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Audio–tactile stimulation: a tool to improve health and well-being?

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Abstract: Stimulation of the tactile sense or the hearing sense can be used to improve a person's health and well-being. For example, to make someone relax, feel better or sleep better. In this position paper, we present the concept of auditory–tactile stimulation for health and well-being. Through carefully selected audio–tactile stimuli a person's bodily, mental and emotional state may be influenced. The state of the art is described and its limitations are indicated. Then, a vision is presented on how auditory–tactile stimulation could be beneficial in several application domains. Three specific research areas are identified: identifying mechanisms of perception of auditory–tactile stimuli, methods for automatic conversions between audio and tactile domains and automated analysis of human bio-signals and behaviour for adapting the stimulation optimally to the user.

Keywords: haptics; tactile stimuli; haptic perception; audio stimulation; acoustic stimuli; multi-modal stimuli; cross modal perception; cross modal conversions; health; healthcare applications; well-being; therapies; relaxation methods; bio-signals; position papers.

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1 Introduction

1.1 Improving health and well-being using touch and hearing

People perceive the world through their senses such as sight, smell, taste, hearing and touch. The tactile (touch) sense is an important one; in fact it is the first sense to develop in the womb (Gottlieb, 1971). Touch can give people strong emotional experiences and is vital for health and well-being (Gallace and Spence, 2010). Tactile stimulation or *somatosensory* stimulation, applying touch to the human body, is often used as a way to make people feel better or to reduce stress. Examples range from basic touch for comforting someone, massaging techniques and physiotherapy to alternative therapies such as acu-pressure, Reiki and Vibro-Acoustic Therapy (VAT).

Besides touch, the sense of hearing can also be used to make people relax or feel better; one might listen to spoken encouragements, relaxing music or nature sounds. Music therapy (de Niet et al., 2009; Wigram, 1996) is an established practice and has been extensively investigated in the scientific community.

The scientific literature shows evidence (see Section 2) that specific ways of stimulation of the auditory (hearing) or tactile sense can indeed effectively reduce stress and muscle tension, increase well-being or promote sleep. Furthermore, there are indications (Dijk and Weffers, this issue); Lemmens et al., 2009; Sha, 2010; van Ee et al., 2009) that stimulating the two senses of hearing and touching *at the same time* can lead to stronger impact on the human mind than stimulating only one of the senses at a time. Hence, a promising area of scientific research is on using a simultaneous combination of sound heard and touch felt by a person, with the goal to influence the person's state of body and mind in a positive way.

1.2 Scope

The research area discussed in this paper we refer to as *auditory–tactile stimulation and its effects on human health and well-being*. We argue that little scientific work has been done so far in this field. The aim of this paper is to present our vision on this research area and to present the research challenges and opportunities that we have identified in there.

Although we often refer to the term *health* as a goal of the systems we investigate, we do not necessarily mean to replace established medical treatment methods with new ones. In healthcare situations the goal could be to augment existing care and treatment methods where possible, by stimulating subjective well-being, relaxation or good sleep of a patient.

1.3 Example applications

1.3.1 Healthcare

One particular use-case example that we propose is a small relaxation room in a care institute, where a user can sit in a comfortable chair with eyes closed. Light, music and sounds are played in the room, and the user feels gentle taps on the body and calming oscillations. Meanwhile the chair senses how the individual user reacts to these stimuli in real-time. The stimuli during a session are personalised by a software system in such a manner, that the combined effect is optimally relaxing for this user. Maybe one user prefers taps, while the other prefers gentle vibrations. And each user may have a personal level of intensity and patterns that he/she likes best.

A similar use case could be envisioned for people with autism, analogous to a multi-sensory environment investigated earlier in the MEDIATE project (Parés et al., 2005). This environment was designed to provide a meaningful response to the behaviour of a user.

1.3.2 At home

Another use-case example is in the home (consumer) environment. Imagine a user at home, who wants to relax after a busy day at work. He owns a multi-sensory relaxation-entertainment system that consists of a blanket with integrated miniature tactile actuators and headphones. The system provides a combination of sounds, music and tactile stimulation that is especially designed to relax. After a session of 20 min, the user feels more relaxed than before and is able to leave the stress of work behind.

1.3.3 Public transport

In public transport, it is vital that bus and train drivers are alert during their work shift. However, the working hours in this profession are often irregular, inducing the risk of decreased alertness at times when this is most needed. The Dutch railway company NS has already experimented (van Panhuis, 2008) with special power-nap relaxation rooms, which have the multi-sensory stimulation chair AlphaSphere (Sha, 2010) installed. The goal is to enable personnel such as train drivers to have a quick, 25-min rest, e.g. during break times, in order to increase alertness later during working hours.

1.4 Structure of this paper

To be able to clearly outline our vision and the research challenges ahead in Section 3, we first provide an overview in Section 2 of the state of the art and its limitations. We end this paper with concluding remarks in Section 4.

2 Relevant state of the art

This section does not aim to be a complete overview or review of the state of the art. Rather, we briefly introduce the research and application fields that are considered relevant, with the help of a few key references.

2.1 Stimulating the sense of touch

The skin is by far our largest organ. The surface in adults is just under 2 m² and it weighs about 5 kg. The skin senses inform the organism of what is directly adjacent to its own body. The skin contains several different types of mechanoreceptors and generally, stimuli will evoke a response in multiple receptor types. The tactile experience is based on the combined response in mechanoreceptors (e.g. Johansson, 1978; Johansson and Birznieks, 2004). Some skin receptors can elicit emotional responses directly, either positive (e.g. in erogenous zones) or negative (pain receptors or nociceptors).

There is a biological law that states that the earlier a function develops in an organism the more fundamental it is likely to be. The sense of touch is the earliest sense to develop in a human embryo (Gottlieb, 1971) and the significance of touch is eminent directly after birth. Most of the major reflexes of neonates are based on the sense of touch (Shaffer, 1989), for instance: the rooting reflex (turning the head in the direction of a tactile stimulus to the cheek), the sucking reflex and the grasping reflex. Besides simple reflexes, the skin's sensory function also mediates complex behaviour and plays an important role in emotional development (van Erp, 2007).

2.2 The skin senses and emotional development and interpersonal interactions

The sense of touch is one of the first media of communication between newborns and parents. The critical importance of this tactile communication was shown by Harlow and Zimmermann (1959). In their experiment, infant monkeys that were separated from their group showed a large preference for a surrogate mother consisting of wires and cloths that resembled the feel of a real mother ape over a surrogate mother consisting of wires only. This preference was also prevalent if the wire surrogate mother provided food and the cloth mother did not. After a thorough study of the literature on the critical role of tactile experiences required in order to develop as a healthy human being, Montagu (1972, p.332) even states that touch or cutaneous stimulation is a basic need which must be satisfied for the organism to survive. Throughout the rest of our life, the sense of touch remains important in social interaction for instance in greetings (shaking hands, embracing), in intimate communication (holding hands, cuddling) and in corrections (spanking). Although norms and meanings are to some extent culturally defined, Gallace and Spence (2010) conclude in their review that interpersonal touch has been shown to play an important role in governing our emotional well-being and physical contact can convey a vitality and immediacy at times more powerful than language.

2.3 The skin's ability to transmit emotions and its effect on well-being and behaviour

A more than a century old model states that emotions are our perception of physiological changes (Damasio, 1999; James, 1890, p.449). Based on this model, it may be expected that the sense of touch is a strong mediator of emotions. There are three effects reported in the literature. The first is direct communication of positively valenced warmth and intimacy or negatively valenced pain or discomfort based on specialised skin receptors. The second is through intrinsic emotional meaning beyond valence and intensity. Recent reports show that the sense of touch can signal at least anger, fear, disgust, love, gratitude and sympathy (Hertenstein et al., 2006). The third is through modulating emotion-related visual or auditory communication. Tactile stimulation is also used in methods to reduce stress or make people feel good, feel cared for, happy, energised, sleep better or simply more relaxed (Essick et al., 2010; Kvam, 1997; Patrick, 1999; Prisby et al., 2008; Wigram, 1996). There are studies on the subjective pleasantness of touch (Essick et al., 2010) and studies on mental, health-related and bodily effects of low-frequency vibration (Kvam, 1997; Patrick, 1999; Prisby et al., 2008; Puhan et al., 2006; Wigram, 1996). Several investigations confirmed the link of touch via physiological parameters to for instance experienced stress level. Physiological effects reported include lower systolic and diastolic blood pressure, heart rate and cortisol and oxytocin levels (Ditzen et al., 2007; Shermer, 2004; Whitcher and Fisher, 1979). In addition to physiological and psychological effects, being touched may also have behavioural consequences including people's tendency to comply with requests, giving tips or free rides and even eating activities. At least some of these effects can be long lasting. Eaton et al. (1986) reported a positive effect on elderly people's food intake when caregivers combined their encouragement to eat with tactile contact, and that these effects were present for several days.

2.4 Artificial tactile emotion presentation

All the above studies on the effects of touch on emotional state and well-being were based on natural touch, provided by a human being. Now, within the light of this paper, a relevant question is whether the same effects or maybe different effects altogether can be achieved with artificial or machine-generated touch. We can distinguish two cases:

1. artificial touch which aims to emulate human-applied touch
2. artificial touch which does not aim to emulate human touch but does aim to achieve specific (emotional or health-related) effects on a person.

These research areas do not have a long and scientific history yet. Most research stems from the last decade and often involves qualitative analyses with small groups of subjects only.

Looking at the first area, the results provide indications that machine-produced touch in a specific experimental situation could be similar to that of touch performed by a human. In addition, there is growing support for the hypothesis that virtual touch is well able to communicate aspects such as ambiance, affect and urgency, and probably can do this better than communicating precise or complex numerical information. For instance, Smith and MacLean (2007) reported objective and subjective observations showing that emotions could be communicated through a haptic display. The experiments of Bailenson et al. (2007) showed that even with touch cues that are extremely degraded (e.g. a handshake i.e. lacking grip, temperature, dryness and texture), virtual interfaces can be effective at transmitting emotion. Haans and IJsselsteijn (2009) recently showed that the effect size of the virtual Midas touch is in the same order as that of a human. However, possible differences between mechanically mediated and human touch and their qualitative and quantitative effects on physiological and emotional responses and behavioural consequences is a topic that needs further research. The same holds for the effect of different body locations in relation to (inherent) meaning and effectiveness of tactile stimuli.

2.5 Touch actuator technology

To fully understand the opportunities in the field of auditory–tactile stimulation, it is helpful to look at tactile actuation (i.e. touch stimulation) technology. In recent years, advances in actuators and embedded computing have enabled a wide range of machine-driven methods for tactile stimulation.

The strong growth of haptic feedback technology in mobile phones has brought a variety of small mechanical actuators onto the market. Such actuators are used in for example jackets (Lemmens et al., 2009; and Figure 1) that can stimulate different points on the upper body or a blanket (Dijk and Weffers, this issue) that can provide tactile stimuli to the whole body. Miniature actuators can be combined with larger actuators as done by Gunther (2001), which enables interesting compositions of effects. With today's technology, a large variety of tactile effects can be achieved relatively easily, at low cost and suitable for daily usage situations. However, reproducing the many subtle effects of human touch is a difficult task that today's technology solutions cannot achieve.

The types of tactile actuators that could be used for the purposes explained in this paper include:

1 Miniature eccentric rotating mass vibration motors, used in many mobile phones. These do not offer precise control of frequency and amplitude of tactile effects. Such motors were used in Lemmens et al. (2009) and Dijk and Weffers (this issue).

2 Small tactile transducers operating in the fashion of loudspeakers, capable of playing effects with precise frequency/amplitude control. These are used in some mobile phones by Israr and Poupyrev (2010) and Gunther (2001).

3 Larger tactile transducers operating in the fashion of loudspeakers, used in some home cinema products and in theme parks for powerful bass effects. These are also called 'rumblers' or 'shakers'. Gunther (2001) has also used such transducers.

4 Common bass loudspeakers, sometimes used as an alternative for large tactile transducers. These are used for example in the AlphaSphere product by Sha (2010). A disadvantage of loudspeakers is a relatively high level of audible artefacts.

5 Actuator systems for mechanical displacement or pressure on the body. For example, solenoids, rotary driven pistons or pneumatic/hydraulic actuators. Systems for motion are used by Virtual Relaxation Solutions (2010) and pneumatic actuators in the TN Games (2010) gaming vests.

6 Fans or other systems for targeted air displacement.

7 Heating or cooling actuators that can locally influence the temperature of the body or skin. Local warming is used in AlphaSphere (Sha, 2010).

See Figure 1 for an impression of some products incorporating vibration motors, actuator type 1 in the above list.

2.6 Stimulating the sense of hearing

Like touch, the human sense of hearing is often used in methods for health and well-being. Examples are relaxation music, nature sounds, or self-help audio guides. In the literature, the effects of music and therapeutic use of music have been well investigated (e.g. de Niet et al., 2009; Wigram, 1996). Many audio-based products exist for health and well-being and mental state influencing, including some that use so-called brainwave entrainment methods, particularly *binaural beats* or *isochronic tones* (Huang and Charyton, 2008).

One specific reason for using audio stimuli such as music or nature sounds can be to distract the attention of a patient away from a negative situation (e.g. pain or negative thoughts).

A good example of innovative audio content with well-being applications is *Meditainment* (a combination of Meditation and Entertainment) by Meditainment Ltd. (2010), which combines relaxing music, ambient soundscapes, nature sounds, voice coaching with guided meditation and visualisation techniques. One particular use of this content which is reportedly being investigated is pain management for patients with chronic pain. Typically, the audio in existing products like Meditainment is static, that is not interacting with the user nor automatically adapting to the user. One of our hypotheses is that making this content more adaptive to the user could make auditory stimulation more effective and at the same time more attractive.

Figure 1 A former Dutch minister wearing a Feel The Music Suit at a public event (top-left). On the bottom left, design sketches of this suit. On the right, a demonstration of another tactile vest showing coordinated dance movements between three users (see online version for colours)

2.7 Combined stimulation of touch and hearing: auditory–tactile stimulation

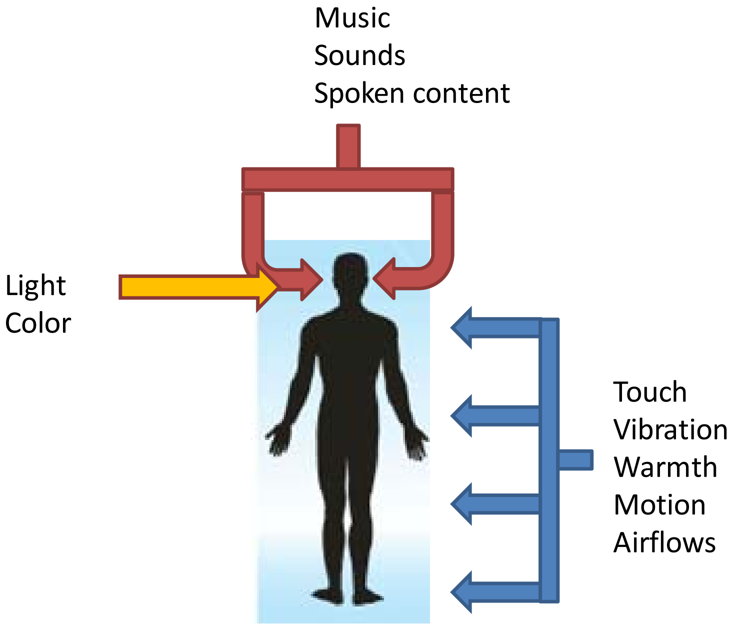
Based on the potential effects of auditory stimulation on the one hand and tactile stimulation on the other hand, an interesting concept is to combine both. If each stimulation method alone can have positive effects, can a combination be even more effective or more enjoyable? See Figure 2 for an impression of this approach to sensory stimulation. As an example, the Meditainment audio content mentioned in the previous section could perhaps be augmented with tactile stimuli to increase the effectiveness.

Next, we look at what the scientific literature tells us about the health and well-being effects of such combined stimulation. Some work has been done on a specific method of combined auditory–tactile stimulation called Vibro-Acoustics (VA) or VAT. Here, a vibrotactile effect is directly derived from the lower frequencies of a special music track and played by typically one or two tactile actuators. Experimental results suggest that this combination may work well for relaxation or sleep (Kvam, 1997; Patrick, 1999; Wigram, 1996).

An experiment (Puhan et al., 2006) with playing the didgeridoo musical instrument, which evokes strong vibrations in the upper body along with the sounds that one hears, shows promise as a specific medical treatment for obstructive sleep apnoea syndrome.

Initial experiments with a combination of ambient sounds, relaxing music and patterns on a tactile blanket (Dijk and Weffers, this issue) also appear promising. The results suggest that the different modalities can mutually strengthen each other to provide a total experience that people like and consider relaxing.

Figure 2 Impression of auditory–tactile sensory stimulation of a person (see online version for colours)



Note: Light and colour stimulation as shown on the left may be used but this is outside the scope of this paper.

On the other hand, a great deal of knowledge does exist in the literature about the mutual interactions of the hearing, tactile and visual modalities, so-called *cross-modal effects*. This knowledge can be roughly categorised into in number of sub-areas (Calvert, 2004; Grünwald, 2008): perception and sensory thresholds, information processing performance, spatial attention, attention (van Ee et al., 2009), navigation/orienting in spaces, synaesthesia, neural plasticity, ageing, perceptual illusions and sensory substitution. Occelli (2009) documents a number of experiments that address multiple of the above sub-areas.

But the aspects of health, well-being and pleasantness are only addressed to a limited degree in existing work. Therefore, we propose a new topic of research (see Section 3.3) to take these aspects into account together with the study of cross-modal effects.

2.8 Audio–tactile composition

A related area of research and creative work is called *audio–tactile composition* (Chang and O'Sullivan, 2008; Gunther, 2001; van Erp and Spapé, 2003). This usually refers to musical composition augmented by a composition of tactile effects that a user can feel at the same time. This is starting to become a commercially viable area, due to the rapid growth of haptics features in cell phones.

There are probably various approaches to audio–tactile composition. Although in this paper this area is not treated in further detail, we illustrate the possibilities by listing the following approaches to audio–tactile composition:

1. Using an existing piece of music (not written with audio–tactile composition in mind) and augmenting it with 'tactile effects' to put emphasis on for example certain notes, bass sounds or on the beat. In general we can use tactile stimuli to put emphasis on certain rhythmic, melodic movements or on certain motivic or thematic properties of the music.
2. Composing a piece of music and composing tactile stimuli fitting to the music, such that the music could also be played separately without the tactile stimuli. But the tactile stimuli are not suitable to be played alone without the music. In music composition terms, one could aim to create a kind of *counterpoint* based on the synchronicity of features in both the musical and the tactile stimuli.
3. Composing a tactile piece, possibly based on existing musical composition rules or even on an existing piece of music. Such a piece can be fully experienced by deaf people.
4. Composing a truly integrated audio–tactile piece, in which one modality cannot be separated from the other. This may include for example a music-only phrase that is followed in time by a tactile-only response phrase.

Other possible approaches are creating (automated) methods or processes to translate music into a tactile composition. Branje et al. (2010) describe a study on translating existing music into vibrotactile stimuli (that are in this case applied on the human back), such that the experience of music can be conveyed even in the absence of sound.

We identify that a number of relevant topics have not yet been addressed in the field of audio–tactile composition:

1. a link to human health and well-being has not been investigated yet

2 automatic audio to tactile conversion methods, suitable for driving multiple tactile actuators have not yet been investigated in a well-being context

3 there is lack of well-founded composition tools to compose audio–tactile experiences, especially when considering applications, like ours, that are outside the limited context of mobile phone ringtone composition.

3 Beyond the state of the art

3.1 Introduction

The area of scientific research that we propose aims to employ a combination of sound heard by a person and touch felt by a person at the same time, to influence the person's state of body and mind in a positive way.

Based on the previous section, we conclude that stimulating the human senses of hearing and touch at the same time has great potential but requires further scientific study. We also found that existing approaches for auditory, tactile and auditory–tactile stimulation for health and well-being use fixed *content* that does not adapt to, nor interact with, the individual user. The term *content* here refers to the combination of sounds and touch effects, how these effects are arranged in time, and how touch stimulation patterns are distributed across the body. The adaptivity that a software-based solution for driving the auditory–tactile stimulation would provide has not yet been used in existing solutions. To make our vision more concrete, we have already provided some example use cases in Section 1.3.

Next, we present in Section 3.2 three key scientific challenges that we have identified. In Sections 3.3–3.5, these challenges are presented in more detail. Sections 3.6 and 3.7 then sketch a vision of the type of system that we believe is interesting for the research community to work towards, combining the results that may come out of the three individual research topics. Finally, Section 3.8 explores what increased interactivity and virtual reality technology could mean for this kind of systems.

3.2 Scientific challenges

Within the wider area of auditory–tactile stimulation, we like to highlight the following three scientific challenges/questions:

1 What are the mechanisms of human perception of combined auditory–tactile stimuli; and how can these mechanisms be modelled and used by a software-based system in order to influence the state of human body and mind towards a desired state?

2 What are good methods for *conversions* between the audio domain and the tactile domain, in this context? Conversions here refers to converting content, e.g. music from one domain to another, but also at a meta level to converting methods or paradigms from one domain to another. For example, how could a known paradigm from music composition be converted into a similar paradigm for tactile composition?

3 How could measurement and interpretation of a user's bio-signals and behaviour during a stimulation session be performed, to adapt the audio and tactile stimuli in an

optimal way? Adaptation should help to better and faster achieve the user's well-being goals.

To start addressing these scientific challenges, we will outline a number of related potential research directions in the next three sections below.

3.3 Topic 1: effects of multi-modal stimuli on health and well-being

In the first proposed research topic, the goal is to study multi-location tactile stimulation of the human body and the effect of this stimulation on human health and well-being, alone and in combination (*cross-modal* effects) with the sense of hearing.

For a user of our envisioned technology, desired states could be (depending on the application) relaxed, peaceful, sleepy, engaged, dreamy, satisfied, active, energetic, etc. The mechanisms of human perception used to achieve such states may include auditory–tactile *sensory illusions*. Sensory illusions – perceiving events that are not really physically happening – can be a very powerful way to evoke emotions.

A first step is to investigate existing literature on auditory and tactile perception and the related stimulation methods that use audio and touch. Based on the experimental tests, requirements from the application field, and findings from the literature, one could apply an iterative, user-centred design and research process to come up with auditory–tactile stimuli that are likely to have a health or well-being related effect. These effects will then have to be investigated in user tests. Artificial intelligence (AI) techniques such as rule-based systems, machine learning, personalisation and (real-time) adaptation need to be investigated and employed to design models and systems that make it possible to link user characteristics and user experiences to the properties of temporal/spatial patterns of auditory–tactile stimuli. Results of this type of research can then be applied in the work described under topic 3 in Section 3.5.

The models just mentioned may use or incorporate existing models of human mental state, known from the literature. One example is the well-known valence/arousal model proposed by Russell (1980). This model could be used for example to represent the arousal-decreasing effects of certain tactile stimuli as reported in Wigram (1996).

3.4 Topic 2: audio to tactile and tactile to audio conversion methods

The second research topic focuses on conversions between the audio domain and the tactile domain. One purpose is for example automatic conversion of existing music or non-music audio content to a set of tactile stimuli. The audio and generated tactile stimuli can then be played simultaneously, creating a combined auditory–tactile user experience. By using the music content as the basic ingredient, a potentially large number of auditory–tactile compositions can be created simply from existing music content.

Automatic translation methods of audio to corresponding tactile stimuli will have to take into account the (well-being) effects on the human and the methods will have to be suitable for multi-actuator tactile stimulation systems. Translation should be done in such a way that the user's health goal (e.g. muscle relaxation, sleep, energising, etc.) and other goals (e.g. pleasantness, compositional coherence) are achieved. Conversion methods may include detecting the structural and symbolic expression of a piece of music, and using this information such that the tactile composition will either reflect the same expression or will in some way augment the musical expression.

At a more general level, we also consider the possibility of conversion of methods and paradigms between the audio and tactile domains. For example, the existing knowledge on music composition and musical expression and communication of meaning could possibly be ‘translated’ into approaches for tactile composition and tactile expression and communication of meaning. For music to tactile conversion and vice versa, a musical ontology can be used as a basis. Specifically, the system of Schillinger (1977) is a candidate. Schillinger explored the mathematical foundations of music, and was particularly inspired by Fourier analysis and synthesis.

The topic of conversion methods for translating tactile stimuli into audio or music seems less obvious at first sight. However, we also envision useful applications here such as perhaps translating an existing tactile massage pattern that is known to work well, into matching music, in order to strengthen the psychological effect of the stimulation on the user.

3.5 Topic 3: audio–tactile systems that adapt to the user based on sensor information

The third research topic involves so-called *closed-loop systems* or *biocybernetic loops* (Serbedzija and Fairclough, 2009): a sensory stimulation system, in which physiological quantities (i.e. bio-signals) and behaviour from a user are measured and in turn used to adapt the stimuli that this user receives. To do the adaptation properly, relevant user influencing strategies should be available. Based on measurements of the user’s state, the system can then select the optimal influencing strategy.

User-adaptive methods have an added potential to be more effective, and at the same time more appealing to the user. This potential is still untapped today. Besides having the possibility of explicit *multi-modal interaction* (Cao et al., 2009; Pantic et al., 2008; van Gerven et al., 2009) with a user, another option is *implicit personalisation* of auditory–tactile experiences. In this case the content for the system becomes interactive. Implicit personalisation is very useful in cases where a user cannot be expected to actively interact a lot with a system, e.g. for elderly, people with impairments, or hospitalised people with temporary impairments. Research into multi-modal (vision, audio, touch, speech and gesture) user interfaces that optimally combine explicit and implicit interaction to provide the best level of personalisation during a session, could be a part of this research theme.

The bio-signals that can be sensed and used for an adaptive system may include brain signals (EEG), heart signal (via ECG or PPG), respiration or electrodermal measurements like skin conductivity (SCL/SCR); but also behavioural signals like the user’s movements, speech utterances, eye movements or facial expressions during a session.

A particular research challenge for the use of bio-signals in an automated system is coping with large inter-person variations. A system using a person’s bio-signals would first have to learn about the user, i.e. calibrating its interpretation of bio-signals towards an interpretation that is reasonably accurate for the current user. This calibration challenge is also part of the research topic that we propose.

3.6 Synergies in the three research topics

The above three research activities may require mutual close cooperation. These topics necessarily involve cooperation between the arts and the sciences. For example, the perceptual mechanisms studied in topic 1 are linked to basic perception and cognition processes in the brain, but also to a topic such as aesthetic perception. The audio–tactile conversions in topic 2 are foremost linked to composition and to the arts, but can only succeed if the physical and mental health goals are respected – topics related to multi-sensory perception, brain and cognition. Similarly for topic 3: although measurement and interpretation of user state mainly links to psychophysiology, perception, brain and cognition, it is also necessary to have influencing strategies in place that guide a user towards a desired state. These influencing methods will probably have a strong creative/artistic component in them because these will need to be aesthetically pleasing as well as effective.

3.7 Sensing + algorithms + content = optimal personalised experience

Combining the work proposed in the above three topics, we can sketch a vision to work towards. With recent advances in information and communication technology such as low-cost embedded data processing, solid-state storage growth, ubiquitous body area networking (Chen et al., 2011), and recent progress in unobtrusive EEG and bio-signal sensors, a novel type of sensory stimulation system becomes feasible. This type of system will in real-time adapt a stimulation session towards an optimal, personalised experience for the current user. The data is (preferably in an unobtrusive way) sensed from the user during a stimulation session.

This personalisation can be based on a generic model of a user and his/her mental state, which is periodically updated based on sensor interpretation and data mining performed on the sensor data. Possible aspects to include in this model may be:

1 Safety limits for sound exposure, mechanical pressure and/or vibration exposure.

2 Average human perception thresholds for sound, pressure, temperature and/or vibration.

3 Average human optimal comfort levels for intensity sound, pressure, temperature and/or vibration.

4 A ‘dose’ or ‘exposure’ model that can trade of stimulus intensity vs. duration, for sound, pressure and/or vibration. Such models exist in the context of vibration exposure safety standards (Stellman, 1998).

5 Average human sensitivities to and effects of particular rhythmic stimuli, which may possibly be derived from music theory, music therapy literature or audio–tactile composition (see Section 2.8).

6 Relative sensitivity of different body locations (to e.g. pressure or vibration stimuli).

7 Current user preferences for tactile stimuli at different body locations.

8 Effects of applied low-intensity vibration on the perception of audio, e.g. influence on spatial perception of audio stimuli (Occelli, 2009) or influence of vibration on subjective perception of low frequency (‘bass’) in the audio.

9 Human sensitivity to synchronisation in time between audio and tactile stimuli.

The measured signals and their interpretation can be used to construct a model in software of the current user state, which may describe current estimated levels of relaxation, sleepiness or comfort. Based on the model, influencing strategies are chosen that help achieve the user’s health and well-being goals.

AI methods could be used effectively in construction of the user state model and in the optimal selection of influencing strategies. This would be a novel approach beyond the state of art for auditory–tactile or tactile stimulation. In addition, this approach could be extended in the future to include also stimulating the visual sense (by images, video, colours or light – see Figure 2, left) or the olfactory sense.

3.8 One step further: interactive auditory–tactile virtual environments?

In Sections 3.5–3.7, we introduced audio–tactile stimulation systems that respond to a user's implicit and explicit reactions by adapting the stimuli. This idea can be taken one step further: allowing a user to interactively control the experience that is being offered, as if controlling a video game. One could see this as a problematic proposition because the visual stimuli (i.e. the graphics) that are dominant in video games are simply not present in the audio–tactile stimulation systems that we propose. Besides, current video games often require active involvement and quick reflexes of the user which contrasts with the purposes of relaxation, health and well-being that we have outlined.

Despite these issues, we see clear opportunities to create interactive auditory–tactile virtual environments in which a user could navigate in the environment or even interact with the environment, all without requiring (3D) graphics or visual displays. Röber (2008) already performed an in-depth investigation of the concept of auditory virtual environments, including the aspects of the user tasks of navigation and orientation.

What we propose here is a combination of three elements:

1. adding tactile or haptic stimuli to the existing concept of auditory virtual environments; e.g. tactile stimuli linked to events taking place in the virtual environment
2. adding user interaction methods based on both explicit and implicit (e.g. bio-signal sensor values) input from a user
3. choosing the application context and the audio–tactile content such that health and well-being applications are enabled.

To illustrate the concept of auditory–tactile virtual environments for health and well-being, we can imagine the use case of Section 1.3.1 where the system supports one of the following situations:

1. A user can briefly raise his/her arms up as an indication of 'move up' or 'start flying'. The system responds by rendering sounds, motions and tactile stimuli to simulate the flying situation. A voice narration could tell the user where he/she is flying to and the user subsequently enters a new location in the virtual environment.
2. A user might be virtually present in a refreshing pool of water – this situation comes from actual Meditainment Ltd. (2010) audio content. By holding his/her breath momentarily, the user can virtually 'dive' in the pool of water to discover a new underwater location in the virtual world. The underwater situation is simulated with matching audio and tactile stimuli (e.g. simulating water currents, underwater sound perception and/or feeling of air bubbles).
3. A user is given a task by a virtual Zen master of being in a 'meditative state' for at least 1 min. Only if the user succeeds in doing this, the Zen master will give approval

> and the user can proceed with a next task (or level). The user is rewarded with some (tactile and audible) pats on the back.

Here, the aim of including such interactive and game-like elements into the overall experience would be to increase the immersion and long-term satisfaction with the experience for a user. Of course, it still remains an open question whether such interactive elements, applied in a particular usage scenario, can actually help users towards improved health or well-being, or not.

4 Discussion

4.1 General conclusions

In this position paper, we have introduced auditory–tactile stimulation as a possible means to increase health and well-being of people, applicable in various contexts. The existing state of the art has been briefly described and based on our findings so far we conclude that there is clear potential for innovation in auditory–tactile stimulation technology. Three specific areas for further research have been identified.

A first vision has been presented (Section 3.7) of a software-based learning system, that can automatically or semi-automatically adapt to the individual user, based on general knowledge about humans augmented with sensor information obtained from the user during a session. The system will then decide which specific auditory and tactile stimuli to render, to optimally achieve the user’s goals.

Finally, a second vision (Section 3.8) has been presented of interactive auditory–tactile virtual environments that allow a user to navigate in and interact with a virtual environment using the senses of hearing and touch – without necessarily presenting any visual information to a user.

4.2 Relevance of the proposed topics

If we look broader to society as a whole, one trend is that due to an aging population, Western economies are increasingly struggling with increasing healthcare costs and shortage of healthcare personnel. Therefore, there is a growing need for preventive healthcare. Preventive care is a useful instrument, not only to improve the quality of life of people, but also to partly avoid the cost of expensive regular treatments. The results of the research we propose could be applied for preventive healthcare, and could therefore have a positive impact on society.

Other potential users of auditory–tactile stimulation technology could be the healthcare workers themselves. Due to the ageing trend and economic constraints, their work will become ever more efficiency-oriented, time-pressured and stressful. Also if looking outside the domain of healthcare, other potential user groups can be identified who increasingly have to cope with highly stressful events occurring at work or have to work under pressure. For example, public transport personnel, school teachers, fire fighters or police officers. All these user groups could benefit from innovative new ways of coping with stress, or ways of inducing relaxation or sleep quickly on-demand. Also increased resilience against stressful events, as a way of prevention, would be a desirable goal.

Other examples how the outcome of the research proposed in this paper could be applied are in products providing enjoyable relaxation solutions for hospital patients and medical personnel; or products that help with chronic pain management in daily life.

A final example of application of future research outcomes could be technology aiming at people with special needs. For example, interfaces to facilitate and enjoy, for people with different kinds of impairments like children with autism (Parés et al., 2005), sight or hearing impairments, blind, deaf as well as deaf-and-blind people.

4.3 First activities in the field

There are various companies that offer sensory stimulation solutions to care organisations, including tactile stimulation products. One of the authors is already involved in field trials in care organisations, using custom tactile jackets (see Figure 1, left) for tactile stimulation combined with musical stimulation. Tactile actuation patterns are derived from the music through custom-developed conversion methods. The music used may vary from Mozart to electronic dance music, depending on the goal and the context. Target users for this technology include people with varying severe impairments and people with severe autism.

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