e-Skin: Research into wearable interfaces, cross-modal perception and communication for the visually impaired on the mediated stage

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Abstract
Today our cultural events are dominated by visual information based on sight and sound, but hardly at all on the combined senses of touch and sound. Visually impaired users, lacking sight are not often able to engage in cultural events. Compensated audio-description or talking books are standard products that visually impaired people can buy to imagine feature film stories or decide what is happening on the stage. Very little theatre, dance or art events exist in which these people can actually participate. Interfaces are not often designed which promote communication between impaired actors, nor allow them to navigate and control audio-visual information on the mediated or digital stage. As neuroscientists suggest, the unique cross-modal potentials of human sensory perception could be augmented by electronic devices, which in turn might communicate with sighted audiences. Our research group is interested to address these problems by constructing ergonomic HCI (Human Computer Interfaces) that can explore the above problems including research into orientation, cognition mapping and external audio-visual device control. Consequently, we are implementing our discoveries in artificial systems, which can interact intelligently with people on the digitally simulated stage.

Keywords: HCI, cross-modal interaction, visually impaired users, mediated stages, ergonomic design.

1. The e-skin approach

"E-skin" is a set of interfaces, which constitute our past and present attempts to electronically simulate the perceptive modalities of the human skin: pressure, temperature, vibration and proprioception. These four modalities constitute our biggest human organ, constantly detecting and reacting to environmental realities.

Our research team is engaged with the mimicry of skin, alongside extensive user testing to assure we make relevant developments for cross-modal potentials, including tactile and acoustic feedback, cognitive mapping and embodied interaction. Cross-modal interaction is the label used in neuroscience to describe how certain features of objects perceived in ones sensory modes go-together with features in another sensory mode.

We are particularly interested in the relationship between tactility and acoustic feedback as well as the mediated stage as a feedback loop or “visual substitute”. What is the actual relationship between pressure and sound, temperature and volume and proprioception and vibration? Our group explores cognitive mapping, touch, movement, electro-stimulation on the skin itself, gesture and relief differentiation, in order to uncover some answers to this large question. Cognitive mapping exercises or tests about the composition of acquired codes, stores, recalls and decodes, determine relative locations and attributes in the spatial environment of the stage itself.

Our mediated stage is a hybrid platform using surround sound and three screens with related potentials of communication and movement and gesture as well as audio-visual response or what theorists call “embodied interaction”. As Paul Dourish (2001) suggests, “Embodied interaction” is not so easy to achieve without taking into account physical and social sensorial phenomena, which unfold in “real time” and “real space” as part of the particular environment in which the visually impaired are situated”. Therefore our impaired user’s relationship to the stage and their consequent levels of skin perception are very important to the development of e-skin. Although Dourish posits that “embodied interaction” can replace the screen, we are interested in the mediated stage as an incorporated platform because digital screens and sounds are an integral part of our society and our cities: a combination of both real and simulated realities. However, HCI interfaces which fall into the category of impaired applications on mediated platforms are often hindered by other complications. First, most commercial enterprises consider interfaces for the visually impaired in cultural environments to be uninteresting investments, due to small market value, and second, communications difficulties often occur when research initiatives cross-disciplines between the arts and the sciences. Our team and our impaired participants, struggle on because we find the subject and the embodied potential use of e-skin challenging and empowering.

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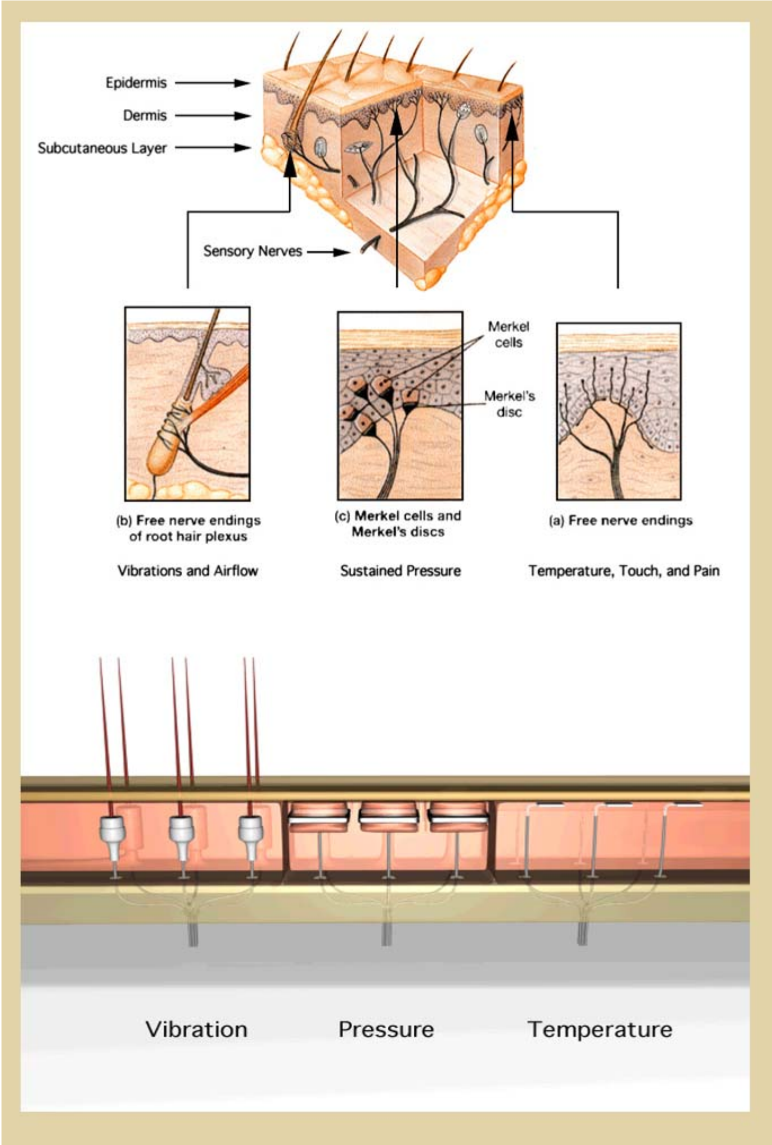

Figure 1 Skin modalities © Bisig & Scott

So far our methodology has been to simulate the skins modalities with off-the shelf electronics tied to a mediated audio-visual environment or stage and then invite our impaired users to test them. Not only can wireless technologies be used to transport electronic tactile and sound cues, virtual communication between visually impaired participants be increased but could also serve as a communication protocol for non-impaired audiences. We believe that tactile stimulation and acoustic feedback by an impaired actor could be transferred into visual stimuli for a sighted audience.

After developing and testing two prototypes, our group still continues to explore the theoretical and practical potentials of cross-modal tactile and sound interaction alongside digital visual output. On the one hand we are developing tactile feedback and electro-stimulation onto the human skin itself, by constructing wearable circuits embedded with micro sensors, actuators, wireless technologies and pocket size computers. For example acoustic and tactile feedback can easily be utilized for navigation and orientation. On the other hand, we are conducting workshops in simulated and mediated stage scenarios, where we can explore more universal levels of metaphors, cross-modal interaction, communication and comprehension in relation to the combinations of tactility and sound.

Through our workshops we have found that electro-tactile simulation can definitely improve the cognitive mapping of mediated spaces, particularly if complimented by metaphorical associations, which are linked to cultural preferences like music or nostalgic abstract sounds from childhood. This paper will trace our previous research, user-oriented workshops and our basic, applied and theoretical goals.

2. Previous research

Our previous research was conducted in two prototype stages and then in a set of specialized workshops. The first set of e-skin interface prototypes was called “Smart Sculptures”. These shell-like shapes were built by Jill Scott (HGKZ), Daniel Bisig (AI LAB), Rolf Basler (ZMB Aarau) and Andreas Schiffler (HGKZ) using basic wireless portable PICs or programmable micro-controller based technology, body temperature sensors, piazzo vibration sensors and pressure pad sensors. The modality of proprioception was mimicked by infrared technology and tilt sensors imbedded in three interfaces. All interfaces were linked to a central Linux server and three client Mac computers running Java Scripts. Through these interfaces and clients, the users communicated to three screens and a four-channel surround sound system. The content on the screens depicted the molecular and neural layers of real human skin and the participant was able to navigate though the layers in real-time. The pressure sensors triggered sounds, the temperature sensors variegated their volume and the tilting of the interface shifted the image. The vibration sensors controlled the speed and response of animated figures on the screen. Two visually handicapped people, one with 10 percent vision and another with 2 percent vision were invited to test the interfaces on this mediated platform.

We not only concluded that skin-based modalities could create unique forms of cross- modal interaction within media environments, but we found that the visually impaired actually prefer portable combinations of tactile and acoustic feedback. The results showed that sound feedback can only be a valuable navigation device, when it is received alongside other embodied sounds in the environment, as visually impaired people often create a type of tongue-clicking sound, which bounces of solid objects and helps them navigate. Blocking the ears severely hampers navigation.

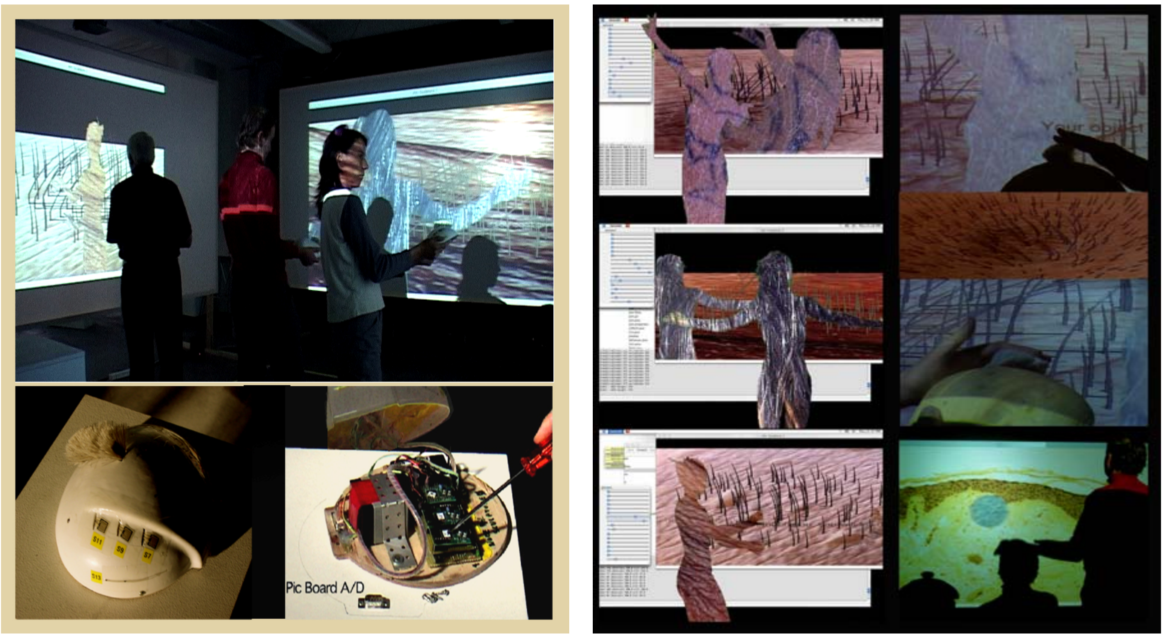

Figure 2 (left) Prototype 1: controlling the mediated stage with 3 interfaces based on 3 skin modalities (right) details of the screen display © Bisig & Scott

They also preferred to customize their own sound samples and once they learnt the associative relationship of the visual database, they enjoyed manipulating visual information on the screens. We continued to design two new mediated stages, which might be more customizable and incorporate more wearable tactile and sound feedback. Our focus turned to the potential of tagging objects so that they could be identified through sound feedback by speakers placed directly on the shoulder and RFID (Radio Frequency Identification) tagging was brought for tests on movable stage-screens and on the bodies of the users. This led us to the second stage, which was also funded by the KTI (The Swiss Bundesamt for Innovation and Technology).

Alongside the difficult endeavour of finding industry support, we developed another e-skin prototype test with RFID- tracking using a PDA (Personal Digital Assistant) with sound files and batteries located on a belt. We conducted tests in both shopping environments (related to our industry potentials) and also with non-impaired dancers for the mediated stage. In dance and theatre, one has more control over the design of objects on the stage; by comparison, in a supermarket there are two many similar looking objects, confusing light, and often too many obstacles in the way.

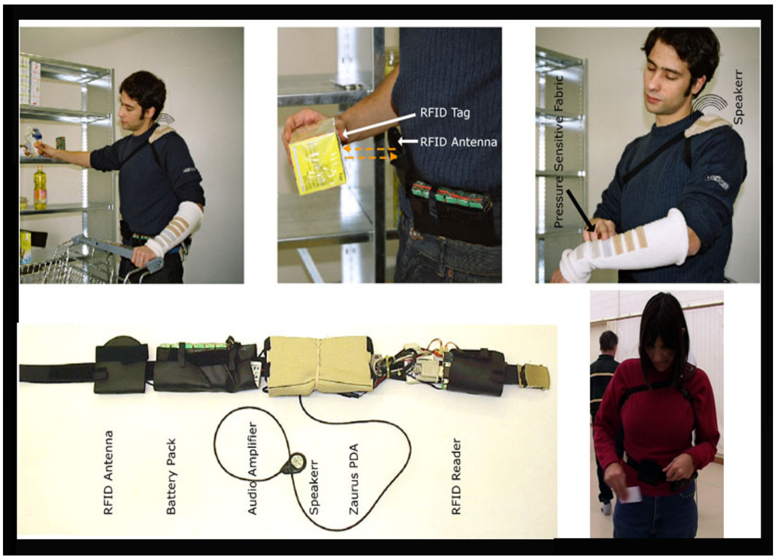

Figure 3 Prototype 2: RFID belt and wearable interface tests © Bisig, Schiffler & Scott

Certainly the RFID prototypes, and their associated sound files were successful aids for recognition of objects, which contained different substances but shared similar shapes. However tracking the location of the objects in a complicated environment would have required a much more extensive-raged RFID system.

Our collaborators, GlobIS Systems ETHZ, conducted a feasibility study in the form of questionnaires to see if visitors could use this RFID based e-skin as a cognitive map when they attended cultural events. The events were the Edinburgh Theatre Festival and the Zurich Museum Night and the results suggested that such an interface could be worn to improve navigation and access to information.

When the RFID prototypes were tested with our eight visually impaired people in workshops, the aim was to see how our visually impaired participants could associate more abstract sounds with the contents of objects (like the sound of knife cutting, with the actual object: bread). Not only were the identification of aspects in highly dynamic and complex environment considerably improved but also our visually impaired participants said they felt a new sense of empowerment.

As we were interested to discover more about cross- modal interaction from users, this stage led to new workshops based on pattern recognition though the skin-perception in relation to cognitive mapping. How might be these modalities be electronically simulated or aided by simulation and incorporated to act intelligently with the real world?

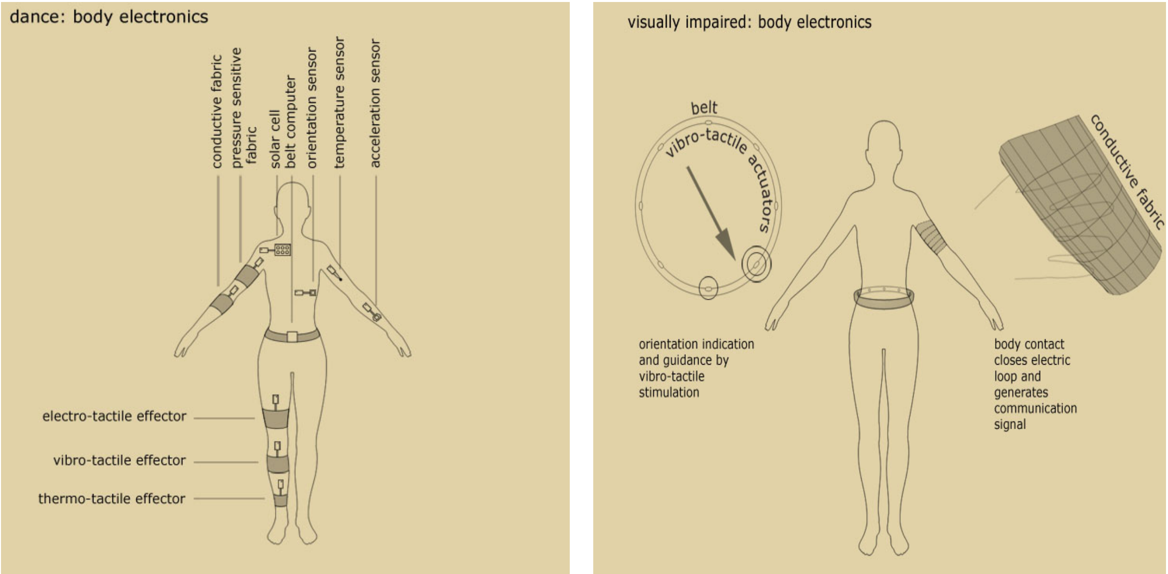

Figure 4 Body electronics © Bisig and Scott

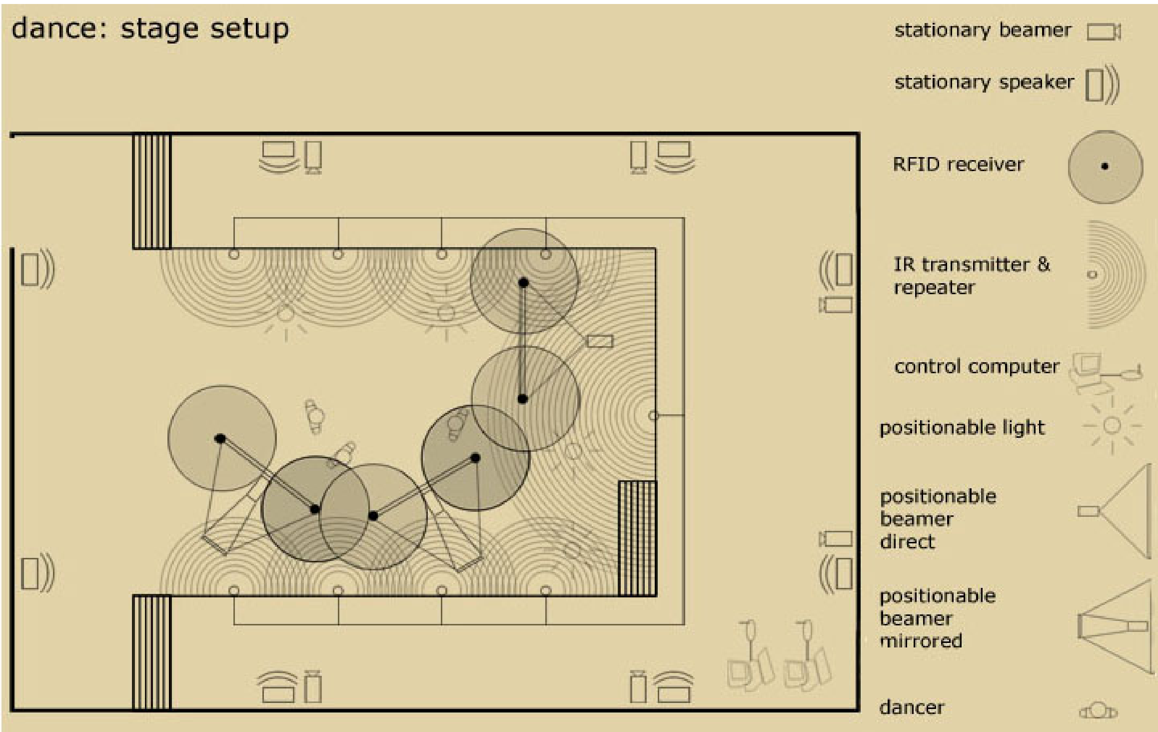

Figure 5 Designs of movable screens and mediated stage © Bisig and Scott

User-oriented workshops:

Our research methodology combines basic and applied research, with constant user testing as inspiration for further development. The workshops were conducted with new partners at Tanzhaus Wasserwerk where we had large amounts of space. Extra participants were organized by the Wohnheim für Blinde und Sehbehinderte, Zürich and movement improvisation specialists were employed. (The Carambole Dance Company, Zürich).

Our testing was observed by "ergonomie & technologie" GmbH and two new PhD students joined the tests: Peter Schmutz from the University of Basel, Department of Psychology and Valerie Bugmann, media artist HGKZ). The four weekend workshops were divided into tasks based on touch, tactile substitution as well as sound and movement/navigation. Some participants were congenitally blind and others impaired by early accidents. The age range was from 20 – 60 years old. A basic list of tasks and results were as follows:

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Figure 6 Task 1-4 workshops results with impaired participants: Andrea Kuehm, Freddy Gromme, Diego Metzger, Pascal Leinenbach, Helen Larcher, Claudia Gatti, Martin Meier, Peter Fisler © Scott

Task One: Electro-Touch Sensitivity and Pattern Recognition

We measured the visually impaired participants' touch sensitivity levels using electronic skin stimulation as a cue to orientation. Although each participant had a different idea about importance of touch culturally and functionally, there was a general agreement about the recognition of patterns though skin stimulation. Results: They all agreed that a type of Braille electro pattern-stimulation on the torso could be easily learnt. The majority of the participants proved to have superior tactile perception and could learn to recognize patterns on the arm of the skin, but had they did have some difficulty recognizing patters with dots more less than 2 cm apart, an aspect which could be problematic for miniaturization of the e-skin interface.

Task Two: Tactile Substitution

We set up scenarios in which the visually impaired could participate in cognitive mapping exercises. Could electro patterns stimulate map recognition in the spatial realm? By applying pressure on the arm, we explored the relation between the arm stimulation and relief differentiation mapped on the floor of the workspace. Two relief maps were tested, a grid and a rope road. These were inspired by the success of raised guidelines in the road, which are already used in Zurich for navigation with a cane. Results: These tests had very positive results, they proved that tactile stimulation from the interface itself on the arm, could increase navigational and orientation abilities. However, the wrist and its stimulation patterns had to be oriented towards the direction the participants were already travelling, in order to not be confusing.

Task Three: Improvisation and gesture-based communication

Along with the guidance of professional improvisation experts, we tested the perceptive levels that the visually impaired participants. What relationship do they have to their own body, to other bodies through touch and how aware are they about the meanings of gesture? Would it make sense to include gesture-recognition actuators in the e-skin interface in order to increase their confidence and interaction with others? Results: All participants agreed that movement workshops would help their communication potentials. They felt that trained movement people and stage directors would really help them to increase their perception, attention and motor abilities. Furthermore they thought that it would be excellent if they could "feel" gestures from another impaired actor.

Task Four: Sound and Navigation

We conducted a questionnaire about sound cue preferences, including the tested of other products available on the market, which use sound as a directional navigation aid. We also and tested the potentials of bone-phone sound substitution and conducted a questionnaire about sound customization. Could the creation of customized sound cues in relation to individual metaphors, not only help mobility and deter obstacle collision, but be transferred as a communication code to the server, which could re-transfer it and allow it to be "felt" on someone else wearing the e-skin interface. Results: All the visually impaired participants wanted to create their own personal sound cues for navigation. While speech plays an important role in directional guidance, abstract and discrete sounds are more preferable. Furthermore, the bone phones transducers, which are able to discretely transmit these sounds through the skull bone, which leave the ears free were a most valuable addition. The participants thought that these personalized cues could enhance their hearing and smell, but they could also imagine that a gesture could be "felt" by another human's tactile perception. Customized sound cues were very preferable to Ultra-sonic frequency modulation or alarms.

These workshops enabled us to study the different approaches by the participants to body awareness, touch sensitivity and cognitive map navigation, giving us a clearer idea of how the next stage of the e-skin interface should be designed. Our third stage of e-skin is related to the results from these workshops. We not only learnt that the tactile feedback can compliment sound as a navigation device, but that tactile pattern stimulation can be easily learnt and that accompanying sound cues can be very easily memorized. Bone phone transducers are an excellent way to transfer acoustic feedback. Although RFID tagging can help in the finer selection of smaller obstacles and the reorganization of them on the stage, combinations of different sensors in tandem, might be more valuable for larger mediated stages. As current research into cognitive mapping suggests (Ungar et al. 1996) the ways in which visually impaired deal with increasing levels of modern devices like mobile phones and GPS, needs more exploration. We are suggesting that visually impaired participants might be able to experience the control of audio-visual devices using more intuitive electro-tactile response and customized sound cues. Consequently, the current e-skin research goals-are to create more flexible skins for cross-modal activity, increase the potentials of communication for the mediated stage, further assess navigation and orientation aids currently on the market and create acoustic feedback which can augment cross-modal activity.

3. State of the art comparisons

These new goals combined with the actual building of a mediated stage at the beginning of our research, have intensified our investigation into four research agendas; the potentials of embroidered circuits for flexibility and available, HCI (Human Computer Interfaces) in which sound and/or touch are already utilized, and other interfaces and workshops for the visually impaired. While large amount research has been taking place in robotic and flexible skins, we found that the10-year-old research into embroidered circuits was in need of new directions.

In HCI, we have found hardly any interest in the design of tactile and sound cross-modal interfaces, which can control and communicate with others on the mediated stage, a great deal of current research is worth mentioning. Of great importance to our research is the excellent work of the well-known neuroscientist Paul Bach -y- Rita (Kaczmarek & Bach-y-Rita 1995). After many years of research and clinical work, he has recently developed an application for the visually impaired called "Brainport". This device, which promises to hold the ultimate answer to augmented vision, allows for camera-captured luminosity levels to be transferred to a micro-array pattern generator. This pattern generator can be worn directly on the tongue and help guide the visually impaired to navigate. There are also a few commercial successes in relation to sound and navigation for the visually impaired; these directions also include evaluation and optimization by users right from the start of the interface-developmental process. We have conducted a fair amount of research into these devices; however, we do not have the space in this paper to elaborate on a full comparison. One of our main interests is to find currently available products like the "Bonephone" by Sonortronics[1], which can be modified and integrated into the e-skin interface. The Bonephone accessory serves as underwater acoustic device, which alerts the diver of the presence of metallic objects. If e-skin must be unobtrusive, usable and ergonomic then acoustic feedback must not block or interfere with the visually impaired navigational hearing requirements. So our workshops act as usability tests to scientifically test existing devices as well as the prototype devices we have constructed ourselves. At present HCI interface design for the congenital impairment is based on outdoor navigation problems, rather than interaction problems, which occur indoors, where our home environments are becoming more mediated and open to digital information flow. For the mediated stage more sophisticated and wearable devices are needed. While most acoustic interfaces block the ears, blocking off surrounding sounds (essential cues for navigation) further research in needed in cognitive science in order to understand how cross-model reception works. It is our team's conviction that a combination of studies in sensory perceptions from a psychological perspective with studies about the perception of content in a cultural environment would inform the design of interfaces.

4. Current developments of e-skin.

[1] http://www.sonotronics.com/udr.html: Accessed May, 2005

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According to the neuroscientist Baddeley (1992) visually presented material is stored and processed in the visual working memory and auditory information is processed in the auditory working memory. Both systems have limited capacity. Thus, presenting information through alternative modalities, which include touch, makes use of the cognitive architecture and may help keep the cognitive load at a lower level. Part of our user tests have involved research into the accuracy of "feeling with the minds eye" (Sathian et al. 1997) and exploring the potentials of touch, which have already been conducted in clinical psychology (Verry 1998). There have also been some very interesting studies on the involvement of visual cortex in tactile discrimination of orientation (Zangaladze et al. 1999) which proves that the eye muscles are still engaged in active orientation even though the patter arrays are not received by the visual cortex. As Merleau-Ponti (1962) suggests the phenomena of cross-modal perception in relation to cognitive mapping of an audio-visual environment still needs exploring because the feedback loop of perception itself, is already mimicked in these technologies. Currently we are combining basic and applied investigations with user tests in cross-modal interaction.

4.1 Basic: wearable embroidered circuits, sensors and computers.

In our previous work mentioned earlier in this paper, we have already experimented with hand-held electronic interfaces to control and trigger associations in a 3D mediated stage because we were interested to construct a device which might improve the level of audience immersion and we achieved a high level of automatic real-time control of the audio-visual information with these devices.

As Dourish (2001) further suggests, the cognitive patterns derived from the sense of touch are an essential component of embodiment and need to be explored at a much deeper level. Many of the physical interfaces that designers have invented tend to concentrate on a level of perceived realism by the grasping of objects and providing force feedback (Stone 2000). Rather our team is interested in interface research, which is capable of providing texture sensation through electro-tactile (Kajimoto et al. 2003), temperature or air pressure stimulation (Asamura et al. 1999). In terms of communication, gesture recognition from actuators placed on the electronic circuit might also loop though the digital feedback on the stage. As Mais suggests (2006) gesture recognition should be based on symbolic gestures, which are gestures within each culture that have come to a single meaning such as "OK". Directive Gestures like "put that there" compared to iconic gestures, or ones that are more about size, shape or orientation should also be considered. We suggest that gestures of unimpaired people can be actually felt by visually impaired people through actuation of points on the embroidered circuit of the smart fabric directly placed on the visually impaired users' skin. After exploring polymers and flexible devices for our first stage of e-skin[2], we decided that flexible fabrics were more suitable for the base of our e-skin interface.

On the basic side our focus is wearable embodied circuits embedded with micro controllers, sensors and computers. This focus includes the re-design of the interfaces to aid easier movement in the space, the construction of tests with embroidered circuits and perceptual analysis and the incorporation of wireless control potentials in relation to touch and sound. Our actual goal is to convey spatial information through pattern stimulation onto the human skin and vibration motors, while outputs from pressure sensors, actuators and temperature sensors provide audio-visual control and communication to other users.

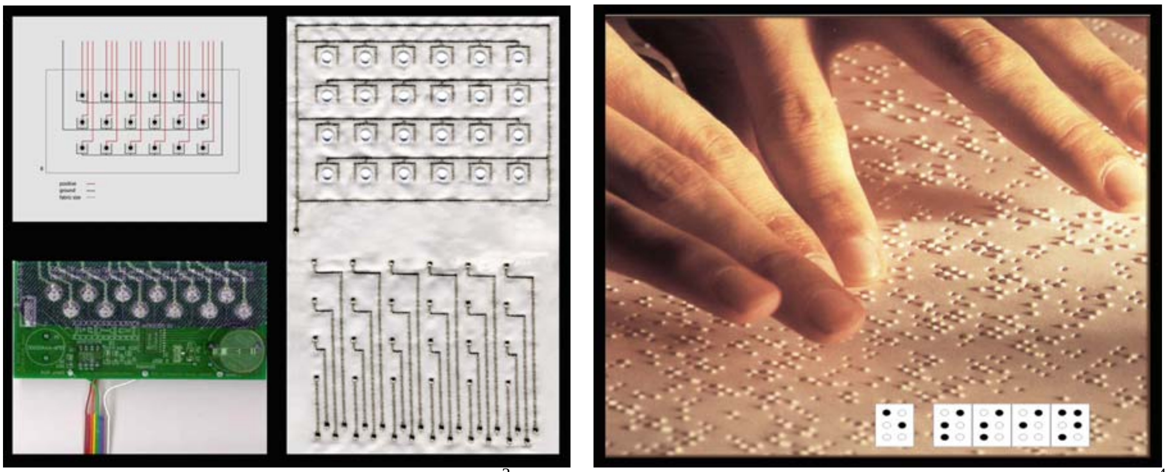

Figure 7 Base of e-skin: an embroidered circuit[3]_ Brail dot matrix patterns have electro stimulation potential[4]

[2] http://www.mal.uic.edu/CAMNA/ MEMS_Announcements/announcements_7_27_01.html, Accessed February 7, 2006

[3] © Bischof Textiles St. Gallen; Bugmann and Scott [4] © Wohnheim für Blinde und Sehbehinderte, Zürich

Our current circuit has been designed with two layers so as to maximise the levels of resistance between them. The ergonomic challenge is that e-skin should feel like an interactive second skin rather that an extra costume component. While Human Computer Interaction is of major interest to interface designers and media artists, skin-based modalities have not yet been researched as potential designs for embroidered circuits. Embroidered electronic circuits have valuable tactile potentials (Kirstein et al. 2003), and these potentials can receive in coming communicating gestures from other visually impaired actors. Temperature feedback will also be used as a proximity detector onto the skin, a metaphor, which connects to childhood games of nearer and warmer objects. Braille letters, which consist of a dot matrix, could be mimicked by electro-tactile stimulations to produce coded messages on the skin. According to our workshops with sensitivity tests, the above feedback sensations can be made on the back of the hand, arm or on the torso.

4.2 Applied: systems integration, workshops, mediated stage

The applied aim is to create eight devices, which can control a mediated stage. The final cultural event will demonstrate the interface and the results of the workshops to other cultural planners and directors, who might be encouraged to also use e-skin for their projects. While navigation and communication on the street requires selection, analysis and decision, attending and participating in a cultural event like dance theatre requires different levels of interaction like gesture and reaction, communication and proximity awareness and controlling or using the digital real time potentials of the environment itself as a communication device. With our prior history of designing immersive mediated environments (Hahne 2003), we are confident that augmented realities can help to explore more ergonomic wearable interfaces on the mediated stage. HCI Interfaces, which can cross borders between real environments (e.g. the streets) and indoor virtual environments (e.g. or audio visual environments), are also rare. Even though, the congenitally impaired person may use his or her well-trained sensitive tactile and acoustic skills to easily differentiate between indoor and outdoor environments, access to devices, which can develop more creative potentials indoors in mediated environments are sadly lacking. The mediated stage is an important test ground. One in which, impaired participants can actively participate in acting, communication and movement.

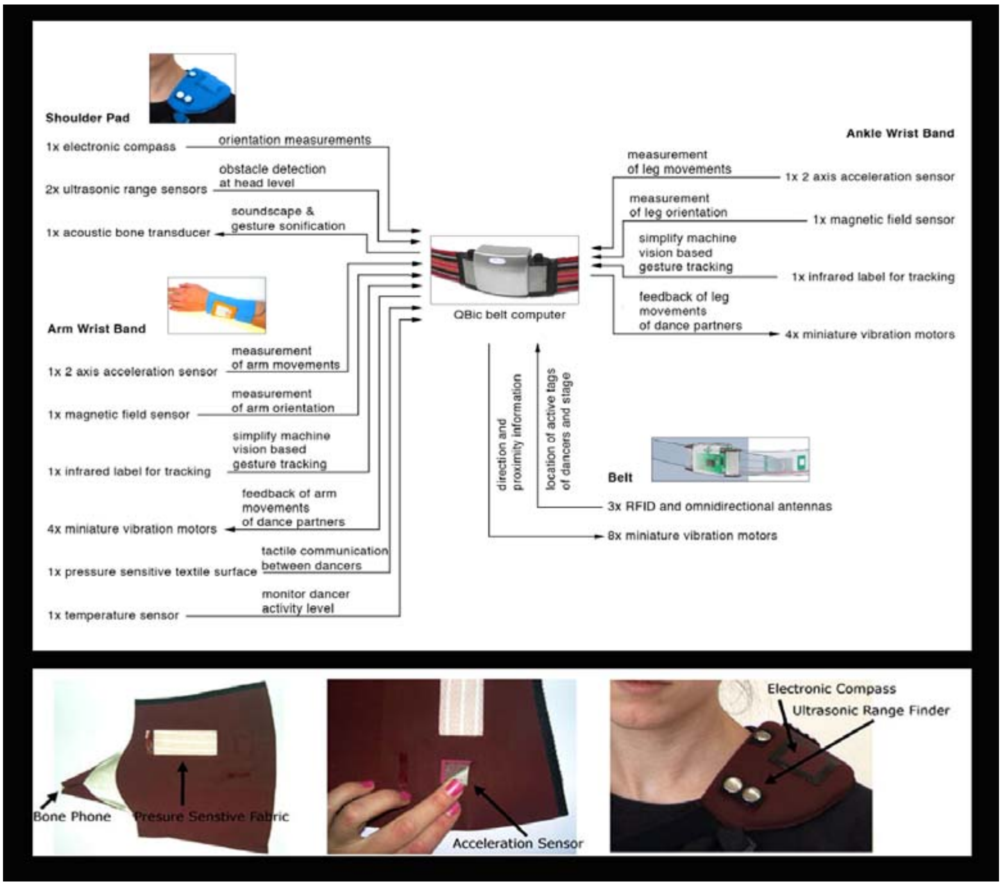

Figure 8 Technical diagrams with QBIC computer, © Schiffler & Scott

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On the applied side we are concentrating on two stages of Systems integration with the mediated stage including user workshops. Here e-skin the e-skin circuit and its sensors would be integrated into a client computer system and two navigation sensors (Compass and ultrasound) as well as linked to sound feedback (bone-phones). This integration will increase their awareness of space, of each other and of their proximity to obstacles on the stage. By further studying study the user's movement, communication and customization potentials and strategies, the workshops participants will become consultants. Finally they will help to develop their own content in relation to the subject of skin, and demonstrate the results of the project to the public at Tanzhaus Wasserwerk. The first stage is to integrate the costume components of the basic research with "off the shelf" bone phones for sound, compasses for vibration direction and accelerometers for gesture recognition and ultrasound for obstacle collision. These components will be linked with the embroidered circuit to a small wearable computer called the QBIQ, which is in turn linked to a central server controlling the stage. This computer will store various languages, sounds and memory routes within a belt integrated computer called the QBIC[5]. The current model is batch produced at the Wearable Computing Laboratory of the Swiss Federal Institute of Technology in Zurich as a research platform to collect and compute sensory data for medical monitoring and context recognition projects. The second stage is to workshop this integrated system and use RFID and WIFI technologies to link it to an audiovisual stage or platform.

[5] http://www.ife.ee.ethz.ch/qbic/index.html Accessed February 7, 2006

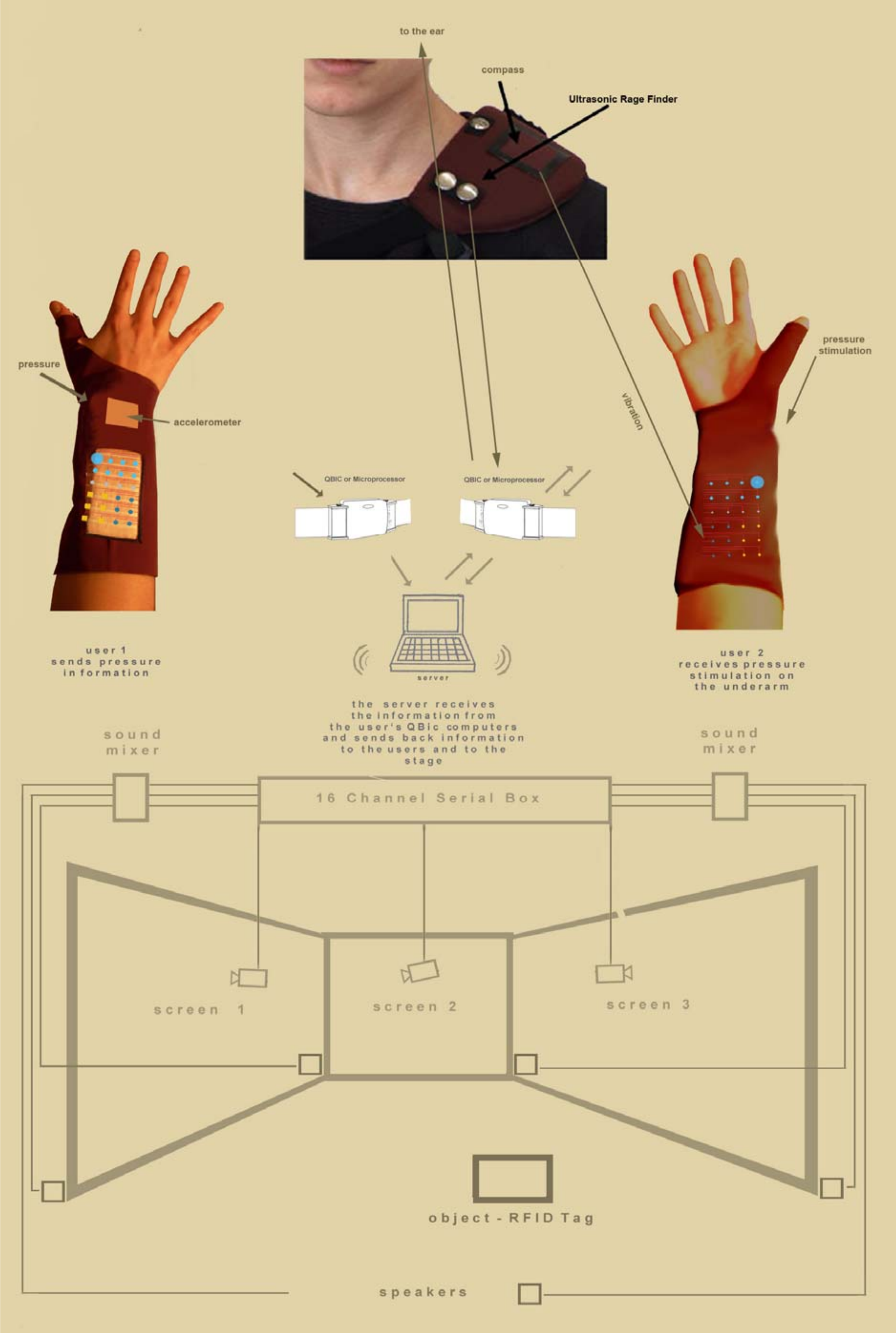

Figure 9 Current design diagrams: e-skin for the mediated stage © Scott

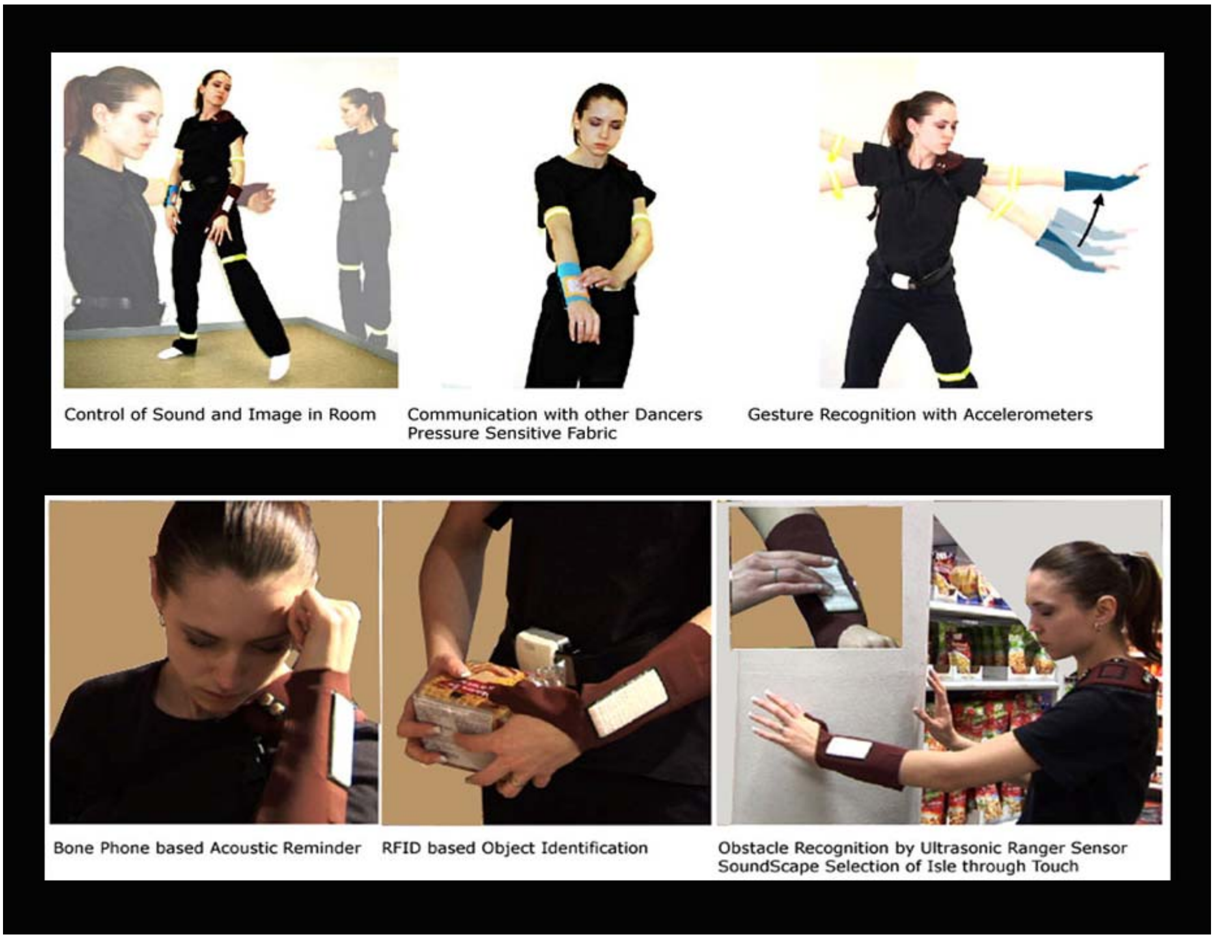

Figure 10 Dancer wearing e-skin for the mediated stage © Scott

5. Conclusion

Our users hope that there is a real possibility of a third stage of e-skin to become closer to the concept of embodied interaction. This can be achieved by augmenting the participant's movement, communication, navigation and control skills and also by working with the potentials of cross-modal education. As movement specialists at The Institute of Special Needs Education at the University of Oslo, Norway[6] have experienced, new movement education for the visually impaired causes a large increase in individual expression and builds up confidence, aspects which most HCI developers are not exploring along side their own engineering and computer science methodologies. By encouraging a combination of interface development and movement alongside the measuring of responses using social science methodologies, the Department of Psychology in Basel and the company Ergonomie and Technologie can helps us to assess the navigation, information and communication of our users. We need to not only identify inherent problems and inconsistencies in e-skin, we are working toward the development of a device that "talks their language" and prove that the human body, is also "embodied" in relation to the senses of tactility, proprioception, hearing and cognitive mapping. Therefore, the third stage of e-skin is based on "human and universal" aspects using acoustic and tactile feedback combinations to access more metaphorical associations. Our aim is to "humanize technology" for the visually impaired. In addition, through the output potentials of the audio and visual information, non-visually impaired persons in the audience could gain more insight into "the world of the visually impaired". Currently, our mediated cities are causing more social separation between impaired and non-impaired people.

We are also beginning to explore the educational potentials of neuromorphology, where tests for inherited eye diseases are conducted. Perhaps sound and tactile metaphors about this research, can inform the development of scripts for the e-skin mediated stage and metaphors can be found to augment essential "visual information" from impaired persons to a sighted audience. With our first two prototypes we have already discovered that electronically enhanced perception can complement visual forms of interaction on the stage

[6] http://www.isp.uio.no/AboutISP.html: Accessed May 2, 2006.

and communicate with the audience in a new way. The next step is to train visually impaired actors to create their own theatre, using e-skin to activate, communicate with others and control the mediated stage. Thus this third stage of e-skin with its enhanced wearability and its continued reliance on the four main skin-based sensory modalities of perception, might not only complement “visual forms” of interaction and empower deeper perception on the stage, but communicate with the audience and with other impaired participants in an embodied way: focussing on ubiquity, tangibility and most of all, shared awareness, intimacy and emotion.

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