

<https://doi.org/10.7577/formakademisk.1269>

Cheryl Akner-Koler and Parivash Ranjbar Integrating Sensitizing Labs in an Educational Design Process for Haptic Interaction

Abstract

New design methods for educating designers are needed to adapt the attributes of haptic interaction to fit the embodied experience of the users. This paper presents educationally framed aesthetic sensitizing labs: 1) a material-lab exploring the tactile and haptic structures of materials, 2) a vibrotactile-lab exploring actuators directly on the body and 3) a combined materials- and vibrotactile-lab embedded in materials. These labs were integrated in a design course that supports a non-linear design process for embodied explorative and experimental activities that feed into an emerging gestalt. A co-design process was developed in collaboration with researchers and users who developed positioning and communications systems for people with deafblindness. Conclusion: the labs helped to discern attributes of haptic interactions which supported designing scenarios and prototypes showing novel ways to understand and shape haptic interaction.

Keywords: vibrotactile, material, tactile, embodied study, deafblindness

Introduction

For over a decade, there has been growing interest in developing a foundation for embodied interaction that questions the dominance of visual interfaces (Dourish, 2004). Haptic interaction research responds to this shift by exploring ways to design interactive systems that are integrated in our everyday physical activities and in tangible forms. However, few haptic interaction design solutions have improved life quality for end-users thus far.

The challenge dealt with in this paper is how to develop an art-based, educationally framed aesthetic method to improve haptic interaction. Our work is within the area of haptic-audio interaction design. We are exploring how to increase a more sensuous and meaningful usability of interactive artefacts by emphasizing haptic somaesthetic experiences during the art/design process (Dourish, 2004; Shusterman, 2013, Schiphorst, & Fraser, 2011). Karana's research group in material-driven design highlights the need for design methods that focus on the experiential aspects of material properties (Karana, Barati, Rognoli & Zeeuw van der Laan, 2015).

To deal with this challenge, we further developed aesthetic sensitizing labs that explore ways to improve tactile and haptic experiences through physical and technical interaction with materials, sensors and actuators. To test the relevance of these sensitizing labs, we integrated the labs in an aesthetic-oriented design process explored through a course for industrial design students developed by Cheryl Aker Koler. The core subject of the course emphasizes the aesthetic gestalt process with roots in a sculptural design tradition that starts with the inner movement and forces of form and their effect on the shape and expression of form and space, founded by Rowena Reed Kostellow (Greet Hannah, 2002). This aesthetic-driven course is integrated, in a provocative way, with a semiotics product design approach (Monö, 2004), which strives to guide the development of signs and symbols in products by exploring shapes developed in the process on four levels: describe, evoke, express and identify. A co-design team (Sanders & Stappers, 2008) was created incorporating the students in collaboration with external partners who shared their work with a number of vibrotactile interactive aids for persons with deafblindness (DB), deafness (D) and blindness (B). This

group had competence in audiology and computer engineering as well as experienced people with D, B and DB, together with instructors and interpreters. The challenge for the co-design team was to better integrate and express the interactivity of the haptic technology with a tangible form and appropriate material choices. The combined aesthetic/semiotic approach is only briefly outlined in this paper to allow for focus on the sensitizing labs that deal with the choice of material in relation to haptic technology.

Aims

The educational perspective we take in this paper is to develop teaching methods that support the learning processes for design students. These methods are also relevant for researchers and professionals working in the field of design. This paper focuses on the following two aims:

- To develop sensitizing methods to experience tactile/haptic properties of physical materials in relation to sensors and actuators to support haptic interaction.
- To integrate the experiences from the sensitizing labs within an aesthetic-driven, non-linear design course that engages design students in a co-design process.

Limiting the field of aesthetics and haptics

Aesthetics

There is a great need for aesthetic research that links properties of physical materials, actuators, sensors and signal processing methods, which are adapted to human and preferences (Johnsson, 2007; Persson, 2013). There is also an equal need to bridge aesthetic studies to a product/interaction gestalt process to support a more expression-oriented design process (Lim, Stolterman, Jung & Donaldson, 2007; Hallnäs, 2011; Schiphorst & Fraser, 2011). However, we lack knowledge in the aesthetics of haptic interaction (Stenslie, 2013).

Dewey (1980) explains, from a pragmatist aesthetic approach, the importance of supporting the full force of an immediate experience at the very moment one becomes aesthetically involved. He sees this immediacy as a key experience that builds emotional involvement and recognizes the holistic features of the gestalt. “It cannot be asserted too strongly that what is not immediate is not aesthetic” (Dewey, 1980, p. 119). In their article “Aesthetic turn”, Lars Udsen and Anker Helms Jørgenson (2013) explain how the interaction design community recognizes the importance of aesthetic reasoning in the design process. Their pivotal article presents these four approaches: cultural, functionalist, experience-based and techno-futurist. We work with a functionalist and experience-based approach integrated in a sculptural aesthetic discipline (Akner Koler 2007) that supports a dynamic gestalt process. This kind of sculptural aesthetic discipline is not represented in Udsen and Jørgenson’s (Udsen and Jørgensen, 2013) chart; however, we would like to inform the reader of our sculptural base. It is a base that works with principles of aesthetic abstraction and procedures that were passed down and further developed through the sculptor Rowena Reed Kostellow and the painter Alexander Kostellow and founders of the first industrial design school at the Pratt Institute in the US (Greet Hannah 2002). Through an art approach, we can open a channel to art movements, schools and institutions that use applied aesthetic reasoning driven by artists. The work of Ingrid Maria Pohl and Lian Loke (2014) on the changing tactile qualities of surfaces reflects a strong artistic profile in the way they created their method and a toolkit for the emerging art of touch-based design. Their work is relevant for the work we present in this paper. Thecla Schiphorst (2010, 2011) is a leading artist in developing haptic and embodied interactive work. Using her background in dance and interest in textiles, she has contributed to expanding the field of tactile and haptic interaction. In Stahl Stenslie’s (2013) emphasizes somatic performative activities where the experience of touch is considered an artistic material. He is interested in studying virtual touch and the somoa-

esthetic-felt experience of two-way touch, where one touches an artefact and the artefact mediates haptic feedback through technologies. In his early work, he used sculptures to express audio-haptic structures. All these artists explore haptic perception and experience through their connoisseurship of aesthetic skills and knowledge that can help to expand the field of interaction design.

Play, User/Player

Play is considered one of our first aesthetic activities, according to Friedrich Schiller (2004), because it engages our body in spontaneous, emotional and immediate ways where interaction and movement are central. A *player* is driven by desires and fantasy, which is very different from the concept of *user*, which relates to needs and function. In this paper, we would like to introduce the hybrid word *user/player* (U/P) approach, which underscores both the functional needs of the user and the more hedonic desires of the player. We show that U/Ps can be both the students during the sensitizing labs and the people with DB.

Haptics

Haptics is defined by Aristotle as the ability to grasp or touch, which involves the process of recognizing objects and textures. In the first major review of Human Haptic Perception, the editor Martin Grunwald (2008) summarized the field of haptics as follows:

Since the beginning of scientific research into touch, the most varied of scientific disciplines have investigated one aspect or the other of this sense (haptics). The questions posed and the methods used to conduct such research are just as varied as the disciplines devoted to it. The particular results of these efforts, however, have not yet led to a comprehensive theory of the sense of touch. (Grunwald, 2008)

Given the illusive nature of the field of haptics, we have limited our approach to three areas of haptics that have relevance for the present study: *haptic aesthetic sensitivity*, *haptic communication* (for people with DB) and *haptic technology*.

Haptic aesthetic sensitivity

Haptic aesthetic sensitivity refers to the immediate physical experience and emotional response from probing material textures, structures and shapes. It is about actively exploring properties through indirect experience with tools and directly with fingers, hands, lips and eventually the whole body. Figure 1 (page 4) shows the *Fusion of the senses – haptic attributes*, identifying nine haptic attributes related to the hand.

This new model shows nine attributes for the hand that combines Lederman and Klatzky's (1987) six haptic explorative procedures with the added attributes of thickness, vibration and breeze. The aesthetic aspect of haptics involves our embodied and emotional awareness that links to our level of sensitivity. Being sensitive to a certain haptic property does not necessarily correlate with conscious embodied awareness or preference. For instance, if we are very sensitive to cold surfaces, this does not mean we have an aesthetic experience or prefer them. A common assumption in the aesthetic discourse is that an aesthetic experience is connected with "pleasure". Haptic preferences are not only about seeking hedonic "pleasure"; they also deal with, as Grunwald (2008) shows, the entire spectrum of human haptic perception, including repulsion, irritation, pain etc. We maintain an open attitude and treat the idea of aesthetics as a driving force that captures our attention and engages us in the world through all human experiences.

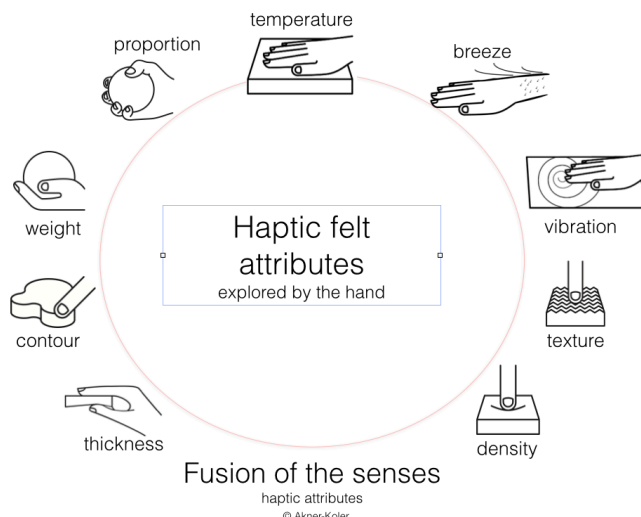


Figure 1. The “Fusion of the Sense – haptic attributes” model, by Cheryl Akner Koler, shows nine haptic attributes explored by the hand. The model is a further development of the Lederman and Klatzky (1987) model.

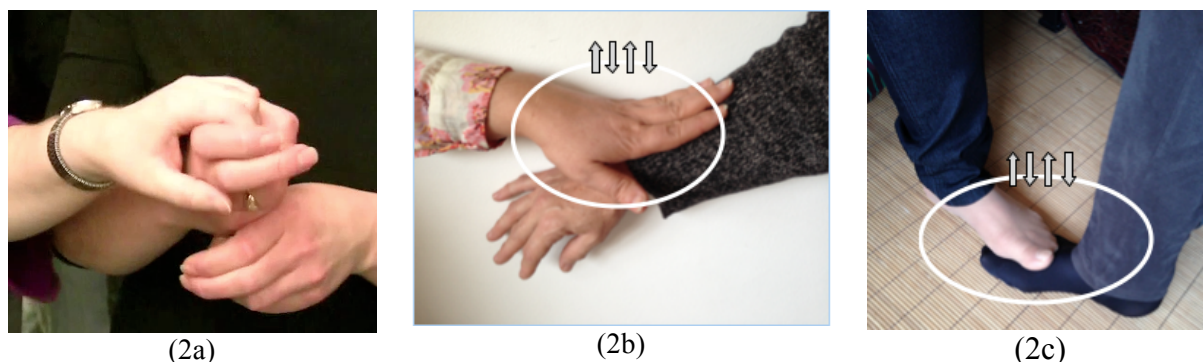


Figure 2. Communication methods for deafblind people. (a) Example of haptic sign language meaning “try”. Two examples of social-haptic communication of the “yes” feedback by (b) hand-to-arm and (c) foot-to-foot – inspired by Lahtinen (2003).

Haptic communication (for people with DB)

Haptic communication is a form of non-verbal communication and emotional expression, where information and feelings are received via active touch on the body. It has always been part of everyday human communication, for example patting on one’s shoulder to show approval/disapproval, shaking hands etc. People with DB use different subgroups of haptic communication, such as tactile sign language, Tadoma and social-haptics. In tactile sign language, the “listener” with DB has her/his hand on the speaker’s hand to perceive the sign language, gestures or finger spelling (see Figure 2a). In Tadoma, the “listener” with DB perceives the spoken language by feeling the vibrations from the speaker’s larynx and movements of the speaker’s mouth. Social-haptic communication for deafblind people has recently become a field of research and was established by Riitta Lahtinen (2008) in close collaboration with Russ Palmer. Lahtinen refers to touch messages between two or more people in a social context (person-to-person), usually combined with tactile sign language. Figures 2b and 2c show two different ways to communicate “yes” given by the encircled person who moves her hand or foot up and down to be felt by the person with DB. The person with DB is able to give and receive haptic gestures that carry information and emotional

expressions that communicate complex content. Research in haptic communication shows that touch can communicate complex emotions such as anger, fear, happiness etc. (Hertenstein & Weiss 2011).

Haptic technology

Haptic technology refers to interaction with users through the sense of touch and grip by applying such things as forces, vibrations and temperature. Examples of haptic devices include computer joysticks in game environments, mobile phones and 3D applications for modelling, navigation and micro/nano-manipulation. The research by Camille Moussette (2011) and his team developed a series of haptic prototypes to introduce different types of haptic interaction and terms to explain key characteristics of the devices. Their hypothesis was that by making simple haptic models, the participants will acquire a more acute sensitivity and knowledge of haptic systems. In the second study, another research team (Moussette, 2012) refined the modular series and introduced a design process with simple box-like mock up prototypes. The work of David Ledo and collaborators (2012) introduced their interesting “Behavior Lab”, which lets programmers explore and “feel” available forms of haptic feedback that is later applied in design projects. In our study, we are interested in experimenting with a wide variety of materials yet limit the haptic technology to vibrotactile stimuli. The vibrations delivered to the skin through a vibrator are detected by different mechanoreceptors in the skin. The vibratory sensitivity of the skin varies depending on the properties of the vibrator (e.g. the size of contact area), the vibrations (e.g. frequency and intensity) and the person (e.g. body site and individual sensitivity). Thus, when designing different devices based on vibrotactile technology, the differences in the vibrator, vibrations and the vibratory sensitivity of the person should be considered. The haptic sense can be improved by training through different sensitizing methods (Spens & Plant, 1983).

Methods

To investigate how to improve haptic interactivity integrated in the use of digital haptic technology, we further developed sensitizing labs. These labs begin with procedures for embodied exploration that emphasize the important role materials play in the design process. The labs support ways to combine haptic interactive research and industrial design processes to impact design education. Our methods have developed over a number of years in different research and educational contexts. The present paper shows an educationally framed study conducted in a five-week course involving 12 industrial design (ID) students with an even amount of females and males working in mixed groups. The first phase of the course was run by Akner Koler exploring aesthetic abstraction and semiotic exercises as well as *sensitizing labs*. In the second phase of the course, both authors worked with the same 12 ID students in collaboration with two researchers; a medical doctor in audiology and an electronic / systems engineer. In this phase we merging an aesthetic-driven design process with a product oriented project with the aim to create aids for persons with DB.

The main focus of this paper is on the sequence of sensitizing labs integrated within a design process; however, due to lack of space, we are not able to give an in-depth description of the entire design process.

Sensitizing labs

We presented three explorative lab sessions we call aesthetic *sensitizing labs*, which were performed in a sequence from material-labs to vibrotactile-labs to combined material/vibrotactile-labs. The labs were conducted in a playful and supportive atmosphere so that the participants felt engaged in their haptic exploration of the materials and interactive technology.

The three labs are as follows:

- The *material-lab* explores and assesses tactile and haptic experiences of the texture and structure of materials through mediated and direct touch, gradually engaging all of the senses.
- The *vibrotactile-lab* maps the individual sensitivities and preferences of the haptic experiences of a vibrotactile actuator placed on different parts of the body.
- The *combined material/vibrotactile-lab* explores and assesses the tactile and haptic experiences of how vibrotactile signals are transferred through materials to different body parts.

Group participation

All three labs were performed by the same group. The participants were 12 ID students in a design course accompanied by a few guest researchers. They were divided into four groups of three to four participants, who were assigned different roles: host (lab leader), blindfolded guest (U/P) and secretary/camera operator.

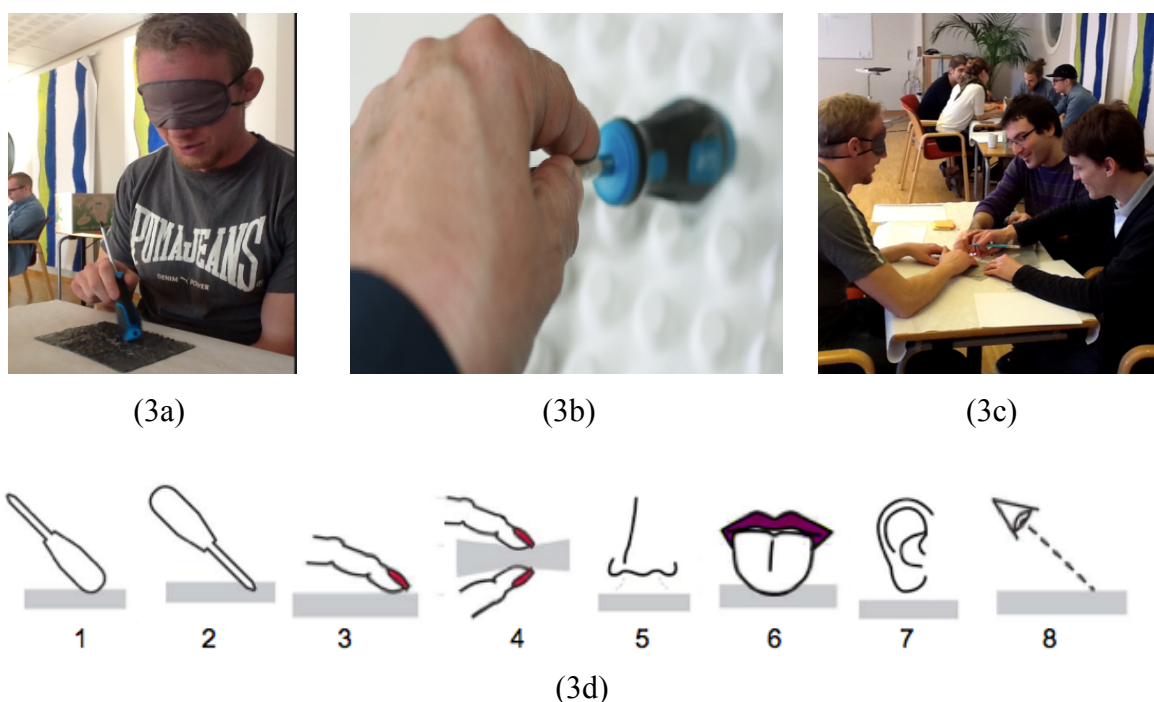


Figure 3. Sensitizing material-lab. (a) The blindfolded U/P explores the texture of the chosen material with the blunt end of a screwdriver. (b) A close-up image showing the sharp end of the screwdriver in the U/P’s hand. (c) The group working together around the table; the host guides the fingers of the blindfolded guest. The last row of icons (d) show the eight stages on the chart: 1–2: tool – the blunt and sharp ends; 3–4: finger and grip-texture and density and thickness; 5–6: nose and mouth – smelling and tasting, which include exploring the haptic attributes defined in Figure 1; 7: ears – listen; 8: eyes – see.

Material-lab

This lab is a revised version of the “mediated touch” lab further developed by Akner Koler. The lab was developed to systematically sensitize the participants to the aesthetic haptic properties of selected materials. To start, each participant independently chose a material they liked from a large collection of industrially manufactured materials. They then placed their chosen material in an envelope to hide it from the other members and returned to their group.

Each group received a chart for each member, which was specifically developed for this lab outlining eight stages through which to systematically explore the properties of each chosen material. The first lab leader instructed the U/P to put a blindfold on and then placed the chosen material on the table in front of the U/P. Then the lab leader guided the U/P to explore the properties of the material, first by probing the material with a tool. The property of the tool magnifies particular attributes of the material and focuses the attention of the U/P to improve their sensitivity. The sharp tip of a screwdriver was placed in the hand of the blindfolded U/P, who then received instructions to gradually feel the structure of the material through the blunt end of the handle (see Figure 3a–c, page 6). The secretary filled in the chart by taking notes on the comments made by the U/P under each stage (see Figure 4a). The tool (screwdriver) was then flipped around so that the blunt handle was placed in the U/P’s hand, and the material was explored with the sharp end, revealing different properties. In the following stages, the material was directly felt by the fingers, hands, nose, mouth, ears and finally eyes. – see Figure 4c. Figure 4b shows a U/P listening to the material by moving her finger over the surface, the sounds offer information about the folded patterns on the surface. This lab is a revised version of an earlier lab called “mediated touch” developed in collaboration with Teo Enlund (Akner Koler & Enlund 2011).



(a)



(b)

Figure 4. Sensitizing material-lab. (4a) Example of a chart with eight stages; (4b) a participant moving her fingers along the material to feel the structure and simultaneously create sounds.

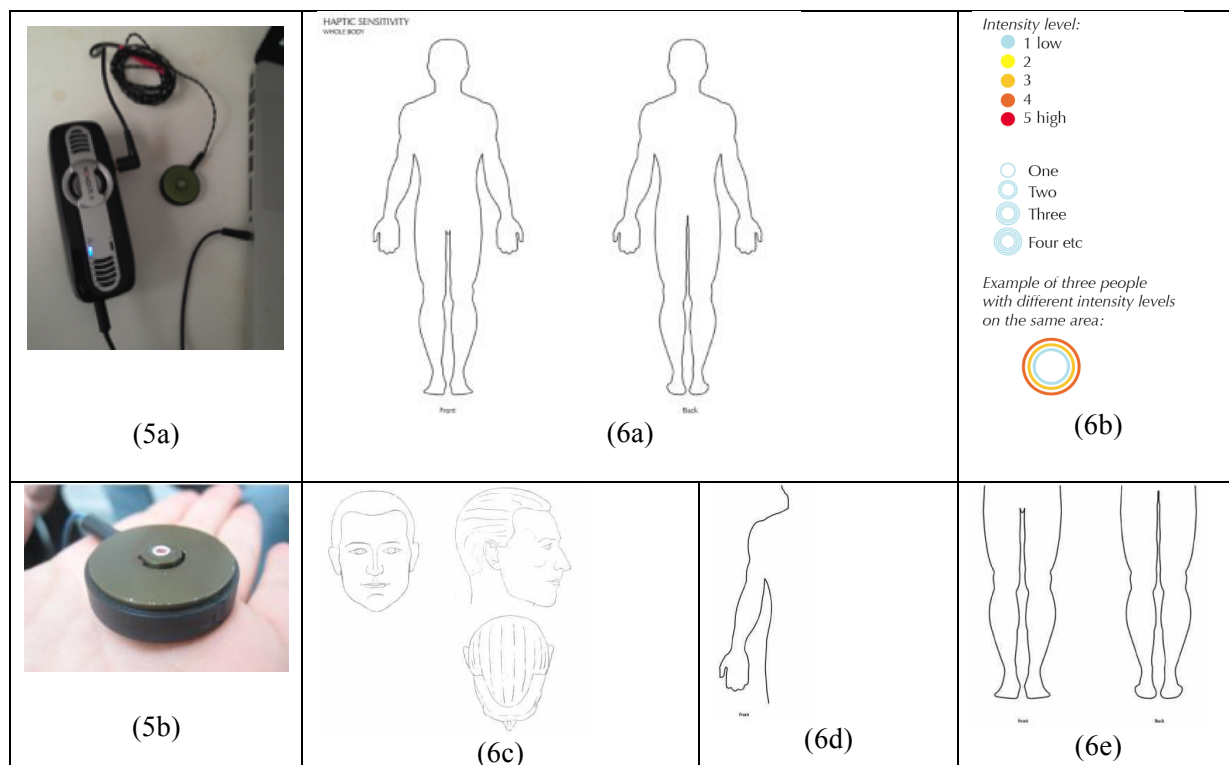
Vibrotactile-lab

In the vibrotactile-lab, the participants were asked to explore their individual threshold of sensitivity for different sine waves from a vibrator. Each group received papers with number of body map and vibrotactile kit as explained below (see figures 5–6, page 8). The lab took two to three hours.

The kit developed by Parivash Ranjbar consisted of a vibrotactile actuator (C2-Tactor vibrator, with a frequency range between 10 and 350 Hz) and a modified amplifier (Wowpotas) (see Figure 5a–b, page 8). Three recorded sine waves, 100 Hz, 180 Hz and 250 Hz, were used as test stimuli and were sent to the vibrator through a media player to control volume and vary the intensity. The technology and test stimuli was based on research in vibrotactile aids for environmental perception for person with profound deafblindness (Ranjbar & Stenström 2013).

The body maps consisted of a silhouette of the entire body: front and back (see Figure 6a–c, page 8) and particular parts of the body, including head and face, arm, torso and legs

from front and back. The participants stayed in the same groups to explore the different vibration frequencies at various volumes. Each group hooked up the vibrator to a laptop and turned on the sine wave for an initial exploratory test. The participants took turns placing the vibrator on different body parts and recording their level of sensation on the body map (see Figure 6). The groups were asked to use a color-coded legend (see Figure 6b) with five different intensity levels from high (red) to low (blue), as shown. A concentric circle code was used to indicate the number of participants. Each sine wave needed to be recorded in a separate set of body maps.



Figures 5 and 6. Figure 5 is the left column, which shows the vibrotactile kit. (5a) Amplifier, vibrator and computer; (5b) close up of vibrator. Figure 6 shows the body maps of tactile sine wave 180 Hz. (6a) Whole figure body; (6b) colour code; intensity level: low 1, high 5, 1= blue, 2= yellow, 3= light orange, 4= dark orange and 5= red. Each participant is marked by a concentric circle. Ex.: 3 circles = 3 participants. (6c) Head; (6d) arm; (6e) legs.

Combined material/vibrotactile-lab

In this lab, the participants worked in the same groups and rotated through the same roles: lab leader, U/P and secretary/camera person. This lab explored combining material properties with vibration signals using the same vibrotactile kit described earlier. The participants were asked to either document their experiences on a newly developed provisional chart (see Figure 7b, page 9) or freely record them on a blank piece of paper. Each U/P took approximately 10–15 minutes to complete the lab. The lab leader/host placed a material sample over or around the vibrator and gave it to the U/P, who could choose to use a blindfold or not (see figures 7a and 7c). The volume level was controlled via the computer, with a suggestion of using four different intensities: 25%, 50%, 75% and 100% of the total volume. In the provisional chart, the vertical axis showed three sine curves (100 Hz, 180 Hz and 250 Hz), and the horizontal axis showed volume (0 to 100%). It also included four symbols (see Figure 7b) for the following experiences: does not feel anything (outlined circle); feels pleasant/good (filled

circle); feels distinct/explicit (diamond) and feels unpleasant/hurts (triangle). As soon as the U/P felt they could respond to the stimuli, they were asked to describe their feelings. The secretary recorded the responses on the chart or freely developed a way to record the experience.

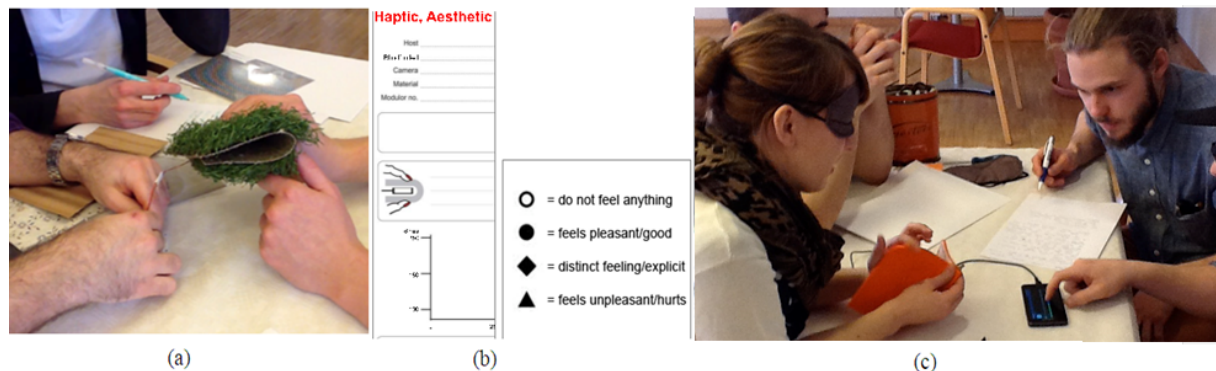


Figure 7. Combined material/vibrotactile-lab: (a) Artificial grass pinched around the vibrator; (b) chart to record the participants' level of sensitivity; (c) vibrator surrounded by soft foam material.

Design process/course

To test the relevance of the sensitizing labs within a design process, the labs were integrated into the introductory phase of a five-week aesthetic-driven industrial/interaction design course developed by Akner Koler. The course underscores the importance of embodiment and the formgiving process in which designers apply previous knowledge of aesthetic compositional principles of form and space and model-making skills to produce “tangible” 3D sketches throughout the entire process from concept development to final solution. The idea is that by making things tangible, it is easier to gain empathy for the user's situation and develop sensitivity to technology in order to better shape the *interactivity attributes* (Lim, Lee & Kim, D., 2011) of the product's physical properties. The course has an art-oriented profile and was initially developed for ID students to combine their experience in 3D *aesthetic abstractions* (Akner Koler 2007) with *semiotics* (Monö, 2004), by working in *co-design* teams (Sanders & Stappers, 2008) of two to three members, collaborating to develop a gestalt process.

Following is a brief introduction to aesthetic theory: *aesthetic abstraction* emphasizes the inner structure of form and how movements and forces in form can activate, enclose, expand and shape space. This approach to form and space is rooted in the work of Rowena Reed and Alexander Kostellow (Akner Koler 2007; Greet Hannah, 2002) and was further developed by Akner Koler to adapt to a Swedish formgiving culture at the Department of Industrial Design at Konstfack University College of Arts, Crafts and Design. The course applies taxonomy for aesthetic abstractions based on geometric law-bound structures in relation to the human body. It supports a non-linear dynamic design process with several *loops* feeding backward and forward. In this process, the designers strive to develop a tangible solution that applies insight into the user's embodied situation (see Figure 8, page 10). In this course, we also introduce haptic interaction design technology in the sensitizing labs by collaborating with a team of medical and technical researchers who work mainly with vibrotactile technology in projects for impaired U/Ps.

A general inter-looping network of a 10-stage design process is illustrated in Figure 8 and further described in Table 1 (page 11). It starts with an introduction of the course content and presentation of ongoing haptic research project(s) combined with sensitizing labs that introduce material and haptic technology. It continues with user studies, background research,

embodied studies, scenario development and making sketches and prototypes that test concepts, stimulating an emerging gestalt leading to a final design solution. The final design solution is a manifestation of the entire dynamic inter-looping process and serves as a basis for examination.

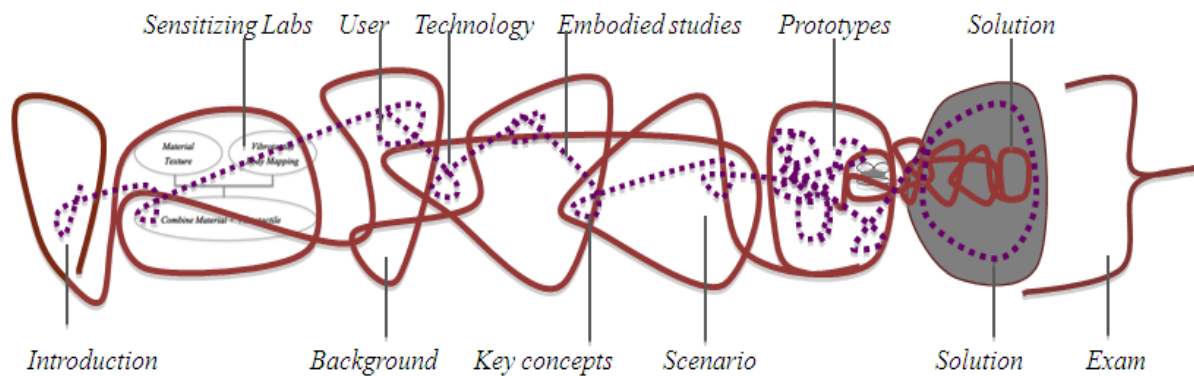


Figure 8. A 10-stage design process with non-linear looping activities that feed backward and forward. The solid line outlines the different activities and how they overlap with each other. The dashed line represents the formgiving process within the overall design process where 2D and 3D sketches, models and prototypes are developed that physically test ideas and manifest aesthetic abstractions and semiotic signs and symbols that eventually feed into the emerging gestalt, expressed through the final design solution. Figure by Akner Koler.

Research team: haptic research projects

A number of user-based haptic research projects were presented by the research team to inspire the students in their design project (see below). They all require some sort of body-worn sensors/actuators that receive signals and transmit instructions/information about on-going activities. An example is the Ready-Ride project, which is a positioning and communication training system to support autonomous horseback riding for persons with DB in a riding arena (Stranneby et.al. 2011). Through interaction with vibrotactile technology involving mobile senders and receivers, a trainer can send position instructions such as left, right, forward and stop as well as modulate and evaluate activities, such as slow, good, continue etc. (see student project inspired by Ready-Ride under Design course section, Table 3.) One important challenge in all the projects was to expand the space for interaction between people with DB and their instructors and assistants, thereby supporting autonomy. Haptic interaction technology can complement tactile sign language and body communication from a distance. A second challenge from a design education perspective was to create embodied interactive qualities (Dourish, 2004; Pallasmaa, 2011) that smoothly integrate the shape of the forms with the intuitive movements of the U/P. A third challenge is to create a physical expression of the haptic interaction integrated within the gestalt of the product form.

The outline of the design course in Table 1 gives the reader some insight into the type of activities involved in this aesthetic-oriented design course. However, the focus is not on describing the entire design process. Instead, the focus is on showing how the aesthetic experience and haptic concept development gained through the sensitivity labs inspired activities in the design process.

Table 1. Design process (non-linear looping activities).

Process	Description / instructions
Introduction by leaders	Present the theoretical and practical aspects of the course. Introduce the collaborating guest research team and the research projects. Group the students in co-design teams and discuss the course and research projects
Sensitizing labs	Take part in the sensitizing labs to explore the materials and technology in relation to the body. Document the labs through video films and notes, group the students in co-design teams and discuss the course and research projects. Write a report explaining the process and summarizing the experience from one of the labs.
User/Player (U/P)	Prepare and conduct a team interview with deafblind people, i.e. U/Ps Assign each team a specific U/P profile inspired by one of the projects. Conduct an onsite visit in the U/P's environment that engages all senses with emphasis on haptics. Prepare and conduct an interview with the U/P
Background	Obtain background information on the historic, medical, aesthetic and social situations of the U/P and the role technology has played in aiding their situation/impairments. Limit your "screen" time with the Google search engine. Make a presentation of the background information using images + text. Continue to build up a presentation on a daily basis.
Technology	Read up on the suggested technology. Experiment with the haptic technology kit.
Embodied studies	Create "embodied" experiences of situations that expose the team to the experience of your U/P and the material/technology. Playfully explore the observed patterns of movement expressed by the U/Ps from an embodied and spatial perspective. Invite others to take part in embodied studies to gain awareness of individual variations. Examine and categorize the experiences gained from the studies. Create a playful, embodied working environment for the team that has an atmosphere and materials that continue to sensitize the team members to the qualities meant to be expressed in the design solutions. Stay embodied through the design process!
Engage experts	Attend the lectures and supervision meetings with invited experts, including people with DB. Contact experts in the field and visit their work/play space.
Key concepts	Formulate a number of key concepts that both drive the process and define the intentions of the emerging gestalt. Test these key concepts on others and ask for constructive feedback in relation to the process and gestalt.
Scenario /storyboard	Develop a scenario/storyboard as a unique fictional story about people, events and environments that presents alternative versions of future solutions. Develop "personas" as credible hybrid characters that represent many different aspects of the U/Ps. Draw a series of 3-5 framed sketches that show the persona in a situation that unfolds over time.
Prototype: explore, test and engage	Develop prototypes throughout the process to study specific problems, test different concepts and express interactive attributes. Explore different prototypes that clarify the intentions and expressions of an emerging holistic gestalt. Categorize the models in relation to the problems, tests, concepts and gestalt. Adapt the key concepts as the prototypes develop. Remember: the key concepts are not fixed!
Aesthetic abstractions & semiotics	Apply and analyze aesthetic principles by abstracting the inner structure and movement of the physical forms and determine how the parts relate to the overall organization and their effect on space. Apply and analyze semiotic signs and symbols carried through the properties of form, material and space.
Prototype: intention of the gestalt	Develop prototypes that express physical and possible technical functions. However, the prototypes do not need to function technically. Aim to clarify the intentions and expression of an emerging holistic gestalt. Describe the development of the different prototypes that support the same gestalt process.
Solution	Explain why a particular prototype was developed into a final solution.
Final presentation	The final presentation is 20 min plus 10 min for feedback. It should give insight into the entire design process, including the early labs and embodied studies. Select several 3D sketch models that show how tangible form is used to drive the design process. Define the key concepts and explain how these concepts developed. Present a relevant scenario that illustrates the embodied/haptic activity integrated in the design solution. Formulate an analysis of aesthetic abstractions that explain the overall composition in terms of volumes, proportions, inner axial movement of form and space etc. Use the specific aesthetic terminology outlined in the taxonomy. Motivate and articulate the semiotic arguments interpreted from the composition. Explain the gestalt process that led to the specific shape of the product form. Clarify the way materials and technologies are integrated in the gestalt process. The final model should be scaled 1:1. Use the best material that shows the 3D features of your final solution. Show a 2D rendering of the final model that can convey colour combinations and surface structure.
Exam committee	Demonstrate how to handle the form and engage in the interactive attributes that are manifested in form, material and technology. Engage guests/critics through a creative performance to share the process. Encourage guests/critics in haptic interaction with prototypes. Articulate the learning outcomes for the course, i.e. aesthetic abstractions, semiotic signs and symbols, material choice and haptic interactivity. Formulate questions for the discussion with guest critics, teachers and students.

Results

The results are presented in two parts; the first part concerns the three sensitizing labs and second part the design process. The results were developed by reviewing (i) the video films, (ii) student reports from the labs and (iii) the constructive and critical feedback from the *world café method (2013)* and at the final presentation as well as (iv) by the authors discussing their direct observations during the entire project.

Three sensitizing labs



Material-lab

The lab started with blindfolding the U/P, who was guided through a mediated experience of texture, which emphasized tactile and haptic impressions. The majority of the U/Ps became relaxed and present in the moment. Moreover, the secretary and the camera person helped create an atmosphere of conscious awareness and trust by actively listening and documenting the experiences and comments from the blindfolded U/P. They also cultivated a mindful and attentive experience.

The material samples were industrially produced, and many were made up of compound properties with layered or woven structures, often making it difficult to attain a coherent aesthetic experience of the sample from one stage to the next. Despite this uncertainty, and at times frustration, many participants felt that the lab helped them become aware of how mediated touch through a tool could separate certain qualities and how their different senses could slowly unveil particular qualities of the materials. Given the complexity of the response to this lab, we found it useful to discuss the results in Table 6 in two ways: 1) *exploration*, which explains the immediate actions, tools and situation and 2) *assessment*, which takes a step back and gives an overall comment on the exploration.

At the exploration level, the U/P actively probed the materials through indirect (tools) and direct embodied experiences, such as actively touching and moving a finger (or other body parts) across the material to check out local patterns and structures. As they explored the materials, they received feedback from their actions as if the material itself returned the action. This reciprocal feedback through touch and grip helps determine properties such as hardness/softness, roughness/smoothness, heaviness/lightness etc. This very basic explorative level can carry hedonic reactions, arousing emotions that can feed forward in an ongoing explorative process (Hertenstein & Weiss, 2011). We believe this explorative level that arouses emotion can also feed an emerging gestalt process.

Table 2. (short version) Two of the results recorded on a three-column table showing Type of Probing, Exploration and Assessment. (Appendix 1: long version)

Type of Probing	Exploration	Assessment
	<p>The tool was held with the shaft so the blunt end of the handle probed the material. When pushing down on the material, one received a mediated sense of the density (hardness or softness) of the material. By moving the tool across the material, it was possible to feel its large-scale 3D textural properties as well as how polished or rough the material was.</p>	<p>The feeling of bluntness was due to the broad round shape of the handle as well as the rubber material the handle was made of. It was easy to assess the difference between the material's density (hard/soft) and friction (polished/ rough), while the details of the material's texture were not possible to discern. Despite the tool's blunt character, it conveyed a certain refined sensitivity for large-scale patterns.</p>
	<p>The materials are brought close to the ear to hear the sounds produced through twisting, flexing etc. Fingers and finger nails were often used first then other body parts could be used to create sounds.</p>	<p>Hearing the structure of the material gave it a new dimension. Surface sound qualities could give clues to the properties of the materials, such as metal, wood, hollowness, density, smoothness etc.</p>

At the assessment level, the U/P brought the features from the explorative level together through assessing the overall haptic dimensions of the material. At this level, they searched for patterns, such as repetitive or non-repetitive textures, symmetries or non-symmetries, how properties such as polished or rough surfaces were distributed throughout the form and how contours continued or changed course as they moved through the material. Three-dimensional, overall, physical qualities were assessed, such as curved or complex surfaces, contrast in proportions throughout the material and how the shape and details interrelated. As the U/P assessed the immediate properties, s/he began to search for meaningful expressions in physical qualities.

To summarize, the material-lab gave the participants a deeper, more discerning understanding of the tactile and haptic aesthetic experience of material textures and structures. Table 2 (in Appendix 1) shows an outline of the results discerning the *exploration level* from and *assessment level*. Table 4 shows a few representative examples of from this outline.

Vibrotactile-lab

The results from one group that performed the vibrotactile-lab are shown in the body maps in Figure 9 using one tactile sine wave (180 Hz) as stimuli. The maps show that sensitivity levels for vibrations could both be similar and vary between individuals, depending on (i) the placement of the vibrator on the body, (ii) the quality of the vibration signal and (iii) individual perception/sensitivity. For example, several participants felt strong vibration sensations on the nose causing their eyes to water, while one person felt only a low sensation (see Figure 9c). One observation was that the mixed gender group of students needed to gain a certain amount of trust for each other because of the level of intimacy the lab entailed. There are social body zones for touching such as hands, arms, upper back and shoulders, which are usually included in everyday communication. However more intimate zones, such as the face, neck and front of the body, are more sensuous, and each student needed to provide consent as to where the test in these zones could be conducted. These intimate zones, and the hands, are extremely sensitive, so they must be included in order to learn about the possible placement of the vibrator. The results of this exploratory study are about sharing and comparing felt experience caused by the stimulants of vibrotactile signals on each student’s body.

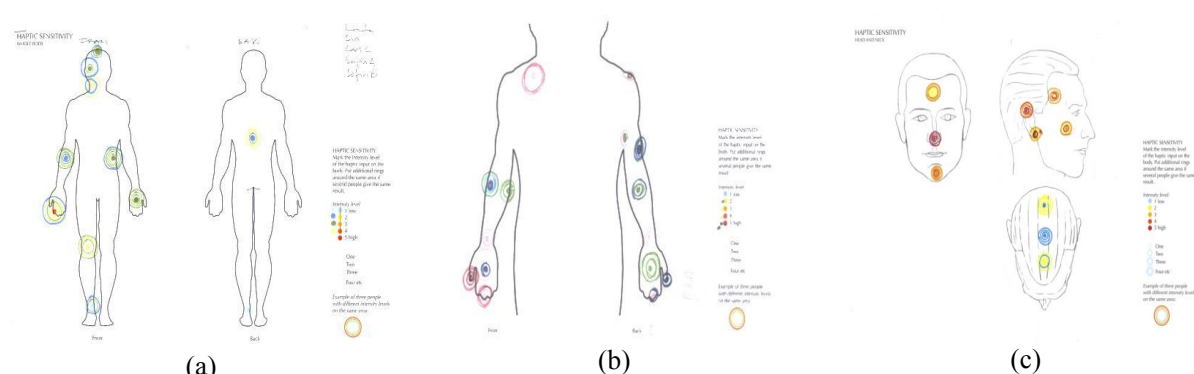


Figure 9. Body maps showing individual sensitivities of vibrotactile stimulation with three to five participants in each group. Map (a) shows the sensitivity of different participants in one group testing the entire body. Map (b) shows the results from the back and front of the arms and map (c) from the front and side of the face as well as the top of the head. Each circle shows one individual response, while each colour represents a different level of intensity.

Combined material/vibrotactile-lab

The results of the combined material/vibrotactile-lab show that the choice of materials greatly affected the participants' experience of the vibration. It was interesting to note that very different materials could transfer vibrations in similar ways – for example, a thin natural cork material in relation to a thin foam plastic material. Moreover, the opposite was also true: two materials that visually looked the same could transfer vibrations quite differently – for example, two soft materials used as computer mouse mats. Although the participants were told they could freely record and explore ways to combine materials and vibrators, many of the groups ended up using the provisional chart shown in Figure 7b. This chart offered a way to plot out the sensitivities (none–explicit) and preferences (pleasant–hurt) to sine waves in relation to volume transferred through material. To deal with the complexity of combining materials and vibrotactile technology, both the preliminary chart and the structure of the lab need to be improved. One suggestion from a number of students to improve the lab was to develop a design task that could define a meaningful intention for using this combination.

This combined lab explored ways to generate embodied experience and conceptual knowledge about material in relation to vibrotactile signals. The students used a free choice language method to describe their experience triggered by the dynamic patterns of haptic interactivity involving emotions and a more reflective exchange between the U/P and the members of the team. These more complex and emotionally charged experiences are important driving forces in the gestalt process needed as the design activities progress. By setting the stage for students to share affective responses in the early phase of the design process, before they know the design challenge, the students may take the opportunity to enhance interpersonal embodied communication on a deeper level. However they may also become frustrated because the lab does not frame a design space, which includes intentions and meaningful challenges. It is still defined as a haptic lab with a focus on attributes. The combined lab and the open instructions that engage perceptual/emotional feelings offered the students a way to work with a spectrum of hedonic tones and values that is necessary in the next stage of the course involving the design process.

Design process/course

The results of the design course showed that the students managed to integrate an expressive sensorial material dimension with haptic interactive technology within their design process. We found that by presenting the sensitizing labs at the very beginning of the course, we kick-started the making process, inspiring the students to test ideas and create prototypes and share sensuous and emotional experiences early in the course. The design process also emphasizes the importance of conducting *embodied studies* for the team members to explore their own *felt experience* of forms and patterns of interaction inspired by studying the U/P's situation. These forms and patterns are shared by the design team with the U/P and the researcher during different phases of the process.

In the sensitizing studies, the students were offered only a kit for modulating vibrotactile actuators; however, we found that the students could playfully work with other types of interactive technology for receiving and sending signals. Given that ID students are not very experienced in interactive technology, it is usually hard for ID students to playfully perform or conceptualize complex interactivity attributes. We believe that the combination of sensitizing labs that included function interactive technology, studying the U/P in their situation and doing embodied studies gave the design process a strong aesthetic awareness yet retained a certain level of applied haptic conceptual theory, which sparked playfulness and creativity. This non-linear design process weaves together different modes of abstraction from semiotic to aesthetic with intuitive embodied experiences through the creation of prototypes and scenarios. By observing the way the students worked during the design process, we could

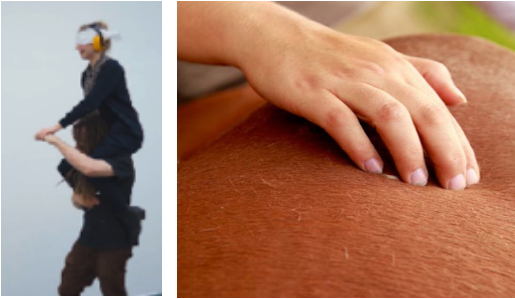

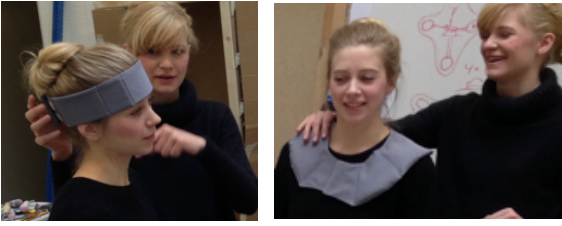
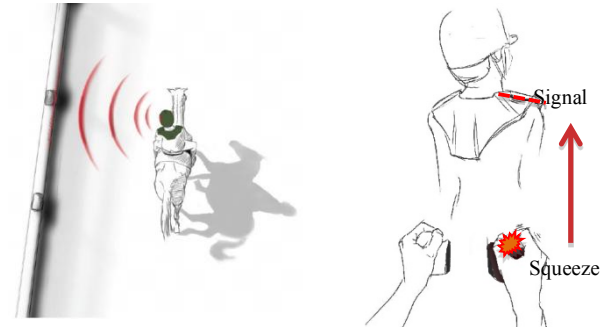

see they managed to maintain a creative and critical framework based on the findings from the sensitizing labs. As shown in Table 3, the students continued to do explorative embodied studies where haptic engagement was central. They were curious about the felt experiences of the team members and also conducted studies with other students/people to explore the semiotic attributes of the solutions leading up to the final gestalt.

Haptic horseback riding guide

A representative design project inspired by the Ready-Ride research project (Stranneby et.al 2012) is presented here, which involved giving people with DB horseback riding instructions for position, direction and intensity of movement (see Table 3). The design process led to the development of a scenario that showed a sequence of images illustrating how the instructor can give direct, gestural signals to the rider. In the scenario, the following three design solutions were presented: a pair of riding instructor *handles to be held in each hand* and a *collar* and *headband* worn by the rider. The instructor's handles were made of soft material that could be squeezed to indicate 1) the direction to ride, such as to the right, left or straight ahead or 2) the amount of tension to use on the bridle's reins. The vibration signal was received by the rider with DB on the top of the corresponding shoulder or at the centre of the upper back and neck region. At the base of each of the soft handles is a flat wood surface with an embedded microphone/haptic pressure sensors. The wood surfaces could be clapped together to create both an audio sound and interactive signal (see solutions in Table 3) to mimic a traditional clicking sound for "giddy-up" or start. Clapping the two surfaces together created both audio and haptic signals from the same gesture, so DB and D riders, as well as hearing riders, could receive the same instruction from the trainer. An algorithm transferred the signal adapted to the frequency range of the skin and the vibrotactile actuators that were placed on the riders with D/DB.

To get further feedback for the process and solutions, the students presented their work to the Ready-Ride advisory board meeting. The riding instructor had had years of experience training riders with D/DB on a competitive level and is a leading expert in the field. She was impressed by the haptic interactive qualities that were designed in an intuitive way that could be integrated with her own instructive gestures. Although at this meeting the mock-up prototype of the handles did not function technically, the instructor grasped the handles and imagined the interactive attributes of the haptic squeeze and the clapping gestures for conveying instructions. She had had prior experience with the earlier Ready-Ride technology and was therefore able to understand this more advanced chain of movement-based interactive events that involved translating her own gestures to the vibrotactile components in the collar of the rider with DB. The work therapist also felt an affinity for the two handles and underscored the importance of gesture-related interaction. She questioned the use of a visual interface, because it interferes with a more direct and intuitive relationship between instructor and rider. Both the instructor and the work therapist have been adamant about developing haptic interaction solutions for the riding instructor's handles. This has led to a quick working prototype using two phones (instead of one) that are placed in each hand to send the gesture based signal expressed by the instructor. A group discussion developed around how a more intuitive haptic interaction, as opposed to visual interaction, would improve the timing and quality of the instruction as well as reduce errors due to visual distraction. Several vibrotactile actuators were available to play with at the meeting, which stimulated a discussion of the somesthetic qualities of the vibration. An important issue concerned the individual preferences of how and where the vibrotactile signal could be received and experienced. The results of the vibrotactile sensitizing lab showed that there is great individual variation between how people experience haptic vibration. Persons with DB often have other physical disabilities that could also affect haptic sensations.

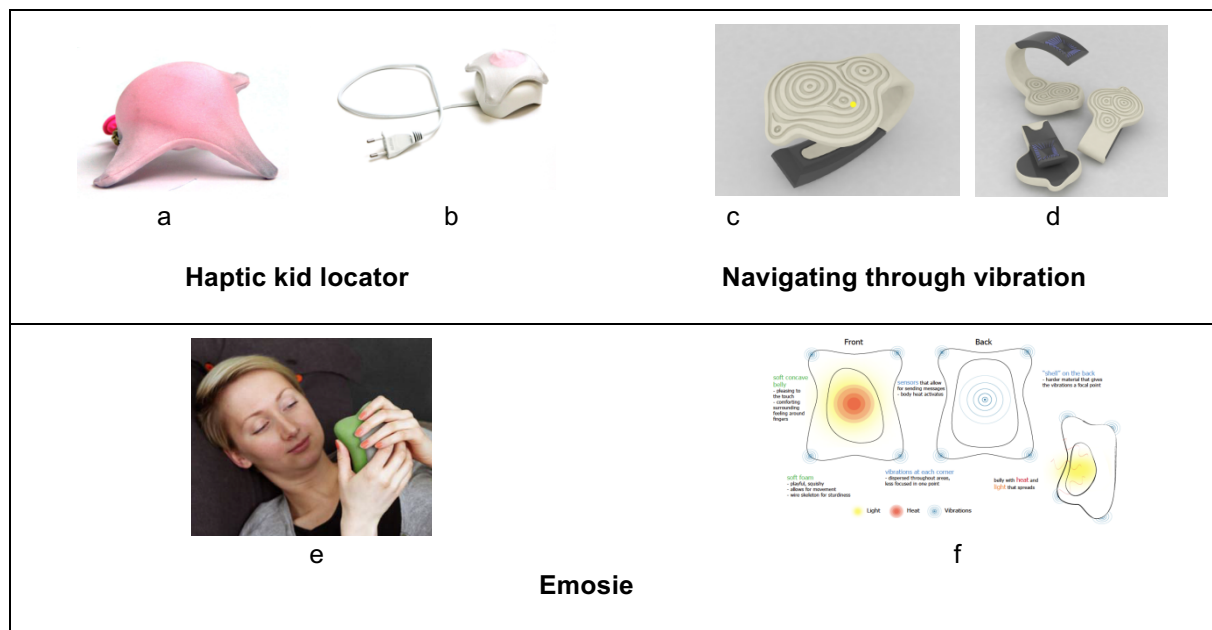
Table 3. Design process: Haptic horseback riding guide (inspired by Ready-Ride).

Different stages in the process	Images
<p>Embodied study Left: Blindfolded student with hearing protection rides on the shoulders of team member acting as horse. Right: Haptic signal on the back of a horse to guide the horse's movements.</p>	
<p>3D physical sketching Left: Blindfolded students explore haptic experiences of form. Right: Exploring the haptic relationship between form, material and plasticity.</p>	
<p>Prototype Left: Test placement of vibrators/pressure actuators on headband. Right: Test collar with signals on shoulder and back.</p>	
<p>Scenario/storyboard Left: IR waves radiate from headband to detect obstacles and give haptic feedback through the actuators on the head band. Right: The trainer squeezes the hand-held unit in the right hand, which translates vibrotactile instructions to the right side of the collar.</p>	
<p>Design solution Left: Two hand-held units used by the trainer to instruct the rider: 1) Sensors and processors are embedded in the wooden surfaces that create haptic signals by clapping surfaces together. 2) Squeezing the soft handles sends a signal to control the reins. Right: Haptic feedback technology is integrated in the collar and helmet for the DB rider.</p>	

Other design solutions

The three design projects in Table 4 show other forms of interactivity developed by design teams in the course.

Table 4. The three other design team solutions: a–b) Haptic kid locator, inspired by Monitor; c–d) Navigating through vibration, inspired by Ready Ride; e–f) Emosie, Long distance communication – Inspired by Monitor (Ranjbar & Stenström 2013).



The *Haptic kid locator*, inspired by Monitor, came from an interview of a father with DB who needed to know where his children were in the home. A vibrotactile actuator that translated the relative distance and position of the children was mounted at the tip of each arm of the starfish-shaped artefact. To convey urgency, an inflatable air bag was designed at the core of the starfish that could be triggered by very loud sounds that signalled a potential emergency. The shape of the prototype is a merged superficial ellipsoid in the centre with two crossing axes at right angles. The soft transitional surfaces between the arms make up the organic contours of the starfish, which also happens to be a symbol for DB.

Navigating through Vibration is inspired by Ready Ride. The students found through the second sensitizing lab that the inside of the wrist was sensitive to vibrotactile signals. The bracelet is designed of soft flexible materials to both magnify the vibration and hold the vibrator in place. The sound pattern designed on the wearable interactive system is meant to communicate vibration through semiotic expression.

Emosie is a long-distance communication device. Three interactive technologies (heat, vibration and light) are integrated into the product to allow children and parents to send and receive expressive messages to and from each other through haptic experiences. The idea is to bring them closer together despite long distances and to ease the difficulty of separation between them in a positive way. The soft shape of the “mother” form is like a teddy bear that express and evokes a hug. It is made of memory foam to evoke the sense of touch; the back is hard to give the vibration a focal point and the heat and light radiate from the belly.

Discussion

Here we discuss the results and how the methods support the students’ learning process, starting with the sensitizing labs and the link between the labs and the design projects.

Sensitizing labs

In the *material lab*, the students' learning process was enhanced by blindfolding the U/P, thereby emphasizing their tactile and haptic perception and building trust between the other members in the group. We observed that the student's choice of materials in the third lab (see below) was more informed about haptic material structures. By zooming in on material through the properties of a mediating tool, a screwdriver, the major patterns of the surface were felt through the tool's blunt handle, while the small details were felt through its sharp tip (see Figure 3 and top of Table 2). Exploring textures through tools heightened the awareness of patterns and small details, which could exaggerate the role of these features in relation to the overall experience of the material. The material of the tool also had a great effect on the probing experience. For example, the screwdriver had a material on the handle, so a feeling of friction was apparent when moving it across the material. The learning experience is about discerning the properties of the tool in relationship to the properties of the material sample.

Going from mediated touch to direct finger touch merged the participants' overall tactile sensitivity for patterns, minute details and temperature. By then grasping the material, the overall haptic experience of the material was expressed. Exploring haptic properties through the lips, teeth, tongue and mouth gave a very precise sense of the material's structure and tactile surface. Since the participants were blindfolded and knew the industrial material was not meant to be eaten, they were not very willing to explore the materials with their mouth. Perhaps some natural culinary materials should be included with the range of industrial samples in order to compare the differences between artificial and natural substances.

In the *vibrotactile-lab*, we chose sine waves with three frequencies so that the students could experience how different frequencies require different amplification in order to be sensed by the same body part. It is well known that skin sensitivity varies across body sites (Verrillo 1963, 1980; Whitehouse & Griffin, 2002). By using one sine wave at a time, the students could learn about their own and other's sensitivities. Given the fact that these labs were all performed by the students with no formal lab leader, it was important that they could playfully determine the conditions of the lab. The lab increased the students' awareness of the substantial individual variation of vibratory sensation on the same body parts. For example, when sensing vibrations on the nose, some students experienced tears welling up, others felt a tickling sensation and a third felt almost nothing. These affective reactions have a strong correlation with emotions such as crying, laughing or indifference, which has relevance for designing the placement of the vibrotactile actuators for haptic interaction. The students experienced their own immediate response to the vibration and witnessed other participants' reactions to the vibration. This combination of mapping individual and group responses supports the emergence of a *somaesthetic* form of knowledge (Shusterman 2000, 2013), making it possible to later recall both the emotional and physical experience during the design process. Such experiences can be drivers within an aesthetic gestalt process.

In the *combined material/vibrotactile-lab*, we found that to improve the students' learning process this lab could be done in two general ways: 1) blindfolded in order to isolate the tactile/haptic and vibration qualities or 2) without a blindfold in order to integrate the visual properties with the tactile/haptic and vibration qualities. This sensitizing lab should be adapted to the needs of the participants and the project. If visual properties are not important, then we suggest doing the lab blindfolded; however, if visual properties are important (which they often are), then the lab should be done without blindfolds or a combination of both. There are pros and cons to both ways. Although some students felt frustration during this lab because of the level of complexity and the more free explorative nature of this lab, the majority of students claimed the labs emphasize the problems involved in the real embodied

experience of combining materials with vibration. It was apparent that the choice of materials used on working physical prototypes greatly affected the haptic aesthetic experience of the vibrations.

Our conclusions relating to the charts used in this lab to record the test results made it possible to compare between direct vibration and vibration mediated through materials on the same body part. However, offering these charts could decrease the drive to create alternative ways to record haptic experiences. This chart could be improved by including icons of all of the senses and the blunt and sharp end of the tool from the *material lab* to remind the U/P to explore with all the senses. Other relevant research projects that also use charts/worksheets to record touch-based design experience and reflection on the tactile perceptual qualities are those of Pohl and Loke (2014) and Ledo et al. (2012).

To summarize, the students' learning process was enriched by offering methods for experiencing, observing and comparing the immediate haptic reactions of students. The purpose of all three labs is to explore for the sake of experiential knowledge. The students also learn about how vital it is to collectively conduct direct embodied exploratory experience of material and technology together with the design team in order to expand the team's creative capacity for designing interactive attributes and gestural patterns. We validate the proposed design process (which includes sensitizing labs) by arguing for the value of mixing rigor with playfulness. The systematic charts give a rigorous way of exploring that offers a certain conceptual precision for the blindfolded U/P and the team members documenting the comments and the explorative gestures using tools and materials. By blindfolding the U/P, the visual speculative assumptions about the material and tools are suspended, supporting a more authentic and direct experience. The charts and maps offer a way to maintain conceptually organized results which help the students reflect back on their collective and individual experience in the coming stages in the design process.

Design process

An important learning experience for the students in the design course is that they work in collaboration to integrate their prior experience from the sensitizing labs with the intentions of the design project. They switch from an explorative phase to an experimental phase which is framed by one of the projects for persons with DB presented by the research team. At this point in the design process, they drive productive inquiries (Schön, 1983) involving tests and comparative studies that strive to both learn about the DB situation and at the same time change their situation by creating forms and using design probes (Mattelmäki, 2006) to playfully provoke and test possible solutions.

The link between the sensitizing labs and the student design projects is evident in their process and final design solutions, as illustrated in this representative example of a student project: the *haptic horseback riding guide*. In this project, the students applied their previous experience from the sensitizing labs as they experimented with different materials for the riding instructor's handles. By combining soft materials with flat, hard wood materials and embedding sensors in these materials, they show how the haptic material properties contribute to the novel shape and pattern of the handles and dynamic pattern of interaction. The "soft" material properties evoke a "squeezing" response (triggering pressure sensor) (Schiphorst 2010) and the "hard" material properties evoke clapping gestures (triggering pressure sensor), which we assume have been directly derived from the students' experiences in all three of the labs: *material-lab*, *vibrotactile-lab* and *combined material/vibrotactile-lab*. The entire haptic horseback riding guide system shows how students embedded sensors and actuators in the material with haptic responsive properties in order to creatively manage to design for interaction (Lim, Stolterman et al., 2007; Löwgren & Stolterman, 2007; Mazé, 2007; Hallnäs, 2011; Lim, et al., 2011; Moussette & Banks, 2011; Moussette, 2012). Although the

technology applied here involves pressure-sensitive technology and not vibrotactile technology, we believe students were able to see parallels between different interactive technologies due to their explorative experience in the sensitizing labs. Furthermore, the design process introduces the students to aesthetic abstractions, user experiences and embodied studies as well as the skills of making prototypes, all of which are applied in the design of materials and haptic technology with the user's experience in mind.

One discussion during examination and later with the advisory board concerned how to transfer the design solutions to other user situations. For example, the vibrotactile horseback riding guide system could also offer an alternative method for training hearing riders who receive verbal instructions. There are inherent problems in giving verbal instruction while moving: the hearing riders might not be able to hear all of the instructions or they could have cognitive challenges with applying the instructions such as discerning right from left. The vibrotactile signals can reinforce what the instructor wants to communicate through simple signals agreed upon in advance. Receiving non-verbal instructions could be preferred at certain phases in a training program – for example, to support riders in developing more embodied contact with the horse. It is possible to develop an intellectual non-verbal consciousness for basic equestrian lessons through haptic signals. Placing the vibrator close to the parts of the body that are involved in the movement creates a more direct channel between the instructor and the rider. This design project supports the growing field of research in movement based interaction that problematized linguistically centred classification of movement and gesture (Hansen & Morrison, 2014).

Others in the field

There are a number of interesting educational research projects (Lim, Lee et al., 2011; Moussette 2012) that have some similarities to this project. In Camille Moussette's (2012) work in simple haptics, workshops are set up to expose students to the different haptic interactivity attributes. The strength of his research is in supporting students in hands-on making and sketching in hardware and programming to generate explorative gestural interaction systems. The similarities between Moussette's work and ours is in our shared interest in creating new haptic interactive patterns; however, we differ by emphasizing the role materials play in exploring possible gestures. Our work, however, does not go into the specifics of hardware and programming. We make semi-functional prototypes that emphasize the haptic attributes of materials.

Thecla Schiphorst's (2010) work in soft textile modelling and interactive kinetic garments develops interactive technology that responds to touch. Her work also involves workshops where playful "experience modelling" is done. She explores technical hardware and programming and puts great effort into creating experiences that build on bodily gestures and textile materials. The main difference between her work and ours is in the educational framing and in the close relation to users with impairments.

A major educational design challenge has been to find ways to avoid overloading the students with information and technology when merging an art-based industrial design process with interaction design. The students were given time to do in-depth sensuous exploration in a collaborative atmosphere where they shared direct and vicarious experiences. These lab hours were an important investment aimed at enriching the students' learning experience before they were challenged with a design problem. The visual model of the non-linear design process clearly illustrates the 10 stages that the design process should loop back and forth through engaging the student in a variety of playful and rigorous activities.

Contributions & conclusions

As stated in the introduction, there is a need for method development in the fields of both *material-driven design* (Karana et al., 2015) and *user-driven design* that supports ways to design dynamic patterns of haptic interactivity. We argue that the presented educational method carried through a complex design process can contribute to development in both fields. Design researchers and educators are now recognizing some of the problems associated with visual and audio interfaces in interactive devices. Haptic technology is advancing; however, there is little educational material to support teachers in developing courses that evoke meaningful and new forms of embodied interaction to apply this technology. By working with persons with deafblindness, we were able to clearly recognize the needs of users for haptic interaction that does not rely on vision or audio interaction. The presented *sensitizing labs* offer ways to improve designers' ability to both explore the tactile and haptic properties of materials blindfolded and to combine these properties with attributes of vibrotactile interaction experiences. Through a systematized exploration, the students could reflect on and formulate their immediate felt experiences and compare their experiences with those of others. These sensitizing labs started with clear conceptual categories for haptic attributes and gradually shifted to free choice language that captured the students' emotional responses and search for meaning. The lab experiences were then integrated within a complex non-linear design process concerning a real practical situation for DB users/players. The representative case illustrates one possible scenario that was developed through this educational method. The course strives to underscore how embodied explorative and experimental activities eventually feed into an emerging gestalt, which shapes the physical and interactive composition of the final design solution, where the solution is not fully developed. We encourage others to apply and modify this method and send us feedback so we can continue to improve the stages of the method to enrich the students' learning experience and prepare them for professional challenges in the merging fields of industrial and interaction design.

Acknowledgements

The authors would like to first thank all the Industrial design students at Konstfack that have participated and contributed to this study. We are extremely thankful to Erik Borg and Dag Stranneby for their research in developing aids for persons with Deafblindness and for supporting the students over the years. We would like to thank our participants with deafness/ deafblindness who shared their experiences with our students and gave them feedback. Finally we thank Anna Thies, Souzan Youssef and Mobile Life for earlier collaboration and Teo Enlund for the first version of the sensitizing lab.

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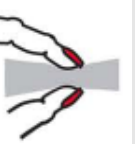

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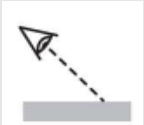
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Appendix 1- Long version of Table 2. Results of using the systematic chart on the exploration and assessment levels.

Types of probing	Exploration	Assessment
 <p>Holding the screwdriver by the sharp end and probing with the handle</p>	<p>The upside down tool (screwdriver) used to probe the material gave a blunt feeling. When pushing down on the material one received a mediated sense of hardness or softness in the material. Moving the tool across the material, it was possible to feel its large-scale 3D textural properties as well as how polished or rough the material was.</p>	<p>The feeling of bluntness was due to the broad round shape of the handle as well as the rubber material the handle was made of. It was easy to assess the difference between the material's density (hard/soft) and friction (polished/ rough), while the details of the material texture were not possible to discern. Despite the tool's blunt character, it conveyed a certain refined sensitivity for large-scale patterns.</p>
 <p>Holding the screwdriver's handle and probing with the sharp end</p>	<p>The sharp end of the tool gave a very different experience than the blunt end. The sharp tool could probe deep down in the 3D texture of the material, making it possible to discern properties such as loops, cut-out holes, wrinkles, woven textures, etc. The hard tip of the tool also inspired repetitive movements that created sounds.</p>	<p>The sharp point made it possible to probe back and forth (in textile materials) between the dimensions of the material and the dimensions of space. However, the exact shape of the loop or hole was not easy to grasp. Sensing friction was not apparent, because of the minimal area of contact between the point of the tool and the material. Listening to the material through properties of the tool engaged hearing in relation to haptic probing.</p>
 <p>Probing-finger</p>	<p>Touching with one finger gave the immediate feeling of temperature, which was sometimes very surprising. Temperature helped them discern the type of material, for example metal, plastic or natural fibers. The finger also felt how polished or matte the surface was. A sense of large-scale patterns and detailed textures merge together.</p>	<p>The finger provided a more nuanced sense of what the material felt like and made it easy to create a more comprehensive image of the material. However, by merging pattern and texture together, there can be less awareness of the small details.</p>
 <p>Probing-thumb and finger.</p>	<p>Squeezing the material between thumb and finger gave a feeling of how thick, soft, or rough it was which added to what was felt when probing the surface with one finger. By grasping, twisting, pulling and stretching the material the U/P gained a more enriched feeling for the combined tactile and haptic structural properties of the material.</p>	<p>Grasping materials creates an all-around three-dimensional haptic feeling for the material. Playing with it reveals the qualities of elasticity, flexibility and fiber strength</p>
 <p>Probing- nose</p>	<p>Instructing the participant to smell the material often caused an immediate protective reaction, as the participant moved the material close to her/his face and nose.</p>	<p>Smell triggers situational memories that relate to a more intimate or emotional experience by connecting our body with the environment and temporal events. Most of the industrial materials did not have a discerning scent.</p>

 <p>Probing- mouth</p>	<p>Exploring material in the mouth involves haptic and tactile experience combined with smell and flavor (without smell there is very little taste). The taste of the materials was markedly different, ranging from no recognizable taste to extremely pungent. There were adverse reactions to the stronger tastes. When the taste was not too strong, the participants were more open to exploring the sensation of the material on their teeth, tongue and mouth, which all gave high-resolution experiences.</p>	<p>The participants knew the materials were not edible, which perhaps can explain their adverse reactions to strong taste. Some materials could be recognized because the participants had tasted them in the past and could thus relate to them. The materials with a strong unfamiliar taste blocked other haptic impressions.</p>
 <p>Probing- ear</p>	<p>Hearing the structure of the material gave it a new dimension. Surface sound qualities could give clues to the properties of the materials, such as hollowness, density, etc.</p>	<p>Sounds produced through deforming the material revealed internal properties.</p>
 <p>Probing- eye</p>	<p>Seeing the color, shadows, light and dark values, and the contrast expressed in visual patterns could either strengthen or weaken the images that had been built up by the earlier stages. Some participants were very surprised when they were finally able to see the material, and others found the visual image to match what they had expected.</p>	<p>Vision was the final stage in the lab and most participants felt it gave the strongest impression, because it unveiled the color and overall contour of the material and gave the participant the visual codes to determine what the material was. The visual impression aims to connect many of the previous impressions into an organized whole.</p>