.1	PeopleSize 1998
Sri Lanka	m	120	17.53	97	144	Abeysekera & Shahnavaz 1987
	f	113	16.10	89	135	Abeysekera & Shahnavaz 1987
USA	m	119.1	8.0	106.0	132.3	PeopleSize 1998
	f	106.4	7.0	94.8	117.9	PeopleSize 1998

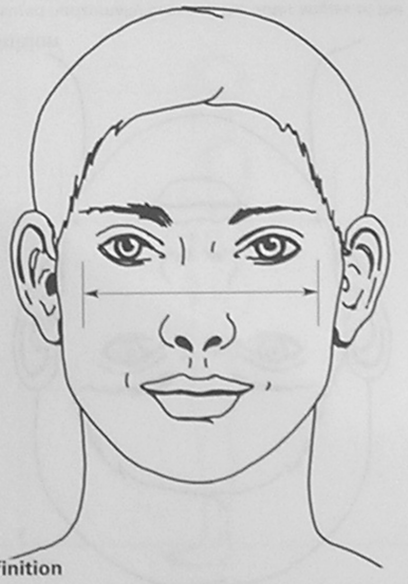
Definition

Measured vertically from the bony tip of the chin to the depression (the sellion) at the top of the nose, below the brow ridge.

FACE BREADTH 28

across cheekbones

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	140.7	5.7	131.3	150.0	PeopleSize 1998
	f	128.9	6.4	118.3	139.5	PeopleSize 1998
Japan	m	144	5.1	131	156	Hoshi & Kouchi 1978
	f	137.5	4.8	127	150	Hoshi et al. 1980
Sri Lanka	m	102	8.32	87	115	Abeysekera & Shahnavaz 1987
	f	99	9.33	85	114	Abeysekera & Shahnavaz 1987
USA	m	141.1	5.8	131.6	150.6	PeopleSize 1998
	f	129.5	7.0	117.9	141.0	PeopleSize 1998



Definition

Measured horizontally between the broadest portions of the cheekbones (zygomatic bones), between the eyes and the ears.

FACE LENGTH 27

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	118.8	7.9	105.9	131.7	PeopleSize 1998
	f	105.9	6.4	95.3	116.5	PeopleSize 1998
China	m	115.0	7.0	103.6	126.5	PeopleSize 1998
	f	110.3	5.9	100.6	120.0	PeopleSize 1998
Japan	m	122.5	7.1	110.8	134.2	PeopleSize 1998
	f	112.8	5.6	103.6	122.1	PeopleSize 1998
Sri Lanka	m	120	17.53	97	144	Abeysekera & Shahnavaz 1987
	f	113	16.10	89	135	Abeysekera & Shahnavaz 1987
USA	m	119.1	8.0	106.0	132.3	PeopleSize 1998
	f	106.4	7.0	94.8	117.9	PeopleSize 1998

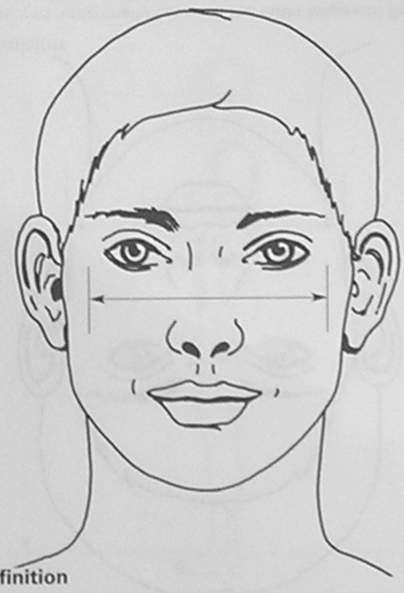
Definition

Measured vertically from the bony tip of the chin to the depression (the sellion) at the top of the nose, below the brow ridge.

FACE BREADTH 28

across cheekbones

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	140.7	5.7	131.3	150.0	PeopleSize 1998
	f	128.9	6.4	118.3	139.5	PeopleSize 1998
Japan	m	144	5.1	131	156	Hoshi & Kouchi 1978
	f	137.5	4.8	127	150	Hoshi et al. 1980
Sri Lanka	m	102	8.32	87	115	Abeysekera & Shahnavaz 1987
	f	99	9.33	85	114	Abeysekera & Shahnavaz 1987
USA	m	141.1	5.8	131.6	150.6	PeopleSize 1998
	f	129.5	7.0	117.9	141.0	PeopleSize 1998



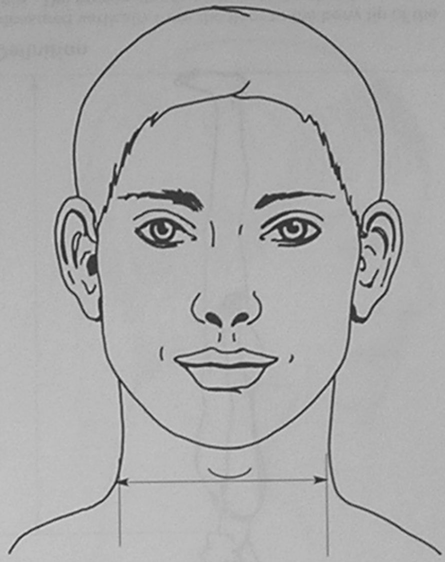
Definition

Measured horizontally between the broadest portions of the cheekbones (zygomatic bones), between the eyes and the ears.

NECK BREADTH 47

just below level of Adam's apple

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	143.6	13.9	120.7	166.5	PeopleSize 1998
	f	124.8	12.4	104.3	145.2	PeopleSize 1998
USA	m	147.1	17.2	118.8	175.4	PeopleSize 1998
	f	128.1	18.4	97.8	158.3	PeopleSize 1998



Definition

Measured across the neck, just below the level of the small protrusion that is the Adam's apple (it tends to be more visible in men than women). The minimal width is measured, perpendicular to the long axis of the neck.

NECK CIRCUMFERENCE 48

just below the level of Adam's apple

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	398.9	25.7	356.7	441.1	PeopleSize 1998
	f	372.8	26.4	329.4	416.2	PeopleSize 1998
Italy	m	403		370	450	Masali et al. 1992
	f	355		320	400	Masali et al. 1992
Sri Lanka	m	342	22.28	310	380	Abeysekera & Shahnavaz 1987
	f	295	19.67	265	330	Abeysekera & Shahnavaz 1987
USA	m	409.0	32.6	355.4	462.7	PeopleSize 1998
	f	386.4	45.0	312.3	460.4	PeopleSize 1998

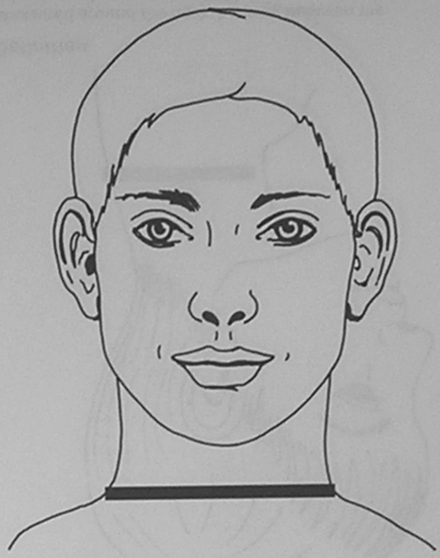
Definition

Measured around the neck, halfway between the Adam's apple and the top of the breastbone (sternum). The tape should pass over the prominent neck vertebra (cervical 7). Pressure on the tape should be minimal to avoid discomfort.

NECK CIRCUMFERENCE 49

around the base of the neck

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	443.6	32.6	390.0	497.2	PeopleSize 1998
	f	414.0	24.9	373.0	455.0	PeopleSize 1998
USA	m	456.1	42.2	386.7	525.5	PeopleSize 1998
	f	428.6	41.8	359.9	497.4	PeopleSize 1998



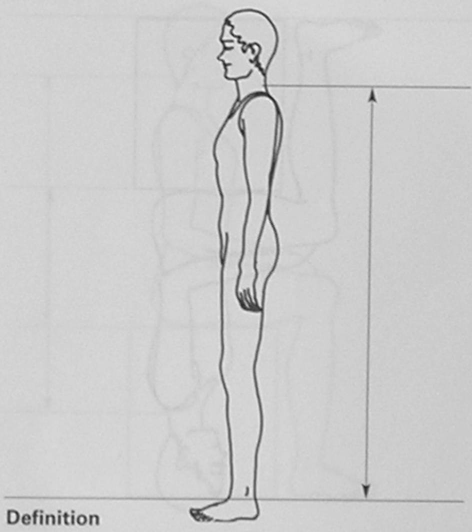
Definition

Measured around the base of the neck, the tape should pass over the prominent neck vertebra (cervical 7) at the back, the junction of the neck and shoulders at the sides and 1cm above the junction of the junction of the clavicles at the front.

HEIGHT OF PROMINENT NECK VERTEBRAE (C7) 50

standing

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	1501.1	65.1	1394.0	1608.3	PeopleSize 1998
	f	1387.4	59.8	1289.1	1485.8	PeopleSize 1998
Italy	m	1484		1385	1590	Masali et al. 1992
	f	1374		1276	1462	Masali et al. 1992
USA	m	1505.7	66.2	1396.8	1614.5	PeopleSize 1998
	f	1393.1	65.1	1286.0	1500.3	PeopleSize 1998



Definition

Measured vertically from the floor to the level of the prominent neck vertebra (cervical 7). The person stands erect, looking ahead, the arms hanging loosely at the sides.

HEIGHT OF PROMINENT NECK VERTEBRA (C7) 51

sitting

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	673.4	39.9	607.7	739.1	PeopleSize 1998
	f	624.5	29.1	576.7	672.4	PeopleSize 1998
Italy	m	653		601	710	Masali et al. 1992
	f	632		574	672	Masali et al. 1992
USA	m	675.4	40.5	608.7	742.1	PeopleSize 1998
	f	627.1	31.7	575.0	679.2	PeopleSize 1998

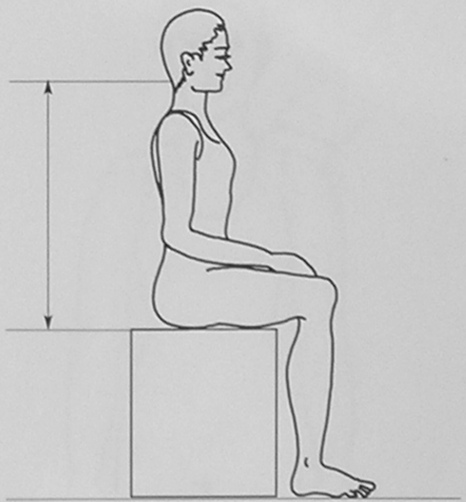
Definition

Measured vertically from the seat surface to the prominent neck vertebra (cervical 7). The person sits erect, looking straight ahead, hands in lap. The feet are either unsupported or supported at a level that ensures the thighs are horizontal.

NAPE OF NECK HEIGHT 52

sitting

Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	697.8	34.2	641.6	754.1	PeopleSize 1998
	f	640.3	31.6	588.2	692.3	PeopleSize 1998
USA	m	700.0	34.7	642.8	757.1	PeopleSize 1998
	f	642.9	34.4	586.2	699.6	PeopleSize 1998



Definition

Measured vertically from the seat surface to the nape (junction between spine and skull). The person sits erect, looking straight ahead, hands in lap.
The feet are either unsupported or supported at a level that ensures the thighs are horizontal.

Appendix D - Laboratory work

Solution-casting production technique - Films

1. Check ingredients

Ingredients	Measured weight (g)
CNF	3,594 g
PEDOT:PSS	16,4759 g
glycerol	0,5823 g
water	50 g

2. First the ingredients are weighed using a digital scale in the laboratory.

CNF Th 2,5 % Batch nr.:362
PEDOT:PSS (Clevios PH 1000, Batch nr.:Charge9001300458, Net.:1,0 kg = 1,0 L)
Glycerol 1/5
DI Water

3. The ingredients are mixed with UltraTurrax mixer under a fume hood.
- first the ingredients are mixed for 5 min using 24000 rpm
- after the ingredients are mixed for additional 5 min using blue colour code

(The ingredients are mixed for overall 10 min using UltraTurrax.)

4. The solution is cleared of air bubbles.

5. The solution is poured into a Petri dish.

6. The Petri dish containing the solution is put inside a dryer.

Fig. 4.3.1 Innventia AB (2017) "Digital scale in the laboratory" [jpg]. Stockholm

Fig.4.3.2 Innventia AB (2017) "UltraTurrax mixer" [jpg]. Stockholm.

Fig.4.3.3 Innventia AB "PEDOT:PSS solution" [jpg]. Stockholm

Fig.4.3.4 Innventia AB (2017) "Ultrasound machine" [jpg]. Stockholm

Freeze-linking production technique - Aerogels

1. Check ingredients

CNF Th 2,5 % Batch nr.:362
Natriummetaperjodat ($NaIO_4$) Art.6597 446K4787697 MERCK
DI Water

2. First the ingredients are weighed using a digital scale in the laboratory.

Ingredients	Measured weight (g)
CNF	28,1205 g
$NaIO_4$	0,6442 g
DI water	22,0568 g

Fig. 4.3.5-11 Innventia AB (2017)
"Process of thawing and solvent-exchanging NFC aerogels" [jpg]. Stockholm.

3. The ingredients are mixed with UltraTurrax mixer under a fume hood.
- first the ingredients are mixed for 1 min using 9500 rpm (green code)
- after the first minute the ingredients are stirred manually to make the solution as homogenous as possible.)
- after the ingredients are mixed for 1 min using 9500 rpm
- followed by manual stirring
- after the ingredients are mixed for 2 min using 9500 rpm
- manual stirring
- after ingredients are mixed using a slightly elevated speed ≈10000 rpm
- manual mixing with a spoon
- the ingredients are mixed with a slightly elevated speed ≈10100 rpm

(The ingredients are mixed for overall ≈5 min using UltraTurrax.)

4. The solution is poured into three plastic lids.

5. All of the lids are placed under „dark" for 60 min.

6. After an hour two of the plastics lids containing the solution are placed in the freezer for 24 hr. The other two remain under „dark" conditions.

7. After 24 hr has passed the two plastic lids, which were in the freezer are taken out and thawed for ≈ 30 min.

8. The aerogels are put into ethanol and acetone for ≈ 2 * 30 min. each.

First experiment - *PEDOT:PSS X NFC aerogel* **- Photo diary**

Fig. Anna Póka (2017) *Mold tools taken out of freezer* [jpg]

Fig. Anna Póka (2017) *Mold tools after 30 min thawing* [jpg]

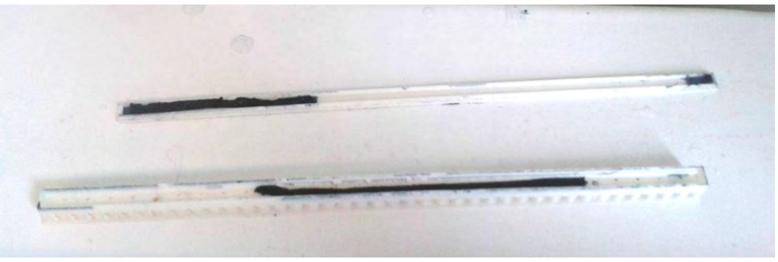


Fig. Anna Póka (2017) *Long mold tool after thawing* [jpg]

Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels in ethanol* [jpg]

Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels in acetone*[jpg]

Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels* after processing [jpg]

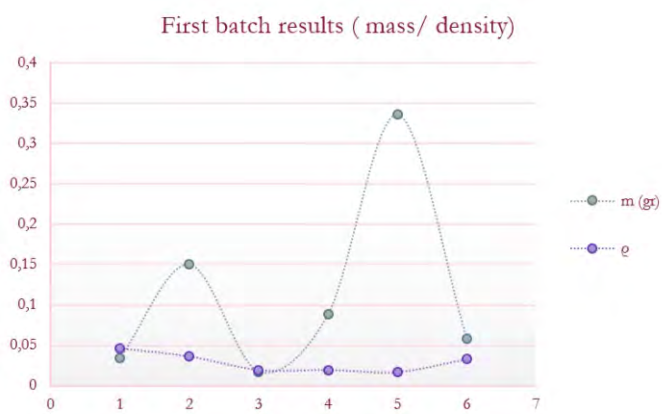


Fig. Anna Póka (2017) *Mass/ density results first experiment* [png] Stockholm

Second experiment - *PEDOT:PSS X NFC aerogel* **- Photo diary**

Fig. Anna Póka (2017) *Mold tools taken out of freezer* [jpg]

Fig. Anna Póka (2017) *Mold tools being water-thawed* [jpg]

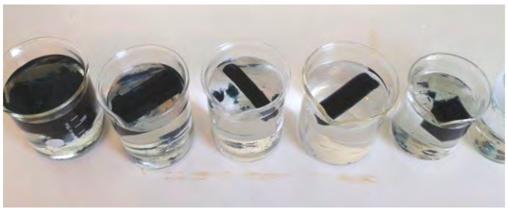


Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels in ethanol* [jpg]

Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels in acetone*[jpg]

Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels* after processing [jpg]

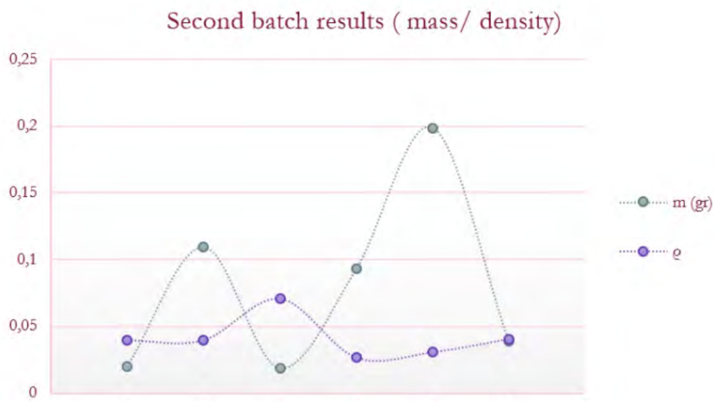
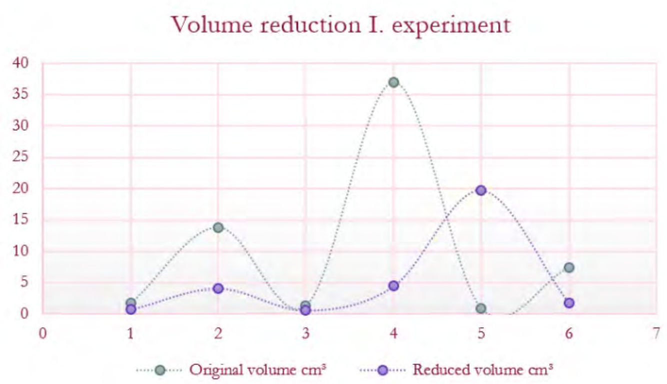


Fig. Anna Póka (2017) *Mass/ density results second experiment* [png] Stockholm



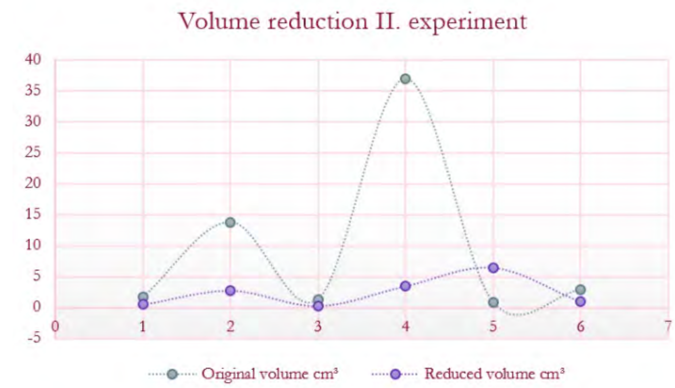


Fig. Anna Póka (2017) *Volume reduction of samples I. & II. experiment* [png] Stockholm

	a	b	c	d	e	f
m (gr)	**0,0341**	**0,15**	**0,0176**	**0,0884**	**0,3357**	**0,0584**
ϱ $\frac{g}{cm^3}$	**0,0467**	**0,0366**	**0,0307**	**0,0196**	**0,0169**	**0,0331**

Fig. Anna Póka (2017) *First experiment measurements* [png] Stockholm

	a	b	c	d	e	f
m (gr)	**0,0204**	**0,1096**	**0,0191**	**0,0932**	**0,1987**	**0,0389**
ϱ $\frac{g}{cm^3}$	**0,0398**	**0,0399**	**0,0709**	**0,0269**	**0,0309**	**0,0408**

Fig. Anna Póka (2017) *Second experiment measurements* [png] Stockholm

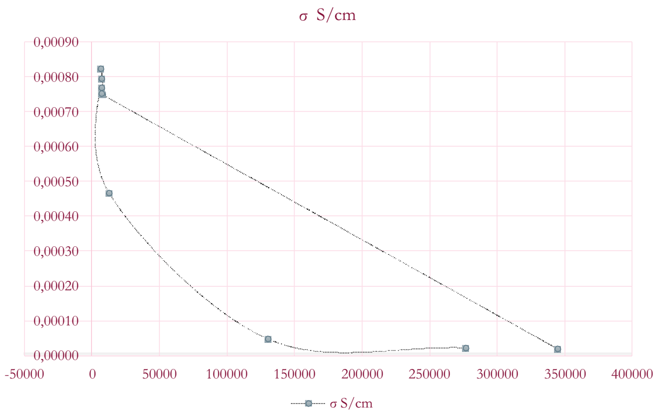


Fig. Anna Póka (2017) *Conductivity measurements using samples from first experiment* [png] Stockholm

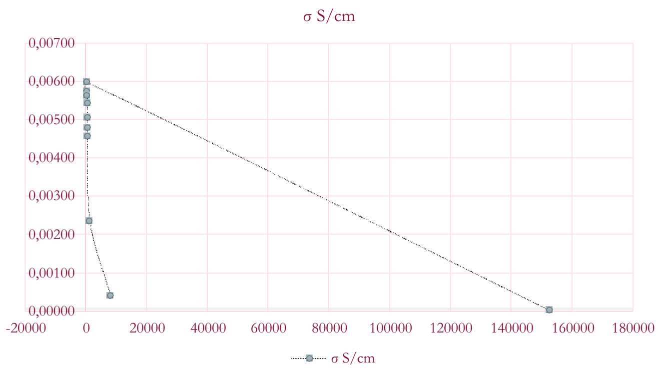


Fig. Anna Póka (2017) *Conductivity measurements using samples from second experiment* [png] Stockholm

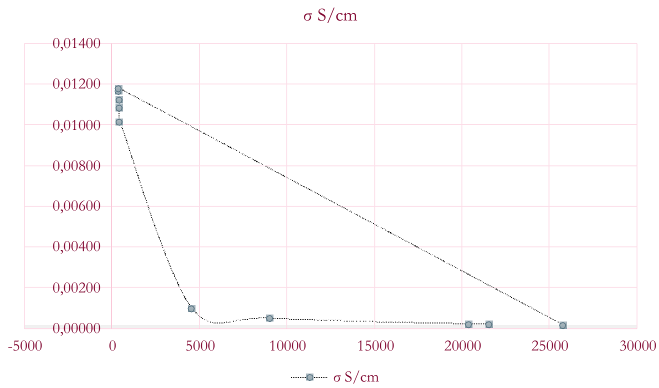


Fig. Anna Póka (2017) *Conductivity measurements using samples from third experiment* [png] Stockholm

Third experiment - *PEDOT:PSS X NFC aerogel* **- Photo diary**

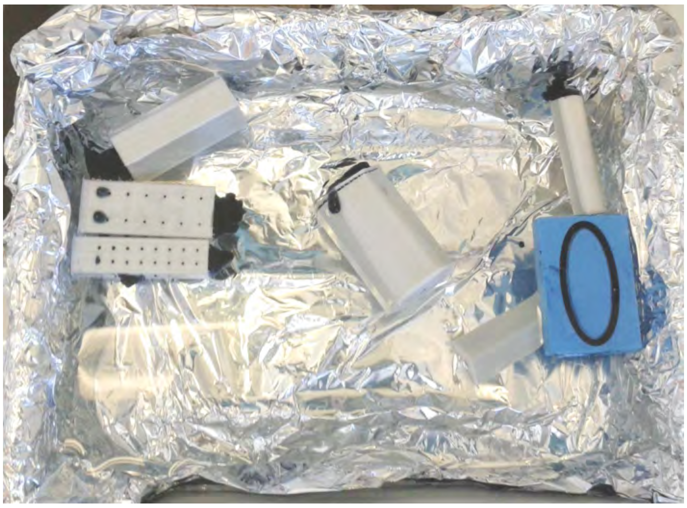


Fig. Anna Póka (2017) *Mold tools being water-thawed* [jpg]

Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels in ethanol* [jpg]

Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels in acetone*[jpg]

Fig. Anna Póka (2017) *PEDOT :PSS x NFC gels* after processing [jpg]