Haptic aesthetics: optimising the feel of a set of headphones

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Preface

As an industrial designer in the making, I have always tried to make things as visually beautiful as possible, nice renders, interesting layouts, good photos (such as in this report). Encountering and working on the topic of haptic aesthetics has made me, and dare I say some around me, feel the objects in my environment differently. I wish to keep this element in my future designs and daily life attitude. This thesis is my attempt to make something feel beautiful, keeping the haptic sense at the center of the design process.

The project has brought me closer to designing for the pure aesthetic pleasure of the senses, and the subtleties that this implies, as well as diving deeper into the field of product experience, an interest developed during the masters, at TU Delft. Its exploratory nature has both allowed me to take any direction I wished, with full creativity, and been the source of many design insecurities, and one of the biggest challenges of the project.

I have to thank my supervisors for their support all the way from the beginning, when developing the topic of the project.

Thank you Gijs for sparking the interest of haptics in me, and introducing me to this very curious world, where everyone I meet seems to be extremely passionate about this very topic (including me now). Also for your biweekly guidance, essential for me not to get lost in a maze of my own thoughts.

And thank you Paul, first of all for getting me a lovely client to work with, and give purpose and direction to my project. But also, the product experience and aesthetic courses during the masters have shaped my path to focus on product experience, finally finding a tad of an identity as a designer.

And Francien, Christian and Jermo, I couldn't have asked for a better client, so supportive and encouraging of my (sometimes crazy) ideas, it was great working with you (and freezing at the Christmas market).

Finally, to my personal chef, who cooked so many meals for me to support my creative process, and the Coffee xxx group, a lot of coffees, a lot of help and just general good energy that made me want to go to the faculty every day. Special thanks to Sandero, for sitting next to me hearing me rant.

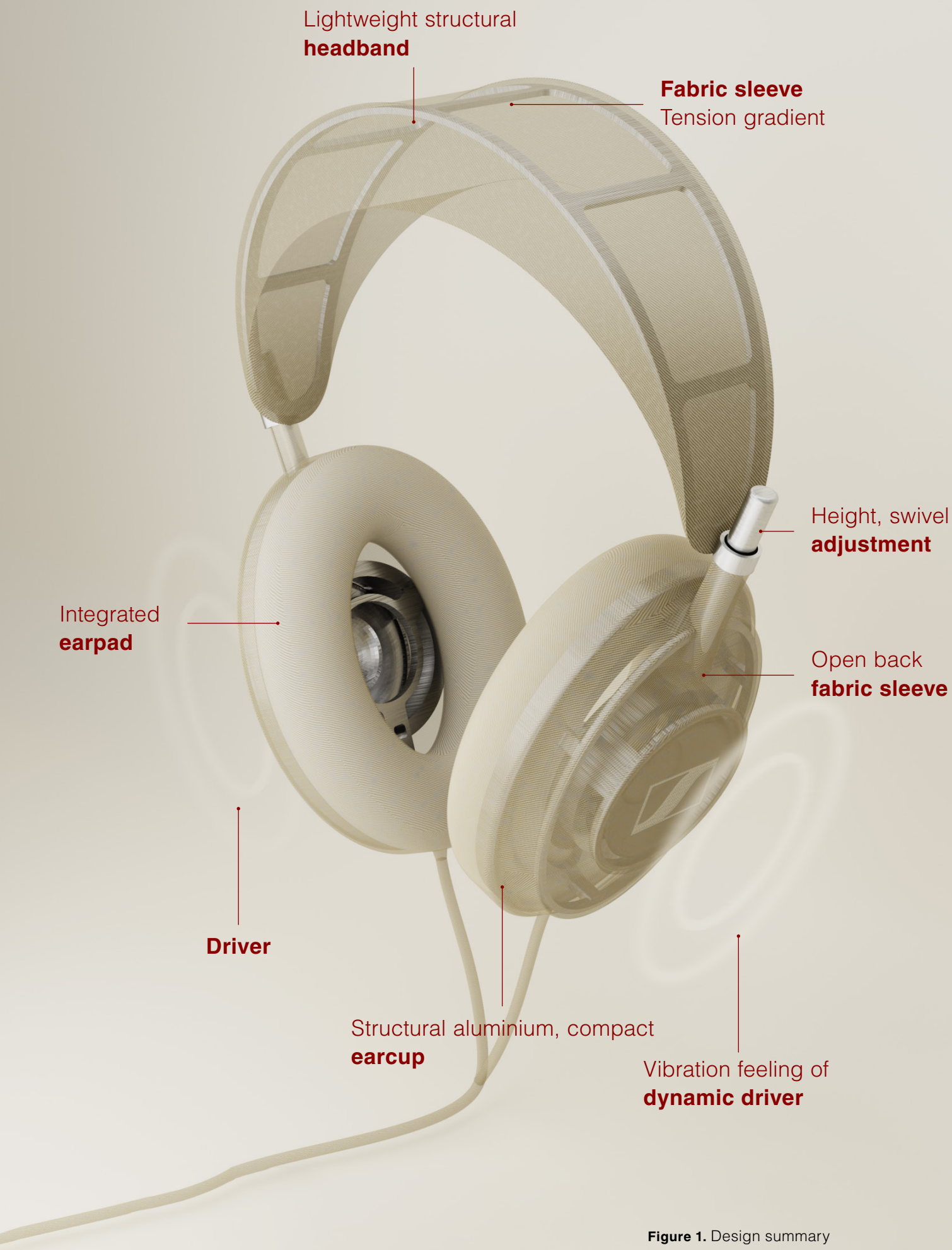


Figure 1. Design summary

Executive summary

The Tensile headphone developed in this thesis acts as a concept headphone for Sennheiser, to showcase new ideas of haptic aesthetic headphones and explore innovative directions. Haptics being the sense of touch, body movement and awareness of it (kinaesthetics), and aesthetics, the qualities of a design which are pleasing to our senses.

It is a redesign of the HD6xx line, which is a staple of the Sennheiser audiophile family, a classic yet old-fashioned design from the late 90s.

The resulting headphone features an aluminium skeleton which holds the driver (component which produces the sound), and which is covered by a tensed fabric. The overall impression is that of a lightweight, airy, open headphone, that encourages actively interacting with the fabric, the structure and the driver. For the design details, see Figure 1. The project as a whole followed the Research through Design approach. That is, the design detailing of the Tensile headphone was used as a medium to gain knowledge about how aesthetic theories for product design (usually developed for the visual sense), are applicable to the haptic sense.

This was the initial driving force of the project, as the importance of the haptic sense in design has been neglected, which is reflected in the lack of haptic aesthetic theory, and which results in products with lower sensorial value.

It was found that the researched aesthetic theories (unity - variety and novelty - typicality) can be applied to some extent to the haptic senses, with some factors to be considered. The RtD also helped understand how to better design for haptic aesthetics in headphones, but also expanding to other product categories.

There were three main design activities that led to these findings. An exploratory session with four groups of design students helped guide the design process to a haptically novel outcome. Once the design was completed, an empirical test was conducted on one aesthetic principle, testing iterations of the design. The chosen iteration was incorporated into a final design with which the second aesthetic principle was tested in a qualitative study with audiophiles (sound and audio gadget enthusiasts).

Glossary

• Haptic perception: process of perceiving objects through touch.

It involves cutaneous perception (skin sensations), kinaesthetic (body motion) and proprioception (body awareness of movements).

• Active touch: the subject engages with the object. It involves the cutaneous, kinaesthetic and proprioceptive senses.

• Passive touch: the subject is touched by the object. It involves the cutaneous sense.

• Aesthetics: the pleasure derived in the senses from processing an object for its own sake.

• Haptic aesthetics: the pleasure derived from engaging with an object through the haptic sense.

• Audiophile: users fascinated by audio quality and the equipment for it.

• Audiophile headphone: designed for audiophiles. Without Bluetooth or ANC.

• Open back headphones: with openings on the earcup to create a more natural sound.

• Transducer / driver: speaker element in the headphone that creates pressure waves (sound).

• CNC weaving and knitting: computerised automated weaving or knitting process.

Acronyms

• UiV: unity in variety. An aesthetic principle used as one of the guiding theories of this thesis.

• MAYA: Most Advanced Yet Acceptable. Design principle by Raymond Loewy that defends designing innovative, future thinking looking products, that hold enough known features to remain acceptable to consumers.

• RtD: Research through Design

• k.i. : key insights that stand out from the content of the project and feed into the conclusions of each chapter.

• ANC: Active Noise Cancellation. It is a feature in some closed back headphones.

ToC

.01 Design brief

As the first chapter of the thesis, this section introduces us to the problem in question (why haptic aesthetics?) and how it is addressed throughout the project, as well as the mission statement and research questions at the core.

.01 Introduction

This Master thesis was conducted in collaboration with Sennheiser, the German audio equipment design and production company, taking the role of project client. Sennheiser provided a set of headphones from their portfolio to be the object of the haptic aesthetic exploration performed in the project, with the aim of developing a “concept headphone” to showcase new ideas and approaches to the design of this audio product.

.01 Client

The Sennheiser team was comprised of: Francien Tiessen (Head of innovation department), Jermo Koehnke (Product manager for Audiophile line) and Christian Ern (Product manager for the Premium line), who supported the project with regular meetings to exchange information and help guide decisions.

The supervisory team at TU Delft was comprised of: Prof. dr. Paul Hekkert, head of the Design Aesthetics group, as chair, and Dr. Gijs Huisman, Assistant Professor of embodied interactions and expert on haptics, as mentor.

.02 Problem statement

Within Western society, vision has been prioritised as the predominant sense. The role of haptic emotions and aesthetics has been mostly disregarded in product design (Hayes and Rajko, 2017). This has thus had an undeniable effect in the way we experience consumer products.

This thesis aims to bring the focus back to designing with the total feel of a product in mind, that is, including the haptic aesthetics and experience, in this case, of a pair of headphones.

The field of Haptic Aesthetics is still largely unexplored, and most efforts have been directed to show the “importance” of the feel of a product. However, if and how aesthetic theories transfer to the haptic sphere, has not yet been fully addressed.

On account of this, this project uses a set of aesthetic premises to guide the exploration of the aesthetics of touch.

Over-ear headphones were selected as the subject of this study, this exploration, because they are a consumer product of daily use, thus, with great outreach and a daily haptic presence, yet related to the highly sensorial ritual of listening to music. They are inherently haptically rich, as they rest on your head, weigh on it and press on your ears with the ear pads, remaining out of visual range while in use.

Goals

• To conduct research on whether the selected aesthetic theories are also applicable to our aesthetic appreciation of tactile/haptic experiences, and in which way.

• To discover what individuals appreciate as haptic aesthetic, and use these insights to redesign a set of headphones to be haptic aesthetic and novel, a “concept headphone”.

Scope

As reflected in the goals, the main focus is the development of Haptic Aesthetic theory on the one hand, and the user haptic preferences in headphones on the other.

Feasibility vs creativity

What remains out of scope is the financial, production and market feasibility of the headphones. The resulting prototype aims to deliver insights into which headphone design creates the most haptic pleasure for users. In this way, the results are not restricted in their novelty and creativity and are left for Sennheiser, the client, to implement to the wished degree.

Furthermore, the way in which the choice of materials impacts the quality of the sound was not considered, as it would limit the design of haptic experience from the very beginning.

Deliverable

For this thesis there were two deliverables, a haptic aesthetic theory developed throughout the exploration, and a “concept headphone”, a look-like, feels-like model of the redesigned headphones, that embody the discovered haptic aesthetic preferences and the theory to some extent.

Sennheiser

The company’s corporate identity and vision was taken into account only two phases of the project, first, in the selection of the product to redesign and finally in the choice of concept.

Other senses

While the haptic sense remains at the core of the work, it can’t be denied that other senses come into play when interacting with the headphones, such as viewing the object, or hearing it. These senses were not designed for, but their perception and influence were also considered, in order to get a more realistic product evaluation.

.03 Relevance for stakeholders

Sennheiser

Sennheiser's innovation is mostly sound and technically driven, as is in most of the headphone industry.

As said by the Sennheiser audiophile line manager, "The essence of the product is how good it sounds. However, it is always a different element that helps people connect with it."

(Jermo Koehnke, personal communication, 2022)

This project brings new insights into what consumers like to feel when using headphones, into the "different element". An opportunity for Sennheiser to design for a full aesthetic experience and expand their product line and target group.

Society

As said, users' aesthetic experience of products is currently often limited to the visual. The sense of touch is one shared by all and the first to develop in a child (Gallace and Spence, 2011b). By promoting the haptic feel of a product, not only is another dimension of meaning and pleasure added, but a further inclusiveness of those users which are visually impaired.

TU Delft

The Faculty of IDE has conducted research in the field of Product Aesthetics and Haptics. This thesis hopes to contribute to both these fields by evaluating the aesthetic theory in the haptic domain, thus, in haptic aesthetics. Furthermore, it hopes to influence IO student's design approach by encouraging designing for all senses.

.02 Approach

The project was originally envisioned to follow the Research through Design methodology (RtD). This method served two goals, informing whether the guiding aesthetic theory is applicable to the haptic sense, and designing the haptic aesthetic headphones. In this way, through the design activity of the headset, knowledge was gained about the research question.

This method was paired with a higher level, overarching approach, the Reflective Transformative Design Process (Frijda, 1986). The latter argues for the flexibility of the design process and values design action to generate knowledge, this design action, in essence, is what is at the core of RtD.

.01 Mixed methodology

The RTDP model is composed of five types of activities, that take place without a specific order or number of times (Hummels and Frens, 2009). The designer determines which phase to start with and continue with. When switching phases, a moment of reflection occurs, therefore, the more switches the higher the reflection in the design activity. When looking at Figure 2, the central activity of the model is ideating, integrating, realising. In the continuous switching of the surrounding activities, one circle feeds into another and reflection moments occur, informing the ideation circle. The surrounding four activities are:

- Envisioning, transforming, our current reality to a new desired one.
- Validating, quality. By which the ideas are tested within society.
- Sensing, perceiving, doing. In which the designer puts to action their motor and emotional skills and produces experiential information.

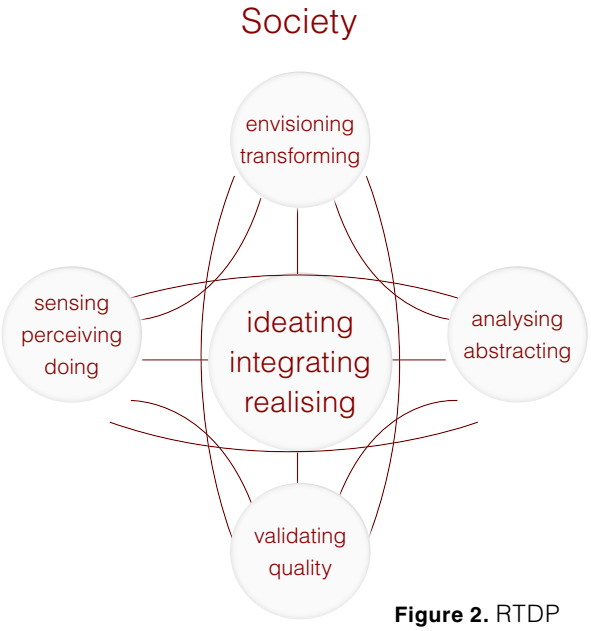


Figure 2. RTDP

• Analysing, abstracting, and gathering the information collected by the designer's cognitive skills.

In this way, the project started with an Analysing phase to establish the theoretical background of the project (chapter 2), as well as which headphone model to work with, the HD6xx line.

The next phase (chapter 3) was characterized by Sensing and Abstracting, in which an exploratory session was conducted to investigate which design factors are most relevant to the haptic aesthetic experience of the product and feed into the ideation.

The main activity in chapter 4 was the central activity, Ideating. The key takeaways from the previous chapters were taken to create three concept directions of haptic aesthetic headphones. These were then embodied in mock-up prototypes (Doing) and evaluated by the client (Validating), selecting one concept and once more informing the central circle.

Even though the previous chapters had already informed in some way the research question, chapter 5 is the strongest embodiment of the RtD methodology, which structure can be seen in Figure 3. In this chapter, three iterations of the selected concept were designed to embody the aesthetic theory (Ideating). Which, after user testing (Validating), served to gather data and visceral stimuli (Lee et al., 2018) (Zimmerman et al., 2007), to inform the second research question (Integrating), and helped to iterate the design.

In the last phase, chapter 6, a final evaluation of the prototype and concept (Validating), through the lens of the first research question, helped once again inform the theory (RtD), and the final design of the concept headphone (Integrating).

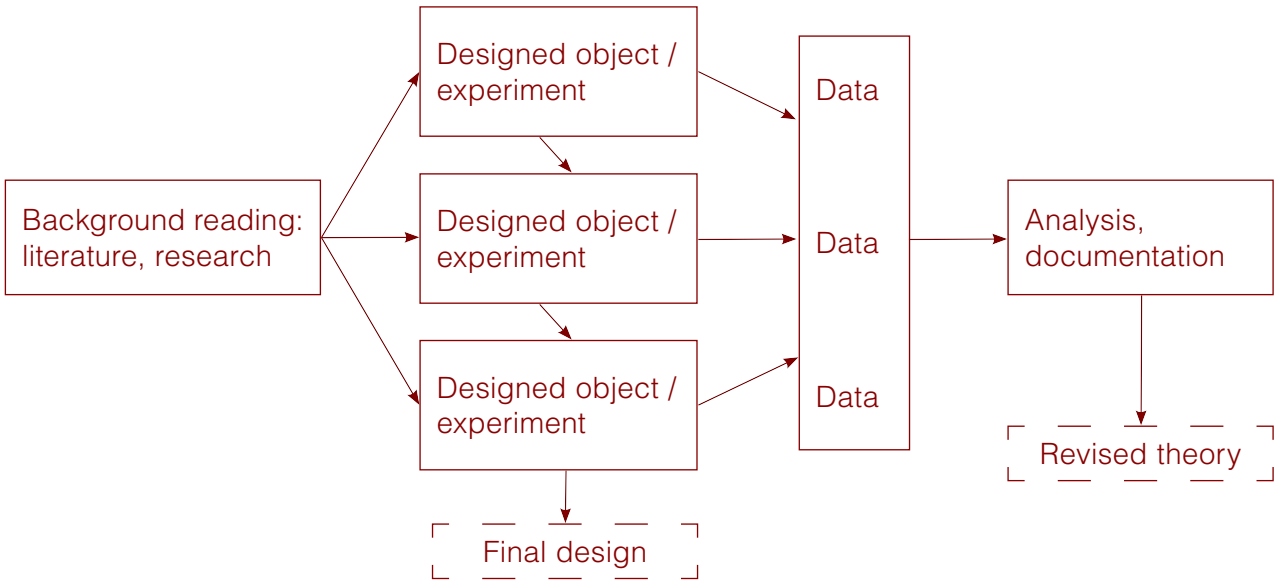


Figure 3. Research through design

.02 Mission statement and research questions

To guide both the research, and the design of the RtD throughout the project (see Figure 4), a broad mission statement and two main research questions were defined. These stem from the literature review presented in the following chapter and speak of two prominent aesthetic theories in the field of product design:

Mission statement

"Creating haptically novel headphones that feel beautiful."

Main research question

To what extent do product design aesthetic theories apply also to the haptic sense?

- Research question 1: To what extent does the maximisation of both haptic novelty and typicality positively influence haptic aesthetic appreciation (when the counteracting influence of these changes in the other variable is controlled for).
- Research question 2: To what extent does the maximisation of both haptic unity and variety positively influence haptic aesthetic appreciation (when the counteracting influence of these changes in the other variable is controlled for).

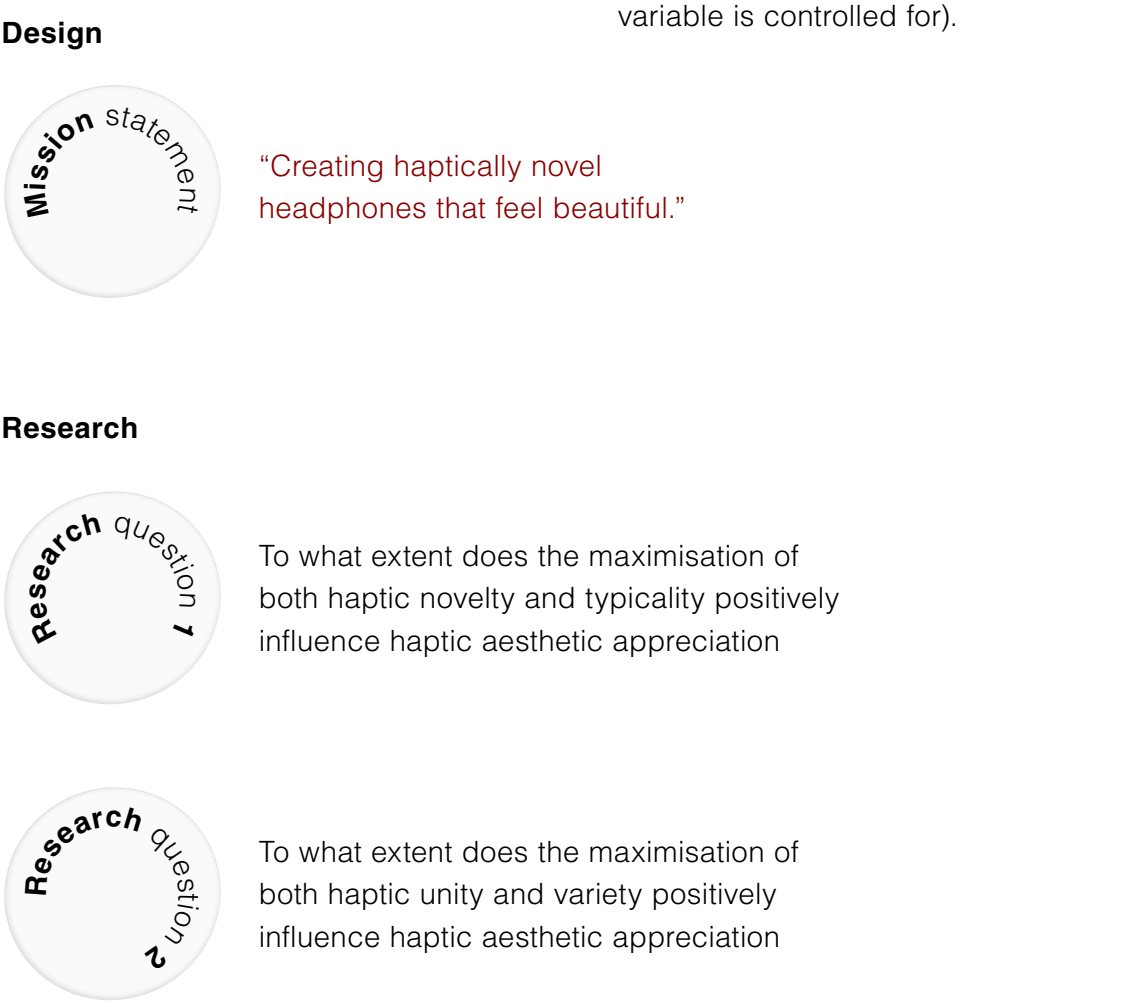


Figure 4. Mission and research questions

.02
Background

This chapter digs into the different topics that shape the project. Learning about haptics, aesthetics and haptic aesthetics. And also about its presence in headphones, specifically, in the HD6xx Sennheiser headphone, the object of redesign of this thesis.

.01 Sennheiser

Sennheiser is a German family-owned company, represented in 50+ countries by a team of 2800 people. This project takes the HD6xx headphone model, of the Audiophile line, as a starting point of the redesign. To understand why Sennheiser is supporting this project we first need to understand the brand, its mission and vision.

.01 Sennheiser's mission

The Future of Audio – since 1945

With the continuous development of new technologies, we are constantly redefining sound. We set high standards and have made it our mission to create even more exciting and immersive sound experiences.

Our goal is to push boundaries further and further, while uniting sound and space and opening up unprecedented sound dimensions for our customers, see Figure 5 (Sennheiser, 2022).

Figure 5. Sennheiser's mission

Design core values

k.i. Robustness is Sennheiser's design core value

As for the brand's design core values, in one word, robustness (Jermo Koehnke, personal communication, 2022).

The product portfolio includes two overarching themes. The Premium line, with products up to 350€ that include Wireless and Noise-Cancelling headphones, and the Audiophile line, wired headphones that prioritise sound quality and are mostly intended for home use, from 200€ up to 8000€.

.02 Audiophile portfolio, product focus

Within the Audiophile line there are three main categories. In-Ear headphones, Headband (over-ear) and Amplifiers. For this project the focus was the Audiophile Headband category, that includes four different headphone model lines, each with its own character (see Appendix 1) (Jermo Koehnke, personal communication, 2022). HD6xx are a reference of neutral sound and a quality mark of audiophile headphones, with a technical design dating back to the 90s.

Audiophile HD6xx model, focus of redesign

The headphone store interviews (see chapter 2.03) revealed that audiophile customers are more perceptive than premium headphone buyers to the different sensations caused by the headphones. Audiophiles seemed to pay closer attention to the sound and the and other subtle elements in the design. This enhanced perception makes them a more suitable user group to design for when stimulating the haptic sense.

Furthermore, within this category there is further design freedom, as the higher profits than those in the premium line can absorb an increase in production costs or a less successful product (Jermo Koehnke, personal communication, 2022).

k.i. The HD6xx needs a revamp

As for the specific choice of line, the HD6xx

Figure 6. Audiophile portfolio

is considered a high quality headphone, with an old-fashioned design, it is “acoustically transparent” (*HD 600,* n.d.). “It is a good design, sound-wise, but totally not sexy. It needs an innovation that will appeal to younger people” (Ears Unlimited expert, personal communication, 2022). In this way, this stripped down design can serve as a blank canvas with which to haptically aesthetically experiment. The HD6xx line comprises the HD600, HD650 and HD660S, which vary in sound but have analogous constructions, aesthetics, and haptic aesthetics (Audiophile Home Listening, n.d.). In this way, when referring to the construction of one specific model throughout the report, it encompasses the rest of the HD6xx line (see Figure 7).

k.i. HD6xx line offers design freedom for the higher margins and closer supply chain

Lastly, for the HD6xx, as for the higher priced products, production and suppliers are within Germany and Europe, allowing for higher design freedom by communicating directly with these parties. For the HD5XX, manufacturing and suppliers remain in China, with an added challenge to part from standard materials and techniques (Jermo Koehnke, personal communication, 2022).

Figure 7. HD600 model

.03 Target group

Currently, the audiophile core target group consists of at least 80% male users who appreciate the teach-driven, performance inspired design (current target group) (see Figure 8). This constitutes a low percentage of the population.

k.i. Sennheiser seeks to expand the user group to younger, non male users

The re-vamping of this model aligns with Sennheiser's goal to expand this target group to younger users and other genders (envisioned target group), which was considered in the concept selection, in chapter 4.02.

For more information on Sennheiser's current target group and demographics see Appendix 1.

Research within the company (Keim, Groth, 2022) states that sound quality is key for all the Sennheiser user groups, but design, comfort and convenience aspects also matter. Innovations in those areas, with the right story and value proposition, can also affect and improve the brand image.

Figure 8. User wearing HD650 model

.02 Haptic aesthetics

Think of something beautiful. What comes to mind? Probably, a painting, a face, the façade of a building. But why not the feeling of the shirt you are wearing on your skin, or the warmth of a blanket? (see Figure 9, Figure 10 and Figure 11).

Our society is a visually focused one (Hayes and Rajko, 2017). This has impacted the way we experience consumer products, pushing the other senses to a secondary level. In order to fully experience a product, we must design for all our senses. Amongst them, the haptic sense.

.01 Introduction to haptic aesthetics

In this introduction we will unveil the following three terms: haptics, aesthetics, and haptic aesthetics.

Figure 9. A matter of tactility

The term haptic is derived from the Greek term “haptikos”, to touch or grasp (Kreifeldt, 2013). It includes the sensations felt externally by our skin, and internally by the body, such as body motion and posture (Sonneveld and Schifferstein, 2008).

Furthermore, as the sense of touch is the first one to develop in humans, already during the 8th week of gestation, it could suggest that visual aesthetics are partly founded on tactile aesthetics (Gallace and Spence, 2011b). Touch gives us access to the physical world, we touch objects and they touch us back, often this is a decision to touch, an active engagement (Bremner and Spence, 2017).

Figure 10. A matter of tactility

The concept of aesthetics can be found in many contexts. In this project we are referring to design aesthetics as a specific response or experience a person may have to an object, often understood as liking or appreciation of that object. It is described as: “The pleasure people derive from processing the object for its own sake, as a source of immediate experiential pleasure in itself, and not essentially for its utility in producing something else that is either useful or pleasurable” (Dutton, 2009).

Aesthetics play an essential role in daily life. A consumer might choose one model of car over another solely due to its style. There are many aesthetic theories that seek to explain the mechanisms of this experience, however, most have been developed and tested keeping only visual phenomena in mind (Carbon and Jakesch, 2013). This project seeks to develop the haptic aspect of the aesthetic theory.

k.i. Haptic engagement can cause hedonic pleasure

But what do we mean by haptic aesthetics? Understanding the aesthetic experience as the hedonic pleasure drawn from haptic engagement. The pleasure, and the emotions, derived from interacting, handling, and experiencing a product with the above described haptic senses.

Figure 11. Daily haptics

.02 The haptic sense

People need touch to understand the world around them. Touch is both active and passive (Gibson, 1962) and thus, interactive.

Touching implies bodily movement, in fact, the tactile experience involves the whole body. However, the type and density of receptors are different throughout it, leading to a variation of tactile sensations in the different regions (Hayes and Rajko, 2017). We will feel differently something we hold in our hands than something that rests upon our heads.

k.i. We perceive objects as one haptic experience

In the interaction with an object there are several contact and pressure points, for instance, when brushing our teeth, the muscles in our hand hold the toothbrush with certain pressure, while the bristles brush against our teeth. However, we perceive the toothbrush as a single object and the haptic experience as one (Sonneveld and Schifferstein, 2008).

k.i. We can actively engage with objects (we touch them), or passively (they touch us)

In this way, an object is the sum of its tactual properties, but each property can be explored and perceived, either actively, with exploratory movements by the user, or passively.

k.i. The haptic experience involves skin sensations but also body motion and awareness of it

Active touch involves our skin sensations (cutaneous), and those felt internally by the muscles, tendons, and joints receptors. These are the kinaesthetic (body motion), proprioceptive (body awareness of movement), and vestibular (balance) systems in our body (Hayes and Rajko, 2017).

The following fragment discusses tactile properties of the object, and tactile sensations felt by the skin, which will be relevant for the redesign of the headset.

Tactual properties

Overall, tactual properties can be related to (Sonneveld and Schifferstein, 2008):

- The substance, the material the object is made of: hardness, elasticity, plasticity, temperature and weight.
- The surface, the geometrical aspect of the object: its global shape, exact shape, texture, volume and weight distribution (balance).
- The moving parts of the object: the way the parts move in relation to one another

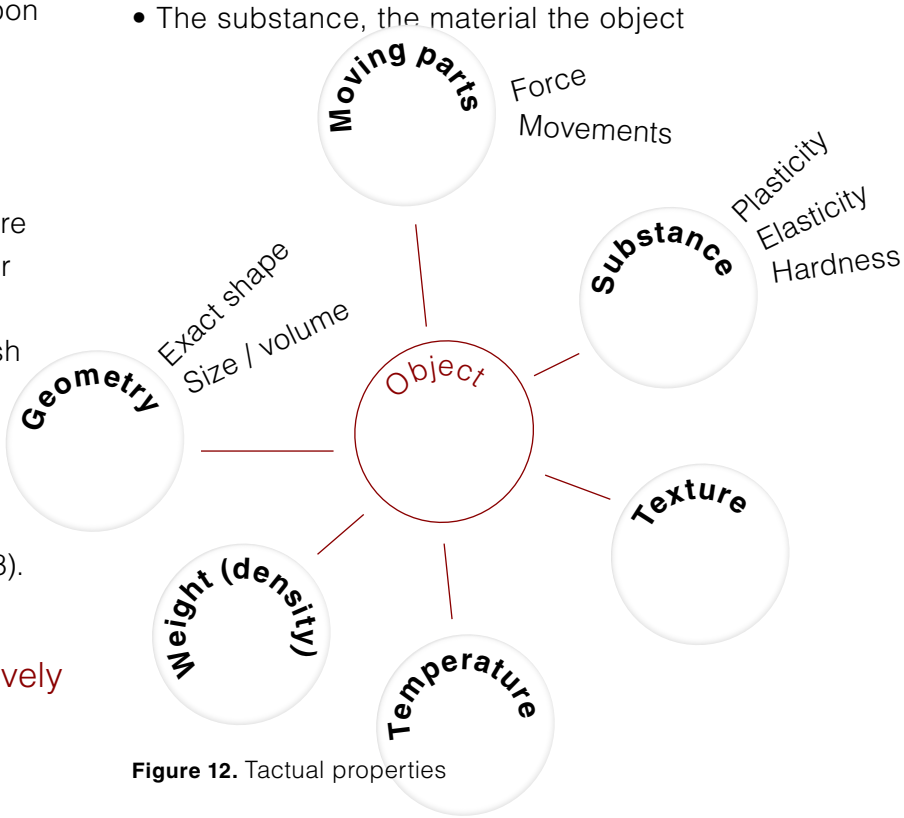


Figure 12. Tactual properties

Figure 12 maps some of the tactual properties that can be perceived by the individual.

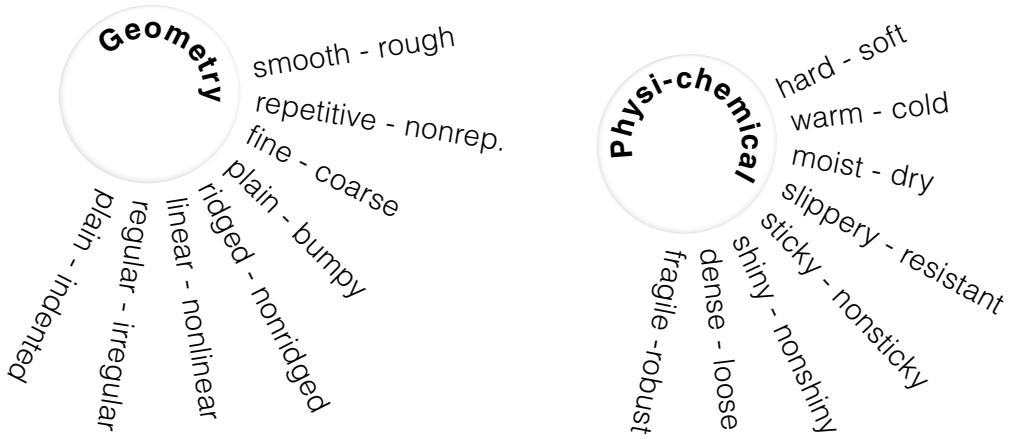


Figure 13. Description of texture

When zooming into the material's texture, Zuo proposes the following lexicon to describe the texture (Zuo et al, 2001). The Geometrical and Physi-chemical dimensions are taken as relevant for this project due to its aesthetic standpoint, which aims to not step into the product emotion realm, beyond the aesthetic experience.

Sensations

As for the sensations in the skin, the following factors can be contemplated: where the sensation occurs (location), what kind of sensation is occurring (quality), how strong (intensity) and for how long (duration) (Gibson, 1963).

k.i. The duration of a sensation is key to the haptic experience

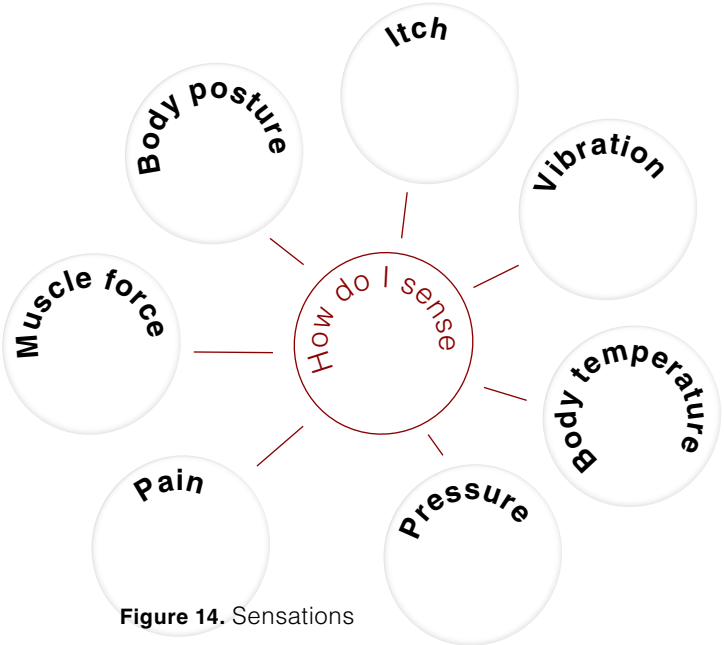


Figure 14. Sensations

A pleasurable sensation will only be so for short instances. If it were to persist, the sensation would quickly transform into displeasure or annoyance (Dr. ir. Sonneveld, personal communication, 2022).

Some of the sensations we can feel in our skin are (see Figure 14):

- Sensations derived from touch: light touch, pressure and vibration
- Warm and cold sensations
- Pain sensations: superficial pain, somatic pain (in the body)
- Itch and tickle
- Physical pleasure

For more extensive information about how the haptic senses work look into Sonneveld and Schifferstein (2008).

Sensitivity

Different sensory responses have been found depending on the stimulated area of the skin (i.e. face, ears, hand…), stimuli moved over hairy skin, such as that on the ears, has been found to create higher pleasure than on glabrous skin, that on the palm of the hands (Lloyd et al., 2015). Passively received stimuli (passive touch) was also reported to have higher sensorial response than actively touched stimuli (Lloyd et al., 2015).

.03 Framework. From aesthetic theory to haptic aesthetic theory

We have already outlined how haptic sensations come about, however, how do we process them to become a haptic aesthetic experience?

A model that explains how the aesthetic experience could occur in a user-product interaction begins with the user performing an initial perceptual analyses of the object (see Figure 15). The user then compares this information with his previous experience, and later classifies it into a meaningful category.

k.i. The aesthetic experience is immediate, perceptual and automatic

These immediate, automatic, perceptual steps constitute the aesthetic experience. This is followed by an interpretation and cognitive evaluation of the object that generates an emotional response which is no longer purely aesthetic (Hekkert, 2006).

Aesthetic guideline

There are many theories that seek to describe what we find aesthetically pleasing. Some examples are the Gestalt laws, the laws of proportion (golden ratio), or other more complex theories that look into human psychology and nature.

Berlyne proposes that aesthetic pleasure will peak when there is an optimum level of psychological arousal; too little arousal will result in indifference whilst too much will result in displeasure (Crilly et al., 2004). The appreciation of this balance in arousal lies in the human need for safety and for accomplishment (Hekkert, 2022), two opposing forces.

The following theories have been researched across several product categories and domains, however, mostly from a visual perspective. These paragraphs aim to describe the underlying aesthetic hypotheses that will be informed for the haptic sense, in this project.

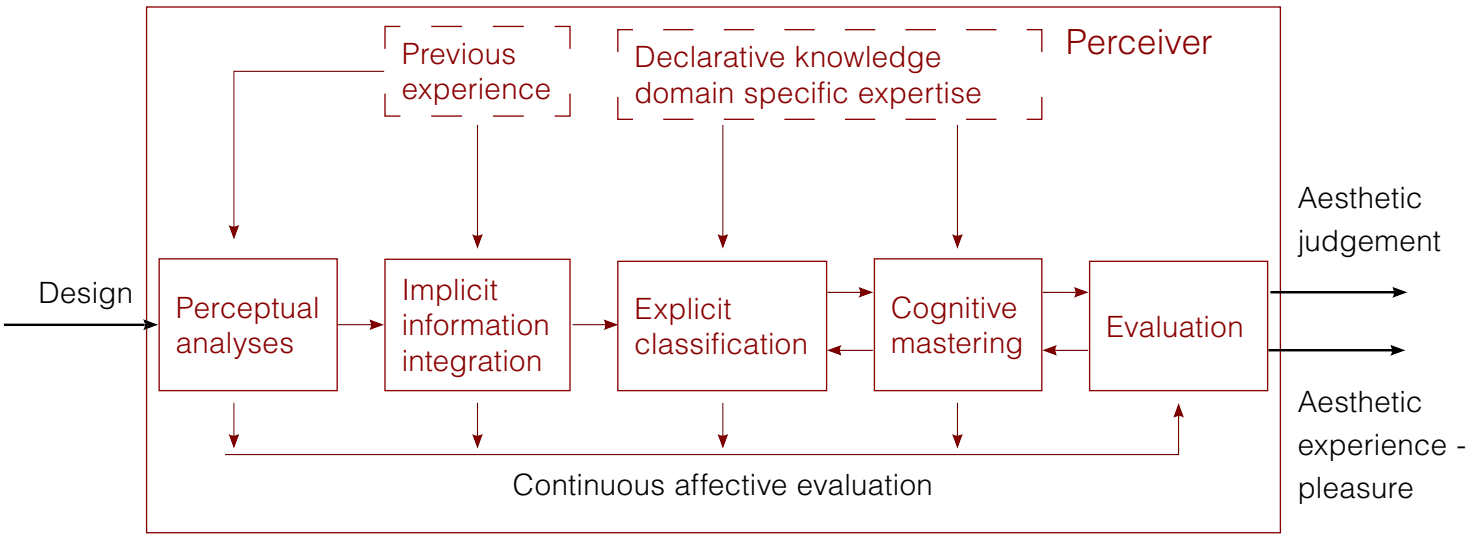


Figure 15. Model of aesthetic experience

Hypothesis 1:

The maximisation of both haptic novelty and typicality positively influence haptic aesthetic appreciation, when the counteracting influence of these changes in the other variable is controlled for.

The theory of preference-for-prototypes suggests that product forms that are closer to the goodness-of-example (a prototype of a product category) are likely to be preferred due to their familiarity and safety (Whitfield and Slatter, 1979). However, individual's search for accomplishment has deemed novelty to also be a determinant of aesthetic preference (Berlyne, 1971).

Research from Hekkert et al. (2003) has provided evidence for the design principle MAYA (Loewy, 1951), which stands for Most Advanced Yet Acceptable.

" In order to create a successful design, the designer should strike a balance between novelty and typicality in trying to be as innovative as possible while preserving, as much as possible, the typicality of the design" (Hekkert et al., 2003).

Typicality (goodness of example), while closely related to familiarity is not its direct equivalent. It is possible to have a novel design that is a good example of its product category (Hekkert et al., 2003). Thus, the maximising of these partially opposing qualities, typicality and novelty, results in an optimal balance, where aesthetic appreciation is at its peak.

Embodiment technique

• Novelty is aroused if users encounter design properties they are not familiar with in that category of product. It arises from the perceived differences between the real product and the expectation of the user (mental model) (Coates, 2003). Changing the material or the interaction with the object (i.e. pushing instead of pulling), are examples of how to create novelty.

k.i. Typicality arises by maintaining the design's category archetype

• Typicality is usually embodied by maintaining the archetype of the product category's shape and contour.

Hypothesis 2:

The maximisation of both haptic unity and variety, in order to achieve a balance, positively influence haptic aesthetic appreciation, when the counteracting influence of these changes in the other variable is controlled for.

Consumers show aesthetic preference for designs that are as varied as possible (accomplishment), but only when there is also unity and coherence in this variety (safety) (Post et al., 2013). This principle, by the name of UiV (Unity in Variety), follows the same mechanism as the novelty - typicality principle exposed above, where the maximisation of two partially opposing qualities leads to an optimal balance and the consequent aesthetic appreciation (Post, 2016).

UiV dates back to the early Greek philosophers (Raizman-Kedar, 2006) and has been applied across several domains throughout history and design education (Post et al., 2013).

Variety is understood as the perceived differences between the perceptual properties and elements of the object. The higher number and intensity of these perceived differences, the higher the variety (Berlyne, 1972).

Unity is the search for coherence between and within the elements and properties of the object, to perceive these as a whole unit (Berlyne, 1971).

Embodiment techniques

Designers can use different techniques to embody variety and unity (Crilly et al., 2004).

k.i. Variety is related to contrast between features that are close

• Variety is closely related to contrast (Coates, 2003), and the combination of dissimilarities in design features that are close. The use of a variety of lines, shapes or textures can be perceived as high contrast (Graves, 1951).

• The use of similarity, uniformity and constancy, orthogonality of the elements and properties within the design can give the sense of unity.

k.i. Gestalt laws can be applied to achieve a feeling of unity

Also principles such as the Gestalt laws of perceptual organisation can be applied. Coates (2003) suggests as guidelines:

• Use of vertical, horizontal and orthogonal orientation

• Proportions of 1:1, 1:2, 1:3, 1:4, 1:5, 2:3, 2:5, 3:4, 3:5, 4:5

• Following continuity and unity principles: continuous, parallel, alignment, symmetry

Furthermore, he refers to kinaesthetics (the feeling of motion) as the quintessential objective order, unity. Remaining up-straight is, aesthetically, the least exciting but most comfortable status. Tilting our heads sparks a signal to restore the comfortable equilibrium, thus, begins the aesthetic experience.

Finally, it is worthy to note that this balance is perceived differently across individuals, depending on product category, background and culture, as well as their promotion or prevention seeking (Hekkert et al., 2022). People may perceive different levels of unity and variety or novelty and typicality, but research has shown their preference for items that, for each individual, maximise these aspects in a design, at the same time.

Tactile Gestalts

The Gestalt laws try to explain why people perceive and recognise patterns, with a concern for visual perception. As these principles are born from innate human preferences, they could apply also to the other senses (Chang, Nesbitt, and Wilkins, 2007). A review of the relevant principles and how they transfer to haptics follows, for

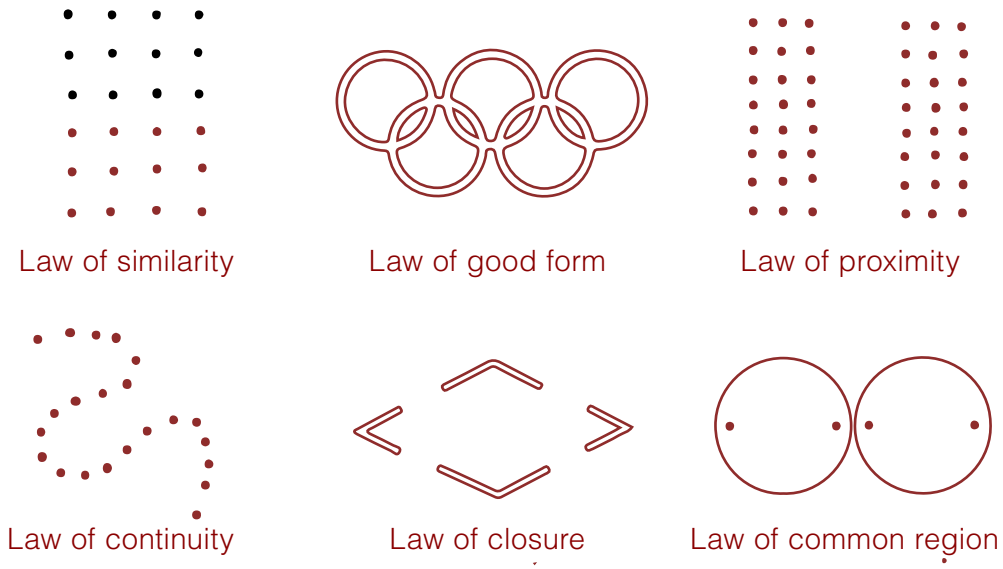


Figure 16. Tactile Gestalts

more, see Gallace and Spence, 2011.

Some of these are (see Figure 16):

• Research shows that we haptically hold and perceive objects using some sort of form completion, which relies on the Gestalt principles of similarity, proximity and good continuation. Thus, these are applicable to the haptic senses. Proximity suggests that elements which are close to each other will be grouped together (i.e. Braille). For similarity, elements will tend to be grouped together if their attributes are perceived as related. Good continuation asserts that aligned elements are perceived as a single group and interpreted as being more related than unaligned elements.

• It is suggested that the principle of good form, by which we organise elements into as good a figure as possible (simple, orderly, balanced, symmetrical etc.) (Todorovic, 2008) arises too during haptic exploration.

• As for closure, research indicates that people can complete gaps between sequentially-presented tactile stimuli.

• Emergence. Users are able to separate a pattern from its background also with touch, after shape exploration.

k.i. Gestalt laws can be applied for the haptic senses

For this project we will take the latter as confirmation that these laws can be applied for the haptic senses.

Comfort and aesthetic pleasure

The term “comfort” is often related to ergonomics, however, how is it related to the haptic aesthetic pleasure? This is important to understand as users frequently use this term to describe a haptic experience.

k.i. Comfort is an aspect of pleasure

Pleasure is more often understood to add gains, it exceeds usability and comfort (Jordan, 2010), while comfort focuses on relieving pain and minimizing loss. Furthermore, a questionnaire and study suggests that comfort can be seen as an aspect of pleasure, but pleasure holds dimensions not included in comfort (Alves Coelho, 2002). Thus, when a participant describes a sensation as pleasurable, it will inherently imply underlying comfort.

.04 Cross modal effect (visual, sound)

It is undeniable that interactions with products are multi-sensory (Hekkert, 2006). When we first see the headphones before we pick them up we instantly form an impression, an expectation of what will be perceived through the other senses (Ludden, 2008), of how heavy they will be or how they will feel on our heads.

These senses are not isolated. Humans have shown to have implicit cross-modal correspondences between stimuli from different sensory modalities (Spence, 2011). See Figure 17, for an example in which five commercial fragrances were matched with colours (Schifferstein and Howell, 2015).

In the case of the headset, the main present senses are the haptic, visual and auditory. The first impression is visual, which is followed by the haptic sense as we handle the object. These movements are paired with their inherent sounds, however, this sense becomes relevant when the object begins performing its function, playing music, but is no longer in view. Thus, two relevant sensory pairs stand out: visual – haptic, and haptic – auditory.

k.i. The haptic - visual sensory pair is relevant for the concept headphone

This project focuses on designing the haptic aesthetic experience of the headphones. However, the visual – haptic cross-modal correspondence (or dissonance) is relevant as it is inevitable that the user will see the object before using it, therefore, we must consider the effect on the visual modality and therefore, on the user.

As for the haptic – auditory pair, it is interesting to consider which haptic cues could pair with the music and create a synaesthetic correspondence. For instance, audiophiles speak of music texture.

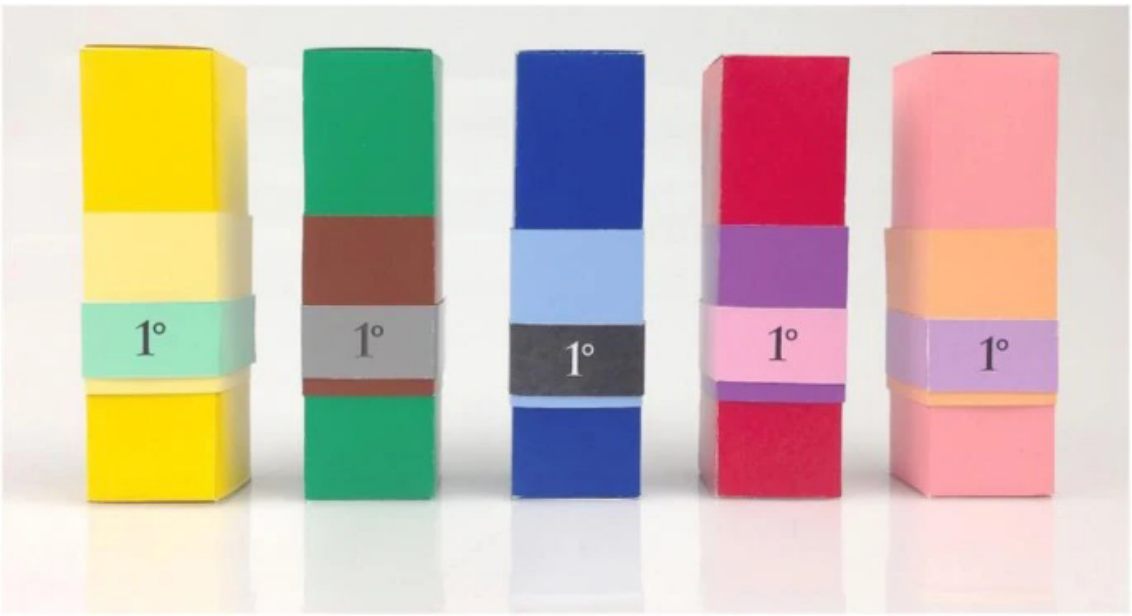


Figure 17. Colour - odour cross-modal correspondence

.05 Haptic aesthetics in design

In products

Although haptic aesthetics can be found in every object due to its inherent material properties, it is seldom considered in the consumer market.

The following is a collection of contemporary designs that do focus on delighting the senses, in particular the haptic sense. Most of these belong to the categories of dinnerware/gastronomy or that of therapeutic toys, which include those for children, disabilities, sexual therapy etc (Sophie Declerck, personal communication, 2022).

Figure 18. Sensory tablewear

Figure 20. Meret Oppenheim's bowl

In the category of gastronomy, we can find cutlery, plates etc. that play with shapes, textures and weights to influence the way we perceive flavours and interact with the food, enhancing the experience of eating to a more sensuous one (see Figure 18 to Figure 21).

Another example is the rethinking of tools to reduce the distance between the food and the hands, reconnecting with the process of preparing food (see Figure 22 and Figure 23).

Therapeutic products aim to stimulate the senses in a calming way. These designs play with texture, shape, material, and often encourage deep touch (firm gentle pressure) (Figure 25).

Figure 19. Michel Fabian hand bowl

Figure 21. Tasting time

Figure 22. Haptics of cooking

Some examples of haptic aesthetics can also be found in the consumer market. The Bradley watch (Figure 24) allows you to not

Figure 23. Pestle, hand tools

only see but also feel what time it is. Within the car industry there is a large focus and resources put into making the car interior feel aesthetic. The grasp of the steering wheel, the movement and interaction with the shifter, the feeling of premium leather on the dashboard (Figure 26)…

It must be noted that the field of haptics has experienced a strong surge in the HMI, car and game industry. And although the development has happened for haptic technologies and not aesthetics, it has opened a door into intentionally designing for an optimal haptic feel in the other interfaces such as buttons or grasp on these devices, to accompany the technology.

Figure 24. Bradley watch

Figure 25. Sensory stimulation kit for dementia patients

Figure 26. BMW iX car interior

Insights

Most of the examples found of products that intentionally incorporate haptic aesthetics without the use of haptic technologies seem to be closely related to the world art in design and small production, rather than commercial consumer driven design. When it comes to the larger consumer driven market, these products focus mostly on integrating haptic technologies.

k.i. There is an opportunity to introduce haptic aesthetics into the consumer market

This suggests that the enhancement of the senses solely based on the object's properties is more related to crafted, small scale products that often evoke an interaction similar to a ritual.

k.i. Hands are a key part of haptic engagement with an object

Another point to note is that most of the discerned products are hand-held and /

or interact with the mouth, this is because hand and tongue are generally related to touch and have a high density of receptors. However, other parts of our body are still capable of sensing and can be included in the scope of a haptic redesign.

k.i. Transforming the interaction can be haptically rich

Many of the reviewed projects rely on specific materials (texture, density and elasticity) and shape of the object to achieve haptic sensitivity. However, the most recurrent theme consists of transforming and magnifying the interaction with the product into a haptic sensorial one, while it seeks to fulfil its purpose. This can be seen for instance in the Echo speaker (see Figure 27). The user creates the sounds by moving and combining the different parts.

Figure 27. Echo, speaker

Figure 28. Haptic moodboard

Haptic moodboard

Based on the above highlighted examples and other sources the moodboard was put together in order to use as inspiration when ideating possible haptic headphone approaches.

Eight themes on how to achieve a haptic sensation through a product have been discovered and showcased in a series of collages.

The overview can be seen in Figure 28, and the individual boards and theme explanation in the Appendix 2.

In headphones

A market study by Sennheiser (Pyro Audio, n.d.), reveals that the headphone market is experiencing more choice than ever. With the emergence of a new kind of audiophile there has been a decay of traditional audiophile products.

Some headphone models from the 80s that took a futuristic approach, such as the AKG K1000 swivelling headphones (see Figure 29), remain a staple for innovation in the sector.

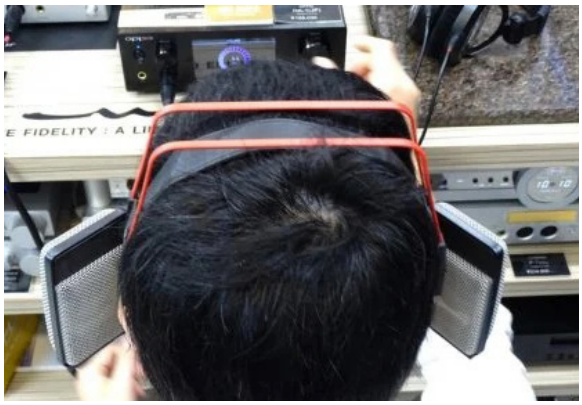


Figure 29. AKG K1000 swivelling headphones

It is worth noting the high innovation in materials, driven by visual aesthetics, by sustainability, using fungus (Aouf, 2022), bioplastics and woods, or by new developments in materials.

A common material choice that can be found in the luxury headphone market is combination of wood, metal or leather, such as the Sony MDR-R10, with voluminous Zelkova wood earcups and lambskin leather (see Figure 30), the Audio-Technica ATH-WP900 (see Figure 31), or the aluminium STAX SR-007A (see Figure 32).

Figure 31. Audio-Technica ATH-WP900

Several shapes and typologies of headphone earcups can also be found that differ from the classic circular/oval shape, mostly to make them visually different and

Figure 30. Sony MDR-R10

Figure 32. STAX SR-007A

aesthetic from the competitor, and achieve some sort of brand identity (see Figure 33). The band-free Human Headphones offer a closer, new type of interaction with the earcups (see Figure 35).

The Crystal-beaded headphones or the Rhinestone headphone crown (see Figure 34), prove that there is a taste for extravagant headphones that part from the minimalist typology, at least in the luxury market.

Furthermore, some brands play with new shapes inside the ear cup to achieve a different comfort and audio sensation (see Figure 36).

Figure 33. Pryma 01

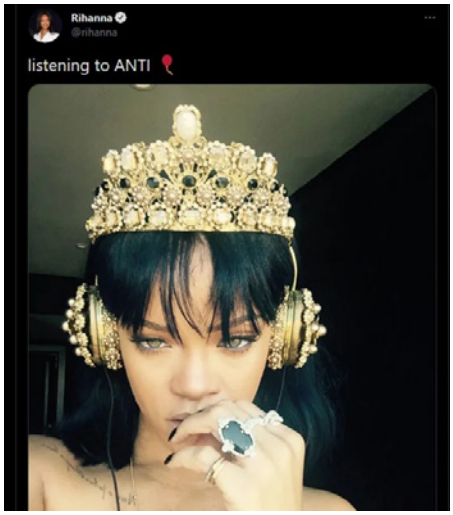


Figure 34. Rhinestone headphones

Sennheiser, this project's client, has released the Orpheus 2, a 55.0000 $ headset which showcases the company's willingness to innovate without boundaries. It offers superior sound quality and a luxurious choice of materials such as German leather or Michelangelo's Carrara marble for the case (see Figure 37).

Insights

All in all we see headphone designers have paid close attention to the look and feel of the headphones, to their aesthetics. Headphones form part of our daily life and are visible to the world we engage in,

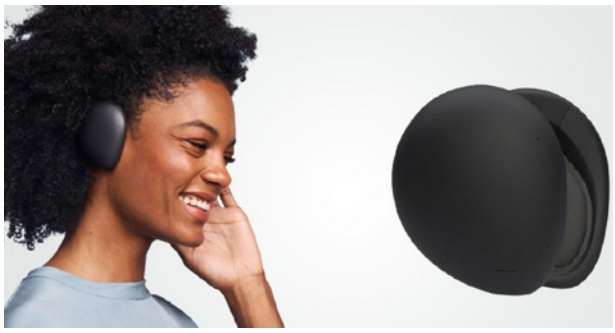


Figure 35. Human headphones

Figure 36. Vie shair

thus, forming part of our style and fashion expression. Designers have selected colours, materials and shapes that convey the desired visual product quality, identity and feel.

k.i. Consumers are open to innovation in the high end headphone sector

From this review it can be said that headphone consumers are open to a variety of product morphologies, that there is an interest for innovation and exotics. But also that it is appealing to consumers to pair supreme sound quality with an aesthetic design of the product, up to now mostly in materials and visual aesthetics through colours and shapes.

However, it is clear that there is an absence of headphone designs that integrate aesthetics from the haptic perspective in

an “analogue” manner, beyond the haptics related to sound emission. These are mostly committed to altering frequencies and vibration to enhance the music and gaming experience.

This leaves a gap, and an opportunity, in the market for rethinking headphones from the “traditional design” perspective, focusing on the objects properties to stimulate the haptic sense.

Figure 37. Sennheiser Orpheus 2

.03 Headphones

This section seeks to understand the subject of headphones in its current status. What are user's opinions about the headphones in the market, to what extent are haptic aesthetics addressed? Another question that is explored is the current haptic impression of the headset, what areas of the body are engaged and in what way, during the user journey?

.01 Headset characteristics and build

The Sennheiser HD6xx headphones are built like traditional audiophile headphones in the market. They are open back and wired, the back of the earcups have openings to let air through and create a more natural sound, avoiding the resonance and low frequency build up of the enclosure (Thomas, 2023). This feature also allows outside sound to enter the headphone.

They are composed basically of 2 earcups joined by an adjusting headband (with a ratchet mechanism), and a rotating hinge. Inside the earcups there is a dynamic driver, held by a supporting structure and covered on the outside by the earcup mesh shell, and on the inside by the earpads. Finally, a lead end of the double cable clicks into each earcup.

This model is made mostly out of plastic, with a metal grid on the outside of the earcups and foam in the earpads, which are covered in velour-like fabric.

Use case

Since the headphones are open back, wired, and high priced, audiophiles use the headphones mostly in a home listening environment, in a safer, soundless surrounding. Placing them on a headphone stand when not in use (Ears Unlimited expert, personal communication, 2022).

Dynamic driver

This is the core of the headphone. It consists of a diaphragm attached to a coil, which is suspended in a magnetic field of a permanent magnet. When the audio signal passes through the coil, a varying magnetic field is created, which reacts to the magnet and makes the diaphragm vibrate, pushing the air and producing sound (Wikipedia contributors, 2023).

k.i. The driver is at the core of the headphone, and vibrates to produce the sound

HD 6xxs haptic description

This model feels light when first interacting with it (260 g) (Sennheiser, n.d.), which is due to its plastic housing, as opposed to metal. The pressure of the earcups on the head is relatively high. The earpads have been designed large enough to fit the average ear and with an oval shape. The cushions are made out of foam, springy, thick, and covered with a soft fabric. The headband is adjustable and covered with foam except for at the center, top part. The earcups swivel and rotate to adapt to the head (see Figure 38).

What competitors are doing

When looking at the current headphone market, the most common materials used are (Schmidt et al., 2008):

- Earcups: metal, wood, ABS and PC. Increasing use of other high end injection moulded co-polymers that can replace metal parts.
- Headbands: injection moulded Nylon 12
- Earpads: EVA

Relevant competitors

When looking at reviews of similarly priced audiophile headphones, some haptic aspects stand out. Some products are criticised for their weight, like HiFiMan Sundara (372 g) (Thomas, 2023b) or HiFiMan HE-500 (502 g) (Mouchet, 2021). Also for their “bulkiness”, due to the drivers they use. On the other hand headphones like the Meze 99 classic (Meze Audio 99 Classics - Reviews, 2015), are highly praised for their lightness (260 g), and build quality. This is usually judged by users by the materials, especially in the connections. HiFiMan HE-500 use metal articulations, and Meze 99 classic are bolted together, not glued. Headphones like the Audio-Technica ATH-R70 X are praised for their use of aluminium and carbon composite

Figure 38. Disassembled earcup of HD600

resin, but critiqued for their hard plastic hinges, that feel “flimsy” . Sturdy hinge movements are thus, also appreciated (Audio-Technica ATH-R70x Review, 2023). The HD6xx bodywork is plastic, in order to make it more lightweight.

All of these designs have a double headband with a suspension band that distributes the weight on the head, unlike the HD6xx line, that has a continuous headband. Higher end audiophile headphones, like the Meze Empyrean have pressure distribution wings on the headband to alleviate pressure points (Empyrean Jet Black, n.d.).

The earpad size and shape and material is also relevant, pleather being negatively perceived, as in the HiFiMan HE-500.

.02 Headphone stores - experts

To gain insights into the headphone community, three audio stores were visited: Audiohuis Delft, Hi Fi Klubben den Haag and Ears Unlimited. The latter being a shop specialised in premium and audiophile headphones (see Appendix 3).

Talking to the shopkeepers about their customer’s impressions, their preferences and interacting with a variety of headphones lead to the following insights:

User preferences

• There is a large variety of user preferences and ear sizes. Designs must be carried out for a part of the customer base (Ears Unlimited expert, personal communication, 2022).

k.i. Built up warmth in the earcups is a significant issue

• The relevant haptic aspects are: cable (bending, outside texture, microphonic properties), headband (surface, padding, material, double-band), heat dissipation (especially closed headphones), ear cushions (shape, thickness, material, texture), clamping force (higher clamping force can be pleasant but uncomfortable, lower gives less feeling), earcups (size and shape, material of outside shape). Swivel and hinge movements are very relevant. Users want the earcups to swivel but feeling sturdy, likewise with height adjusting.

k.i. Metal bodywork is liked

• Metal bodywork is most appreciated by users, followed by wooden textures and finally plastic, in different finishes.

• On ear headphones are less preferred by most users, compared to over ear.

• The earpad material is something users notice even if the properties are subtly different (Audiohuis Delft expert, personal communication 2022).

Other insights

k.i. Innovation and design is technology and audio driven

• Most shapes, volumes and materials in earcups are selected solely based on sound quality.

• In the premium headphones, innovations is driven by new NC (noise cancelling) and BT technology.

k.i. Audiophiles are more perceptive

• In the premium headphone market (those around 200€), users do not display as much sensitivity to the build quality

details, and material differences as in the audiophile market. There is not much variety in terms of bodywork material, earcup material or headband.

• The use case of audiophile headphones is home listening, they are not used in transport or moving.

• High end headphones do not rest around the neck, due to their elevated price tag. Also, foldability may not be needed, users would rest them on a stand or in a case.

k.i. The impression of the headset differs over time

• Some sensations disappear, others build up. Weight may be perceived as a quality aspect but eventually become irritating.

k.i. Sennheiser's design is good, but "not sexy"

• Model HD600 is appreciated in its sound quality but has an "old fashioned design". "It is a good design, sound-wise, but totally not sexy. It needs an innovation that will appeal to younger people" (Ears Unlimited expert, personal communication, 2022).

.03 Haptic impression of the headset

User insights from the internet

An internet dive into headphone aficionado websites such as Head-Fi.com reveals that user's mostly talk about the fit of the earphones over the ears and the feel of the headband on their head, whether it's clamping force is too high or too low, or their cushioning area adequate. Another important factor is that heat from the head is released through the ears. As headphones block this pathway, it is important to consider what material to use to achieve a good thermal balance (Klasco, 2019). However this is less of an issue for open back headphones.

Sennheiser's user insights

Sennheiser's over-ear headphone expertise revealed the following points of attention for comfort in the design (Christian Ern, personal communication, 2022):

• There is a high number of individuals who are extremely sensitive on the top of their head, around the center of the skull.

• The area around the ears, where ear pads of over-ear headphones usually rest, can be a slightly sensitive.

  • With too little pressure, the ear pads don't seal properly and ANC and bass performance are reduced. Also, users might be afraid of losing the headphone.

  • With too high pressure, many users feel uncomfortable, although this specific area is not so sensitive to pressure.

  • The heat under the headphones builds up in this area after some time.

• One area that is particularly sensitive around the ear is the junction of throat and jawbone.

• Another issue is when the inner diameter of the ear pads is not large enough, or if there is not enough height for the ears inside the ear cups. Then you may exert pressure on the ear itself. After some time, this can become painful. Even the release of the pressure might then give you a painful impression for a little while.

k.i. There are key aspects that contribute to the comfort of the headphones

All in all, the elements that contribute the most to the user's haptic impression of the headset are (see Figure 39):

- The earphone and headband cushions and area
- The clamping force of the headband
- The weight of the object on the head
- The heat dissipation capability

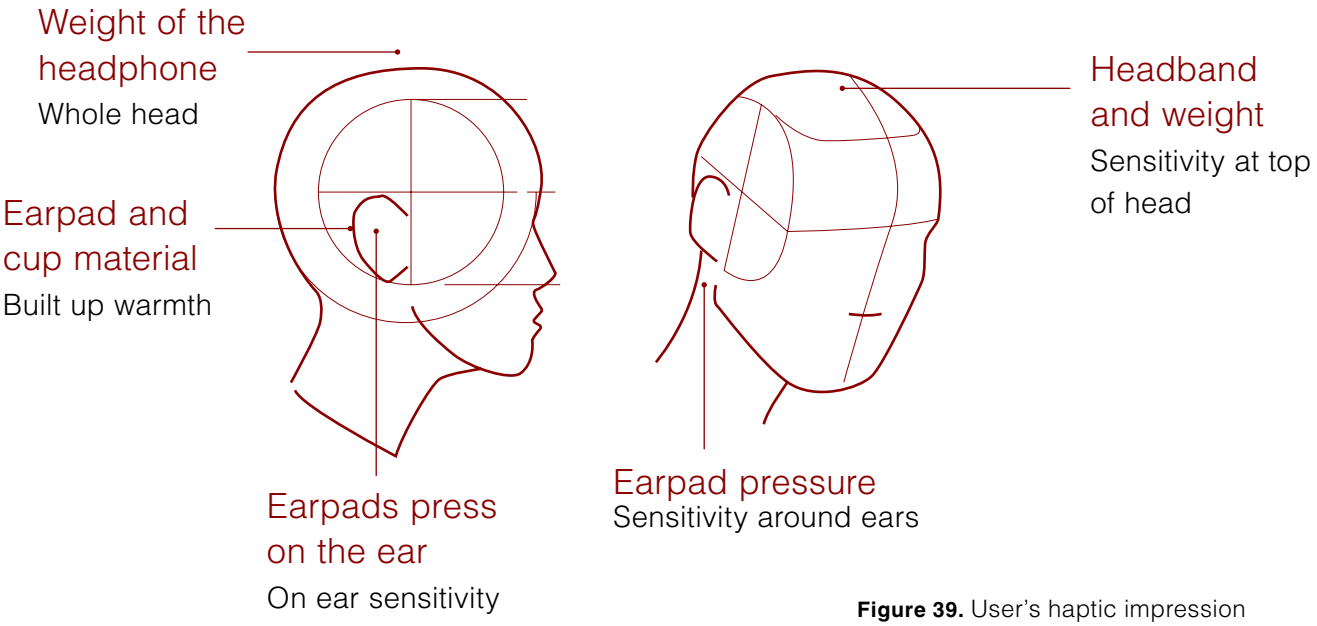


Figure 39. User's haptic impression

.04 User interaction and journey

When the user reaches out to the headphones and places them on his head, he is actively exploring the object and discovering its properties (active touch), but also feeling the properties that the object impresses onto his body (passive touch) (Gibson, 1962).

The interaction with a headset shouldn't necessarily be limited to the moment when the object is on our heads, already emitting sounds. Rather, other interactions become possible as the user picks them up, moves them onto or off their head, and manipulates the cables. For instance, during the listening experience, the user could be inclined to reach out and touch the outside of the earphones if there is a welcoming texture (active), or the cushions could tickle the ears in a specific moment (passive).

The following question arises: can we fully experience the product by encouraging other moments of contact during the user journey?

If we analyse the current user journey of the headset in question, taking into account the studied headset impression in the previous page, it is limited to a few steps, that can take place in different order, in which the user (see Figure 40):

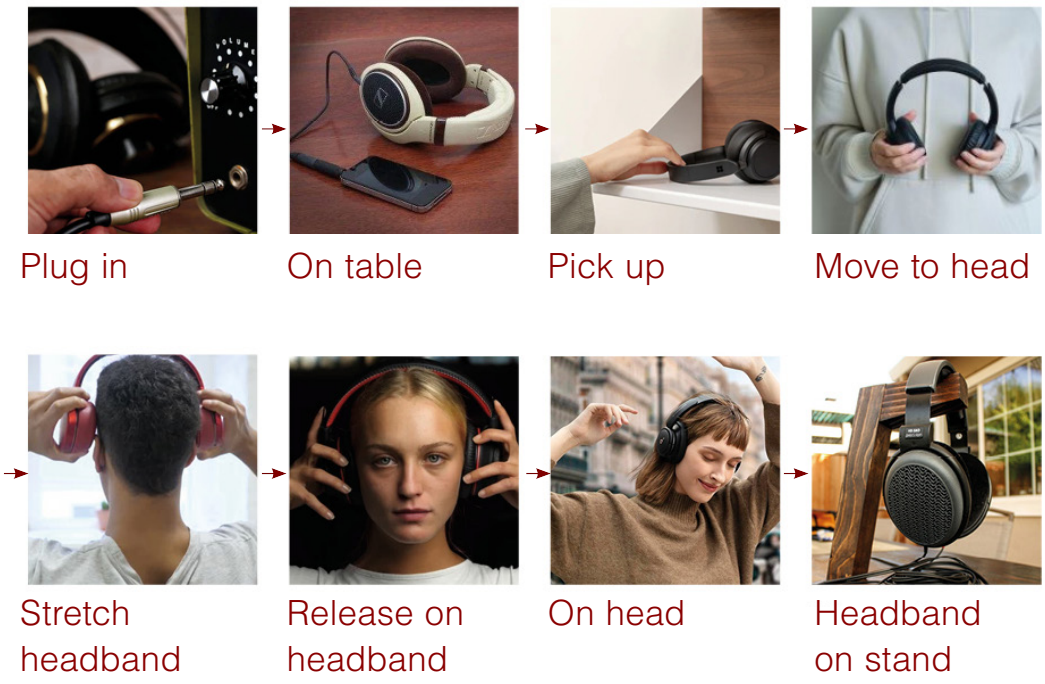


Figure 40. User journey

Let's look further into the interaction. The initial motivation of the user with the headphones is to use them for their function, listening to music. However, once again, other interactions are also possible if the user journey is expanded, with different motivations. These other motivations could be, playing, a non-functional reason, to explore the object, or by accident (Sonneveld and Schifferstein, 2008).

Relevant moments in user journey

k.i. The initial interaction moment with the headphone is relevant, expectations are confronted

• The instant when the user picks up the headphones initially, haptic information is gained and compared with the previously formed expectation (see chapter 2.03).

• This happens again the instant the headphones lay independently on the ears and head. The user will once again gain information on the object's haptic properties.

k.i. Sensations build up or disappear in the user journey

• A second type of moment occurs in the passing of time. After a while, all existing sensations felt by the user will have either vanished or built up, the latter resulting in a negative haptic experience (see chapter 2.02).

Haptic body map and relevant object properties

This user journey reveals what parts of our body are involved in the interaction and how we might come to discover and experience the object's properties. Figure 41 shows the relevant parts of the headphone and areas of the body, involved in the haptic user journey.

To see the full user journey with the involved body and object parts see Appendix 4.

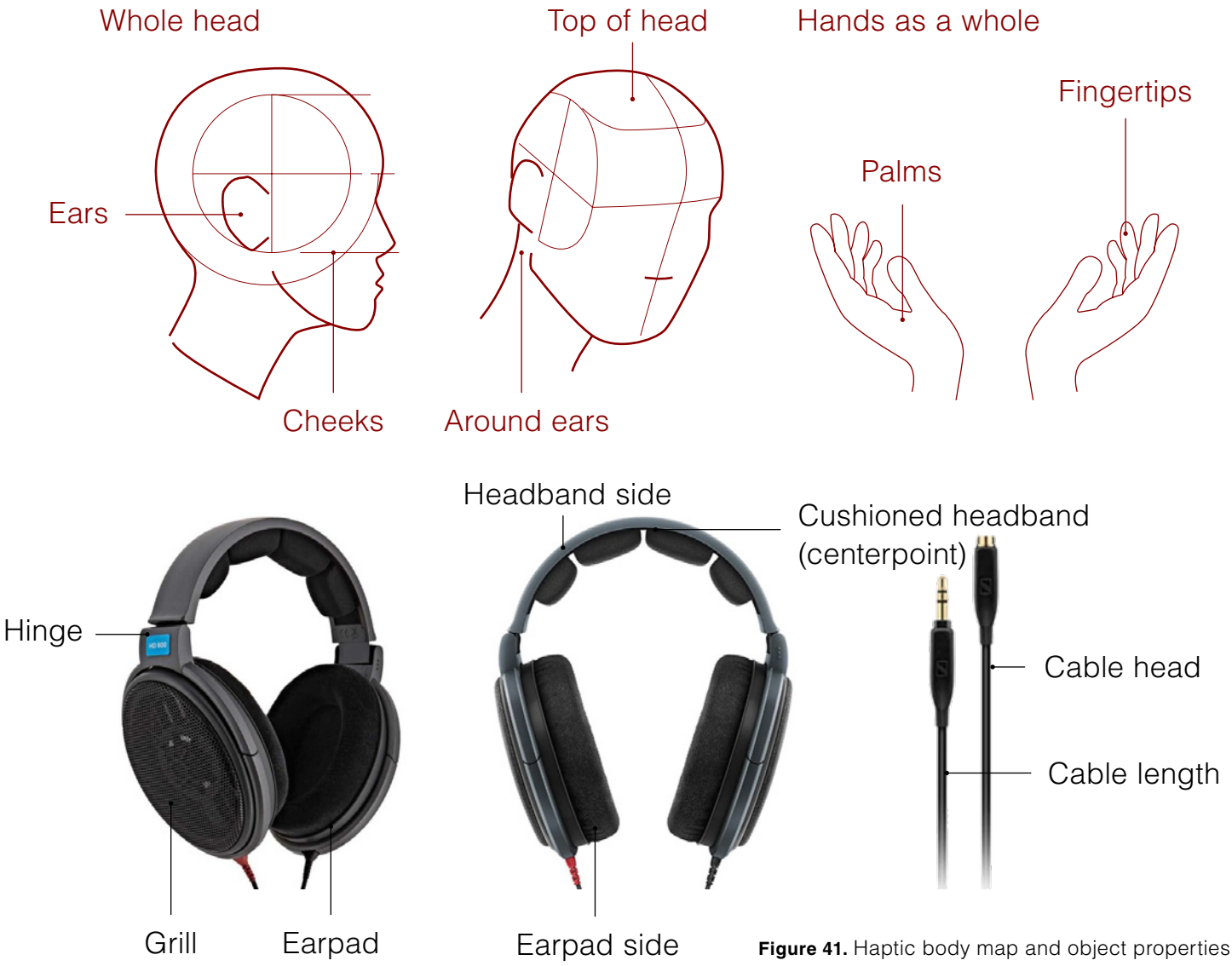


Figure 41. Haptic body map and object properties

Key insights

Looking back at the key insights gained throughout this chapter, there are some main points that stand out.

Potential for HD6xx haptic redesign

The HD6xx line offers a good opportunity to be subject of the redesign. On the one hand because of the freedom in design, possible thanks to the higher prices and local manufacturing of the audiophile line. But also because this model is considered a staple of Sennheiser, but an old fashioned one. Its redesign could offer expanding the user group to younger female crowds, in line with Sennheiser's intentions. Also, the audiophile target group is more perceptive to build quality and fine design features, thus more appropriate for a haptic redesign.

Furthermore, there seems to be an opportunity to introduce haptic aesthetics into the headphone market, as it has not been explored yet. High-end headphone consumers seem to be open for innovation in the market.

Haptic aesthetics and time

Despite the aesthetic experience being an immediate, automatic response to what our senses perceive, it is a response to stimulation we feel in time. How long a sensation lasts is a key aspect for whether we feel pleasure or not. Pleasure being the positive aesthetic appreciation that can result, in this case, from haptic engagement. In the case of the headphone, the initial moment when we pick up the object is key, it confronts the user with its expectations of the headphone.

Haptic aesthetics in the headphone

In order for there to be pleasure (haptic aesthetic liking), there needs to be underlying comfort. The literature review disclosed the aspects that contribute to comfort in a headphone, the most relevant being the weight of the headphone and the heat build up in the earcups.

As for what users like, there is an appreciation for metal bodywork instead of plastic.

Looking at the HD6xx line, a key haptic aspect of the headphone is the driver, which vibrates to make the music.

Haptic sense

There are many ways to interact with an object, we can actively decide to do so, or passively receive the impression, touch, sensations of it. Hands are our usual way of interacting and an essential gateway to the haptic sense. When we interact we form one overarching haptic impression of the object. The haptic sense not only involves touch, but also our body movement (kinaesthetics), and perception of it, which can make interactions haptically rich.

.03
Exploring

As has already been shown in the previous chapter, there are many factors that contribute to a haptic aesthetic experience. In order to determine what approach to take in the redesign of the headset, an exploratory session was held. Chapter 3 explains the session and its outcomes.

.01 Session

For this session the participants were able to actively engage with low-fi prototypes in a given context (experience prototyping). In this way identifying potential design directions and opportunities for haptically rich headphones, and highlighting questions for further research (Buchenau and Suri, 2000).

The study was not focused on the outcome of the session, but on observing which tools and methods the designers used for this task, as well as how they experienced, understand and design for a highly haptic head worn object.

.01 Research objectives

The main questions the test aimed to answer were related to the goals, mission and research questions of the project (see chapter 1.02):

Q1 Which object properties are most relevant to feel pleasure (haptically) while using headphones?

Q2 What haptic (including kinaesthetic) property combinations are able to embody novelty, typicality, unity and variety?

Q3 Does the integration of other interaction moments and points (active and passive touch) in the user journey add to the haptic aesthetic experience?

.02 Method

This test relies on the phenomenological research methodology, which studies the lived experience to unravel consciousness of the participants and gain qualitative insights (Sonneveld, 2007). It is based on the method of experience prototyping.

Four groups of three design students (two groups per session) were presented with a toolbox containing headphone components, materials and techniques to modify the headphones, as well as a set of guidelines to do so. In the previous days to the test, the students were asked the following sensitizing question: What objects are pleasant to touch, hold, wear, move around, interact with? Why are they pleasant?

In this way the students were more aware of their body sensations and what they perceive as haptic, for the session (Sanders and Stappers, 2020), (Sonneveld, 2007).

In a first part of the session, the students were asked to explore novel haptic experiences using the toolbox. In the second part they were instructed to converge their exploration to build a haptic novel headset that feels beautiful.

The designers were asked to think out loud during the process and participated in a semi-structured interview.

Because the goal of the session was to find ways (relevant tools and properties) in which to increase haptics, design students were chosen as participants for the exploratory session instead of audiophiles. It can be argued that the designer, with usually a more creative mindset and relevant design knowledge, is particularly adequate to discover new ideas in which to create a haptic headset.

The context was set, and the user journey of an audiophile was explained to help the designers immerse themselves in the mind of an audiophile, and perform movements that were relevant to that specific context (Sonneveld, 2007).

Participants

- N=12, in two sessions of N=6
- Design students
- 9 male, 3 female

Stimuli and equipment

The main stimuli used within each group was a toolbox, comprised of a series of materials, components and tools that enable the participants to create experience prototypes that cover the spectrum of

Figure 42. Stimuli

material properties suggested by Sonneveld and Schifferstein, 2008. Their classification can be seen in Appendix 5.

The weight, geometry and moving parts are highlighted by providing the participants with materials and tools to explore these aspects. The collection included led strips to build weight, and different kinds of foam and wires to build volume. As well as the necessary cutting and assembly equipment.

Procedure

1. The participants were first given a set of headphones to place on their heads and interact with (this was omitted for the second session to avoid referencing to traditional headphones).

2. Then, an explanatory introduction was given, where the theoretical background was explained. Then, a demonstration of the haptic toolbox was given, and finally the participants were given their task and set to work in their respective groups (15 minutes). The participants were divided in two groups of three members each.

3. Their first task was to explore what feels haptically novel, using the toolbox components in order to understand their haptic preferences (25 minutes).

4. The next task was to converge their results into a “hybrid prototype” of a haptically novel headphone, as a team (25 minutes) (see Figure 44).

5. A plenary session was held for each

Figure 43. Sensitising materials

Collection of sensitising materials and objects. These have been selected to highlight the properties of material, texture and temperature described by Sonneveld (Sonneveld and Schifferstein, 2008), and the geometrical and physi-chemical dimensions of texture suggested by Zuo (Zuo, 2011).

1. Foams: soft, rough, elastic
2. Warm, soft fabrics
3. Soft, multi-layered materials
4. Dense, elastic synthetic fabrics
5. Hard, warm wood
6. Fine smooth light fabrics
7. Fine, smooth, dense fabrics
8. Animal fabrics, soft
9. Coarse fabrics
10. Dense, fine, warm dry, paper-based
11. Slippery, plastic
12. Coarse, meshes with holes
13. Hard, cold, ceramics, metal, glass

group to share their results and discuss their outcome, answering questions in a semi-structured interview. Each group was allowed to interact with the other team's "hybrid prototype". (20 minutes).

Data collection

The collected data was of qualitative nature and collected by:

- A background questionnaire: asking about the user's headphone experience.
- Observation and video recording of the group sessions and plenary sessions where participants were asked to "think out loud".
- Semi-structured interview
- Experience prototype of each group'

In this way the dataset is comprised of video footage, images, notes, and transcriptions.

Analysis

The analysis was conducted by coding the data. Coding is an approach to qualitative data analysis, that serves to identify patterns of shared meaning in a data set and assign an essence-capturing attribute to these patterns (Saldaña, 2013). This method was chosen for its flexible nature. The analysis was driven by an initial list of codes, determined beforehand to harmonize with the study's theoretical framework and research questions (Saldaña, 2013). This approach gives a less rich description of the data set but provides a more detailed analysis of aspects of the data that are relevant for the scope of the project. The analysis was conducted both by directly observing and at a latent level, reading into the assumptions underlying the data. This was also enabled by the video footage, allowing to observe participant's techniques and reactions when experiencing and building the prototypes.

A first round of coding using the pre-codes (in the form of words), was conducted using structural coding, to identify large segments of text on broad topics (MacQueen et al., 2007). The similarly coded segments were collected for more detailed coding and analysis in a second round, this time using pattern coding. Pattern codes identify emergent themes in the data. "They pull together a lot of material into a more meaningful and parsimonious unit of analysis (Miles and Huberman, 1994).

The following phases were conducted:

- Familiarising with the dataset: transcribing and reading the data, making observations from the video recording.
- Generating predefined codes (main themes) using the theory and the research questions.
- Structural coding: searching for themes in the dataset, using the codes.
- Pattern coding: reviewing themes and searching for subthemes.
- Defining and naming subthemes
- Analysing the resulting prototypes and choices in terms of the aesthetic theory (information vs consonance).

The pre-codes that were generated (main themes, shared patterns of meaning) are:

- Haptic aesthetics (object properties): related to research question Q1
- Haptic novelty: related to Q2
- User journey: related to Q3
- Sensations: in order to understand how the students perceive and design with sensations.
- Mental models to build haptic aesthetic headphone: in order to identify the student's approach to build a haptically rich experience.
- Techniques to build haptics: in order to identify methods to physically construct a haptically rich sensation.

.03 Results and discussion

The collected insights and observations were colour coded following the above themes and procedure. The full collection of insights, and their coding, can be seen in Appendix 6.

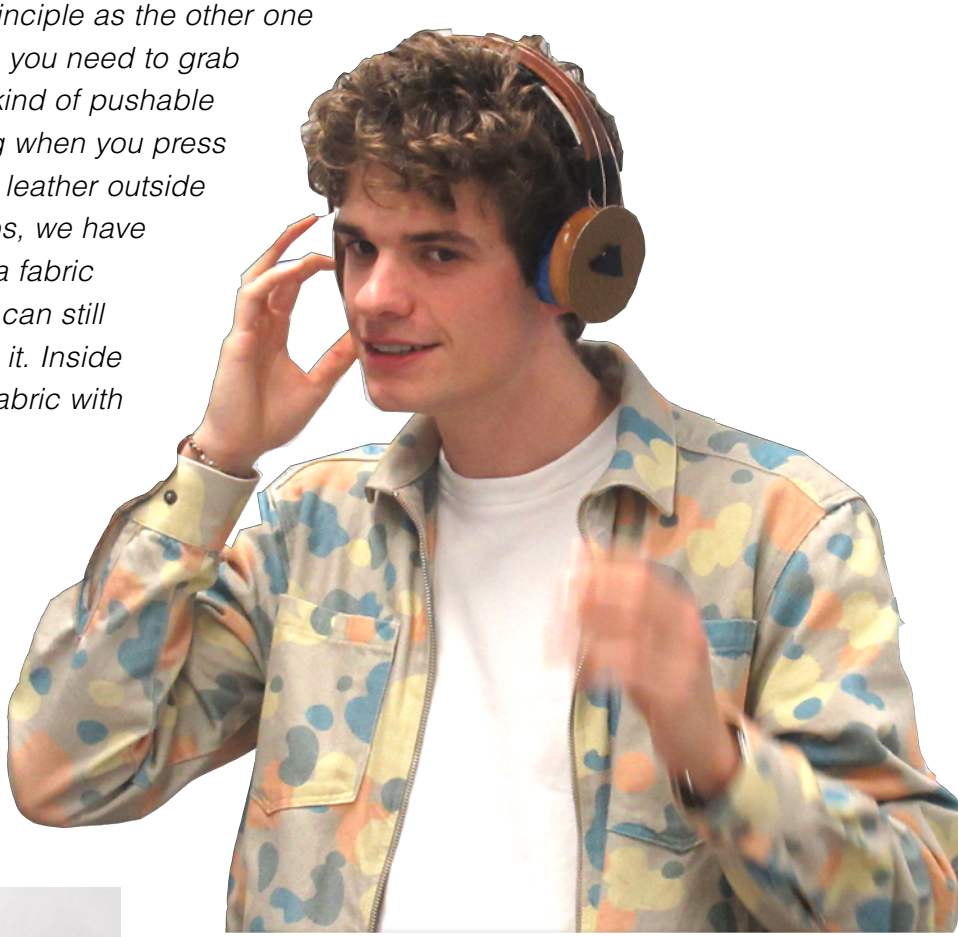
Outcomes of the session

The prototype outcomes of the sessions were analysed using the guiding aesthetic theory as a lens. What degree of haptic novelty have the designers embodied, have they incorporated elements of typicality within, and unity/variety, for an aesthetic (haptic in this case) design?

Figure 44. Participants interacting with the toolbox

Group A

"The headband follows the same principle as the other one (referring to reference headphones), you need to grab it to fit your head, so we use some kind of pushable foam, and it has a really nice feeling when you press it. We wanted to combine it with the leather outside to make it feel warm. For the earcups, we have a metal outside with a pattern, and a fabric layered on top in the middle so you can still feel the pattern of the metal through it. Inside the earcups we have a breathable fabric with foam."



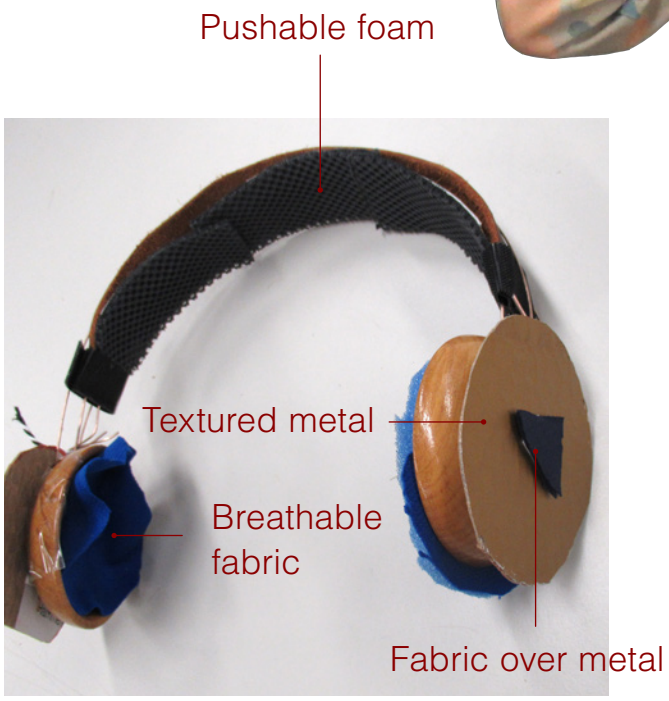


Figure 45. Prototype outcome of group A

Discussion

The novelty of this prototype (Figure 45) lies in the many textures and material layers that comprise the outside of the headphone.

This design is low in information (haptically), in that the typology and interaction remains as in traditional headphones, typical. Active touch and exploration of the outside textures is encouraged, but not part of the user journey.

The interior of the headphones remains haptically similar to known ones, seeking comfort and ergonomics but not stimulation, with a cushioned interior covered with fabric.

The group altered the headphone materials in texture by layering to increase the information, the novelty.

However, this is balanced out by the choice of materials: metal, leather and wood, similar to what is found in classic headphones.

Group B

"The main theme is heat, and using that as a function of longevity, because if you are going to be wearing it on your head for a long time, heat was the biggest frustrating component for all of us. There is a led band at the top, which gives it a heavy exquisite feeling, and is just sitting there. The headphone is a foam ring covered in neoprene. On the inside of this ring there is a thin ring of wood that is the last point of contact with your head. The wood touches your skull, and the actual foam bits touch your ear (inside the wooden ring), so by the time it gets to your skull there is not much pressure."

Discussion

Overall, this group chose for a novel feeling inside the ear cup in that there is a contrast between warm/hard and warm/soft materials, see Figure 46.

These are conventional materials, wood and neoprene with foam, yet applied in unconventional areas.

The contrast in sensations can be understood as haptic variety.

The choice of headband also speaks for novelty as it enables a different interaction when placing it on the head, as well as an unfamiliar weight distribution. The novelty and variety are matched by the typicality of the product components and unified layout.

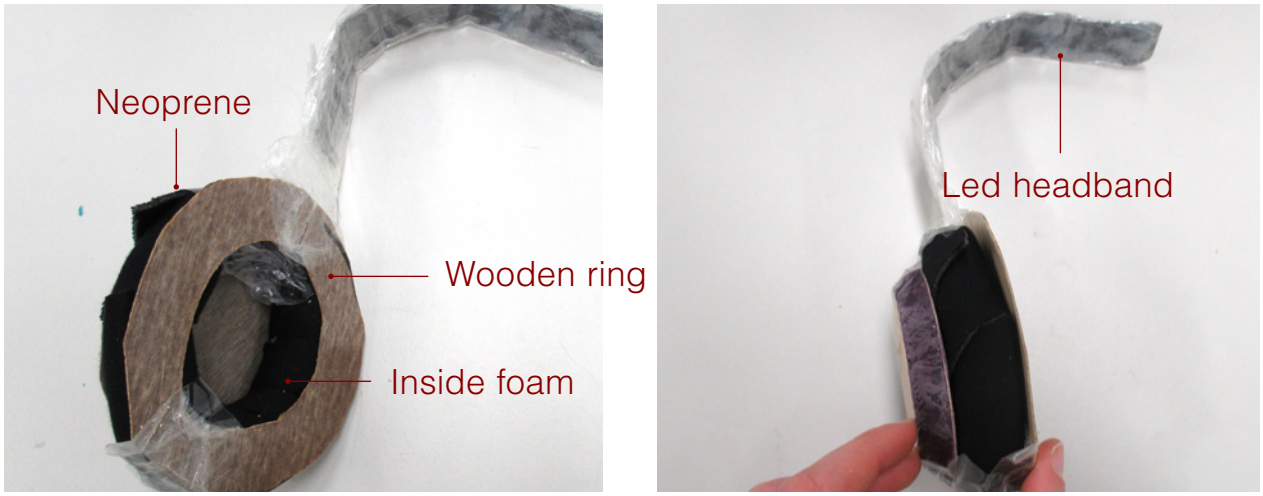


Figure 46. Prototype outcome of group B

Group C

"For the part that touches your ear, we picked memory foam, one part uncovered, one part covered in the red plastic paper. Because it feels fresh and novel. On the outside there is cork covered with silk, you feel through the silk the texture of the cork, and in the contour we have a strange type of plastic which is novel because usually it is hard plastic.

For the headband we have chosen led because it gives structure but also flexibility. On it there is a massage wire. When you put it on and off it scratches your head, it feels really good. I think it really signifies the moment that you work 8 h and you decide to stop. And we have the supporting headband, which band gives you the opportunity to wear it either at the back of your neck or the front. The asymmetry of the earcups, will help you feel which side is which."

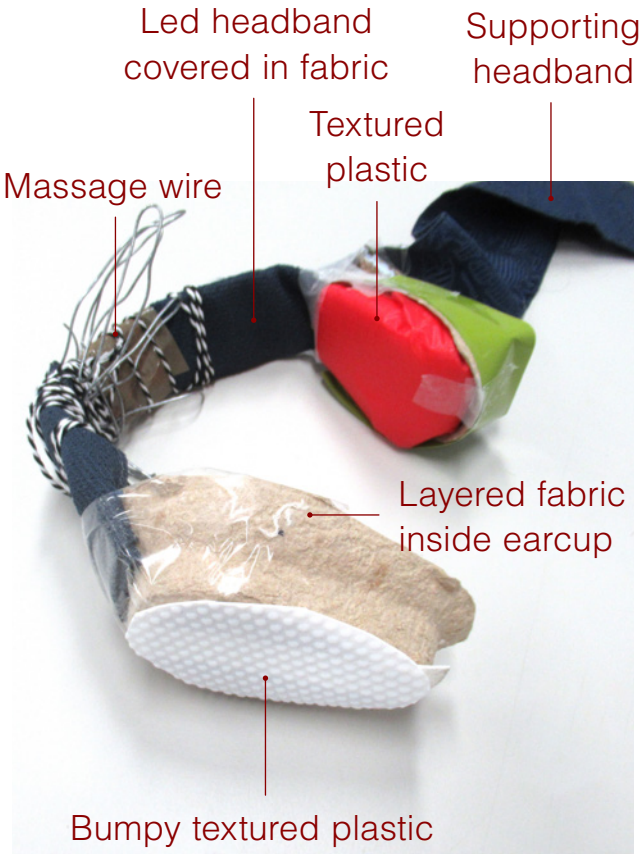


Figure 47. Prototype outcome of group C

Discussion

The resulting prototype, see Figure 47, displays high novelty and low unity in that it presents interior and exterior asymmetry in textures, which is not found in current headphones. Also in the choice of highly textured materials and contrast in these, from smooth silk to bumpy plastic, increasing the design's variety in textures and sensations. The extra components, adjusting band, led headband and massage wire, allow for a user journey that expands slightly on the current one, as the band and the massage wire add more haptic points and moments of contact and thus sensations. Once again, the typicality is found in the familiar construction of the object, two earcups and a headband, however, at a lesser extent than the outcomes of group A and B, perhaps at the cost of haptic aesthetic value.

Group D

"We thought the headband on top can become quite tiring in long sessions. The headband alleviates the pressure on top of the head. The leather gives it some structure and a fancy feeling. And because it's a band it has a very different haptic experience, you stretch and tie it.

Normally the outside of the headphones is hard, but we wanted to do the opposite. The inside is hard where the electronics are and you can explore the electronics because the outside is soft. We thought a cool interaction you can have with it is that you can squeeze it.

Often I try to adjust my volume and I skip a song, so we added a directional feeling to it, you really feel what is what. Also, if you want to get rid of your music you can take one headphone off, or slide it back etc. On the inside we have this soft luscious feeling, very soft, kind on the ears and very comfortable."

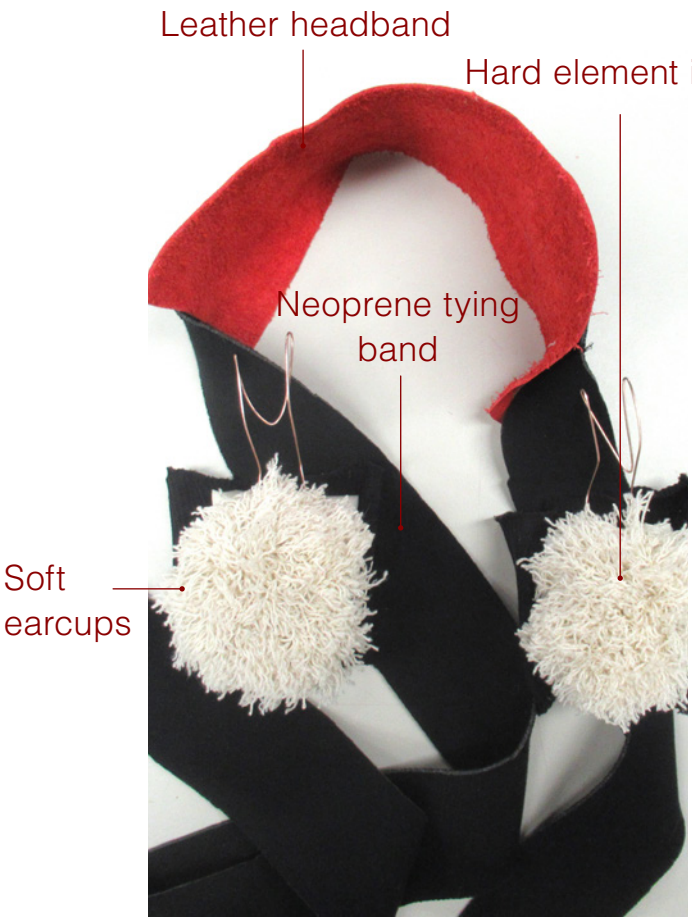


Figure 48. Prototype outcome of group D

Discussion

The sensations felt when experiencing this group's prototype (Figure 48) are opposite to what is expected in a headphone, yet pleasant to interact with as it is soft for the ears and the hands when engaging with it. The hard mass inside the soft earcups gives these weight and depth, encouraging the user to actively squeeze and explore the hard element. The user must wrap and tighten the band around the head. The pressure is now on the perimeter of the head, leaving the earcups to dangle. In this way, it is a highly novel interaction, different from what is known.

However, as it is composed of two earcups and a bridging element, typicality is present.

The group chose leather for the headband as a staple of known quality and smoothness. Furthermore, it could be said that the product is novel but doesn't have high variety, the overall feeling of softness when interacting with it feels unified and coherent.

.02 Themes

Figure 49 shows an overview of the themes, and the subthemes within each one. The following pages narrate this overview with added depth. For the full set of original insights see Appendix 6.

k.i. The subthemes discovered in the session reveal aspects of what makes a haptic aesthetic experience

Haptic novelty

- Feeling of structurally different designs with other weight distribution
- Feeling multiple sensations simultaneously
- Haptic novelty can be related to dislike
- Involving different body parts and creating other interactions
- Switching sensations to what is known: soft instead of rigid, or asymmetry

Sensations

- Making multiple or extreme sensations by: pairing in harmony, contrasting, overlapping...
- Sensations in time are seen as a negative experience. They are/can be overloading
- Appreciation of snuggling and support but dislike of vacuum
- Limiting sensations in certain areas, to leave only comfort
- Viewing sensations either as an independent experience, or accompanying one

Object properties

- Appreciation of weight for quality but also concern of heaviness
- Appreciation of smooth yet sturdy materials: rounded wood, leather
- Appreciation of softness of foam and memory factor
- Feeling of texture is liked: deep texture or superficial texture
- Matching weight and form factor
- Concern for built up warmth. Preference for dry, resistant surfaces

Mental models

- Accompanying an envisioned experience with haptics
- Matching material and haptic property to the feeling of an interaction
- Following ergonomics concerns
- Transforming current negative experience into a positive one
- Design driven by the desired sensations. Deductive strategy
- Design driven by material selection. Inductive strategy.

User journey

- Adding steps to user journey that create sensations
- Changing the interaction, different areas are stimulated
- Encouraging active touch can change the user journey

Techniques

- Using a material for one of its properties
- Layering materials
- Redistributing the weight in the object
- Stimulating with: multiple sensations, texturing, several densities, surprising textures
- Creating warmth / cold with materials

Figure 49. Theme and subtheme overview

.01 Themes and subthemes

This theme seeks to understand how designers create and perceive novelty for the haptic senses.

One subtheme that was present in most groups was *creating multiple sensations at the same time.* As said by a participant, “I like it when there are more things going on”. For this, the designers textured elements that are usually flat/plain, often tried layering different textures, and expressed surprise when exploring materials with a variety of textures, ridges, densities etc. (variety).

Participants also experienced *unusual structures*, something “structurally bizarre” as novel. Non-rigid parts such as a mesh where usually there is a rigid part, or a flexible, bendable component in place of the headband. These alternative structures also meant that the *weight was distributed differently* on the head and ears, creating also a novel feeling. The designers were trying out different weight and pressure distributions in their heads.

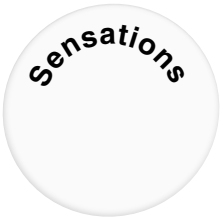
Changing the interaction and user journey, for example, by adding an extra band to wrap around the neck, meant other areas of the *head and hands were engaged in different stages*, which was also felt as novel (see Figure 50).

Also, participants were creating unfamiliar experiences by *switching sensations* to what is known, using soft plastic where the known is hard plastic, a bendable element where usually it is rigid, or with asymmetry etc (see Figure 51).

Lastly, it seems that some designers, when selecting very novel elements, did not find these pleasing. One participant said “It’s very interesting but I absolutely hate it”, which indicates that *novelty* can *be related to dislike.*

Figure 50. Participant tying cloth around her head

Figure 51. Soft, flexible plastic as headband



Sensations, as a theme, not only includes what sensations were appreciated by the designers, but how they utilised sensations in their design.

A subtheme that was found in most groups was the search for a “snugly” feeling, one of support and security, without feeling vacuum and stifling in the ears.

Several groups spoke about *limiting sensations* in *certain areas*, for instance, in the ears, they looked to design a comfortable experience lacking of stimulation. Another participant spoke of a slightly ticklish feeling, by which we can understand that the magnitude of the sensation can also be limited.

Most participants thought about how the *sensation would evolve in time*, mostly to a negative one, “This is cool but if you do this for 8h it would end up wet”. Especially heat, pressure and weight, thus discarding certain materials.

Another subtheme established is that *a sensation can be an experience* in itself if it is predominant in a certain moment “The dryness of how things feel” (see Figure 52).

But *it also can accompany an experience*, for instance a sensation of release when taking off group c’s headphone prototype.

A subtheme found in the session outcomes is the attempt to create *multiple and intense sensations* by either complementing each other in *harmony, contrasting or adding and overlapping.*

Figure 52. Participants experiencing the dryness of the cardboard

This theme refers to the object properties that designers considered to build a haptically aesthetic headset, what they perceived as aesthetic and what not.

During the session, many participants showed a *concern for built up warmth*, from wearing the headphones for long periods of time. In this way, some expressed a liking of dry surfaces that do not feel wet or slippery, as would some with sweat. They also showed a linking of *classic natural materials such as smooth wood and leather*. Most

groups chose soft foam for the earpads. Also during the exploration, participants expressed *pleasantness when interacting with foam, especially memory foam*.

Another highly present subtheme was the *appreciation of weight in the product*, with a concern for it *feeling too heavy*. Many of the students expressed liking the weight on the top of the head, as a perception of safety and quality, but disliking the clamping force that usually comes with headphones, in consequence, they searched for a redistribution of it. One student also mentioned the dislike of the object's *weight and form factor* not *matching*.

The designers exploration showed that there is a *liking of texture in two ways: Deep and superficial texture.* Deep texture, which allows for information in its depth, achieved by layering materials, inserting one in another, or with dense and springy materials (see Figure 53). As said by one student, "I like the consistency of one with the surface of the other". Or superficial texture, adding ridges, extrusions, recesses and creating a pattern.

Figure 53. Participants feeling layered material created by himself

The following theme looked for ways in which the groups changed or played with the user journey of the headphones.

A main subtheme was *adding steps into the user journey* which, inevitably, *increase the sensations in the journey.* For instance, adding the adjusting band means and extra wrapping action that engages also the neck. Also, many *novel interactions* were discussed and tried out by the designers, that generate *different motions and areas of stimulation*, such as wrapping, tying, sliding, tightening, twisting and squeezing.

Lastly, the user journey was also changed by adding elements that encourage *active touch* (initiated by the user), as said in one group about their design, "The inside, where the electronics are, is hard, and you can explore it because the outside is soft".

As for what the student's approaches were, to build a haptic aesthetic headphone, they are captured by the theme mental models.

Most groups showed at some point *ergonomic concerns*, the first subtheme. The participants' haptic aesthetic pleasure mostly started from ensuring comfort.

One strategy that was predominant in the groups was *envisioning a product experience*, and thinking of *how haptic elements are able to help construct this experience or expand it.* For example one participant's vision, "You can feel secure and isolated from your environment", or "It gives me the feeling that it's me time", the latter referring to the all soft textures.

Along the same line, some participants tried to think of the *current experience and their current wishes for it,* a*lso transforming the negative elements into positives.* As said in by one of the groups, "To get rid of the strangling feeling, if it is soft then it's a hug".

Some groups followed a more *inductive strategy.* Starting with selecting which materials they liked, then choosing which area in the body they should be in contact with, and then integrating this into the design. Other groups followed a more *deductive strategy*, choosing which sensations they would like or not, in a certain area and then working backwards to create it with the object's properties.

The final subtheme in this category is *working from the wanted interaction, thinking of what direction of movement it has, what feeling pairs well with it, and what material matches* these.

This last theme looks at what techniques the designer's use to physically build a haptic sensation.

Figure 54. Participant texturing surface through layering materials

As mentioned above, one technique used by many participants was l*ayering materials* one on top of the other to combine textures or create deep texture.

To create haptics, the designers looked into *texturing previously flat elements* (see Figure 54), *combining densities and pairing properties that cause simultaneous sensations.*

Finally, certain *materials were associated with warm/cold, and used to manage the warmth.*

.02 Conclusion and limitations

Looking at the outcome of the sessions, the participants were instructed to create: Novel, haptic headphones that you aware of and feel great.

k.i. The designs can be translated to the elements of the aesthetic theory: unity - variety, novelty - typicality

The analysis of the prototypes (see Figure 55), looking through the lens of the theory, led to a subjective interpretation of the aesthetic mechanisms behind them. For instance, it could be said that group A achieved a more typical than novel design, while groups B and D seem to hold high novelty matched with typicality. Group C's design's novelty is high and hasn't been completely balanced out by typicality, resulting thus in a less haptic aesthetic design.

Figure 55. Prototype outcomes

In this way, it can be argued that the designers, when instructed to create something haptically novel and aesthetic, also used elements that created haptic unity and variety, but most of all novelty and typicality, looking for their own balance and following subconsciously the aesthetic theory. This evaluation is no proof of the aesthetic theory, but serves as an indication of how the theory may manifest itself.

As for the patterns of meaning discovered, these have been used as input for the ideation phase.

k.i. Working from a vision to design the desired haptic experience

The mental models theme gives a perspective with which to design a haptically rich object, zooming out. The experiential and deductive strategies allow for broader design possibilities as they work from a vision, a wish, and then seek how to materialise it. The inductive strategies, those that start with concrete solutions such as the use of a specific material, and then seek how to apply them, are more limiting in their output and therefore less "exploratory", thus, were less interesting for the ideation in this project.

The object properties and sensations themes lend a zoomed in view of how to achieve the haptically rich and aesthetic design. For example, many participants expressed a liking for weight in the headset or a concern for built up warmth. As could be expected, many participants were "limited" in their preferences by ergonomic concerns such as liking a stimulating sensation but discarding it for comfort.

k.i. Comfort is at the base of a long term pleasurable experience

This indicates that ergonomics, while limiting the haptic aesthetic possibilities should still be considered as a base on which to build the haptic aesthetic pleasure, as seen in chapter 2.02.

k.i. How sensations evolve in time is key to the haptic aesthetic experience

It also highlights once again the importance of time in haptic pleasure, how sensations can become unpleasant after a certain timespan.

The insights gained within the user journey and haptic novelty themes are a rich resource of strategies to embody the zoomed out view envisioned with the mental models, such as adding extra steps and interactions in the process of using headphones.

k.i. There is a close relationship between haptic novelty and dislike

It is interesting to acknowledge the connection some participants had between novelty and dislike, rendering especially relevant the compensation of this novelty with order and sense.

Limitations

Finally, looking once again at the resulting prototypes, it must be noted that although creative, they still reference traditional headphones to some degree. This is due to the task given of creating, haptic aesthetic headphones, which could have been phrased more abstractly, such as “create a haptic aesthetic head wearable”, to generate more exploratory results, perhaps at the cost of more focused “useful” ones. To alleviate this between the first and second session, the headphones given as a reference to interact with, was removed.

k.i. The haptic and visual senses are intertwined

Finally, during the session, it became apparent that the haptic impression cannot be separated from the visual one when interacting with an object, as already explained in chapter 2.02. The designers expressed surprise when something felt different than expected (“it looks a bit flat but when you touch it there are little sensations”), or attempted to make the headphones look haptic, (“it looks hard so I covered it”).

Key insights

For this chapter we must look into key insights as well as the results of the qualitative analysis to form a conclusion.

Subthemes present in the concept headphone embodiment

Some of the subthemes discovered in the exploratory session fed into the ideation and are present in the final design as will be seen in the following chapter. The concept headphone plays with switching the sensations, hard inside, soft outside, to achieve novelty, as well as maintaining the archetype shape, while changing the structure. It limits the sensations on the inside, to leave only comfort, and relegates the sensations and stimulation to the active touch of the outside, encouraging the user to engage during the user journey.

The main topics it attempts to address is warmth and weight, and takes care that sensations do not build up in time.

Designing for a haptic aesthetic experience

The session highlighted ways with which to approach the design process. Working from what sensations are desired in which area of the body, and at what moment of the interaction, rather than directly selecting a material for its haptic properties. It also underlined once again the importance of time, the changing of the impression of the headset and the duration of sensations.

Many participants put focus also on visual aesthetics stemming from the haptic properties, which brings out once again the importance of the visual - haptic sensory pair.

Unity - variety, novelty - typicality

Haptic novelty was appreciated by some users for its novelty but not aesthetically. This puts extra focus on bringing haptic typicality in the design, to balance it out.

Different levels and embodiments of these aspects could be identified within the prototypes. For instance, the use of certain materials for typicality, or to create contrast in sensations (variety) etc. These serve as an indication of how these aspects might be haptically appreciated in products.

.04
Concept directions

This chapter unveils why the final concept was chosen for the headphone design, and shines light on the ideation process and its results.

.01 Ideation

With the insights gained while discovering the background of haptic aesthetics and headphones, and those of the exploratory session, the ideation process began, in-keeping with the following mission statement:

"Creating haptically novel headphones that feel beautiful."

.01 Ideation process

In order to keep the essence of the audiophile line, the following product qualities were established as fixed in the ideation:

- The headphones should remain with an open back, to create the desired sound.
- The concept should not include any additional electronic components but achieve the haptic feeling based on the object properties.
- The headphone controls should not be incorporated into the headset, but in the amplifier.

For this, the key insights from the different topics were gathered to create a mind-map. Through this mind-map it was possible

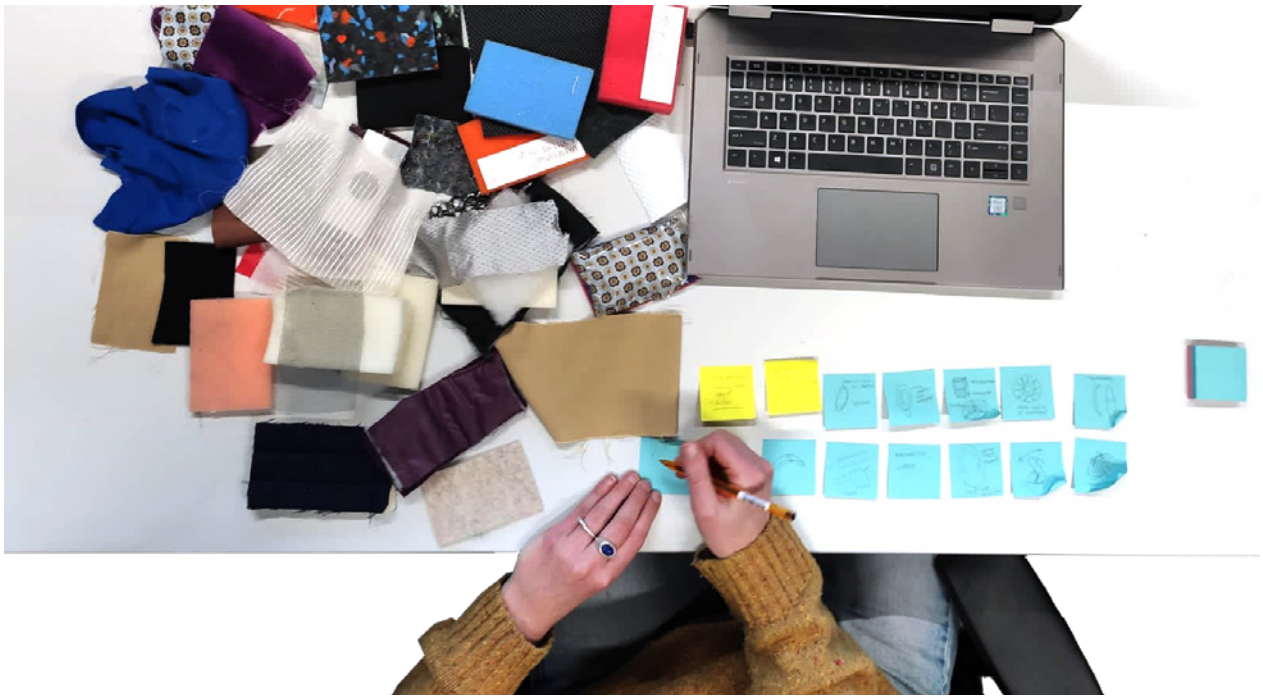


Figure 56. Solving How-To's by engaging with materials

to get an overview of the opportunities to make a headset haptic aesthetic and novel (Knapp et al, 2021).

A selection of these was conducted to ideate upon them using the How-To's method (Daalhuizen, 2020), ideating on opportunities instead of problems (as is usual in How-To). This process was supported with the haptic moodboard created previously, and by engaging with a selection of materials as a sensitising tool during the ideation.

The insights taken from the exploratory session to feed into the mind-map avoided including actual object properties such as specific shapes or materials. Instead, these were in the shape of perceived object properties and sensations, such as warmth, contrast etc.. In order to keep a broad spectrum of object properties as solutions in the ideation. Unity, variety and typicality were incorporated in the concept development, but not yet in the ideation.

Using a morphological chart, the solutions to the How-To's were combined to form three principal solutions (Daalhuizen, 2020).

To access the ideation documentation see Appendix 7.

.02 Results of ideation

The morphological chart resulted in three principal directions that aimed to cover the solution space. Each one was developed further to form a more complete concept, using sketching and a moodboard and finding the key qualities of each direction.

All three results follow to some extent the traditional headphone typology. This is because the insights of the previous phases didn't lead to any clear advantage of stepping away from this, as well as wanting an outcome that is to some extent applicable to the HD6xx line.

Experience prototypes

As this project seeks for the haptic aesthetic ideal, it was imperative to create experience prototypes to embody the haptic sensations of each direction. Each experience prototype was essentially a low-fidelity model that aimed to capture the essence of its concept (see Figure 57). Although these models were feel-like, and not look-like or work-like, their development did give an indication on the difficulty of embodying a sensation and of the visual aesthetics that accompany every haptic aesthetic choice.

Figure 57. Creating the experience prototypes

Figure 58. Kinetic wall

Figure 59. 3D Print on stretch fabric

Figure 60. Half Sphere Dome

Tensile fabric

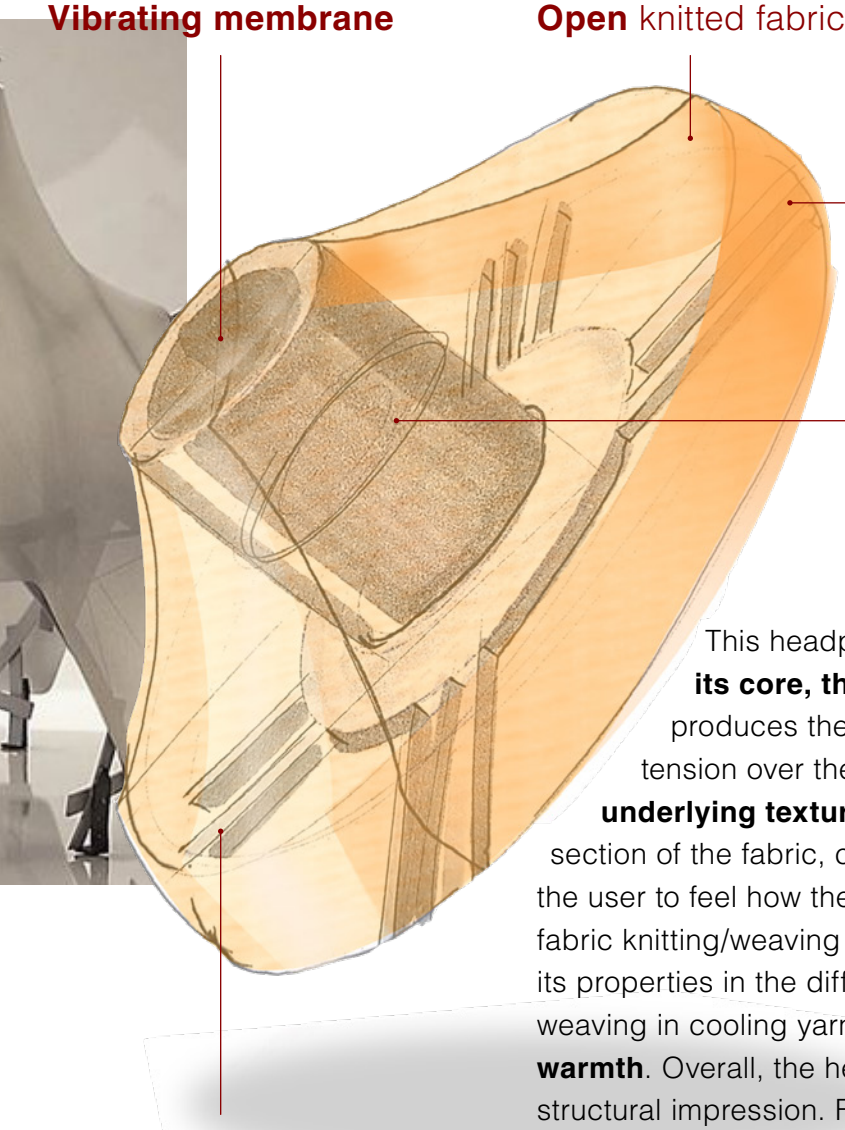
Prototype

For this prototype, two kinds of elastic meshes were used. A structure mimicking the current build of the HD6xx line was 3D printed, which was then covered with the fabrics by sewing or gluing them stretched out (see Figure 61). The model gave an indication of the principle, but failed to convey the progression of the weave, more or less tight, across the different parts of the headphone.

Client evaluation

As explained in the next section, this was the preferred concept. This is mainly because the open character of the design goes hand in hand with the open back headphones, creating a lightweight, structural element. The client thought it would fit best the target groups, also because of its visual appeal.

Figure 61. Prototypes



This headphone inspires the user to **discover its core, the driver,** which is the component that produces the music. Through the fabric that is in tension over the structure, the user can **discover the underlying textures,** actively touching the object. A section of the fabric, could become a membrane that allows the user to feel how the driver **vibrates** to create the music. The fabric knitting/weaving opens up the possibility of changing its properties in the different parts of the object. For instance, weaving in cooling yarns in the earpads to **release the built up warmth**. Overall, the headset gives a **lightweight**, open and structural impression. For inspiration see Figure 58 to Figure 60.

Key qualities: **open, light, tension and elasticity**

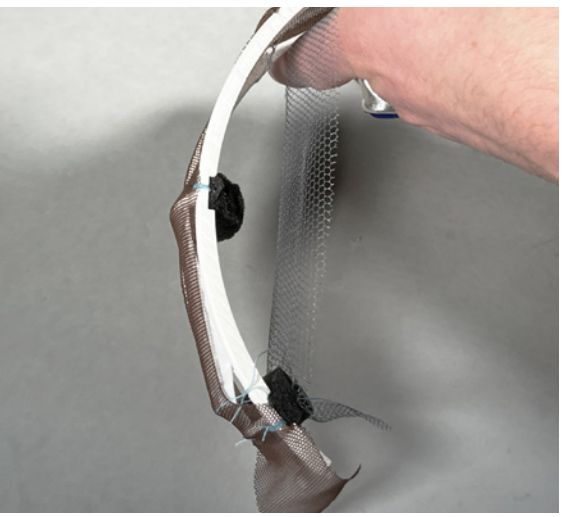


Figure 62. Head movement to music

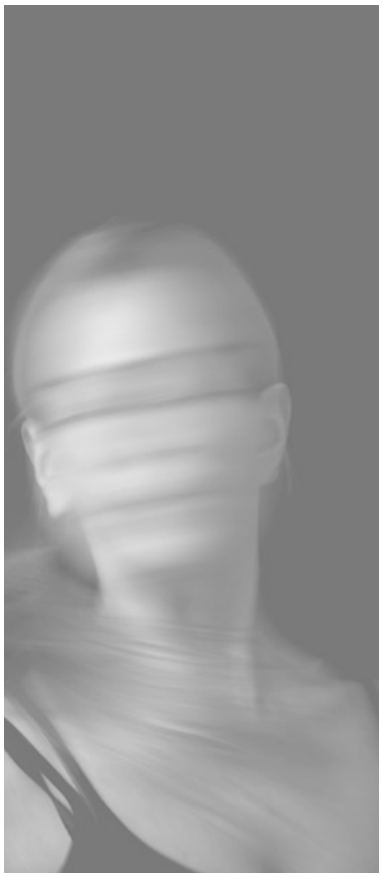
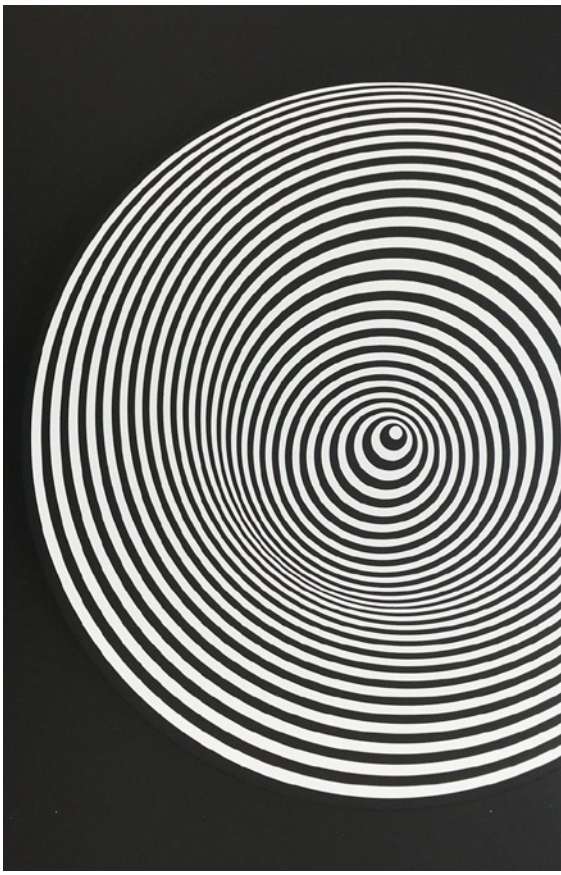


Figure 63. Holdness

Figure 64. Dinamica Circolare 6



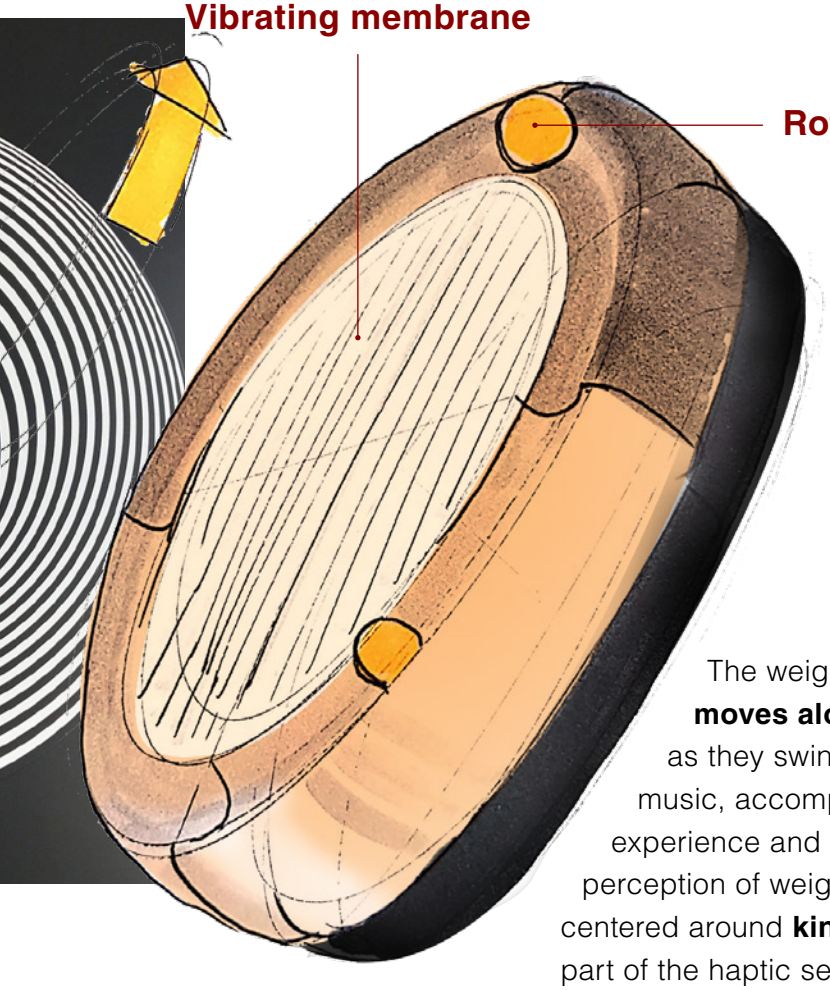
Prototype

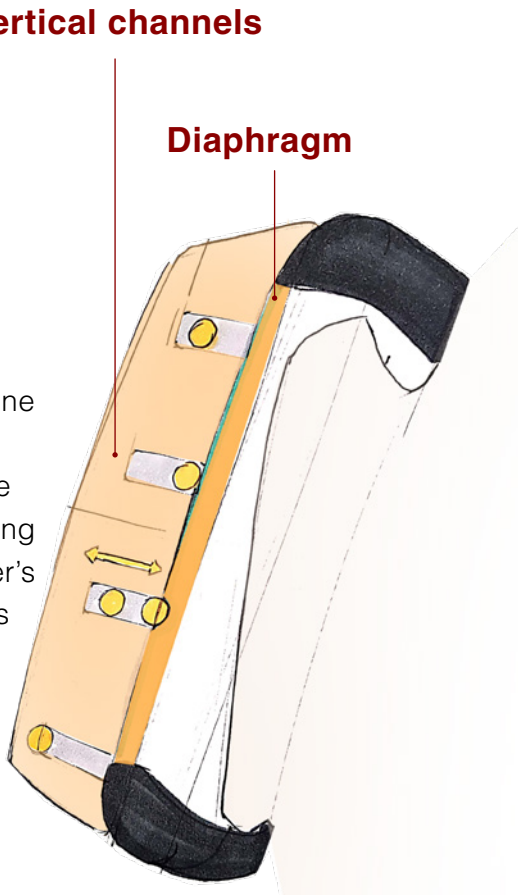
The shifting of the weight in the headphone can be embodied in many ways. For this experience prototype the first attempt was to create channels in the earcup, in several directions, where steel spheres (weights) rolled when moving the earcup. Another attempt was made by attaching a spring with weight to the earcup. The prototypes did not manage to convey the desired smooth weight shift, but rather felt like a rolling element (see Figure 65).

Client evaluation

It was discussed that the movement of the weight could potentially irritate the user, making it a difficult experience to design and prototype. Furthermore, this concept dictates only one design aspect of the headset, it feels more like an “add on”, instead of a holistic haptic aesthetic experience.

Figure 65. Prototypes





The weight in this headphone **moves along** with the user as they swing their head to the music, accompanying the listening experience and shifting the listener's perception of weight. This concept is centered around **kinaesthetics**, the part of the haptic sense that refers to the movement of the body and our perception of it. For inspiration see Figure 62 to Figure 64.

Key qualities: **kinaesthetics, smooth shifting, time**

Figure 66. Clay

Figure 67. Tube chair

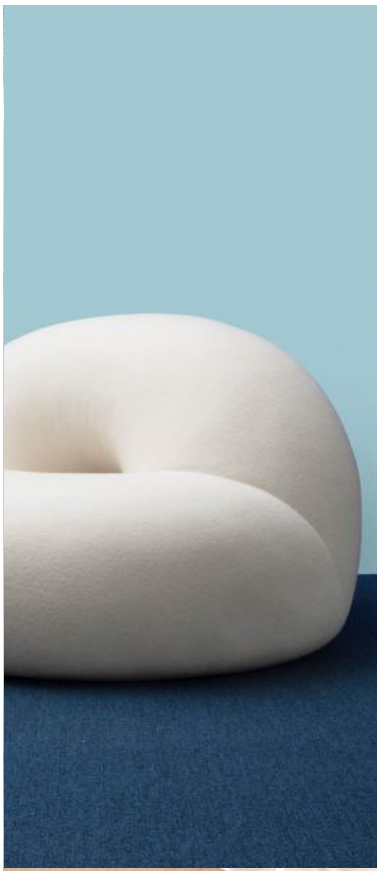


Figure 68. Seduction, Pair 02

Concept C

Cocoon the ears

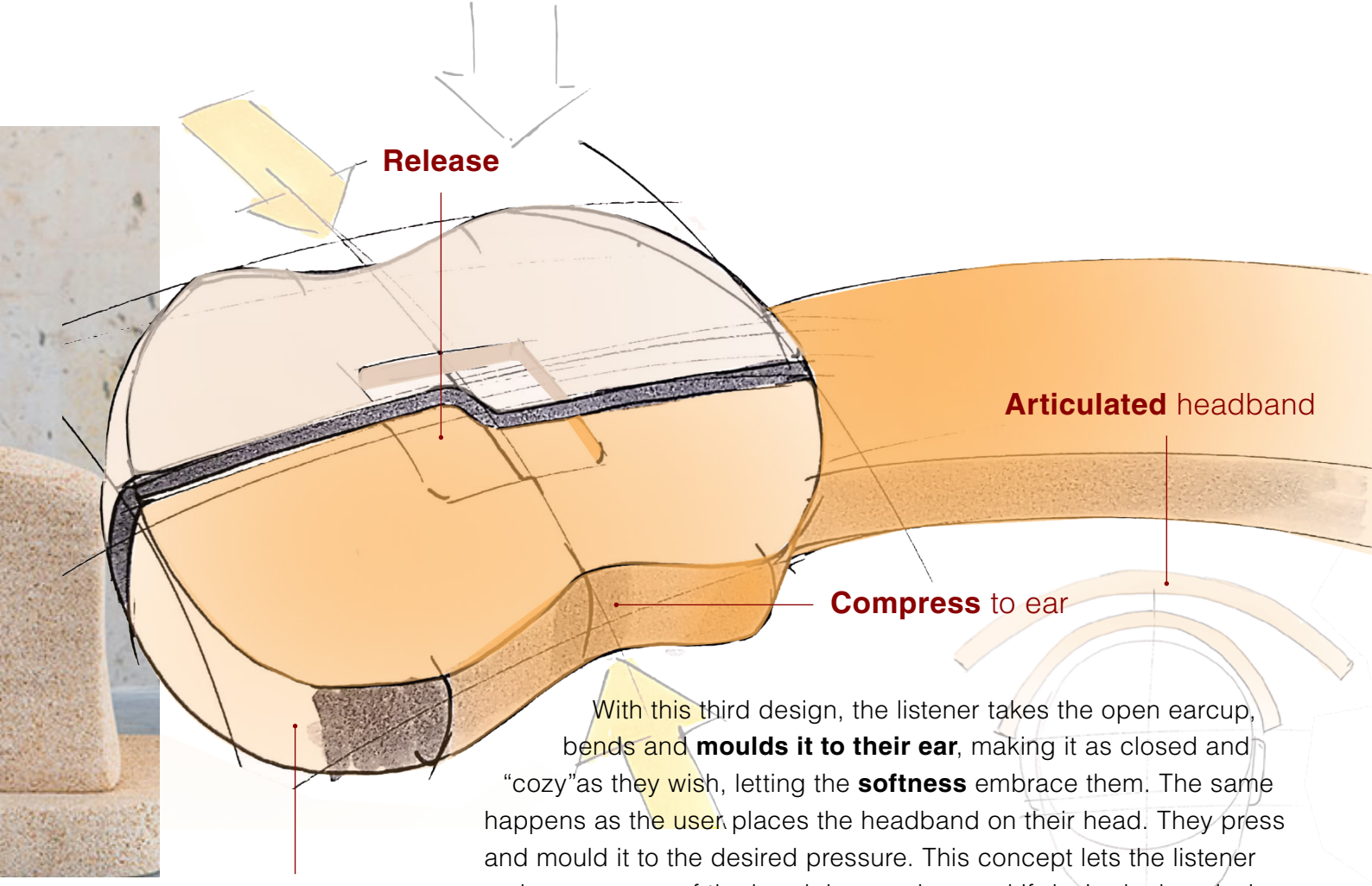
Prototype

The earcup, made out of foam and covered in felt, has a flexible lead structure that allows the user to smoothly bend it into shape. The arch, and pressure, of the headband can be adjusted by sliding the felt sliders up and down the double arch. When sliding them up, the arch closes to create a smaller angle, thus, more pressure. Figure 69 B shows the closed headband and earcup, and C the open headband and earcup bent open.

Client evaluation

While the concept adapts well to the haptic desires of users, (softness, cozyness, adaptation in time), it was discussed that the target groups would not be drawn to the warmth of the object, as it is one of the main pain points. Also, its haptic properties fit more with the ANC closed back headphone category.

Figure 69. Prototypes A, B C (left to right)



With this third design, the listener takes the open earcup, bends and **moulds it to their ear**, making it as closed and "cozy"as they wish, letting the **softness** embrace them. The same happens as the user places the headband on their head. They press and mould it to the desired pressure. This concept lets the listener make a **cocoon** of the headphone, when and if desired, also playing with the sound as the earcup cavity increases or decreases in volume.

To create the softness, the earcup and earpad become **one** soft, padded **element**, with rounded corners and soft fabric, which ensures its soft, smooth bending. For inspiration, see Figure 65 to Figure 68.

Key qualities: **cocoon, softness, immersion**

.02 Concept selection

A session to select the concept direction was conducted at the Sennheiser HQ, with the client, to evaluate and select a concept direction and develop it further.

.01 Workshop with client

The three concepts were presented to the client, together with the interaction prototypes. A decision matrix (Daalhuizen, 2020) was used to evaluate each one and trigger a discussion over the preferred direction (see Figure 70). As a team, the criteria with which to rate the concepts was first selected. By comparing each criteria point to another, a weight was discussed and decided for each one (from 1-5). The concepts were then rated evaluating them as what they could potentially become, rather than directly rating the low fidelity prototypes, and scored as a team (from 1-5), looking at what degree they fulfilled the criteria to.

Criteria

As seen in Figure 70, the highest weighed criteria are those of achieving a haptic aesthetic design, one that feels beautiful and

		Tensile		Momentum		Cocoon	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score
Haptic aesthetics	5	4	20	2	10	5	25
Haptically rich, intense	5	5	25	3	15	5	25
Target group - envisioned	3	5	15	2	6	4	12
Haptically novel	4	3	12	5	20	5	20
Target group - current	3	5	15	2	6	2	6
Sennheiser brand	1	4	4	5	5	3	3
Visually aesthetic	4	5	20	3	12	4	16
Easy implementation	3	3	9	2	6	4	12
Total	29		**120**		80		119

Figure 70. Decision matrix

a haptically rich one. Both of which are at the core of the project and in line with the defined mission statement.

k.i. Haptic novelty is relevant for the client

k.i. Creating a visual aesthetic design is relevant for the client

Achieving haptic novelty in the context of consumer electronics was also set as high priority, as was considering the visual aesthetics of the design in order to make something with which you can “see that it feels good” (Francien Tiessen, personal communication, 2022). Both the adaptation of the concepts to the current and envisioned target groups (see chapter 2.01) were also considered, as well as their ease of prototyping, to ensure a feasible outcome that can embody the desired feeling.

k.i. Fitting the brand ‘s design core value is of low importance for the client

Finally, how well the concepts fit the Sennheiser core design value (see chapter 2.01) was considered as low priority by the client, wanting to focus on novelty instead.

.02 Concept selection

As shown in the decision matrix, the concept with the highest score is: Tensile fabric.

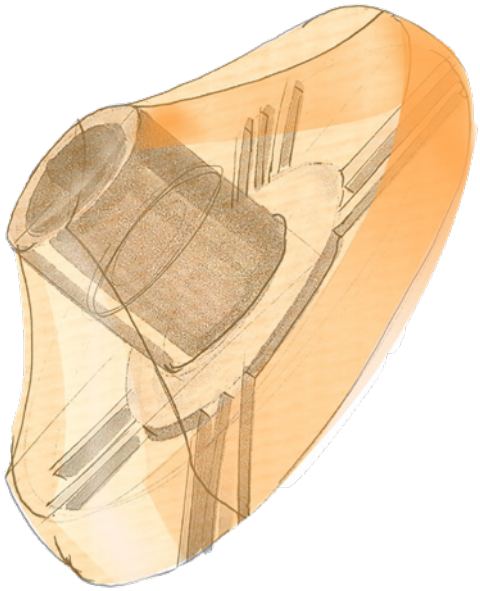
k.i. The openness of the concept fits the open back headphone

The openness that this concept offers fits well with the open back feature of the audiophile headphones.

The Tensile concept was rated high from a haptic aesthetic point of view as it encourages the user to explore the structure of the headphone (active touch) potentially encountering different sensations along the journey and providing deep tactility by engaging with the elastic fabric.

The incorporation of the fabric opens possibilities of changing the weave across the headphone, changing the tension or weaving in cooling yarn or other fabrics in certain areas to cater to other haptic aesthetic properties, softness, cool sensations etc.

The object as a whole results in a lightweight and open structure.



k.i. The haptic novelty of this design was deemed lower than the two others

k.i. The Tensile concept fits better the target group

This direction was considered less novel than the other two, but more fitting both to the current and envisioned target group, this is due to the closer connection of the user (the audiophile) to the core of the headphone, the driver and its vibration to

create the music, that can be felt through the membrane in the center of the earcup.

k.i. The Tensile concept is more visually aesthetic

Furthermore, the Tensile concept was considered more visually aesthetic than the other two, rendering it more appealing to the larger public. Its construction offers the possibility to make a headphone that looks homogeneous and aesthetically appealing, but hides textures and sensations beneath the fabric that can create surprise when interacting with it.

Points of development

The second part of the session consisted on a short ideation to expand on the concept. The following points of development were discussed:

k.i. The balance between created sensations and lack of them, comfort, throughout the user journey is essential

- What sensations should be created through the active touch of the fabric and the underlying surfaces?
  - What is associated with these different sensations, should there be a haptic surprise/novel element?
  - What underlying textures, materials and structure can create this?
- How can comfort be created in this concept and the ergonomic concerns addressed?
- How should the driver transfer the music vibration to the membrane?

k.i. Creating a lightweight product could be perceived as poor quality

- What should this headset feel like in the progression of the user journey, with special attention on the initial interaction moment of picking the object up?
- As weight is often related to perceived quality, but also uncomfortable after long wearing periods, how should the lightweight aspect of the fabric be outweighed by the material of the structure?

These points are addressed in the following chapter.

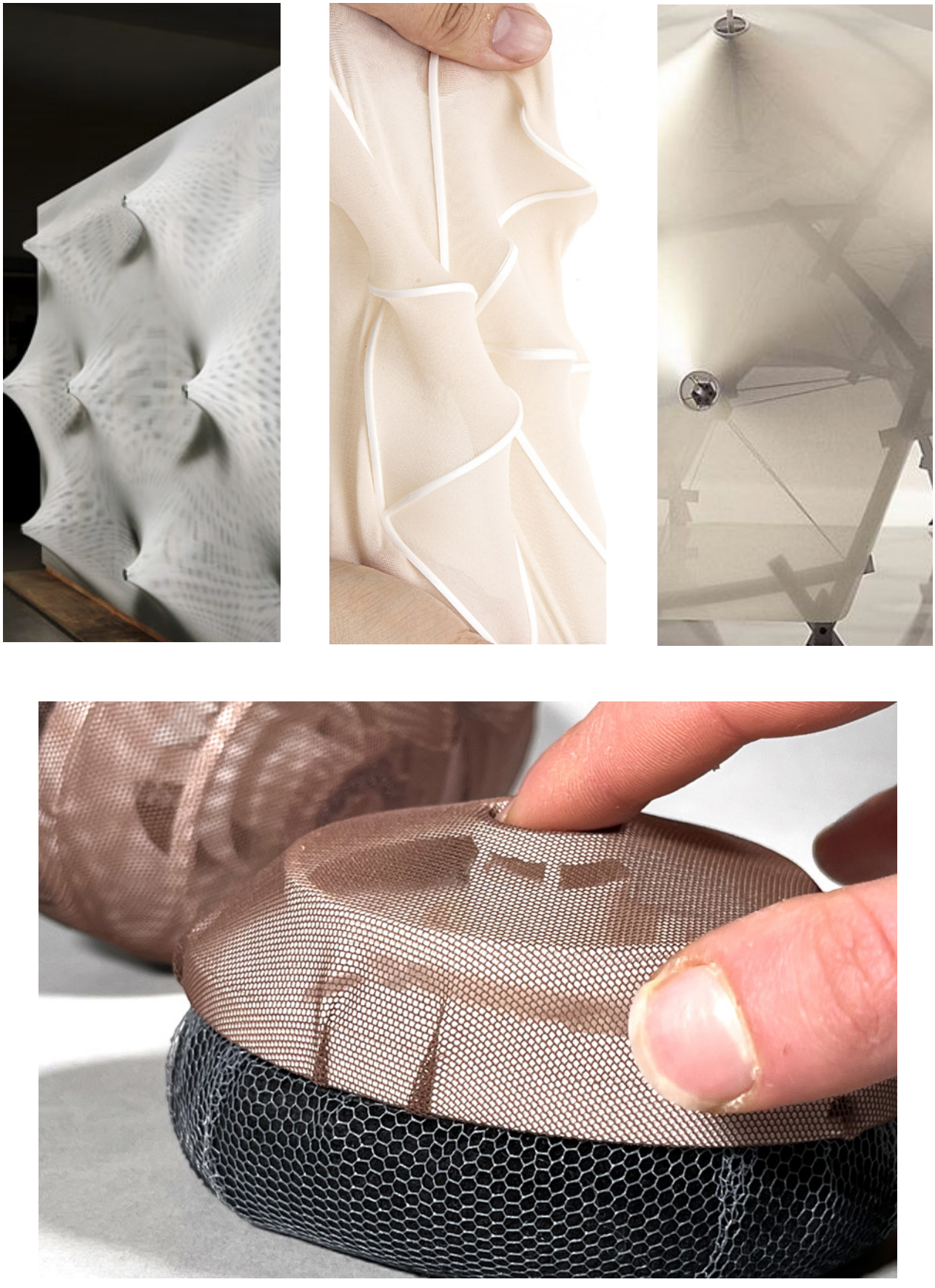


Figure 71. Inspiration for Tensile concept

Key insights

This chapter helped choose the design for the concept headphone.

Certain aspects defined the most fitting direction for the design goal and the product

The session highlighted that creating a haptically novel and rich design was of importance to the client, as well as its visual aesthetics. In this way the Tensile concept was selected, it was deemed less novel but more fitting to the target groups and the product itself, being an open back headphone. This concept also fits better with the redesigned object, an open headphone, and plays with the haptic - visual sensory pair, while the Cocoon fits more with ANC ones and Momentum plays with the haptic - auditory sensorial pair.

Development focus

Having chosen a concept, some aspects were highlighted as important points of development. The first one, finding out which sensations should be created through the mesh, to fit the concept, and when should there be no sensations. Secondly, as lightness is an essential aspect of the Tensile headphone, it is important to ask whether this will affect the quality perception.

.05
The concept headphone

This chapter goes through the development of the selected concept to the final showcase model, including the incorporation of the unity in variety principle into the design and the development of the theory (RtD). A series of key design aspects for the design were formed as the chapter evolves.

.01 Concept design

The selected direction was developed to become a concept headphone, which showcases new ideas of a haptic aesthetic headphones and serves Sennheiser as a tool to explore innovation (Sarmiento et al., 2016). While the concept headphone does not stride for feasibility, it aims to represent what the HD6xx line could feel and be like, thus, needs to respect some technical and ergonomic aspects inherent to it.

.01 Development starting point

In a nutshell, the concept headphone is an open back headphone in its extreme. The haptic novelty mainly lies in the choice of the materials, but also in that it encourages active touch, unusual in the headphone domain.

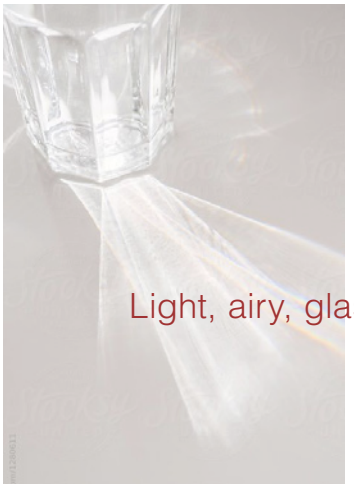
The use of the fabric throughout the whole body instead of hard plastic makes it lightweight, and where the fabric is more stretched, open. Thus, the passive haptic experience is an open, airy and lightweight one. The active haptic experience is playful, the user can decide to engage with the headphone and what is at its core by touching the membrane that lightly vibrates to the audio, feeling the music. The feeling of interacting with it is once again light, but also elastic and responsive, as holding and touching the object is done through the stretched tensed fabric, lending to a novel kinaesthetic interaction. See the moodboard and key words in Figure 72.

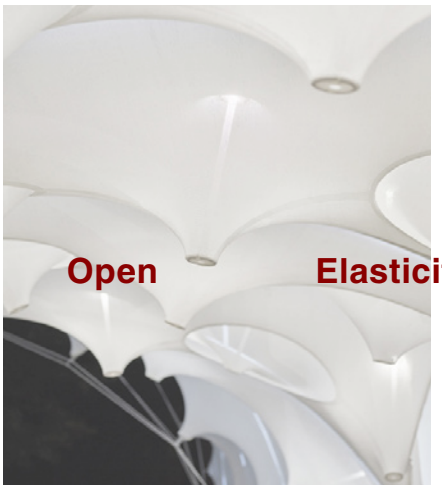
k.i. The concept headphone should retain the essence of the HD6xx.

The following are the key design aspects, that ensure the concept headphone remains comparable to the HD6xx line.

Key design aspects .01

- The design is composed of two main elements: the structure and the overlaying fabric
- The resulting headphone is lighter than the HD6xx
- The vibration of the driver can be felt through the membrane
- The headphone is open back
- The earcup height can be adjusted
- The overall dimensions and components mimic those of the HD6xx:
  - Headband curvature and length
  - Ear-pad shape and dimension
  - Driver element





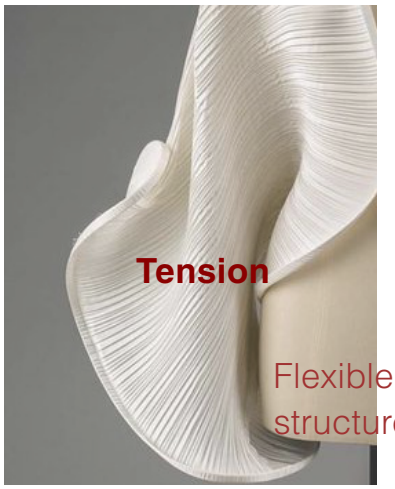


Figure 72. Moodboard and key words

.02 Interaction design

Interaction and sensations

k.i. Material displacement feels pleasant

Material compliance (how much a material displaces to load) is linked to pleasantness (Pasqualotto et al., 2020). The Tensile concept plays with this, allowing the user to interact with the elastic mesh, pushing and pulling on it. This compliance feeling lends itself to be extended to the interaction throughout the user journey. However, the Sennheiser design core value, robustness (see chapter 2.01) has to also be a part of the interaction.

Sensations in the user journey

As seen previously, instant sensations can result in pleasure, while lasting ones often result in discomfort (see chapter 2.02).

k.i. The concept pays attention to key moments in the interaction

k.i. The interaction is novel in active touch and typical in passive

The concept headphone is designed to provide a passive haptic experience that is comfortable, without strong sensations, and an active haptic experience (interaction initiated by the user) that is stimulating, pleasurable and/or haptically playful.

These sensations can manifest themselves throughout the user journey in these key moments (see Figure 73):

• As the user picks up the headphones, they feel one continuous element, robust. The user holds the earcups and while touching the metal earcup contour with the palm of the hand, engages with the tensed fabric with the fingers.

• The movement of the headphone towards the head is that of one unified lightweight element. When placing it over the ears, the headband feels very stretchy and elastic,

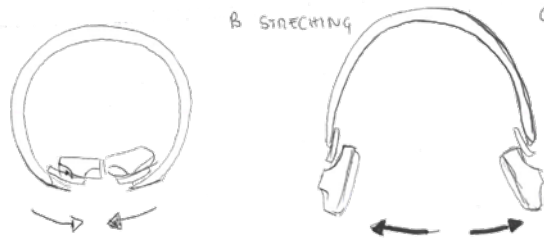


Figure 74. Unfolding interaction

Robust. Feeling one continuous element, the metal structure and the tense fabric.

Lightweight. Moving easily the headphones towards the head.

Flexible yet sturdy. Feeling the flexibility of the metal headband.

Playful. Actively engaging with the sensations the object has to offer.

Figure 73. Sensations in the user journey

yet requires some force to unfold from the initial closed in position to go over the ears (see Figure 74). Some areas of the fabric sleeve are under more tension during this movement, changing the weave stretch.

• The user plugs in the fabric covered cable and is free to actively explore the object. Under the fabric different elements can be discovered. The membrane over the driver, lightly vibrates to the music and can be felt when directly touching it. The user can adjust the earcup height moving a slider through the fabric (Figure 75).

Comfort and ergonomics

The concept potentially addresses some of the ergonomic concerns unveiled by

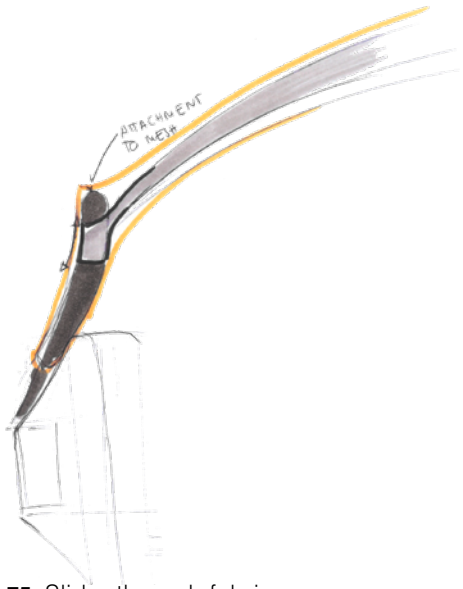


Figure 75. Slider through fabric

the users (see chapter 2.03) as part of the concept, mainly weight and heat dissipation.

k.i. Some ergonomic concerns remain unaddressed

However, other points have not been directly tackled and remain as in the HD6xx. These are the clamping force and the pressure points, at the top of the head and around the ears, which could be alleviated by the tensioned fabric headband.

Fabric

Ideally, the concept works with a mesh that can be more or less open (tightly woven), to change the properties of sound, opacity and fabric tension, throughout the headphone in one continuous sleeve.

k.i. CNC weaving allows to create a changing, continuous, weave

A technique that allows to do this is CNC knitting (see Figure 76), or weaving different patterns and densities (see Figure 77). This also offers the possibility to intertwine cooling yarn that helps conduct the heat towards the outside of the headphone. A sensation of thermal contrast could be created by using fabrics or yarns of different conductivities, since under conditions of hyperthermia, (high temperature in the ears under the earpads) cold sensations are more pleasant (Mower, 1976).

The design requires a fabric that is thin and light enough to fee the underlying structure. Also elastic to stretch over the structure and react when pressed by the user, yet sturdy enough not to feel fragile. Smoothness is also a desired quality as it is related to haptic pleasure pleasant (Mower, 1976).

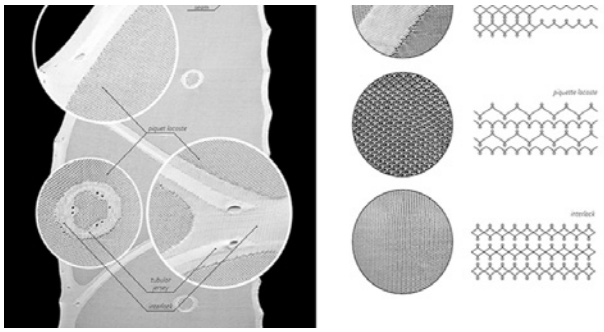


Figure 76. Hybrid tower CNC knitted structure

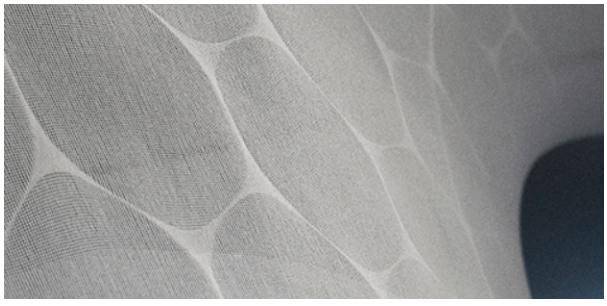


Figure 77. Variegated surface structure close up

Weight

The design offers the possibility to make a lightweight headphone which is more comfortable for long wear. However, research has shown that consumer's quality perception is strongly influenced by perceived weight (Lashkaripour, 2020).

k.i. Aluminium is lightweight yet can be perceived as high quality

The material of the structure is key to balance the headphone's weight. By using an aluminium structure the perceived quality increases, because users associate this with metal headphones (see chapter 2.03), while still reducing or matching the weight of the HD6xx (260g). The weight of open back headphones ranges from 250g (Audeze LCD-1) to 430g (Meze Empyrean).

.03 Conclusion

The envisioned concept, while feasible with a larger development time, could not be realised within the a month (available time).

k.i. The embodiment of the headphone has feasibility limitations

The following were the limitations that had to be adapted in the showcase model.

- The progressive tension in a CNC woven fabric. Despite having access to CNC weaving, the development of the sleeve was too time and resource intensive. Thus, an existing fabric had to be sewn.
- In this way, the cooling yarns could not be woven in, eliminating the "heat sink" aspect of the concept.
- To create an elastic yet robust interaction when stretching the headphones onto the head, a spring system should be integrated into the headband, which requires extensive prototyping.
- The metal headband was not able to embody the desired "spring" as this requires hot rolling spring steel with industrial machinery.
- Originally, an array of sensations to be felt through the fabric was envisioned. However, these were left for a future design iteration, due to its development time.

Taking these considerations into account, the design aspects were iterated to .02, and envisioned as in Figure 78.

Key design aspects .02

- The design is composed of two main elements:
  - Thin, elastic, light fabric, in a continuous closed tensioned sleeve
  - Structural spring steel headband and aluminium earcup in one continuous element
- The headphone provides a comfortable passive haptic experience (typical), and a stimulating, playful, active haptic experience (novel)
- The resulting headphone is lighter than the HD6xx
- The vibration of the driver can be felt through the membrane
- The headphone is open back
- The earcup height can be adjusted with a sliding, smooth motion, manipulated through the fabric
- The overall dimensions and components mimic those of the HD6xx:
  - Headband curvature and length
  - Ear-pad shape and dimension
  - Driver element

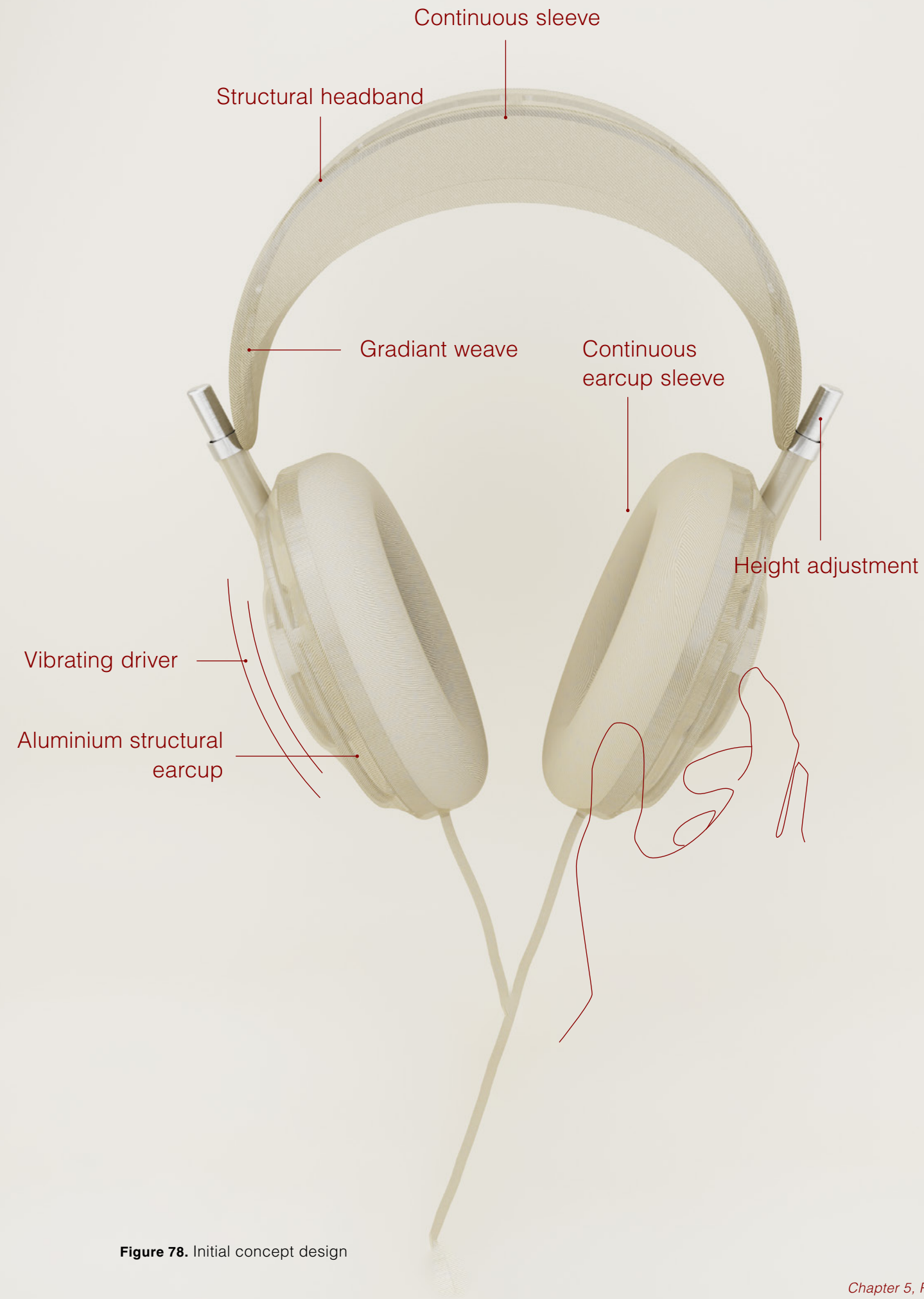


Figure 78. Initial concept design

.02
Haptic unity-variety

As discussed earlier (see chapter 1.01), one of the goals of the project is to discover whether the selected aesthetic principles are applicable to haptic experiences. An empirical study was conducted to this effect using different variations of the headset as stimuli (RtD). The learnings from this study also helped inform the design of the concept headphone.

.01 Research question

The research goal is to understand to what extent the aesthetic principle of unity in variety applies to the haptic sense and how this should best be embodied in the headphone design. In doing so, the effect of novelty and typicality was also examined. In this way the main research questions are, in line with the project's (Figure 79. Project research questions):

Q1 Are the maximisation of both haptic unity and haptic variety positively related to haptic aesthetic appreciation? (When the counteracting influence of these concomitant changes in the other variable is controlled for)

Q2 How are the perceived novelty and typicality related to haptic aesthetic appreciation?

Q3 In what way can maximising UiV contribute to the design of the concept headphone?

To what extent does the maximisation of both haptic novelty and typicality positively influence haptic aesthetic appreciation

To what extent does the maximisation of both haptic unity and variety positively influence haptic aesthetic appreciation

Figure 79. Project research questions

.02 Method

The RtD approach was used to test the research questions and develop the selected concept further in an empirical study. In this way, the first step of this study was to determine the stimuli with which to test the hypothesis.

For these stimuli, the variables of unity – variety were independently manipulated to achieve different degrees. These opposing forces, while negatively correlated, hold a degree of unshared variance that allow them to be manipulated independently (Eggink, 2010). The next step was to determine through pre-tests if the stimuli were adequately embodying the intended levels of unity in variety. A focus group with four design students was gathered to analyse and discuss this.

The main test played with different levels of unity and variety, to see the effect of the combination of both principles in aesthetic appreciation. However, as the different stimuli could also be perceived as more or less novel or typical as an effect of the manipulations, novelty – typicality ratings were also collected, to observe their influence. This test focused on the initial moment of engagement of the participant with the earcup, the first haptic impressions.

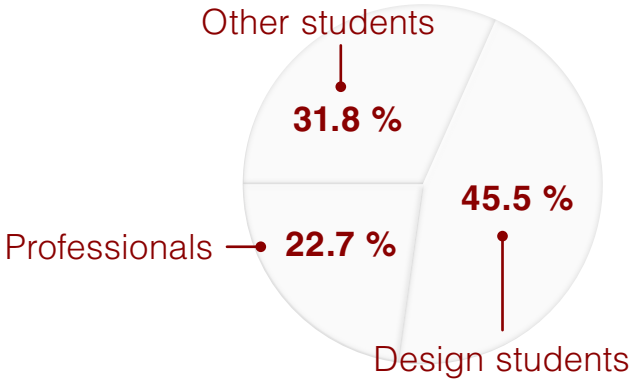


Figure 80. Participants background

Participants

The number of participants was calculated with an a priori power analysis, using G*Power 3 (Faul et al., 2007). With a power of 80%, for a large effect (p = 0.5) and alfa one tailed of 0.05, as calculated in Post, R., 2016. The calculation resulted in a sample size of 21 participants. 22 individuals participated in the study, all in the age group of 20-30 years old, 54.5% Male, 45.5% Female: 45.5% were industrial design students, 31.8% students of another discipline and 22.7% were professionals (see Figure 80). The large percentage of participants related to the design profession could have an effect on the results, however, in a study made by Hekkert et al. (2003) there was no evidence found for differences in aesthetic preference between experts and non experts concerning stimuli of different novelty and typicality levels.

Stimuli and equipment

Unity and variety were altered independently in several design iterations. This was performed using the earcup structure, as it is the area the user first interacts with when manipulating the headphones.

Three variations were made to cover the relevant spectrum of combinations see Figure 81:

- High unity with high variety (UV)
- High unity with low variety (Uv)
- High variety with low unity (uV)

After the focus group session the following was decided. To manipulate unity, the Gestalt principle of similarity and the universal design principle of constancy were used. The first principle describes that individuals will tend to group together

elements that are perceived as similar, as described in chapter 2.02. Constancy is the ability to perceive elements as having constant properties despite slight variations (Lidwell et al., 2003). In this case, this was

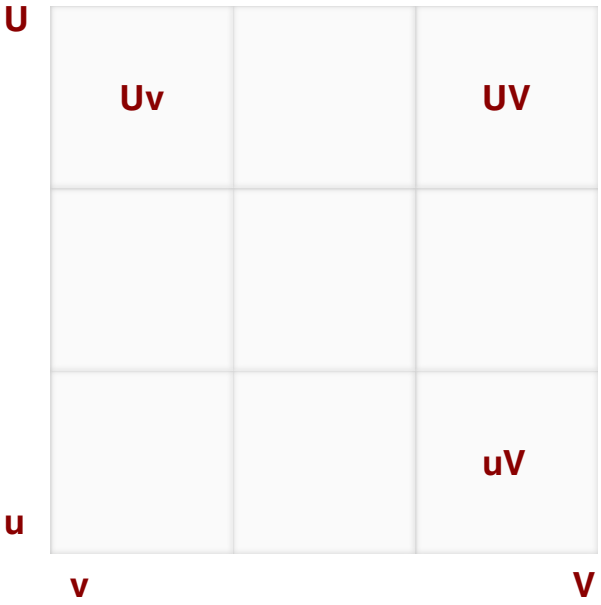


Figure 81. Unity - variety combinations for stimuli

Figure 82. Stimulus A - UV

Figure 83. Stimulus B - uV

Figure 84. Stimulus C - Uv

achieved with the contour and shape of the earcup rings. The most unified design consists of two circular rings of different dimensions, whose similar rounded contour provide the feeling of one. In the least unified design the top layer is a ring while the bottom one is diamond shaped, with rounded corners. The shape of these elements no longer repeat each other, thus, feeling less unified.

Variety was altered making designs with a different number of elements. The most varied design has two levels (two rings) above the baseplate, while the least varied has only one ring above the baseplate. As users engage with the earcup they feel either one or two levels under the fabric.

See Figure 82, Figure 83 and Figure 84 for the different earcup structures of the three different stimuli covered by the fabric sleeve.

Focus group

The above described stimuli were a result of the focus group session conducted with three design students and the main researcher, myself. The focus group was initially presented with stimuli that aimed to embody the unity and variety levels. These were discarded as the participants discussed the difference in feelings between the stimuli was not enough or was hard to convey. After a short brainstorm session the new stimuli were designed.

For instance, Figure 86 shows a series of earcups that plays with the elliptical contour of the baseplate. Breaking the contour to make a less unified design (principles of continuity and emergence).

As for variety, it was attempted to create contrast (dissimilarity) in sensations of contiguous elements by combining two types of fabric covering the earcup.

Figure 86. Unity manipulations

Making the stimuli

All stimuli were produced using the same manufacturing techniques, in order to guarantee consistent feeling and association across the non manipulated parameters. Visually, the stimuli differed, however they were not in view during the user test.

The earcups were printed wit PLA filament with 30% copper infill, in order to give the object some weight similar to a “real headphone”. The headband structures were printed with PLA to give them enough flexibility. The earpads were cut out of foam and a pattern was developed, cut and sewn to cover the earcup and headband structures. The fabric used was 90% Nylon, 10% Elastane, for it to be elastic enough to stretch over the skeleton.

Procedure

1. Participants were informed that they would have to rate the stimuli on how they felt, on the haptic aesthetics and not on visual aesthetics or functionality.

2. Participants were explained the aspects by which they would have to rate the stimuli.

3. Each participant was allowed to familiarise with the set of stimuli during the desired time, wearing each one, to understand the differences between them. The headphones were placed onto the participant’s head, out of visibility, to evaluate only with the haptic sense.

4. After familiarisation, they were presented with the stimuli one by one, in randomised order, wearing each as instructed (see Figure 37). Participants rated each stimulus, relative to each other, first on aesthetic pleasure, then on unity – variety, typicality – novelty in a randomised order, using a 7 point Likert scale (Fully disagree (1) to Fully agree (7)). They were asked to think out loud while doing this.

To describe each aspect to the participants, statements from the Aesthetic Pleasure in Design Scale were used (Blijlevens et al.,

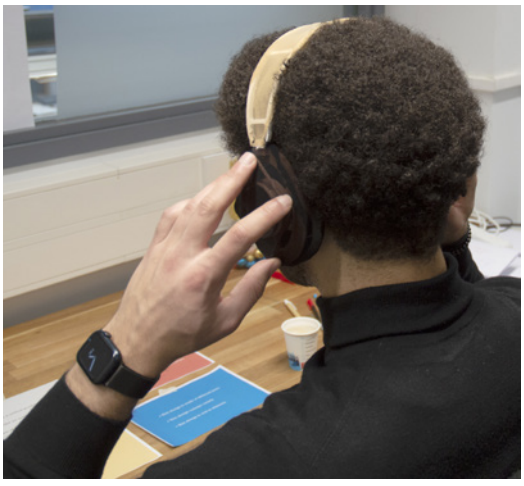


Figure 85. Participants engaging with the stimuli

2017), adapted to the haptic sense, as those used by Post et al. (2016) in a similar study. Participants had to rate aesthetic pleasure, unity, variety, novelty and typicality, each as a single item, according to how much they (dis)agreed with the description statements as whole. However, other aesthetic studies rate each description statement instead, as individual items, and calculate the mean of these for each aspect (Post et al., 2016).

Aesthetic pleasure

- This product feels attractive to interact with
- This product is pleasing to interact with
- I like interacting with this product

Unity

- This feels like a unified product
- This feels like an orderly product
- This feels like a coherent product

Variety

- This design is made of different parts
- This design conveys variety
- This design is rich in elements

Typicality

- This feels like a typical pair of over ear headphones
- This feels representative of over ear headphones
- The feeling of this design is common / characteristic for over ear headphones

Novelty

- This feels like a new example of over ear headphones
- This design feels innovative

Data and Analysis

The data collected was the evaluation of the different stimuli by the different parameters (1 to 7), which were collected through an online form into an excel. The reasoning behind the evaluations was recorded and analysed later to gain insights into the theory and design development.

The qualitative analysis of the transcripts was conducted by coding the data as in chapter 3.01 (Saldaña, 2013). This method was chosen as it is well suited to find themes across a higher volume of non-numerical data (insights from 22 participants).

In this study, the codes were generated directly from the data, as opposed to those in chapter 3.01, to give a richer description of the dataset and go beyond the research question. The coding methods used were part of the Grounded theory research methodology, which develops theory from the data, without preconceived theory (Koo and Li, 2016).

Once again, the analysis was conducted both by direct observation and at latent level, reading into the assumptions underlying the data.

The stages of the process were (Strauss and Corbin, 1992):

- Open coding, where key concepts and sentences are identified and given a code (Saldaña, 2013). The data from the participants is compared to one another and the whole data set is broken down into concepts.
- Axial coding, where the connections within the data are identified and the codes are arranged into categories.
- Selective coding, where the core categories are identified and categories redefined. These are the concepts around which other categories are built. The code categories help generate the grounded theory.

.03 Results and implications

Results

All calculations in the results were conducted using SPSS software. The mean ratings of each parameter were calculated for each stimulus (see Figure 87), see Table 1. Stimulus UV, manipulated to achieve high unity and variety and expected to be the most liked, was perceived as the most unified and second most varied, and the highest rated on haptic aesthetic appreciation. Stimulus uV was perceived as the least unified and most varied, and second highest on aesthetic appreciation, and Uv was the least liked and perceived as the least varied and second most unified.

It can be said that the manipulations of unity and variety were to an extent successful when looking at the average ratings over participants. However, Uv was perceived as less unified and UV less varied than expected.

Figure 87. Stimuli

	Mean aesthetic appreciation	Mean unity	Mean variety	Mean novelty	Mean typicality
○ Uv	4.50	4.91	4.32	4.91	3.91
	σ = 1.47	σ = 1.51	σ = 1.39	σ = 1.27	σ = 1.41
◇ uV	5.00	4.23	6.14	6.14	3.05
	σ = 1.88	σ = 1.63	σ = 0.89	σ = 1.04	σ = 1.40
◎ UV	5.41	5.68	4.73	4.91	4.73
	σ = 1.44	σ = 1.13	σ = 1.20	σ = 1.11	σ = 1.20

Table 1. Rated means for stimuli

When looking at novelty and typicality, UV, the most liked, was considered both novel and typical, which could account for its aesthetic appreciation. uV was rated as highly novel.

Figure 88 shows the means for each stimulus, the more saturated colour indicates a stronger aesthetic appreciation. Figure 89 shows the intended manipulations.

In this way, unity and variety ratings could be considered as subjective evaluations, and the stimuli and participant as random effects.

An ICC reliability analysis was conducted for unity and variety ratings, to determine if participants reliably assessed these. The results, for unity, ICC(2,22)=0.467 and ICC(2,22)=0.473, for variety, indicate poor reliability of the participants' ratings of unity and variety in the different stimuli (Koo and Li, 2016).

Also, a repeated measures ANOVA was conducted for unity, variety and aesthetic pleasure, which resulted in Wilks Lambda's $\sigma < 0.05$, which determined that there is a statistically significant difference between the means of the 9 total ratings.

Pearson correlations (1-tailed) were calculated to understand unity and variety's effect on aesthetic appreciation and on each other. Unity correlated positively with aesthetic appreciation ($r_{ua} = 0.208$, $p < 0.05$), and so did variety, to a similar degree ($r_{va} = 0.223$, $p < 0.05$). As expected, these correlated negatively to each other ($r_{uv} = -0.441$, $p < 0.01$), which indicates that they could be mutually impairing each other's effect on aesthetic appreciation. In this way, partial correlations were also calculated. Both for unity ($r_{ua\text{-}v} = 0.351$, $p < 0.01$), and for variety ($r_{va\text{-}a} = 0.359$, $p < 0.01$), the effect increased when controlling the other variable, and have similar influence on aesthetic appreciation.

Pearson correlations were also calculated for novelty ($r_{na} = 0.396$, $p < 0.05$), positively correlated to aesthetic appreciation to a large extent. Also for typicality ($r_{ta} = -0.605$, $p > 0.05$), which shows there is no significant correlation between typicality and aesthetic appreciation, in this empirical test. As expected, these two variables hold a negative correlation to each other ($r_{nt} = -0.420$, $p < 0.05$).

To understand the extent to which unity and variety have an influence on aesthetic

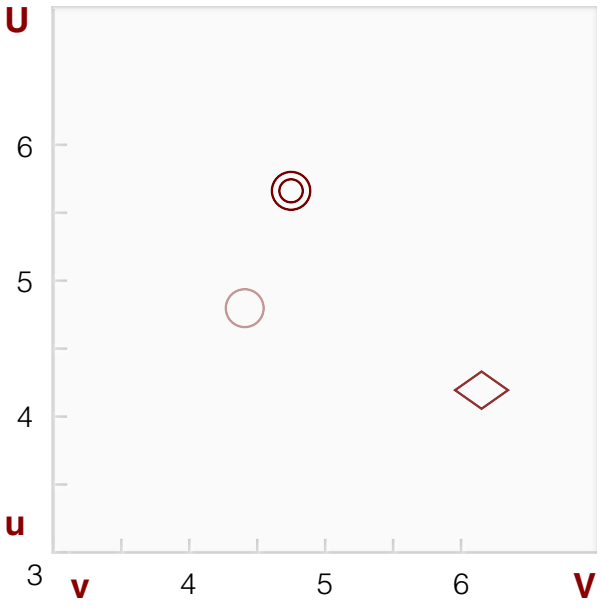


Figure 88. Unity - variety rated means for stimuli

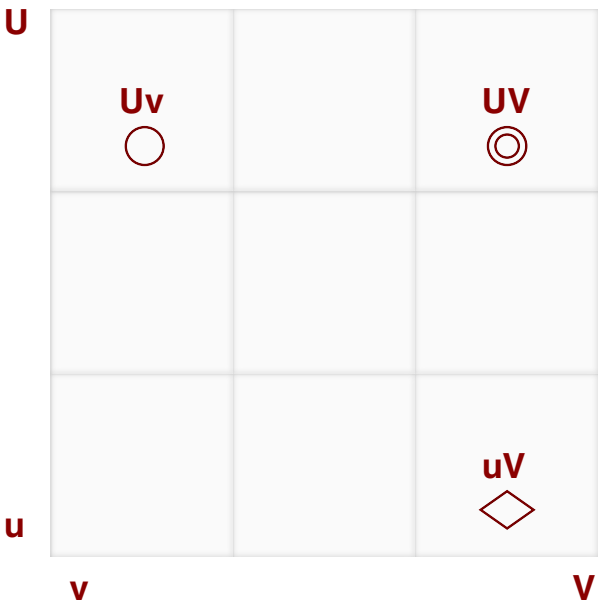


Figure 89. Unity - variety intended levels for stimuli

appreciation, when controlling for novelty and typicality, a hierarchical regression was calculated.

In step 1, the two latter variables were entered as predictors using the stepwise method and aesthetic pleasure as the dependant variable. Unity, variety and stimuli (as a dummy variable) were included into the regression in a second step.

The variance in aesthetic appreciation accounted for by novelty and typicality was R^2 = 15.4%, F(2, 65)= 11.692, p<.05 with novelty being the only statistically significant variable, $ß_n$ = 0.393.

The change in variance by entering the predictor variables, unity and variety, resulted in an increase of ΔR^2 = 16.4%, F(5, 65)= 7.095, p<.05. Unity and variety both contribute to aesthetic appreciation, with $ß_u$ = 0.388, $ß_v$ = 0.135, and $ß_n$ = 0.447. In this way, unity and novelty seem to contribute the most on aesthetic appreciation, while variety contributes to a lesser extent.

However, it must be noted that when calculating a linear regression for unity and variety without controlling for the other variables, the model explained a variance (R^2) of 17.9%, and the two predictor variables had similar influence on aesthetic appreciation, $ß_u$ = 0.344 and $ß_v$ = 0.361.

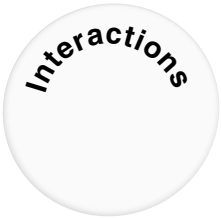
The same process was conducted to understand the influence of novelty and typicality. In this case, the regression model eliminated the variables of unity and variety. The model explains R^2 = 21.2% of the variance, F(3, 65)= 5.562, p<.05. Novelty is the only variable that contributes significantly to aesthetic appreciation, with $ß_n$ = 0.428, while typicality is not statistically significant and of very low weight $ß_t$ = 0.079. However, when looking at the means, the most liked stimulus UV, is also perceived as the most typical.

For the full tables and plots of the results in SPSS, see Appendix 9.

Qualitative insights

The rating rounds reveal that the empirical tests disregard the individual preferences expressed, and seem to flatten the results. The low ICC also indicate a poor reliability of the results. Thus, a qualitative analysis of the transcript was conducted to complete and give nuance to the empirical data.

Codes were compared and connected to each other to form subcategories and then categories and enrich the theory. The full list can be seen in Appendix 10. These are:



Integrating affordances, perceivable action possibilities (Norman, 2013) allows the user to know how to playfully interact with the object and that it is possible to do so. These should be ergonomically fitting the interaction and feel varied, potentially serving to perform a function.

When engaging with the stimuli, participants showed interest in interacting with the headphone. Having elements that invite interaction was appreciated. Some of these were the presence of the in-between circular layer, which they followed with their finger, or the rhomboid layer, with angles that allowed them to grasp the shape in certain ways. Also, the distance between the different elements was essential for

users to be able to fit their fingers and conduct the desired interaction.

Interactions were mostly described as interesting when the design was perceived as varied and complex enough to have a learning curve, both with positive and negative connotations. Most participants deemed the low varied and highly unified stimuli as “boring”. Pleasing interactions were those where the element fit the length of the hand well (the rhomboid), or where the softness and give of the fabric was felt (“trampoline effect”).

Despite being instructed not to think about functionality, most of the participants wanted to give purpose to their interaction, a function such as volume control, or taking of the headphones.

Repeating a shape in different sizes at close, similar, distances, while combining it with a different, yet not clashing shape, helps maximise unity in variety.

Repeating a shape in different sizes did result in a unified perception, however, the distance between the elements was imperative. Too big a distance or inconsistent distances, created a feeling of low unity, of separate parts, and also a low haptic aesthetic one.

High variety was mostly found due to contrasting shapes (rhomboid with circle), with two mains schools of thought. The first one found the shapes clashing, and the variety confusing and “disturbing”, whereas the second one found this variety interesting and pleasing to engage with.

It is essential to consider, beyond haptic aesthetics, the emotions elicited by the design. Embodying the desired haptic aesthetic properties in a way that avoids references to existing products with undesired connotations.

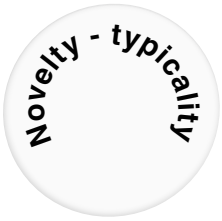
The ratings of the stimuli were conducted using the aesthetic scale. Even so, participants expressed emotions that were elicited by the product interaction that go beyond aesthetic pleasure of the senses (Hekkert, 2006b). For example, despite liking the interaction and the pliability of the soft fabric, this was also perceived as fragile and scary to interact with by most, “it almost feels like I shouldn’t be touching it”. Some participants also disclosed associations they made to the designs, it was felt by some “like wearing a panty hose”, or the mesh of a backpack, relating it immediately with products using the same fabric.

Features felt as organic, natural, were perceived as more pleasing and haptic aesthetic. These were the circular, rounded and long shapes in the earcup, following the length of the ear, the human body.

Also, the stimulus perceived as bulkier (Uv), due to the lack of the middle ring which makes it feel like it protrudes more, was

rated with lower haptic aesthetics. This is often found in the headphone sector in visual aesthetics, where users dislike headphones which are visually wider when looking from the front (Jermo Koehnke, personal communication, 2022).

The user test only focussed on the initial moments of engagement with the prototype, however, during the timespan of the test itself, many participants showed an evolution in their liking as they familiarised themselves more with the stimuli. This shows there is a learning curve, or liking curve, to consider in the journey of interacting with the headphones.



To bring typicality to the outside of the headphone while keeping novelty, a more rigid feeling in the fabric should be created, by adding structure, tensioning the fabric, and using thicker textile. Circles can be integrated to reference the archetype of the speaker and increase typicality within the novelty.

For most participants, wearing the headphones felt like a typical over ear headphone experience, while, engaging with the soft outside, feeling the structure through the stretch of the fabric, felt both novel and atypical. The stimuli that had more structure, UV, felt more typical as it approximates the outside hard shell of the headphone more.

The rhomboid shape was described as more novel and even “funky” by several participants. Furthermore, it was the circular shapes that felt representative, typical of headphones, as they reminded of speaker elements that make music, connecting the headphone to its function, its purpose and making it coherent and haptic aesthetic.

The headphones were felt as lightweight and soft, bringing the interaction closer to the core of the headphone. However, they also felt fragile to engage with due to the fabric give, into the headphone.

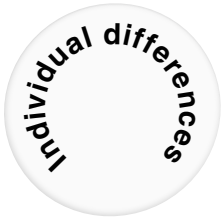
Despite not directly being asked about their impression, many participants made remarks about the lightness of the headphone, and some commented on the comfort and softness of the fabric and headband, both ergonomic and haptic aesthetic aspects that the design intended to address.

Some, described feeling the structure of the headphone and the music element, as being closer to the music element, the core of the headphone, as is intended in the design.

However, the lightness and softness were paired with the product association of fragility. Some though that by engaging with the fabric, the speaker could be damaged and so would the headphone.

Round shapes, referencing headphones once again, were considered as more visual aesthetic in the design.

Even though the test was conducted without visibility of the stimuli, some commented on how they thought the stimuli looks, based on the feeling. When finally seeing the designs, prototype UV was thought to be more aesthetic than uV even for those who thought the latter as more haptic aesthetic.



Perception, sensibilities and associations differ across participants. Haptic aesthetics has high subjectivity.

Some easily understood the differences between the stimuli, while for others it took a longer interaction time to do so. Also, while engaging with the stimuli participants perceived different aspects of these, for instance, some focused on the ring support structure and the space between elements, while others on the feeling as a whole. Different individuals also rated the same stimulus with opposite ratings.

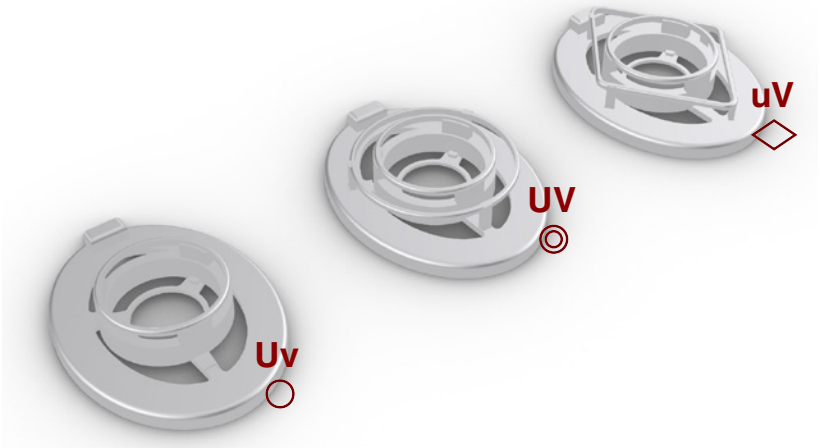


Figure 90. Stimuli earcups

Conclusions

Conclusions for Unity - Variety

As can be seen by the rated in Table 1, the averages do indicate that the most haptic aesthetic stimulus is the one with high unity and variety. Going back to the first research question, it seems that maximising haptic unity and variety positively influence haptic aesthetic appreciation. This is further confirmed by the Pearson correlations and partial correlations, which indicate a similar influence of unity and variety in aesthetic value.

k.i. Stimuli are perceived differently across participants

As discussed earlier, the stimuli were perceived at an individual level, not exactly as intended (see Figure 90).

• Stimulus Uv was perceived as less unified and more varied than expected. The center ring was felt as standing out more from the baseplate, feeling like two different parts. As for the aesthetic pleasure, it was rated the lowest and “boring” (low variety), also because, as it lacks the in-between ring, the fabric is held less and thus felt more fragile.

• Stimulus uV has the highest deviation of aesthetic appreciation. There were two main reactions, one group felt that the rhomboid shape clashed with the circularity and smoothness of the rest of the earcup, making it highly varied and not unified, and rating it less aesthetic. The other group found this stimulating to engage with, finding unity in the length of the shape.

• As for stimulus UV, some participants felt that the height difference of the two rings was smaller than in uV, despite being the same. They interpreted this as not unified. The manipulated variety of having two rings and the unity of them being circular was mostly accurately perceived.

k.i. Unity and variety can increase the haptic aesthetics of the headphone

Despite the discrepancies in ratings across the participants, one thing is clear and helps us answer the second research question. Participants sought for interaction in the shapes, asking for a more complex, varied one, with a learning curve, yet with an organic feeling, coherent, thus unified.

Participants who judged prototype Uv as boring, also rated it as not pleasing, and those who deemed uV as interesting, because of its information and variety, and found unity in the elongated rhomboid and straight edges, also found it more aesthetic. In this way, it can be interpreted that the discrepancies lie more on how these specific shapes are perceived, but that having a more varied, interesting haptic shape, that is also perceived as unified could increase the haptic aesthetic appeal.

k.i. Variety has a higher influence on aesthetic appreciation in this context, than unity

The linear regression also showed that the influence, weight of variety is higher than that of unity in aesthetic appreciation. When looking at the participant’s comments, this could be explained by their interest in stimulation and interacting with the design.

k.i. Repeating a shape at consistent distances to maximise UiV

However, taking care of the distance between repeating elements did mostly create a feeling of high UiV.

k.i. Manipulating UiV in a complex design causes undevised haptic interpretations

The complexity of the headphone structure meant that, when manipulating one parameter, other associations arose for the users. For instance, eliminating the intermediate ring for stimulus Uv made it feel like two separate parts, instead of less varied.

Conclusions for novelty - typicality

The UiV manipulations inherently affected the perceived novelty and typicality of the designs.

k.i. Haptic variety creates a novel feeling, and unity a typical one

k.i. Haptic novelty has a strong influence on aesthetic appreciation

From the hierarchical regression results it can be deduced that participants found the increased perceived haptic novelty as aesthetic, while typicality seems to have little to no influence. This could be because

typicality was strongly correlated to unity (r_{tu} = 0.357, $p < 0.05$), and associated to lack of stimulation and boredom. Novelty was correlated to variety (r_{nv} = 0.538, $p < 0.05$), and associated to stimulation and playfulness.

Conclusions for haptic aesthetics

The user test also gave insights into the field of haptic aesthetics as a whole.

k.i. Emotions and associations arise during haptic exploration

Touch is the way we feel the world, and in this way it is linked to affection and intimacy (Sonneveld and Schifferstein, 2008). In this way, haptic exploration is especially intimate, and accompanied by emotions.

k.i. Interactions and affordances are a part of haptic aesthetics

Participants found pleasing the possibility to ergonomically interact with the elements, i.e. comfortably run their finger across the circle etc. Especially so when there are cues that encourage the interaction in the object properties.

k.i. Organic shapes that follow the body are pleasing

The length of the rhomboid and flatter earcups were liked as they felt “organic”, following the length and flatness of the ear.

k.i. Typicality was related to unity and found haptic aesthetic

The circular patterns brought typicality to the users as it reminded them of speaker elements, this was also felt as more coherent and unified and haptic aesthetically liked.

k.i. Haptic aesthetics crosses to the visual sense

Those who rated the uV stimuli as aesthetic, once they were able to look at the three designs, found it not visually aesthetic, preferring the circularity of UV. In this way, haptic and visual aesthetic preferences were contradictory.

Conclusions for design

Despite not being directly addressed in the user test, participants gave remarks on how they felt the headphone passively on their heads and ears, and actively when engaging with it.

k.i. The concept headphone is understood through the stimulus

As mentioned, the headphones were felt as lightweight and as bringing the interaction to the core of the headphone closer.

k.i. The fabric sleeve makes the design feel fragile

For some participants, the fabric feeling was felt as fragile, fearing damaging the speaker element. This leads to the suggestion of using a thicker, more robust fabric, and tensing it to a greater extent.

k.i. The headphone was perceived as typical and novel

The concept in itself was deemed novel by most, having a soft fabric instead of a hard shell. However, the haptic experience in itself while on the head, the passive touch, was deemed comfortable and similar to that of existing headphones. This is in line with the design’s interaction intention: the headphone provides a comfortable passive haptic experience, and a stimulating, playful, active passive experience.

The comfortable passive experience trying to be an enhancement on the feeling of a typical high end audiophile headphone, and the active experience bringing the novelty to the design.

Limitations and recommendations

In future testing a higher number of pretests and focus group rounds are recommended to ensure accurately manipulated stimuli.

As for the actual rating of the participants, rating each item on the aesthetic scale instead of the aspects holistically could ensure more accurate evaluations.

Also, as already discussed, the haptic manipulation of the aspect caused unexpected interpretations. Thus, it is recommended to conduct this test with a less complex product that allows for a more straightforward haptic manipulation.

k.i. Evaluating the emotions elicited by the design can be insightful

Along the same line, further evaluation of the product could also include evaluation of the participants' emotional response, using tools such as the Premo tool (*Premo | Emotion Measurement*, n.d.).

Finally, the empirical test was conducted with N=22 participants, of which almost half were design students. In future tests it is suggested to conduct the test with a higher number of users from a more spread out background, to gain statistical significance.

Recommendations for the design

k.i. The insights gained in this test also helped modify the design.

From a unity - variety perspective it was decided to change the shape of the second ring to a more "interesting" one, yet unified, by making it elliptical, which should also not compromise the visual aesthetics of the prototype, keeping somewhat the typicality and reference to speakers. The ellipse also maintains the length of the ear, to make it feel organic.

The sleeve was changed to a more robust and tense design, providing a less elastic sensation to the user.

Finally, the distance in height between the rings was made constant, to provide a more unified feeling and ergonomic interaction with the rings.

These modifications can be seen in the key design aspects .03 list.

Key design aspects .03

- The design is composed of two main elements:
  - Thin, robust, elastic, light fabric, in a continuous closed, highly tensioned sleeve
  - Structural spring steel headband and aluminium earcup in one continuous element
- The earcup structure is composed of three components with equal height differences
  - Bottom plate
  - Elliptical ring
  - Middle circular structure, to hold the driver
- The headphone provides a comfortable passive haptic experience (typical), and a stimulating, playful, active haptic experience
- The resulting headphone is lighter or same weight than the HD6xx
- The vibration of the driver can be felt through the membrane
- The headphone is open back
- The earcup height can be adjusted with a sliding, smooth motion, manipulated through the fabric
- The overall dimensions and components mimic those of the HD6xx:
  - Headband curvature and length
  - Ear-pad shape and dimension
  - Driver element

.03 Embodiment

Taking the key design aspects developed in the concept design (.03) and the feedback gained during the user tests, the design was modified once again and embodied in a showcase model (see Figure 91). The embodiment was a challenging prototyping process that highlighted the difficulties of making a model that not only looks like, but feels like real.

Figure 91. Prototype

.02 Details and manufacturing

Sleeve

The fabric used for the sleeve is elastane (PU), instead of the one used in the previous stimuli (was 90% Nylon, 10%), as it feels more robust. This fabric is netted, lightweight and elastic.

k.i. Existing fabrics did not meet all the desired properties for the sleeve

It must be noted that the previous fabric felt thinner and smoother, making for a more pleasant interaction with the underneath structure, but felt too fragile and was associated with garments such as a pantihose.

A pattern was designed to make the sleeve, that had to contain seams instead of a continuous weave. The material was layered to create an effect of higher opacity in some areas (double layer in the earcup). The pattern was developed by making a 3D CAD model of the sleeve in Rhino, and developing the surfaces can be seen in Appendix 8.

As for the heat dissipation capacity, PU is a breathable material often used in sportswear. Its netted structure allows for airflow and an open feeling.

Structure

The skeleton is formed by two parts: the headband and the earcups.

Headband

The headband is laser cut 3mm stainless steel, bent to the right radius (see Figure 92).

k.i. The stainless steel headband doesn't provide enough spring

To provide the springiness that characterises a metal headband, spring steel and the industrial machinery to hot roll it is needed.

Earcups

The earcups are mainly composed of aluminium. The bottom plate was milled (see Figure 93), the in-between layer, the ellipse, was laser cut and filed, and the circle top was cut out of an aluminium tube.

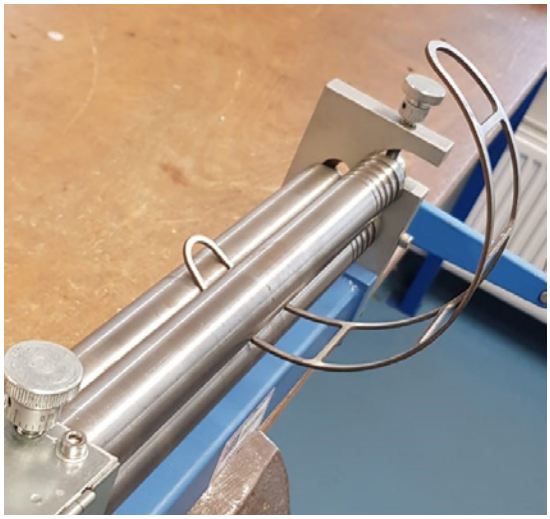


Figure 92. Roll bending steel headband

Figure 93. CNC machined aluminium earcup

Connectors and height adjustment

The sliding mechanism is an aluminium rod with a 3D printed PLA slider connecting it to the headband structure.

To securely join the aluminium rod to the ellipse, the two parts were braised using an aluminium filler (see Figure 94).

The connection elements and intricate parts were 3D printed PLA connection elements.

The connectors for the audio cable were cut and adapted from the HD600 headphone.

Figure 94. Brazing connection to earcup

Earpad

The existing HF6xx line earpads were used and fitted into the model.

Vibrating membrane

The original drivers from an HD600 headphone were used initially (see Figure 95), however, their fragility led to substitute them for other available speaker elements that are more resistant to touch (enabling the interaction) (see Figure 96). These were soldered and integrated to the earcups.

Figure 95. Original driver

k.i. Substitute drivers allow for a better interaction but higher weight and volume.

However, these elements suppose an increase of weight in the headphone of 2 x 31g, and of height in the earcup, that was not planned for.

Assembly

The parts were designed to fit and click into each other, but glue was used to secure the bonds. In this way, the metal elements were first sanded, and then glued with epoxy to the PLA connection parts, to form the structure (see Figure 96).

k.i. The pressure distribution around the ears is uneven

The PLA connector to the slider was not rigid enough under tension, making the earcup tilt when wearing the headphone, and resulting in an uneven pressure distribution of the earpads.

Finally, the fabric sleeve was put over the structure and adapted to fit.

Figure 96. Assembly without sleeve

k.i. The earcup cover created compression in the earpad

The cover was made to fit tightly over the earcup, however, this also created too tight a fit when placing it over the earpad, which made it compress instead of retaining its softness.

.03 Conclusion

The resulting prototype (see Figure 97) includes all the elements defined previously, however, making a feels-like prototype was harder than expected as the precision and rigidity / flexibility of the parts has to be on point to create the desired feeling.

k.i. Many techniques were involved

The manufacturing and assembly techniques involved in making this prototyping process are: milling, laser cutting, 3D printing, cutting, brazing, roll bending, filing, gluing, spray painting, sewing and soldering. This demonstrates the complexity of the prototyping process.

As most of the prototyping and assembly was done manually, and some manufacturing techniques were out of bounds, achieving the desired feeling was a challenge.

The most notable example of this is the slider over the height adjustment, made out of PLA, which bends creating the uneven pressure distribution of the earpads.

Or the steel headband, that lacks the required flexibility, as spring steel was not accessible.

Furthermore, the weight of the prototype is of 330g instead of the original 260g. This is mostly due to the change of driver, which weighs 2 x 49g instead of 2 x 18g, increasing the total weight by 62g. The use of spring steel in the headband would also decrease the weight.

In this way, the prototype manages to convey the concept and the feeling as a whole, but not all the basic headphone features have been fully achieved.

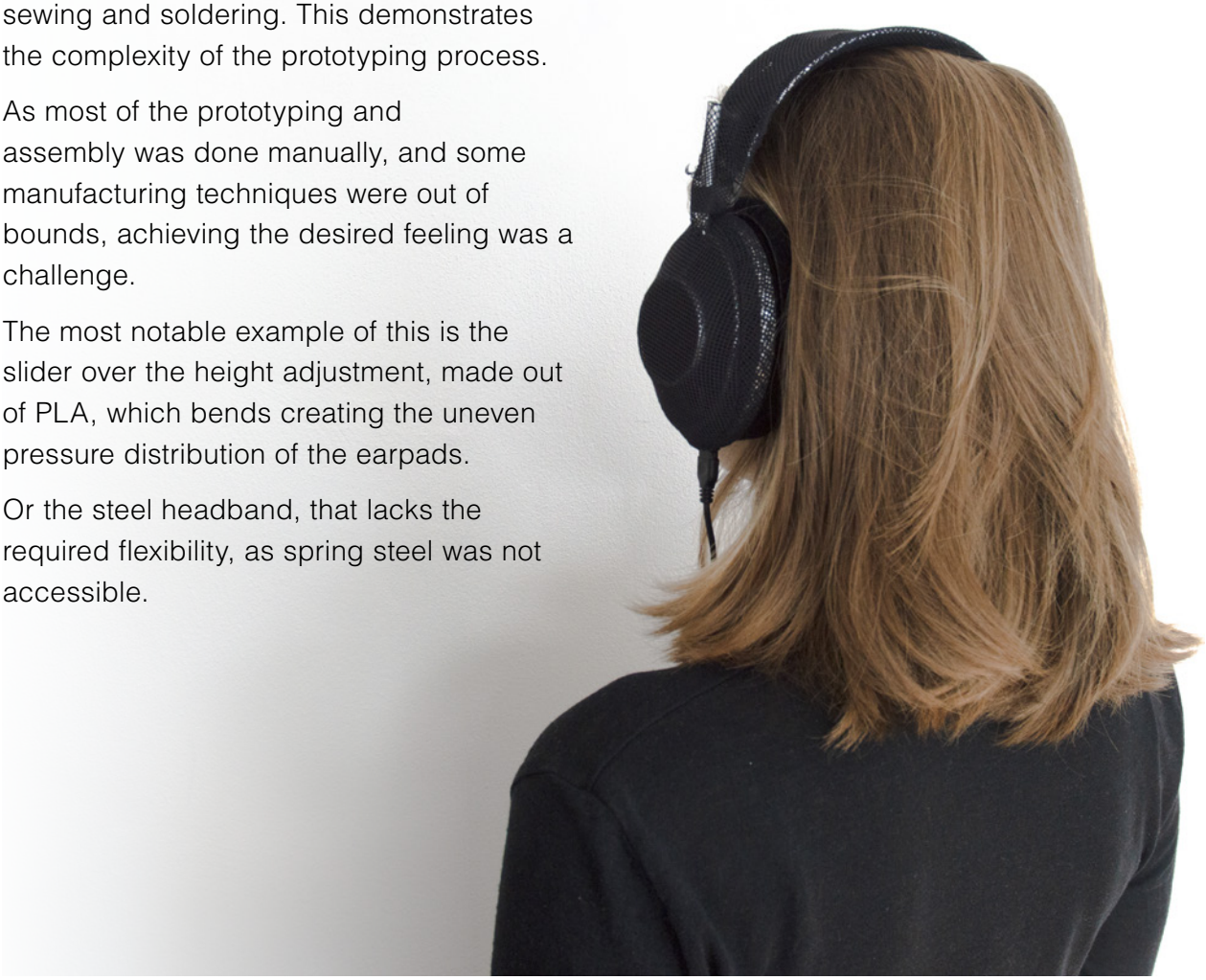


Figure 97. User wearing prototype

Key insights

Looking at the key insights gathered throughout the chapter, the following points stand out.

Key design aspects for the concept headphone embodiment

In the first half of the chapter, the most relevant aspects for the design were explored. To avoid the lightweight, structural and open aspects of the design from being perceived as fragile, the structure material was defined to be aluminium. Ergonomic concerns were addressed and the desired interaction was designed, based on the active touch and compliance of the elastic fabric, as a pleasurable experience.

An essential part of the concept was the changing weave across the headphone, which had to be abandoned due to time and equipment limitations.

The user test also helped inform the design and iterate on the design aspects, but most importantly showed that the concept was indeed understood by the participants.

Designing for a haptic aesthetic experience

The user test tried to evaluate the stimuli from a purely aesthetic point of view, the immediate automatic response, however, haptic exploration elicited emotions in the participants that cannot be ignored and go hand in hand with the aesthetic experience, making it an intimate and personal one.

Perhaps because of this intimate connection with the body, stimuli described as organic, fitting to the corresponding area in the body, were judged as more haptic aesthetic.

At least for the case of the headphones, participants were looking for interaction with the elements. Thus, it could be said that encouraging novel interactions through object properties, using affordances, can create haptic aesthetic experiences. Perhaps related to this, the perception of novelty was found to have great influence on aesthetic appreciation.

Lastly, the difference of experiences across participants could be attributed once again to the intimacy and subjectivity of this sense. This highlights the importance of informing the design of the haptic aesthetic moment through participants' experience and user testing.

Unity - variety

The UiV manipulations indeed resulted in the positive aesthetic appreciation of the UV stimulus (high unity high variety). This informs that the project's second research question is indeed a true statement. However, the qualitative insights indicated that this preference could be due to other factors. This means it cannot be said definitely that the increase in unity and variety are the sole reasons for the higher aesthetic appreciation, but only to some extent.

Embodying the envisioned feeling

The prototyping journey showed that making a feels-like model that also looks-like, is a challenging process that requires precision.

.06
Evaluation

This last chapter consists of a final evaluation of the headphone concept and embodiment. The evaluation is used as a means to answer the first research question, the influence of novelty and typicality in haptic aesthetic appreciation, but also to reflect on the final concept, the haptic aesthetic theory and the project as a whole.

.01
Novelty - typicality

Despite the final prototype not fully embodying the concept vision due to prototyping limitations, being this the closest manifestation of the concept, it was used to qualitatively evaluate the concept headphone with audiophile users.

.01 Research question

The main research goal is to understand to what extent the aesthetic principle of novelty in typicality applies to the haptic sense and how this should best be embodied in the headphone design, in line with the project's first research question (see Figure 99). However, as was discovered in the previous user test, the emotions elicited by the design,play a big role in haptic aesthetics, so does the influence on visual aesthetics, making these also a relevant research questions:

Q1 Are the maximisation of both haptic novelty and typicality positively related to haptic aesthetic appreciation? (When the counteracting influence of these concomitant changes in the other variable is controlled for).

Q2 In what way can maximising novelty in typicality contribute to the design of the concept headphone?

Q3 What emotions and product associations are elicited during the haptic interaction with the prototype?

To what extent does the maximisation of both haptic novelty and typicality positively influence haptic aesthetic appreciation

Figure 98. Project first research question

.02 Method

This evaluation takes once again the RtD approach, gaining insights about the design and the theory.

This evaluation was not an empirical test but rather a qualitative study in the form of and interview and ratings. The interviewees were asked to engage with the original headphone, in this case the HD650 model, and then with the concept headphone while thinking out loud. After this, they were asked a series of evaluation questions, to trigger their opinions and answer the research questions, rating the headphones on novelty, typicality, aesthetic pleasure and expressing their emotions and associations to the stimuli.

Participants

The evaluation was conducted with four male users of open-back wired audiophile headphones, with interest in the audio gadgets, of ages 20 to 30. These were:

• Participant 1: audiophile, owner of several headphones including the HD600.

• Participant 2: user interested in headphones, owner of Meze 99 classic (closed back headphones).

• Participant 3: sound technician, working for long periods of time with open back headphones, owner of Meze 99 classic.

• Participant 4: DJ and music producer, working for long periods of time with open back headphones, owner of Beyerdynamic DT990 PRO.

Stimuli and equipment

Procedure

1. Participants were informed that they were taking part in a product evaluation in which they would have to rate the stimuli on how they felt and later how they looked, but never on functionality. They were asked to think out loud throughout the whole process.

2. Each participant was allowed to familiarise with the HD650 headphone and the concept headphone during the desired time. The headphones were placed onto the participant's head, first out of visibility, to evaluate only with the haptic sense.

3. After familiarisation, participants rated the concept headphone on novelty - typicality using a 7 point Likert scale (Fully disagree (1) to Fully agree (7)) and taking the HD650 as a reference, with value 4.

Once again, items from the Aesthetic Pleasure in Design Scale were used to describe these aspects (Blijlevens et al., 2017).

4. Participants were then asked to explain what they liked or disliked when engaging with the prototype, in comparison to the reference product.

5. Participants were asked to report the emotions elicited first by the HD650 headphone, and then by the concept headphone, using the PREmo tool. PREmo is a non-verbal instrument to self report emotions, through animations that cover 14 emotions elicited in product design, seven pleasant and seven unpleasant (Desmet, 2005).

6. After this they were asked about any associations that arise from interacting with the product, positive or negative.

7. Finally, participants saw the prototype and were asked to comment on its visual appearance, also compared to the HD650.

Data and Analysis

The data collected was mostly of qualitative nature. The interviews were recorded and the transcripts analysed to gain insights into the theory and design development, once again, coding the data as in chapter 5.02.

The Likert scale ratings were used not so much for their numerical value, due to the qualitative nature of the study, but rather to understand the participants' perceptions of novelty and typicality. The PREmo tool helped collect the elicited emotions.

.03 Results and conclusions

The concept was evaluated with an average of 5.25 out of 7 in novelty, when compared to the established 4 out of 7 of the HD650. Its typicality was rated an average of 3.83, compared to the 4 of the HD650. In this way, it can be said that the participants perceived the concept as slightly novel, and quite typical on average.

The PREmo tool helped gather the emotions elicited by both designs.

Emotions in the HD650

The emotions that arise when interacting with the HD650 headphone (see Figure 99) are mostly those of joy, satisfaction and contentment. For the two users that were not familiar with the headphone, they were also curious about it. Boredom was also highlighted as it is a very straightforward comfortable headphone.

Emotions in the concept headphone

As for the concept headphone, participants

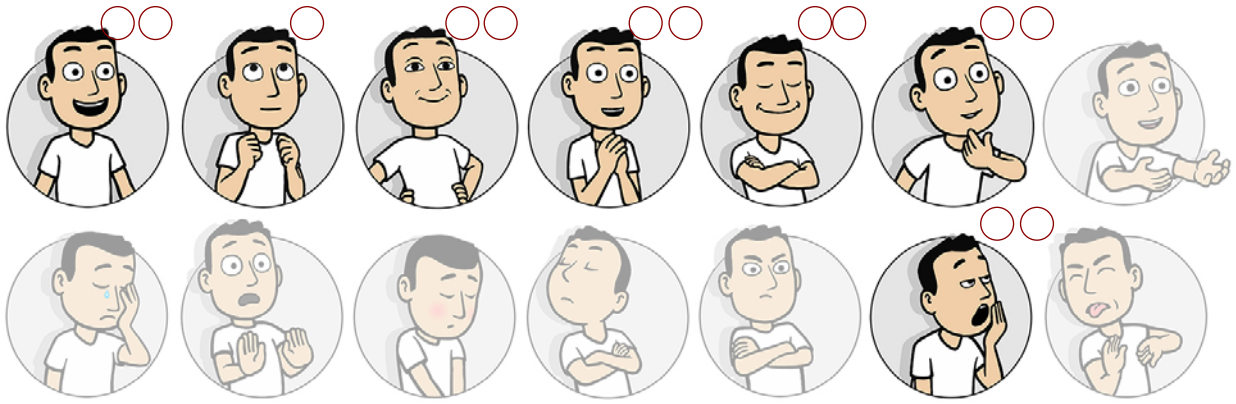


Figure 99. Emotions for HD650

Figure 100. Emotions for concept headphone

felt mostly excitement, curiosity and desire to engage with the headphone, as well as joy. One participant expressed also fear of not knowing what to expect and confusion at not understanding.

Qualitative insights

The following represents the insights gathered from analysing the content of the interviews, the full dataset and codes can be seen in Appendix 11.

The headphone is perceived as robust and industrial, with rough edges. Eliminating the fragile associations of the previous design.

The associations to the concept headphone are contradictory. The feeling of the metal structure and mechanical slider made the participants perceive this as an industrial, rough, sturdy prototype, comparing it to Grado headphones. However, the fabric exterior gave the association of the softness of a teddy bear to one participant, as in the Fidelio X3, that clashes with the structure.

Figure 101. Grado SR325

Figure 102. Fidelio X3

Feeling the vibration of the music, the sound pressure, is a pleasant interaction that connects the body to the music, an experience present with speakers, but not headphones.

Most of the participants expressed their liking of the vibration of the driver, in order to immerse oneself more in the music. One user indicated that rather than it being felt through the hands, it should be transmitted to the head / ears in some way, to not actively have to engage in order to feel it.

The fabric sleeve is not fully integrated in the concept headphone's embodiment.

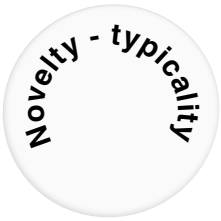
For one participant the presence of fabric immediately evoked a softness that was not matched by the structure. Another user felt the fabric was a quick solution to cover the structure, and another one initially doubted if it was part of the concept. This showcases a contrast in finish and lack of integration of the fabric to the structure.

The integration of the aluminium and steel structure is perceptible under the fabric and appreciated by the users, yet makes the prototype feel rigid.

The structural aspect of the headphone was appreciated by the participants, who liked the industrial feel of the metal structure, making the headphone feel sturdy, though slightly rigid, yet lightweight and compact. Especially so the headband, which has the benefit of the double headband present in other headphones (the head finding its own pressure points in the fabric), while remaining compact and light. The headphone was felt as heavy, when compared with the HD650 by one participant.

Stimulation through the use of textures, pliability and vibration is pleasing and exciting, lack of stimulation can become boring.

As highlighted by the PREmo tool, the presence of the fabric with its inherent texture and pliability and the vibration did make the participants feel excited about the headphone. One participant described the joy in the journey of getting to know the different frequencies of vibration and the ways of engaging with the headphone in the user journey. On the contrary, another described the HD650 as comfortable and pleasant, but “lacking spice” in certain occasions.



The prototype was felt as both novel and typical. The novelty was conveyed through the fabric outside but also the structure and its edges. The typicality was conveyed through the overall headphone feeling and positively valued.

The headphone was considered novel by the participants, however, not exceptionally so. This is because the novelty was relegated to the active engagement with the outside, and not the inside of the headphone and its passive touch, which is considered the more crucial parts of the product. The typicality was found, once again in the oval shape of the structure, but mostly in the overall construction and feeling of two earcups with a headband, which was liked by the participants.

Conclusions

Conclusions for haptic novelty - typicality

The prototype indeed was felt as novel due to a change of the outside material to a soft one, fabric, as well as the edgy structure underneath and the feeling vibration. This demonstrates that it is possible to create a haptically novel feeling.

k.i. Haptic typicality within novelty is liked

Within this novelty, participants showed that they found reassuring that the headphone still felt like a headphone, the archetype. This seems to indicate that, for a product design felt as novel, the maximisation of its typicality in feeling, brings positive appreciation, which informs the first research question.

k.i. Haptic novel stimulation can spawn curiosity and excitement

Users also expressed boredom from the comfortable, down to earth headphone feeling, expressing the interest and excitement to engage, and feel something novel.

As for the novelty of the design in itself, in this case it manifests itself on the outside of the headphone.

k.i. Radical haptic novelty arises when changing the passive haptic experience

This evaluation helped learn that, in order to feel radical haptic novelty, this has to stem from the inside of the headphone, from the passive feeling of wearing it, with the inherent risks of overloading. When thinking of other products this would mean changing the element creating the passive touch and experience.

Conclusions for haptic aesthetics

During this evaluation, the elements that were considered most haptic aesthetic of the design were the metal structure with its industrial feel, and the vibration feeling.

The appreciation of metal as a material had been established since the field research. However, in this case, the aluminium height adjusters and the “industrial style” were also appreciated.

k.i. Haptic properties which match the object’s purpose are aesthetic

The admiration of the industrial style is probably product specific, and stems from audiophiles’ interest in performance driven design, as seen in chapter 2.03. This, once again, brings up the topic of how emotions and associations are strongly linked to what is appreciated by the users, and must be considered in the design phase.

k.i. Connecting the body to feel the object performing its function can enhance the kinaesthetic experience

The same can be said about the vibration feeling. The participants liked interacting with it because it connects their body to the experience of listening to music. In this way it could be said that a strategy to design something haptic aesthetic is connecting the body, feeling in the body, something connected to the purpose of the object.

k.i. Matching the sensations to haptically unify the product

Finally, the participant that indicated expecting a soft shaped structure underneath the fabric, shows an inclination to have a unifying feeling between the different parts. This speaks to the desire for unity in feeling of the designs explored in different chapters.

Conclusions for the prototype and design

As mentioned before, issues in prototyping caused the headphone not to feel completely as desired. These issues are:

• Ergonomic issues such as the size of the headband and the pressure distribution in the earpads.

• The weight is higher than the HD6xx line, due to the substitute drivers.

• The headband is not pliable enough due to the use of steel instead of spring steel.

• Connections are 3D printed instead if precision manufactured.

The evaluation also put focus on some design aspects to take care of to make the concept succeed:

• The vibration mechanism should be explored to transfer the “right frequencies”, potentially feeling the vibration in other parts of the head.

• Minimising the weight using the minimum structure thickness to withstand the required loads, and using spring steel in the headband.

k.i. The lack of the right fabric is a substantial part of the concept embodiment shortcoming

• The development of a custom fabric is essential to convey the concept. Participants felt it as detached instead of well integrated and fitting to the underlying structure.

• The design details of the earcup structure are yet to be explored. Elements such as the optimal distance between the components and the curvature and thickness of the edges etc.

On the other hand, with the adaptations from the previous user test, the participants no longer commented on the associations to fragility or to delicate clothing, but rather, the design was perceived as robust. Looking at the third research question, the design was received mainly with excitement and curiosity, but also fear of the unknown.

Finally, to answer the second research question, the participants seemed to find comforting the archetypical feeling the design brought, which indicates this is a design aspect that should be maintained. However, the embodied novelty could be increased, for instance, by including more novel elements in the passive experience.

.02 Discussion, design

This segment describes what a final design could be like beyond the limitations encountered in the embodiment, developing a set of recommendations for the client, Sennheiser.

.01 Design review

Going back to the mission statement, the question of whether the concept headphone is indeed haptically novel, and if it feels beautiful, arises.

Haptic novelty in the design

The final evaluation of the design showed that the prototype was perceived as novel by the audiophiles, but not hugely so.

In order to create more novelty two approaches could be taken. On the one hand, as was originally envisioned in the concept design, a variety of sensations could be present underneath the fabric sleeve, that the user discovers when interacting. This was discarded in the concept in order to avoid creating a too intricate design, but offers the possibility of increasing the novelty without overloading the user.

Another approach would be to bring the novelty to the passive experience, to the feeling of the headphone on the ears and head. Furthermore, passively received stimuli have a higher sensorial response (Lloyd et al., 2015). For instance, the vibration of the driver could affect directly the ears or head. This however runs the risk of overloading, and must be further studied.

Haptic aesthetics in the design

The evaluation helped understand which aspects of the concept headphone were found haptic aesthetic by the audiophiles. The most liked was the feeling of the vibration, as it enhances the musical experience, and enables feeling the sound pressure waves in the body. The metal frame was liked by all participants for conveying and industrial and sturdy feel.

The remaining part of the concept was appreciated very differently across the participants. This doesn't allow to determine whether the concept as a whole manages to be haptic aesthetic, but it gives an indication of what should be developed to achieve this. One participant valued the lightweight potential of the structural design, while another liked the pliability and interaction with the fabric. The structure of the earcups and headband were liked in for being compact, also the headband, as the head finds its own pressure points.

However, the fabric was judged as a quick solution and the underlying structure as not matching. This is due to the insufficient development of both the earcup structure exact geometry, the fabric, and their interaction and attachment to each other.

Despite this, one thing can be said: the concept headphone provides a richer haptic experience than the original HD6xx.

.02 Recommendations, Sennheiser

This final iteration of the design is a recommendation in itself, a vision of what the concept headphone might be beyond the embodied prototype (see Figure 103).

Develop the fabric

The development of the fabric into a CNC woven seamless sleeve with the desired properties is essential to the design feel.

The resulting fabric should be thin, elastic and lightweight (similar to the one used in the first stimuli), yet strong and smooth to the touch, such as Dyneema (Bowden, 2018), a strong, light fibre used in outdoor equipment.

The sleeve should have more or less tense areas depending on the openings needed for airflow and cooling.

The integration of conductive yarns to create a heatsink effect in the earpads and cups should also be explored.

The emotions and associations elicited by engaging with the fabric should be controlled for.

Finally, this fabric should be developed in a way that it works also from a technical aspect, to create a good sound. This is similar to Sennheiser's HD800 headphone, which features a mesh covering the earcup.

Create more novelty

As has been mentioned, the concept could increase in novelty by including sensations and patterns underneath the headband, to be discovered by the user, such as an underlying texture. Which sensations to include should be extensively tested to make sure it adds to the haptic aesthetics.

The use of smart textiles and electronics could help create a bigger contrast in sensations, for instance, in temperature.

Test in time, and adapt

The concept has only been tested in short moments with users, where they rated their initial impressions. However, the research has shown that the haptic impression changes over time, thus, it is recommended to evaluate and test the headphone in a full audiophile user journey.

Play with the haptic - auditory pair

Something that was left out of scope was the impact of the haptic properties on the sound. Exploring this topic opens opportunities to further design the headphone thinking of how the different interactions with the fabric affect sound. Letting the user play with the fabric to achieve the desired soundscape.

Develop the earcup structure

The exact proportions and shape of the earcup structure are still in need of refinement. This should be developed in parallel to the fabric to create the desired feeling.

Furthermore, functionality could be added to the earcup structure. Many participants suggested the integration of volume control to the top ring in order to force the interaction to occur.

Explore the vibrations of the driver

Finally, the vibration of the driver is a topic to develop, with great potential for Sennheiser, as it was the most liked feature by the audiophile users.

What frequencies it should transfer, how it should be felt in the body, as well as how to technically implement it to make it sound optimally, are the topics to be explored.

Develop
CNC fabric
Thin, elastic, strong
Change in tension, weave
Technical

Include
underlying texture
Sensations
Textures

Include
passive touch
Sensations
Textures

Develop
vibrational membrane
Frequency
Transition
Sound modifying

Develop
Earcup proportion
Height
Edges, details

Figure 103. Final design proposal

.03 Discussion, theory

After the exploratory session, the UiV user test and the novelty - typicality evaluation, this section discusses if the selected theories are indeed applicable to haptic experiences. It gathers the final set of key insights, but also, what has been learnt about how to design for haptic aesthetic experiences.

.01 Haptic novelty - typicality

The first research question was answered mainly through the exploratory session and the validation moments.

It is possible to embody a haptically novel feeling

The first point to address is if novelty can actually be conveyed through the haptic sense.

The answer is yes. During the exploratory session the students were asked to “design haptically novel headphones that feel beautiful”. This moment helped learn of ways in which to create a novel feeling in the design. The other two evaluations gave impressions on what is actually perceived as novel. Some of the relevant ways found to create this novelty are:

• Creating sensations that were not previously present: combining them differently.

• Switching sensations to what is known: soft where hard is and vice-versa.

• Involving other body parts and creating other interactions and kinaesthetic experiences.

• By applying the novelty to the passive experience, that is imposed to the user by the object, a higher novel feeling, even accompanied by surprise can be achieved.

Looking at the two validation moments, what was perceived most novel in the headphone was indeed the unfamiliar pliable fabric outside, and the edges and geometry of the earcup structure. This leads to believe that working with materials used for other applications, and playing with the exact shape of the object, are useful properties to manipulate novelty.

It is possible to embody a haptically typical feeling

As for typicality, it is also possible to convey this through the haptic sense.

Maintaining the overall construction of the product category, in this case two earcups

and a headband, is a key way of embodying typicality.

By modifying the active haptic experience but not the passive one, high typicality can be achieved, however perhaps at the cost of novelty.

Interesting to note too, in the case of the headphone, the circle and oval shapes were associated by the users to the product category, as this is the shape of the speaker element (driver). Identifying the core shape or pattern of a product or that of its purpose of use, can be a useful tool to bring typicality in feeling to a design.

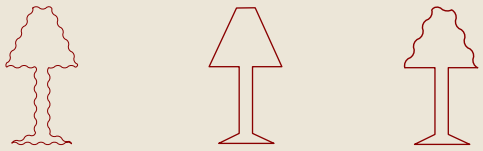
The relationship between haptic novelty, typicality, and aesthetic pleasure

We know now that these two qualities can be haptically embodied in a design, but, how do they influence aesthetic appreciation in individuals?

During the empirical test it was seen that an increase in rated haptic novelty in the stimuli was matched with increased aesthetic appreciation, while typicality did not seem to have a significant effect. Participants clearly sought out new ways of interacting and engaging with the product features. However, it must be noted that the most liked stimulus was indeed rated as the most typical, on average. Furthermore, the circularity of the shapes were perceived as archetypical and fitting to the design, thus, liked.

The same was found in the product evaluation. The audiophiles seemed to like the typicality brought by the prototype, the fact that it indeed felt like a headphone.

Although the latter is no empirical proof of the theory in question, the balancing out of the novel feeling (which can quickly become “weird”) with the familiarity of the typical was observed to help create more haptic aesthetic experiences.



.02 Haptic unity - variety

The second research question and proposed aesthetic theory was mostly targeted through the empirical user test, where unity and variety were intentionally manipulated.

It is possible to embody haptic unity

During the empirical user test, the unity and variety manipulations were indeed somewhat perceived, on average, by the users.

One crucial strategy that was identified to create a unified feeling is making the different elements that comprise the design convey the same haptic quality. For example, making the curves and edges in the earcup structure rounder to match the smoothness of the fabric.

Another strategy is repeating a shape at consistent distances, even in different sizes. The Gestalt principle of similarity and also constancy were applied in the manipulations and perceived with the haptic sense. However, it was found that the distances between the elements in all directions (x, y, z) must be considered.

It is possible to embody haptic variety

Participants were also able to discern more varied stimuli from less so. An interesting finding on how to create a varied feeling, is by stimulating the haptic sense and adding properties that encourage interaction.

Also, directly increasing the number of elements in a design did not always result in the perception of higher variety. Rather, it is the relationship between these component that embodies this property. For instance, elements that are too far apart can be perceived as more varied than having an in-between extra element. Or elements conveying a contrast in sensations, such as cold and warm, or smooth and touch textures.

The relationship between haptic unity, variety, and aesthetic pleasure

Finally, as was already mentioned in the previous chapter, the design rated as most aesthetic was the UV stimulus (high unity high variety). Although this preference could also be due to other factors, this informs that there is some truth to the application of the UiV principle to the haptic sense.

The desire of one of the audiophiles, during the final evaluation, to create have a structure that matches the smoothness of the fabric indicates the wish for a more unified feeling, within the variety.

This allows us to conclude that having a more varied, interesting haptic shape, that is also perceived as unified could increase the haptic aesthetic appeal of the design.

.03 Recommendations, haptic aesthetics

In trying to fulfil its goals, this project has developed learnings and recommendations about haptic aesthetics and how to design for it. Some learnings are product specific, but others have been abstracted to inform the field of haptic aesthetics as a whole.

Time

Even though the aesthetic experience is an immediate response, one thing became clear from the literature review: the haptic experience takes time. Our receptors enjoy or dislike sensations that increase, decrease or disappear in time. Thus, the haptic aesthetic experience could perhaps be understood as a series of moments of interaction that are inevitably linked together to form one overall sensorial impression in our memories.

Although this project tried to pay attention to the whole user journey and the element of time, the user tests were focused on the immediate response. To better design for this sense, it is recommended to pay attention and leave room to how sensations might evolve in time, especially so when evaluating with individuals.

This was also manifested during the evaluations, as participants expressed their change in impression and liking as they discovered and explored the stimuli in time, a sort of haptic aesthetic curve.

Emotions and associations

Referring once again to the definition of the aesthetic experience, it consists of an instant previous to the formation of emotions and associations in the mind, a moment of delighting of the senses.

However, in practical terms, it is not possible to design for this instant in a product, as emotions and associations arise immediately. In the case of the headphone, the thin soft fabric was judged as fragile and thus, disliked, despite being more pleasurable to interact with than the thicker one.

Thus, as the haptic sense is so intimate, it is imperative to take into account the elicited emotions and associations that stem from the haptic engagement, to create a pleasurable one. Also considering the individual preferences that this intimacy entails.

In the same way, when designing for a specific product category, the haptic properties that match the object's purpose will usually be most appreciated, as they work towards a positive product use experience.

Connection to the body, organic

During the evaluations it was observed that shapes and geometries mimetic to areas of the body, were found more pleasant. Not only from an ergonomics point of view, but rather the interaction was more natural to the participants, more organic.

This could manifest that there is aesthetic pleasure found in connecting the object to the body. Which was also found as the participants found pleasant feeling closer to the physical making of the music, by feeling the sound pressure through the vibration. This also enhances the kinaesthetic aspect of the sense in question, encouraging body movement and awareness.

Affordances for active engagement

Creating affordances in the design is a tool to invite the user to engage with the object, without the need for a function, but for the pleasure of interacting with the form and stimulating the senses. The affordances should be designed also from an ergonomics point of view, to physically facilitate and make the interaction comfortable.

It must be noted though, many participants expressed the wish for the interactions to be accompanied by a function, in order to engage purposefully.

Playing with active, passive touch

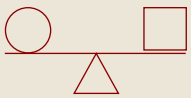
The balance between created sensations and lack of them, comfort, throughout the user journey was a key aspect of this project. Thinking about this duality allows to create pleasurable experiences without running the risk of becoming overloading. The user has the control and intention in active touch, but passive touch also opens more opportunities for surprise in the interaction and a richer sensorial response.

For each design, each experience, a different balance could be optimal. In the case of the headphone, one of the recommendations at the end of the project was to bring a more stimulating experience also to the inside, to the passive touch of the headphone to the user, in order to create more radical haptic novelty.

However, it must be noted that comfort must always be present in a haptic experience that lasts longer than an instant, in order for it to be an aesthetic one.

The other senses remains present

Despite the goal of designing for the haptic sense, the reality is that the senses are not isolated. As was witnessed throughout the project, every haptic alteration entailed visual expectations and reactions from the participants. The same can be said for sound, especially for the case of the headphone. Each product category has its most relevant senses, and the relationship between them must undoubtedly be taken care of.



Creating a balance of arousal

A final note on the aesthetic theories. When rating the haptic unity and variety of the designs, the connection between haptic variety and novelty became clear, as did that of unity to perceived typicality. This corresponds to Berlyne's theory, and the framework this project is based upon, where aesthetic pleasure will peak when there is an optimum level of psychological arousal (Crilly et al., 2004). In this case users found the more varied shapes also as psychologically arousing and novel, whereas the highly unified ones were perceived as boring, too familiar and typical (low arousal). When designing for haptic aesthetic experiences, it might be sufficient to think of creating this balance between arousal and stimulation, and lack-thereof.

.04 Recommendations, process

With the project having come to an end, there are many steps to reflect upon.

Including emotions in the scope

Initially, the project proposed investigating haptic aesthetic theory. It is now clear to me that designing exclusively for aesthetics is more challenging and perhaps less valuable than including the elicited emotions every step of the way, especially when it comes to the haptic sense. Thus, I recommend including these emotions throughout the design process.

User validation and prototyping

The design process included prototyping in three different moments. Throughout all three of them I discovered the challenges of making something that, not looks like, but feels like it should. Achieving this was of great importance to convey what the haptic experience should feel like. However, the complexity of the product made this goal only partially completed.

A more fitting approach for this purpose might have been to try to embody a concept in the earlier stages of the project, and do many rapid prototyping and evaluations.

RtD and grounded theory

RtD was used to guide the process and successfully achieve the project goals. However, the exploratory session was used to inform the concept design, rather than the following user test. In hindsight, it is recommended to use to a greater extent the qualitative analysis results from one evaluation, to develop theory and inform the next research step (grounded theory).

.05 Personal reflection

As for my personal journey in this project, I would like to share the following thoughts.

Focusing on the fabric

When I discovered the possibilities that CNC knitting and weaving had to offer, my mind immediately started dreaming about what I was *obviously* going to do with it, so many possibilities... As you can obviously see (if you read my report), it never happened. The reality of the development time, team and resources needed made it an impossible task. It did however start a spark in me that would like to explore this topic further, if given the chance one day.

Dreaming and adapting

I had so many dreams for this project. Some became true and some disappeared. During this project, for better or for worse, I was highly adaptable. I always had a plan, but the plan was constantly changing. I believe this is was a good practice, a kind of flow within the structure, and I want to thank my supervisors for going with it.

The challenges of prototyping

As mentioned earlier, prototyping was no joke, in the final prototype a total of 12 techniques were involved. This was a source of great stress, but also, a fast and steep learning curve moment. I even learnt how to sew.

Finding my niche

From the beginning I was excited to discover aesthetics and haptics. And now, at the end, I still am! This project has furthered my interest, and specialisation, in all that concerns design for the aesthetic experience of the senses, and also of course, in headphones.

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• Figure 73. Sensations in the user journey

• Figure 74. Unfolding interaction

• Figure 75. Slider through fabric

• Figure 76. Hybrid tower CNC knitted structure: from CITA, KET, A. ferreira & filhos, & duisburger. (2017, 14 februari). *Hybrid tower*. designboom | architecture & design magazine. https://www.designboom.com/technology/cita-hybrid-tower-guimaraes-portugal-02-14-2017/

• Figure 77. Variegated surface structure close up: from Ahlquist, S. & ggggallery. (2012). *Material Equilibra*. https://www.icd.uni-stuttgart.de/projects/material-equilibriums-installation-and-exhibition/

• Figure 78. Initial concept design

• Figure 79. Project research questions

• Figure 80. Participants background

• Figure 81. Unity - variety combinations for stimuli

• Figure 82. Stimulus A - UV

• Figure 83. Stimulus B - uV

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• Figure 98. Project first research question

• Figure 99. Emotions for HD650: adapted from *Premo | Emotion Measurement*. (n.d.). Premo. https://www.premotool.com/

• Figure 100. Emotions for concept headphone: *Premo | Emotion Measurement*. (n.d.). Premo. https://www.premotool.com/

• Figure 101. Grado SR325: from Grado SR-325x Prestige X Series Headphones | Auditorium Onlineshop. (n.d.). Auditorium. https://www.auditorium.de

• Figure 102. Fidelio X3: Philips Fidelio X3 - Over-ear Koptelefoon - Zwart | bol.com. (n.d.). Bol.com. https://www.bol.com/nl/nl/p/philips-fidelio-x3

• Figure 103. Final design proposal

Appendix