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Tactor Devices

**Using Tactile Interface Designs
for Mobile Digital Appliances**

A Practice-Based Research Thesis
for the fulfilment of a
Master of Design Degree

College of Design, Fine Arts, and Music
Massey University, Wellington

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2003



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Abstract

This Thesis focuses the potential of communication interfaces that use tactors (tactile actuators) to improve user interactions with mobile digital devices which are currently based on audio and visual technologies. It presents two product concepts, which use tactile signals to enable new ways in tele-operations, such as tactile telecommunication and tactile navigation.

Tactor interfaces, although still in its infancy as elements of modern digital communication and technology, have considerable potential for the future as designers attempt to maximise the use of all human senses in people's interaction with technology. Only the military and a few entertainment companies have introduced tactile signals into Human-Computer Interactions (HCI). Human touch perception uses the hands as the main sensing organs. They perceive tactile signals while handling, typing or navigating with digital devices and receive direct confirmation of physical actions. In contrast to other senses, touch perceptions are based on interactions with the sensed objects.

The study analyses, experiments and evaluates if these interactions are useful in interface designs and recommends how tactile stimulations can be introduced to interface designs besides images and sounds that dominate the control of current digital appliances. Tactile actuators and sensors enable devices to use tactile signals, such as impulses and vibrations, to communicate with the users. Users and tactor devices will be able to communicate in a physical and direct way. Touch reflective interfaces, could react like living creatures that respond to touch, for example a cat that starts purring when touched.

Digital product design is always challenged to create human-computer interactions that meet people's needs. Designing digital devices is difficult because they are not necessarily three-dimensional objects. They are stimulator of the human senses and can be as small as the sensing nerve endings that detect sensations. By miniaturisation, form and function become invisible and Product Design is increasingly incorporating Process Design that explores and enables new interactions between users and products to work interactively

and efficiently.

The study is divided into four chapters:

Chapter 1 gives an introduction to the thesis.

Chapter 2 presents a survey on current literature which examines the five human senses to define the limits and possibilities in interface design. It reviews current research on materials and technologies as well as the psychology and physiology of touch as a potential sense in human-computer interactions. It evaluates the technical feasibility of tactile signal performances and how they could be used as tele-touch codes in navigation and telecommunication.

Chapter 3 is focused on primary research undertaken to extend the knowledge in tactile sensing. It includes experiments, questionnaires, and concepts that give examples how tactor interfaces can be used in tele-operations. This section focuses on specific user groups, that may primarily benefit from tactile signal transmissions, such as sight and hearing-impaired people or professionals who have to deal with limited perceptions like fire fighters, for example. These case studies are aimed at exploring and expanding a wider range of possibilities in tactile device innovations in the networked society.

Chapter 4 gives a conclusion of the research.

Acknowledgements

Writing this thesis was a discovery in many ways that would not have been possible without others help. After finishing this studies, I realise how challenging they were and how much I have to thank one person in particular: my supervisor Professor Leong Yap at Massey University who supported and guided me. The studies in New Zealand have extended my horizon.

Grateful acknowledgement also to my editor Steven Oxenham and my friend Penny Brander and family. Without their help I would not have succeed in finishing this thesis.

My thanks to all those participants who were willing to be involved in the research. Their interest and views were the basis for the findings of this study.

Lastly, I would like to thank my parents for their critics, encouragement, and financial support.

Glossary

- *Bluetooth*: Short-range radio link intended to replace cables and to connect mobile digital devices.
- *disambiguate*: to clarify, to clear up
- *fricative*: sound or vibration caused by friction
- *GPS*: Global Positioning System
- *HCI*: Human-Computer Interaction
- *LPS*: Local Positioning System
- *SMS*: Short-Message Service
- *Tactor*: Tactile actuator
- *UMTS*: Universal-Mobile-Telecommunication System

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1 Introduction

This practice-based research presents the analysis, conceptualisation and evaluation of alternative ways to improve human-computer interactions by tactile signals. With an emphasis on mobile device operations, it explores tactor interfaces to open up tactile information channels. New ways of using touch sensations to transfer information from human to human, human to machine, and machine to human have been analysed, designed, and evaluated. The study explains how tactile sensations work and how they can be used in interface design to transmit information. It presents new ideas which provide new possibilities in mobile tele-operations.

Secondary and primary research examines, analysis, and evaluates touch and touch interactions between users and computers. The introduction of tactor interfaces is not a panacea but it can help to make mobile device operations more user-friendly. Two design concepts about telecommunication and tele-navigation have been realised to show the potential of mobile tactor interfaces for information input and output. The study also explores aesthetics to bring fun and new experiences to users.

The development of tactor displays has been investigated in the USA since the 1950s. The first aim was to find new ways for the deaf to receive information.¹ Due to the mechanic character of the displays and the size of the apparatus, those devices were created for static use only. They have been found to be

inadequate for mobile use. Mobile tactor displays had been out of reach until recent developments in miniaturisation emerged. New technologies put into focus tactile signals for mobile device operations. Nicholls and Lee report on an increasing number of publications

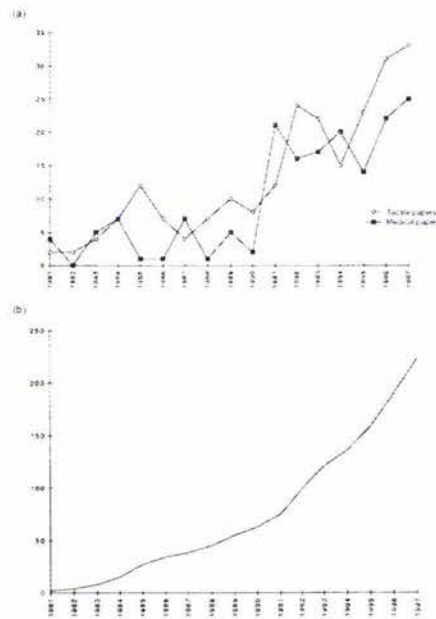


Fig. 1 (a) Journal paper count per year; (b) cumulative count of tactile papers

about tactile sensing in scientific and medical papers from 1991 onward.² The publishing rate was doubled in 1991 and is still increasing every year (fig.1).

Tactor interfaces are useful in various applications. Electronically generated touch feedback can help to operate digital devices that normally do not cause any mechanical tactile feedback. Tactors provide a channel of human-machine communication that was lost when mechanical machines became digital. According to Doerrler the use of touch can help to organise tasks more efficiently or allow information be received simultaneously to other perceptions like hearing and seeing.³

Touch has a big influence on our whole psyche and feedback system. Tactile feedback makes learning easily, provides better precision and makes some tasks more enjoyable. Touch is significantly undervalued in human-computer interactions, although direct contact and tactile feedback is an important source of information in many man-made tools or machines. The screwdriver, a hammer, a pen or tooth brush are good examples of simple tools that require good tactile feedback for their efficient use. Every mechanical process produces pressure, friction, vibration or heat that can be detected by the sense of touch. But, the decreasing physical interaction with automatic digital machines has led to a decreasing use of tactile information about the state of a tool or a machine.

1.1 Touch - A Potential Sense in Interface Design

Touch sensations are not new in interface design. They are always present when hands are used in HCI. Buttons, regulators, keys, and scrolling wheels give tactile feedback. They confirm an action by a click, clatter or impulse. This feedback is passive rather than active, because it is only a mechanical reaction. Active tactile feedback, generated by electro-mechanical tactors can transfer much more information through touch. Digital machines that utilise tactile feedback can interact with their users and can inform users about the state of machines, working processes, or hazards. They can judge interactions and may support operations by sending tactile signals such as vibrations or impulses about right or wrong use, expectations and warnings.

A silent way of tactile data transmission, independent of hearing and vision, can be used to enhance or even substitute hearing and sight perception. The emphasis on the conceptual work in this study is to demonstrate different examples of tactile interaction processes. It includes human factors' analysis, concept explorations and design.

Tactile sensation or touch does not exclude anybody. The user groups engaged in this study included the young and able-bodied as well as old or disabled people. Even paralysed people normally have touch-sensitive areas on their body. Deaf and blind people totally depend on touch interactions to communicate with others.

It is important to state that the sense of touch is fairly underestimated in western society and current product design. Touch is the most important sense during childhood and touch experiences or the missing of them effect our life. According to Ackerman premature infants who spend the first weeks in an incubator develop much faster when they are touched and massaged.⁴ Massaged babies gain weight as much as 50 percent faster than unmassaged babies. They are more active, alert, and responsive, more aware of their surroundings, better able to tolerate noise, and they orient themselves faster and are emotionally more in control.

What is good for babies cannot be bad for adults. Considering an increasing number of isolated people, stress and depression in modern societies, touch might be an alternative medium to communicate and to express emotions, respect, and reliability. The handshake, the clap on somebody's shoulder, the kiss or the embrace introduces a conversation and builds up a confidential atmosphere. Even the slightest touch is recognised subliminally and may have an influence on behaviour. Ackerman states:

"In an experiment in Boston, a researcher leaves money in a phone booth, then returns when she sees the next person pocket the money; she casually asks if they have found what she lost. If the researcher touches the person while asking for their help, touches them insignificantly so that they do not remember it later, the likeli-

hood that the money will be returned rises from 63 to 96 percent.”

Touch and touch feedback are extremely necessary for our well-being. The technology-driven interface design has not taken into account this human need up to the present day. It is timely to introduce touch output signals and force feedback into human-centred design of digital appliances. Touch sensations by pressing buttons are minor information compared to the capability of human touch to convey complex data. It can be used in many ways to interact with machines and people. Redesigning the Morse Code into a tele-touch code, for example, is one possible approach to silent tactile telecommunications.

1.2 Trends in Human-Computer Interactions

Nowadays people cannot avoid contact with digital technology, even if they do not want to. Communication, transportation, professional or leisure activities are nearly unthinkable without using computer-aided systems. This trend of increasing use of computers will surely not diminish in the future but will certainly be enforced and increased. Tactor interfaces are one option to improve computer interfaces.

A new interface design and the redesign of human-machine interactions have become evident with the advancement of digital technologies. Most human-machine interactions will become human-computer interactions in the future.

Not only experienced people have contact with computers - all kinds of people are confronted with them. For example, senior citizens have to use cash dispensers to get money, or ticket machines before they use public transportation. To design easy and intuitive communications between humans and machines is particularly necessary for user groups that do not have any experience with computers.

1.3 Increasing Complexity of Digital Devices

Operating machines with an increasing number of functions provided by technical systems does not only imply advantages for the user. Since every function has to be started or

selected, and some function-specific parameters have to be set and the operation of machines becomes more complicated with every additional feature. One solution is to add more buttons and switches to the control panel, but it is limited by space that is available and the amount and complexity of the functions offered by the device.

Satisfying interfaces for digital device operations are difficult to design because increased complexity also increases the psychological and physiological demands on users. This can easily cause frustration and stress. Consequently, product design has to create easy processes and functions in new forms.

Tactor Interfaces present one alternative in interface design that is based on human perception rather than on technical possibilities. It is clear that the practice, which puts the emphasis on purely technology-based visions, will be obsolete in the future. Such a technology must be complemented by:

- User-friendly designs, looking at new ways, users will interact within digital systems;
- New services and applications that become possible with new technologies.

1.4 New Technologies

In the past, technical devices offered limited numbers of different functions. A significant increase in functionality can be observed, today, mainly through the success of modern microelectronics. Miniaturisation and cost reduction of electronic circuits enable the designer to provide mobile appliances at little extra costs compared to static systems. Tasks that never could be performed without powerful and cheap microelectronics are now executed by new mobile digital devices. Some examples of this trend are:

- Laptops that are small but as powerful as static computers;
- Small digital video recorders and camcorders providing a wide range of possibilities that was limited to professional devices in the past;

- Mobile phones serve as organisers, alarm-clocks, cameras and provide video-games;
- Mobile MP3 music players that are as small as pocket lighters.

There are many possibilities for new mobile applications. Due to the breakthrough in mobile telecommunication technology, high rates of mobile data transfers can be provided. New mobile services that demand a high data flow are possible: videoconferences, complex navigation systems, and virtually augmented realities are recent innovations brought about by new technologies.

1.5 Innovations

In the future, technical elements will become even smaller and more powerful. Various radio signal systems will offer the networking use of mobile devices. It is expected that major innovations will come from new designs and new interactive processes within mobile systems.⁵ Useful ways of HCIs and comfortable interfaces are becoming more important than the technology itself. Product design and interface design are key activities to make the digital networked world accessible.

Who could foresee the incredible success of Short Message Service (SMS) that provides text-messaging on mobile phones, for example? Cell-phones were originally designed solely for verbal communication. This example shows how unpredictable and complex new ways of human-machine and human-human interactions could be in the future.

The success of SMS surprised most people in the mobile telecommunication industries. Few have predicted that this user-unfriendly service would be accepted. There was hardly any promotion for or mentioning of SMS by network operators until SMS started to be successful.

Mainly the younger generation accepted SMS as their medium because it was difficult to use. High entry barriers to learn the service became an advantage because parents, teachers and other adults were unable or unwilling to use it. A whole new alphabetical or numerical phonetic shorthand has emerged because SMS messages are difficult to type.

They are shortened because people try to say as much as possible with a few keystrokes. Abbreviations such as "C U L8er" for "See you later" have sprung up for time-saving and coolness. Short signs like Smilies that look like happy or sad faces are composed of colons, dashes, and brackets. They are used to reduce the abruptness in short text messaging and to show the mood of the person in a way that is difficult to express with words.⁶

The success of SMS is a total paradox to common marketing and innovation strategies. It is a good example for the need of 'lateral thinking' as proposed by Eduard De Bono, one of the most influential promoters of a non-linear thinking.⁷ Combining things which have not been combined before is the key to innovations. It is almost impossible to come up with totally new ideas, but putting existing ideas into new contexts or combining ideas in formerly unthinkable ways offer a range of new options, such as tactor interface designs.

2 Secondary Research

2.1 Outline and Methodology

The review of previous research presents the background of this thesis. Acquisition of current research results in tactile signal transmission and mobile digital technology were mainly based on publications on the internet. Books about tactile operations were only useful for general information about human perception. They did not provide information about the current situation in micro-technology which is a prerequisite for mobile digital devices.

Leading institutes in the field of tactile information processing and micro-technology publish their current research results on the internet:

- Massachusetts Institute of Technology,
- Carnegie Melon University,
- John Hopkins Univesity.

Research on the internet was intensive, because actual trends and emerging technology could be evaluated easily. However, the specific field of tactile human-computer interaction is still in its infancy.

2.2 Human Perception in Tele-Operations

This research is aimed at developing new devices that extend the possibilities in reception and interpretation of information when perception is limited or stressed. This chapter explains key elements of sensory perception which need to be considered in product designs created to interface easily with their users. Designing human-computer interactions as natural as possible is the best way to handle tele-operations. Current interface designs for tele-operations use only a part of the potential in human sensing, mainly hearing and sight. This chapter examines new options to use alternative senses.

Tele-operation and control of machines are complex tasks that demand high cognitive capabilities. In the case of failures, human cognition remains the backup system for computer-controlled devices, such as cars, aeroplanes, cameras, or coffee-makers.

2.2.1 The five human senses

The five human senses (fig.2) are the constraints for any human-machine interface design.

Machine signals beyond the human range of perception are useless for any human interaction. The human body can rely on five different channels to receive information from the environment. They are smell, touch, taste, hearing, and sight. Each is based on different sensory mechanisms. These mechanisms are organs with distinctive constructions and functions to convey sensations to the brain. The sensory organs are not the senses themselves, but are part of them. Nose, skin, tongue, ears, and eyes would be useless if their signal detection could not be transferred to the brain where the data are evaluated.



2.2.2 Sensory reception

Humans and machines work together in many situations where physical conditions may not be ideal. Rescue services, for example, have to analyse and communicate various kinds of information quickly, accurately, and independently of limited perception and stress.⁸ An overview of the main sensory receptions show how senses can work together.

fig.2

Sensory reception occurs in higher animals through a process known as transduction, in which stimuli are converted into nerve impulses and relayed to the brain. The four commonly known special senses (sight, hearing, smell, and taste) are concerned with the outer world, and external stimuli are received and conducted by sensory receptors concentrated in the eye, ear, olfactory organs, and the taste buds respectively. The somatic senses respond to both external and internal stimuli. Although most of the somatic receptors are located in the skin conveying the external sensations of touch, heat, cold, pressure, and pain, others are located in internal organs, such as heart and stomach. Somatic sensa-

tions such as hunger, thirst, and fatigue are thought to originate in specific areas of the nervous system. The sense of balance, or equilibrium, is related to the flow of endolymph, a fluid found in the inner ear.⁹

Psychologically, perception is a mental organisation and interpretation of sensory information. According to Marks it is influenced by a variety of factors, including¹⁰:

- The intensity and physical dimensions of the stimulus;
- The human's past experience;
- Attention factors such as readiness to respond to a stimulus;
- Motivation and emotional state of the subject.

Within the range of perception and during the perceptual process humans focus on limited numbers of stimuli, and ignore those that are considered less important.

2.2.3 Synaesthesia

The word synaesthesia derives directly from the Greek (syn-) union, and (aisthesis) sensation, thus meaning something akin to a union of the senses.¹¹ Synaesthesia is relevant for networked perceptions or substitutions of one sense through another sense, for example, the substitution of hearing through touch.

Synaesthesia is the general name for a complex of various cognitive states having in common that stimuli to one sense, such as smell, are involuntarily simultaneously perceived by one or more other senses, such as sight or/and hearing. Some people see colours while hearing music or eating food. They perceive a bright blue when a piano plays and a dark green when drinking an espresso. The yellow colour of a lemon, or even the thought of it, can lead to mouth watering. Most humans have a basic form of synaesthesia in which higher sounds are considered to be brighter and lower sounds to be darker.¹¹

The human body uses synaesthesia to gain as much information about a sensation as possible. Although it might be an illusion, it helps to categorise the perceived information.

Touch, for example, can support hearing. Deaf people cannot hear but they can get an idea of sounds by detecting vibrations.

2.2.4 The five senses in communication

People and computers need to be able to communicate. Communication between humans and computers is essential for understanding and operating. The interface is the medium or translator between user and computer that makes computer functions accessible to human perception. To improve the human-computer interaction, communication between humans has been investigated to evaluate natural ways of interaction that provide new patterns for human-computer interaction. In particular, touch interactions have been examined. Besides hearing and sight, touch is the most potential sense in human-human communication and it could be helpful in human-machine communication as well. It has direct access to the subconscious brain. For example, handshakes transmit information about people's mental condition. Sweat and the temperature of the hands transmit information about a person's confidence. A clap on the shoulder provides information about the muscles and the strength of someone and smell tells something about the state of health and even character of someone.¹²

2.2.5 Multi-channel telecommunication

Telecommunications hitherto rely on one sense only. However, for user groups with limited abilities to communicate due to impairment of their sight, hearing, or speech, devices that involve at least two senses should be designed for their use to improve communication.

Mono-channel telecommunications like current phone-calls (fig.3) are sufficient for basic conversations, but they are not satisfying in transferring complex contents, discussions and emotions. Confirmation and emotional feedback are often difficult to detect in mono-channel interactions. Bi-channel telecommunications by picture-phones or video-conferences (fig.4) have advantages compared to mono-channel telecommunications, because commu-



fig.3 Mono-channel communication via conventional telephone



fig.4 Bi-channel communication with picture cell-phones

nicators receive more information, which makes understanding easier and more meaningful.

In the future, multi-channel communications based on hearing, sight, and touch will be appropriate to match the increasing number of possible tele-operations, which include not only communications between humans but also between humans and machines. New mobile telecommunication technologies will provide high-speed data transfers making tri-channel communications possible.

2.2.6 The sensory feedback system

Human-computer interaction could be better facilitated by providing more feedback information about functions or processes. The more senses are used in communication the better the understanding. Human perception often depends on feedback. One sense needs the feedback or confirmation by other senses or combination of senses. All senses can work parallel, if required. And each one can effect another sense, depending on the experience and condition of the individual and the information. Before eating something for example, sight and smell prepare the sense of taste. It is uncomfortable eating with covered eyes, because evaluating food with taste only might be harmful in terms of poisoning.

2.3 Touch Sensing - A New Channel in Human-Computer Interaction

People tend to minimise the significance of the sense of touch, equating it with the manual as opposed to mental skills. Interface design should make a difference, because it cannot ignore the extent which the combination of touch and intellect constitutes. The skill of a pianist or surgeon, sculptor or mechanic are very good examples.

Touch sensing is quite similar to hearing. The auditory system uses specialised mechanical receptors (mechanoreceptors) to sense environmental disturbances in the air, while the sense of touch depends on pressure-sensitive cells (also mechanoreceptors) distributed over the body's entire surface. Both hearing and touch transduce pressure and vibration,

thus both of these sensory channels are capable of communicating speech.¹³

Regarding the capacity of hands as sensing organs, interface design that avoids tactile information ignores their supportive character. The use of the hands only as executing organs to operate machines does not fully employ human abilities. Especially in complex operations and multi-tasking, adaptation of working procedures could be eased, if hands were more demanded as sensing organs. Interfaces that utilise new processes to operate digital devices are necessary to increase the use of the hand. One of these new processes might be touch-code based device operations.

Touch can be used as an alternative channel in mobile teleoperations to release or replace visual and acoustic information transfers. Tactile human-computer interactions are useful in situations when visible or audible tele-operations are impossible or inappropriate, for example in meetings, concerts, or cinemas. Specific professions which have to cope with limitations in hearing and sighting can rely on tactile tele-operations, like divers, pilots, or fire fighters.

The most significant potential user group for tactile human-computer interactions is disabled people that are hearing or sight-impaired. A supplementing channel in user interfaces can help to support or replace the impaired perception.

2.3.2 The hand

The hand is the most important transmitters of tactile information. To improve intellectual abilities and to execute thoughts the hand is irreplaceable. Touch forms associations with other senses to keep learned things more easily in

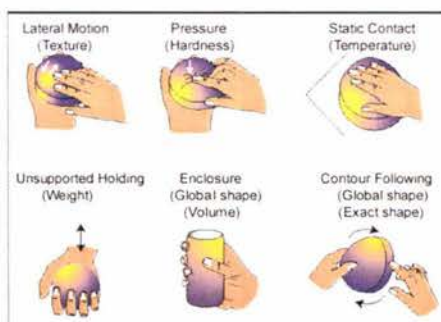


fig.5 Different kind of hand interactions

mind. The importance of the hand for cognitive understanding is already reflected in infancy. Babies learn by grasping and feeling objects. The hand is the most active part of the human body and hand control alone occupies big parts of the brain. Tactile perception with the hands is divided into different kinds of actions. Fig.8 shows different hand actions that

are the basic motions for any interactivity with factor interfaces.

As executive organ the hand can be sender (output) or receiver (input) of information. It is a sensing organ and can be used as a non-verbal medium to communicate. People who are able to use sign language can 'talk' with their hands. Conscious or subconscious hand gestures support speech or show the inner condition of someone. Due to the universal actions of the hand, the areas within the brain responsible for body movements and sensory activities take a lot of space. Fig.6 shows the 'homunculus' that depicts how much space the brain allocates to different parts of the body.¹⁴ The body parts which have high acuity of perception, such as lips or fingers, comprise large areas of the 'homunculus' and less acute parts comprise much smaller areas.

Through thousands of touch-, pressure-, temperature- and pain-receptors the hand provides numerous variations to discover the environment. The skin of the fingertips and palm transmits sensations to thousands of touching-cells and tens of thousands of free nerve endings, which lie beneath the skin.¹⁵

2.3.3 Passive and active touch

There are two classes of touch: passive and active. Passive touch refers to the skin sensitivity that is felt as pressure, temperature, or pain when objects come in direct contact with the skin. Tactile information describes the type of contact with the object - such as static, slipping, or vibrating - and certain properties of the object - such as texture. It is conveyed by the responses of several types of skin receptors within and around the object's contact region. Active touch is used to investigate objects and their properties, and to interact with the environment. Active touch involves tactile information, both the skin's sensations as well as the body's kinesthetic sensitivity to spatial position and movement. Kinesthetic information is conveyed by sensory receptors in the muscles, tendons, and joint capsules, together with receptors in the skin around the joints.¹⁶

2.3.4 The bi-directional character of touch

Touch involves a bi-directional flow of energy between the human and the sensed object, whereas for the other senses the energy only flows from the object to the human. Vision or hearing means receiving photons or sound waves respectively. But, there is no information or energy emitted by the human receiver. In touch sensing, mechanical energy is transferred from the human to the touched item as well as the other way round.¹⁷ This is the reason why touch is often called the most complex human sense. Although, touch is not as thoroughly studied as the visual sense and the sense of hearing.^{18,19}

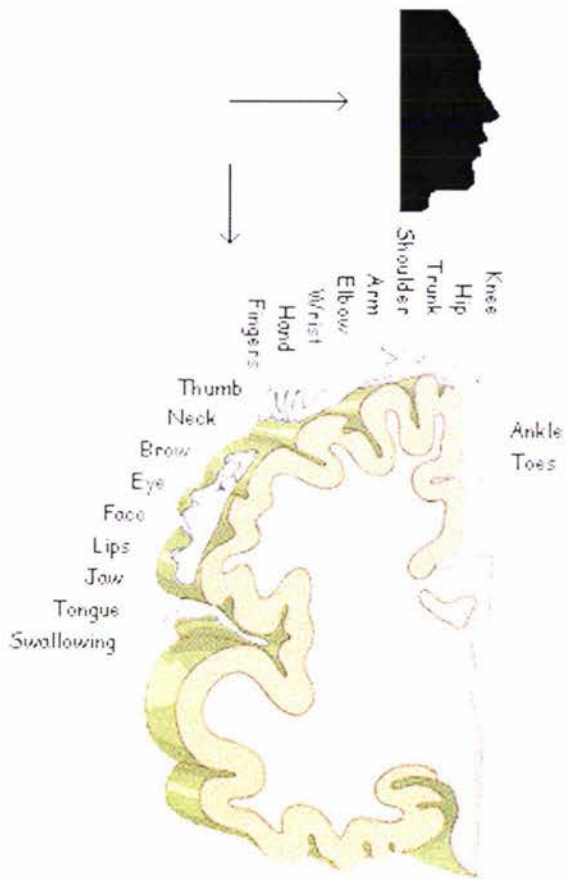


fig.6 The sensory homunculus

2.3.5 Tactile signal processing

According to LaMotte and his colleagues, pressure thresholds are as low as 5mg on the face, which has been likened to having a wing of a fly dropping from about 30mm onto the skin. They determined that the careful observer can feel microscopic bumps or asperities in an otherwise smooth surface as small as 1-3 μm in height.²⁰ Many of these thresholds have been found to vary over the surface of the body. Fig.7 illustrates variations in threshold over the surface of the body to bursts of 200-Hz sinusoids and pressure stimuli. Tactile thresholds can be extraordinarily small. The fingertip can detect static skin deformation of about 10 μm .²¹ A finger moving across a surface can detect minimal height decreases to 0,85 μm .²² Vibrations can be sensed in the wide frequency range of 5-10kHz, with a major sensitivity of 40-400Hz.²³ A person can feel vibratory stimuli on the palm of the hand that

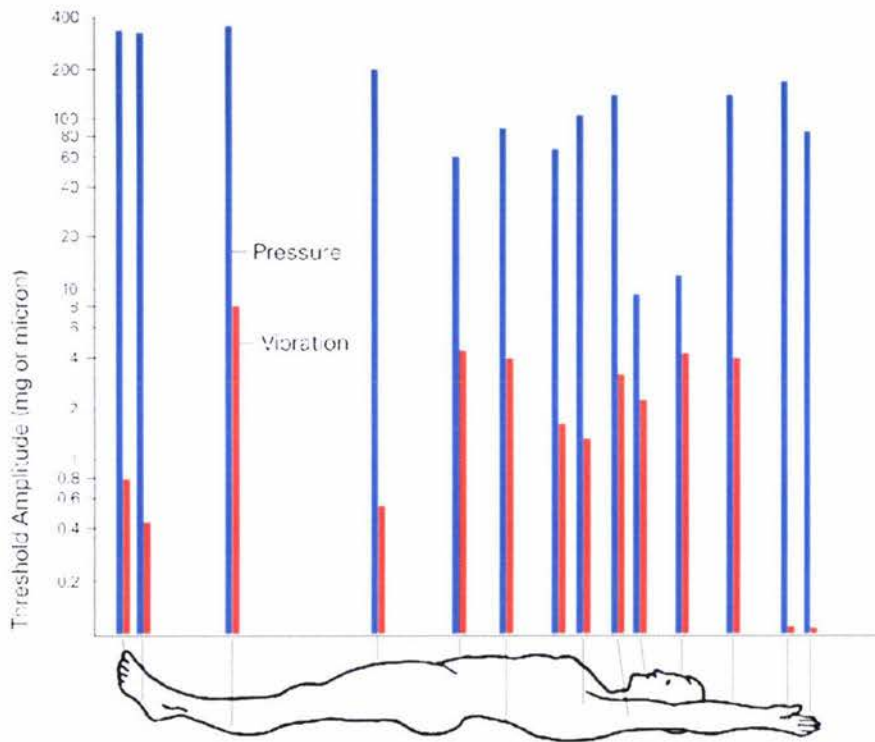


fig. 7 Threshold responses for pressure (blue) and vibration (red) as a function of body site

has an amplitude of $0.2\mu\text{m}$. The spatial resolution of the fingertip amounts to 3mm for static and 2mm for vibro-tactile stimulation. This distance is the threshold to discriminate two simultaneous stimuli. The minimum pressure is $0.2\text{N}/\text{cm}^2$.²⁴

In order to develop factor devices that can be used successfully for sensory substitution, factors that match these perceptual capabilities of human observers need to be integrated into design.

2.3.6 Localisation of touch sensations

Without the ability of touch localisation, discrimination of tactile signals on different parts of the body would be impossible. The localisation of a tactile stimulus is an important ability for the use of tactile signals in human-computer interactions. The brain can localise very readily what part of the skin has been touched. All sensations from the left side of the body or face appear on the right hemisphere, and vice versa. The arrangement in the brain strip makes it possible to tie a single cortical cell to a surface spot of skin, its receptive field.²⁵

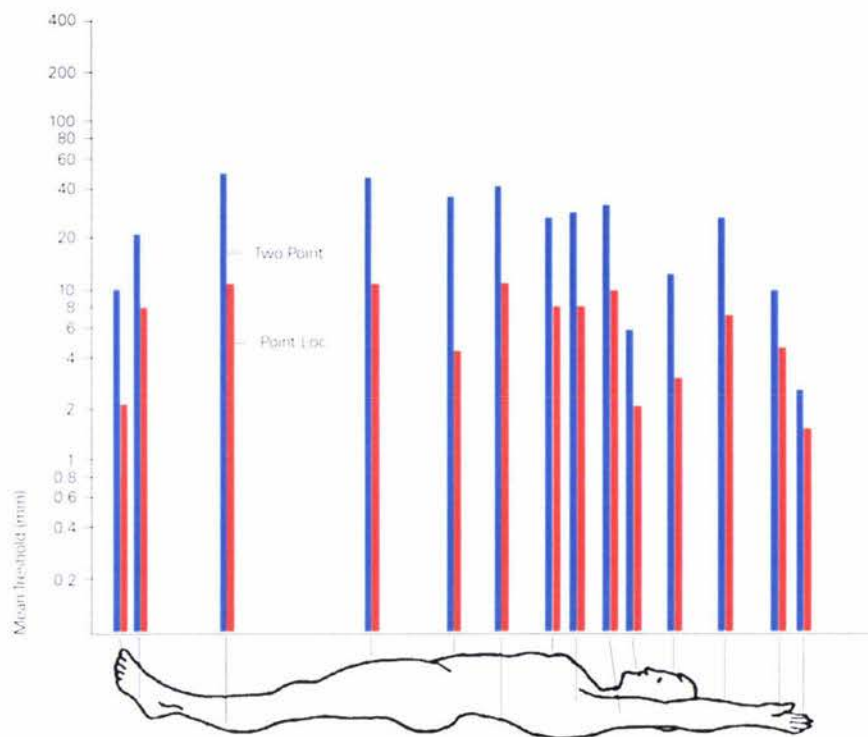


fig.8 Measure of spatial acuity on different body sites. Two-point threshold (blue) and errors of localization (red) are shown for 14 body sites.

2.3.7 Two-point discrimination

The two-point discrimination provides an indication of the spatial resolution of the skin (fig.8). If two points are presented to the skin at the same time, a discrimination of these two points is only possible if they are not too close. Below a certain distance, only a single sensation can be reported.²⁵

2.3.8 Intuitive touch cognition

A very important characteristic of tactile perception is the possibility of intuitive and unconscious information processing. Whereas visual and audible signals have to be processed in the brain, some of the tactile information can be evaluated directly in the spinal nerves.

This reflex reaction enables an information processing about four times faster, because no interpretation by the user is required before an adequate action can be started. Visual and audible reaction times are considerably slower than tactile reaction times on touch.

Moreover processing of tactile stimuli requires less concentration and can happen uncon-

sciously.²⁶ For example, hands are typing almost automatically on computer keyboards, and rely on the spatial knowledge about the layout of the keys to permit typing. It is possible to tell when a key has been hit through auditory and tactile feedback. The position of the keys is known, even though the user might not be able to provide oral directions for their location on the board. Nonetheless, users have no difficulty accurately typing while looking at the monitor. Very blurry peripheral vision of the keyboard remains, but it is insufficient for identification of the individual keys. Thus, users often take their tactile skills for granted, while the focus of their attention is directed toward visual or auditory matters.^{27,28}

The characteristics and speed of intuitive touch perceptions and operations promise significant possibilities in the future of human-computer interaction. They will open up new possibilities for designers in the design of communication interfaces for leisure, work, medicine, military and the ability challenged community such as the deaf, blind and physically challenged.

2.3.9 Tactile feedback

Integration of tactile signals into digital interfaces are useful and have to be considered in general. Touch is the logical supplement to the perception of hearing and sight and it provides a reliable system of perception. Tactor devices can be designed to introduce tactile sensations into human-computer interactions with digital machines. With tactile feedback or force-feedback, machine manipulation is more intuitive and easier. It is important to bear in mind when designing new interfaces that humans should not adapt to new technology, but new technology should adapt to the human capabilities and limitations. The more frequent the contact between human and machine becomes, the more important it is to have an easy and intuitive way of operating them. Experiment and analysis of tactile feedback in human-computer interactions needs to be undertaken before they are designed into communication devices.

An example of touch activation is pushing a button. When using a computer mouse permanent contact between finger and button is given. Normally the user does not feel this continuous touch. But if the mouse button is pushed, the operator expects to get a tactile

feedback - they expect to feel the contact of their finger with the button, the movement of the button and a 'click' when the electric contact of the button is closed. If the tactile feedback is missing the execution is not confirmed because the expectation of the user for pushing a button is not fulfilled. Substituting the tactile feedback by generating acoustic or visual feedback is not sufficient. Virtual buttons on a screen may be highlighted if they are pushed and an acoustic 'beep' is generated. Thus this procedure cannot be done unconsciously. Of course, after a certain amount of training humans will be able to interpret the substituted signals, but for a longer time this still need some concentration and active thinking. Tactile feedback signals provide the most intuitive way of confirming actions because they do not demand any attention of the users.²⁹

2.3.10 Touch communication

Literature on touch communication views investigations about tactile sensations that have led to interesting possibilities. According to Geldard it is possible to utilise a touch language in which letters of the alphabet would be associated with certain frequencies of vibration at certain strengths lasting for a certain length of time and applied at certain points on the body.³⁰ The length of vibration bursts can be judged reasonably well. Humans can note sufficient changes in the strength of a signal to be useful in a tactile code.

2.4 Ergonomic Constraints of Tactor Interface Design

User interface designs determine machine operations. They have to be ergonomic and should employ the users' perceptive faculties to avoid stress, errors, and inefficiency.

2.4.1 Input-output

Interactive interfaces receive and send input signals to and from users. Digital devices normally provide keyboards, joysticks, mice, or keypads for data entry. The output signals are normally transmitted by screens and speakers.

The problems with input/output devices, which are intended to mediate between the real

and virtual worlds, are their limitations in interactivity. The mouse, for example, that allows users to connect to the virtual world, only uses one or two fingers and has hardly evolved since it was first invented. The hands are needed for data input whereas eyes and ears are needed for both input and output signals. The rest of the body is not involved in current digital interfaces apart from being a support system.

2.4.2 Ideal interfaces

Ideal input/output devices and human-computer interactions need to incorporate the user's abilities. Cars are good example of such a system. They demand physical operations of feet and hands as well as cognitive operations of sight and hearing to make the interaction between users and machines as easy as possible - to the point where the car can feel like an extension of the user and driving becomes a pleasurable experience.

Furness and Barfield list the following characteristics concerning an ideal medium for an interface:³¹

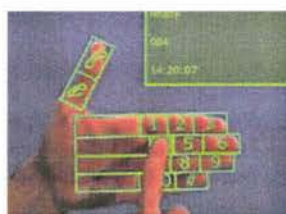


fig.9 Hand as keyboard in digitally augmented reality

- interface matches with the sensorial capability of the user,
- easy perception,
- easy learning and understanding of the interface,
- high band width of information transfer to the brain,
- dynamic adaptation to the users' tasks,
- possibilities of changing adaptation for individual approaches,
- natural semantics,
- filtering of information flow,
- no need for reserved capacities,
- easy prediction,
- reliability,
- high semantic content,
- easy presentation.

An ideal medium for the interaction between users and large amounts of information, for example, should be designed for the sensorial and perceptual abilities of the users. The information has to be structured in a way that the mental condition of the user matches the representation of the interfaces. If the information display and the mental model fit together people can deal with a complex amount of information. Stress will occur where they do not fit well.

2.5 Trends in Mobile Telecommunications

This chapter views current trends in mobile telecommunication and investigates non-verbal telecommunications as possible future trend. Factors are already in use to signal calls as vibrations. Based on a tele-touch code, tactile signals can be more differentiated and can provide more options to use non-verbal and non-visible information channels.



fig.10 Wristwatches with GPS and TV

2.5.1 Statements about Current Telecommunications

'Anything, anywhere, anytime' is the maxim of a new life style, a world of boundless communication, submitted by a fast developing digital technology. The new generation of mobile telecommunication systems provides a bigger capacity for data exchange. New features are integrated into mobile devices and new designs express these features in very different solutions, such as digitally augmented realities (fig.9).

These statements by the chief-designers at Siemens, Ericsson, and Mitsubishi about future telecommunication sum up the significance of new technology:

"Today, the customer assumes the functionality of the product and he pays more attention if the product fits into his life-style and if he can identify with the product. Therefore the design dominates more and more the technology...Products in the future will be more various. At the moment the development leads to organisers for mobile data exchange. It will be possible to integrate GPS, to surf the Internet, writ-

ing and voice recognition et cetera."³²

"The variety will make the difference."³²

"I am sure, that within the next three years almost all devices for communication will be mobile. We will need a new definition, what and how we really want to communicate in the future."³²

2.5.2 Telecommunication devices as accessories

Due to miniaturisation of technical components, mobile telecommunication devices become very small. They fit into smart clothes with integrated computers or they are reduced to earrings and wristwatches with PDA, cell-phone and GPS functions (fig.10). Such products are also accessories and elements of adornment.

Telecommunication devices are no longer purely functional service products. They also function as entertainment devices. Function and fun are designed into the same device to increase the entertainment factor. Modern life has to be fun, exciting as well as convenient. It demands the design of service functions parallel to emotional features. Multi-sensory interfaces help to improve both - function and emotion of human-computer interactions.

2.5.3 Computer games - new patterns in interface design

The entertainment industry motivates other industries to introduce new interfaces. Virtual computer game interfaces have become a pattern for real products. Game players often experience augmented realities long before they appear as real products (fig.11). The car industry, for example, has started to integrate head-up displays for virtual augmentation,



fig.11 Interface for car navigation in computer games



fig.12 Head-Up-Display for car navigation in reality



fig.13 Force feedback steering wheel for computer games

which use similar graphics to computer simulators (fig.12).

The same is happening to force feedback devices. The first commercial force feedback devices were designed for computer games to make the interaction with weapons and vehicles more realistic. A force feedback mouse has been used in this study to examine different vibration frequencies, that might be useful in user interfaces others than games.

2.5.4 Force feedback interfaces

Force feedback as human-computer interaction in cars is a good example of simplifying multi-tasking. To relieve the driver's concentration it is necessary to provide new channels of perception in order to split up the information flow. In the early years sight, hearing, touch, and smell were the main senses involved in controlling a car. The car was loud, produced smoke and the driver could immediately see, hear, feel and smell if there was something wrong with the car. Later, the demand for more comfort and convenience such as less vibrations, less noise, and less smoke supplanted the control option of touch, noise, and smell. Today, the air inside the drivers' cabin is clean and filtered. Cars are silent and drive smoothly because of excellent suspension and sound insulation. To the drivers' disadvantage, road conditions cannot be felt through the steering wheel anymore. Force feedback features can reintroduce some control features. Force feedback steering wheels can simulate and transfer road conditions through factors that react on information from road-observing sensors.

2.5.5 Non-verbal communication codes

Every society has its own non-verbal communication codes that are transmitted through objects of status. Modern societies change their objects of status quickly that are part of a trend, but in earlier societies such objects were more lasting and sophisticated. Many of them were just symbols but some of them incorporated complex contents. A good example are sticks or sceptres that represent the genealogy. The sticks are adorned or carved to communicate the status of authority. Some cultures, especially those without a distinctive writing but with a great narrative tradition,



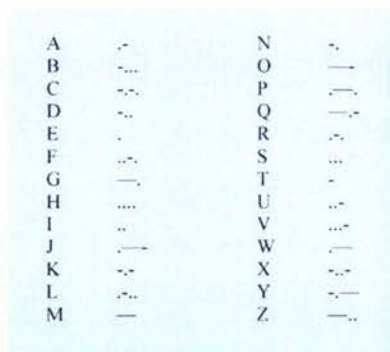
fig. 14 Tokotoko, a Maori talking stick from New Zealand

still have 'talking sticks', like the native North-American Sioux and the New Zealand Maori.

2.5.6 The Maori talking stick

The investigation into Maori talking sticks should show if there are aspects of non-verbal communications that could be incorporated into digital devices of modern societies. The discovery of talking sticks was an initial link in this research because it created the idea of tactile telecommunication devices. Three samples of Tokotokos are exhibited at Te Papa, the National Museum of New Zealand (fig.14).

The Maori Talking Stick (Tokotoko) exemplifies a fascinating support to personal conversations, created by carvings. It is a non-verbal aid for understanding and a tactile reminder for the users and a visual reminder for the spectators. Orators use talking sticks to express themselves and as a prompt during speech. Many sticks embody the memories, personality, and local history. There are collectors of tokotoko and some elders have several to choose from whenever they go to a meeting. Some are named and have been passed down the male line to their present owners. The owner of the stick is an orator and has the authority to speak.



| | | | |
|---|-------|---|-------|
| A | .- | N | -. |
| B | -... | O | — — |
| C | -.-. | P | .-. — |
| D | .. — | Q | —.-. |
| E | . | R | .-. — |
| F | ..-. | S | ... |
| G | — . | T | - — |
| H | | U | .. — |
| I | .. — | V | ... — |
| J | .- — | W | .- — |
| K | .-. — | X | .-. — |
| L | .-.. | Y | .- — |
| M | — — | Z | — .. |

fig.15 Morse Code alphabet

Tokotokos are shaped and carved to suit the individuals' preferences. Decorations are localised or even personalised so that certain proverbs and tribal sayings are incorporated into the plan. The figures carved into the stem or at the top end may represent some of the speaker's ancestors. The stick can be given a name that has significance for the orator. Thus it becomes a means of inspiring the speaker or of providing ideas for him to talk about.³³

The talking stick as indigenous cultural object has many aspects which can be seamlessly integrated into modern culture, transferring tribal contexts into modern contexts. Considering product design as cultural attainment, devices which show authority and digni-

ty could mean, in a modern interpretation, that they express wealth and status of people in public. They show attitudes or life styles to signal connections to others with the same style, creating modern tribal structures. Unique decorations are necessary for a market of individualists who want to celebrate their personalities. In the way that many talking sticks embody the memories, stories and personalities of the local history, mobile telecommunication devices can store information about personal history or other personal data. Collecting talking sticks for specific occasions finds an equivalent use in modern contexts, when digital products become collectibles such as swatch watches.

2.5.7 Morse Code

Non-verbal codes instead of language have always been used in telecommunication. They reduce the amount of data without reducing the content, making communication shorter and quicker. The Morse Code of Samuel F.B. Morse is probably the best known telecommunication code. It is a simple code that provides a whole alphabet by using only short and long impulses. The SOS signal, for example, contains nine impulses written in dots and dashes: ...—... (three short, three long, three short impulses).

Telecommunications via Morse Code can be as fast as oral conversations. The output signals are normally acoustical or in writing, a dot for the short and a dash for the long signal. Fig.15 shows the alphabet converted into Morse Code. Tactile telecommunication devices will demand operation codes, such as Morse Code, to transfer information.

2.5.8 DeBonoCode

The DeBonoCode communicates complex situations in short number codes. It is a verbal code but the content is reduced to two numbers that are easy to communicate as Morse Code. This pairs of numbers are separated by a slash and pronounced separately in a conversation: 20/11 becomes 'twenty eleven' and 21/9 becomes 'twenty one nine'.

The first number refers to the entry topic, like 'information', 'travel', 'relationship', or 'mood'. The second number is a code that specifies something within this topic. There are 18 different codes and 257 entries. On his website E. De Bono gives samples of his code and its contents:³⁴

"Code 1:pre-code

1/3 I need very specific and very detailed information on the matter indicated.

Code 7: information

7/5 This is a subjective category, description or review. The personality of the person making the commentary is an important ingredient."

The code provides a very high compression ratio in time, space and storage. This is of value for rescue services, security services, internet, and for mobile-commerce. The code can be used as inter-language, if used in writing or by tactile signals. Tele-touch codes based on this could utilise new ways in short messaging that are fast and universal.

2.5.9 Little Tactile Device (LTD)

A different approach to tactile communication is the reconversion of voice into vibrations. The Little Tactile Device does this and is available as commercial product that supports deaf people in lip-reading. David Franklin who designed the Little Tactile Device for deaf people to support lip reading describes his device:³⁵

"In essence the LTD works by converting sounds into vibrations in two different ways. Lower frequency sounds (roughly 100 Hz to 1000 Hz) are simply amplified and presented on one of the vibrators. The reason for this is that the tactile sensory system (the sense of touch) can feel these directly. For frequencies higher than 1000 Hz, the sounds are subjected to a divide-by 8 process and presented on the second vibrator. In terms of speech signals, the lower real frequency signals provide most of the cues about voicing, presence or absence of sounds, rhythm cues, intensity cues, beginning and ending characteristics (attack and releases) of different words and some inflection/spectral/intensity dynamic cues.

The higher, frequency lowered (encoded) channel, mainly is useful as a fricative detector /s/, /f/ and so on. It also disambiguates certain sounds that look the same on the mouth, but differ in terms of whether or not they are voiced /tha/ versus

/da/; /pa/ versus /ba). The way that works is that the unvoiced versions (/tha/ and /pa) only have outputs in the high channel during the initial sounds, while the voiced versions have outputs that start before the vowel is formed. This disambiguating of visual cognates is very useful for speech reading."

About the use of the LTD, Franklin says:

"So far as how they are worn, it depends on whether you are talking about an adult or a child. Most adults will wear both vibrators on their wrist side by side. When talking to someone, some of them will use the fingers of the other hand to feel the vibrators for finer cues. In the case of children, usually the two vibrators are worn side by side on the chest using a harness. A few moms have made vests for their children with the vibrators in little pockets similarly located."

The LTD shows that it is possible to convert language directly into tactile signals and that these signals can be understood by the user. The LTD supports lip reading but it does not totally substitute for hearing. The direct amplification of spoken words into vibration that can be detected by the skin might be an option to design tactile telecommunications.

2.6 Technology for Mobile Tactor Interfaces

Tactor interfaces stimulate the skin to generate sensations of contact. The term 'tactor' describes an tactile actuator that can have different designs.

2.6.1 Origin of tactor arrays

Tactor arrays (fig.16) were originally designed for blind to make scripts or pictures perceptible. The blind do 'see' with their fingers, with their canes, and with any other sensory power they have. They use the sensory nerves of their fingers to read Braille and to explore their environment.

2.6.2 Tactile aids

The Braille reading system for the blind is probably the most successful tactile aid. Several

other systems and devices have been developed which have achieved varying degrees of success. Optical-to-tactile converters can enable blind people to 'read' visual images of printed alphabet characters. They convert pictures into tactile images through a tactor array (fig.17).

The Tadoma method of speech reception uses cutaneous stimulation to communicate speech to individuals who are both deaf and blind. By placing a hand on parts of the speaker's lips, face, and neck, the listener's hand receives not only vibrations, but also pat-

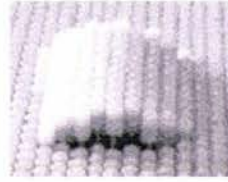


fig. 16 Tactor array

terns of movement produced by the speaker's articulatory actions. Experienced Tadoma method users have achieved almost normal levels of understanding.³⁶ To these people, their brain has become resilient enough to allow them to experience aesthetic pleasures, and to enjoy discovering their visual world without the benefit of light sensing organs. The theory of tactile sensory substitution dates back to the early 1900s, but it was not until the 1960s that electronics had matured to a point where significant efforts could be made to put this theory to more practical use. In the 1960s, Dr. James Bliss and his colleagues developed the Optacon, a tactile sensory substitution reading aid for the blind. The

Optacon consists of a 6x24 element photodiode (light-sensitive) array that is mapped onto a 6x24 matrix of vibrating reeds. The user places his finger to sense the image picked up by the light-sensing array. Subjects trained on this device were able to achieve reading rates of 60 words per minute.

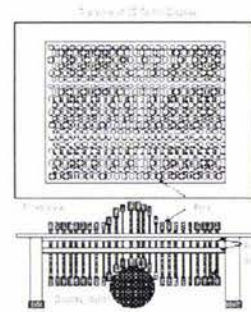


fig. 17 Simple mechanical tactile display

Also in the 1960's, at the Smith-Kettlewell Institute of Visual Science, Dr. Bach-y-Rita and his colleagues developed a large electromechanical array of 400 points mounted in a dental chair which transmitted patterns of vibration onto the back of a person sitting in the chair.³⁷ The vibration patterns were dictated by images sensed by a television camera under the control of the person in the dental chair. If the camera was directed towards a white vertical line on a black background, for example, the person would feel a vertical line on their back. If the camera was moved to the right, they would feel the line move correspondingly on their back. Although such a system did not have the ability of the human eye to gather

visual information, it showed that the brain was capable of perceiving visual information through the skin. With the tremendous scientific advances made in electronics, materials and manufacturing techniques since the 1960's, multi-channel electro-tactile system were developed that are able to stimulate the skin in a safe and comfortable manner.



fig. 18 Braille Laptop using an array of small pins that can be individually raised or lowered

2.6.3 Function of Tactors

Vibrations that are generated by tactors can relay information about phenomena like surface texture, slip, impact, and puncture. The frequency range of interest is a few Hertz to a few hundred Hertz.

Current designs are tactor arrays of closely-spaced pins (fig.18) that can be individually raised and lowered against the finger tip to approximate the desired shape. Finger tips are able to detect pin spacing of less than a few millimetres, but other body parts demand a lower resolution of tactors. Single tactors such as piezo electrical designs are useful for these body sites. The appropriate distance between two different tactors is depending on the two-point thresholds on different parts of the body (fig.7).

Thermal displays are a relatively new area of research. Because human fingers are often warmer than the room temperature or objects in the environment, thermal perceptions are based on a combination of thermal conductivity, thermal capacity, and temperature. This allows to display material compositions as well as temperature differences.

Many other tactors have been developed during previous research, including electro-cutaneous stimulators, ultrasonic friction displays, and rotating disks for creating slip sensations.^{38 39 40} The variety of different vibrations and frequencies, which can be used for tactile data transmission, is sufficient to base a tactile language or code on it.

2.6.4 Tactor designs

Current research on tactors use different technologies, including tactile pin arrays, vibro-

tactile displays, and single piezo electrical tactors.

2.6.5 Shape-Metal Alloy (SMA-) tactors

Many tactile displays are working with Shape-Memory Alloy wires.⁴¹ They consist of a various number of individually actuated pins that are raised against the finger pad to form the communication interface (fig.19). SMA wires are used to drive the pins. As electric current heats the wire, it goes through a phase transformation and shortens, thus pushing the pin up. With this design, each pin can move 3 mm and produce over 1 N of force. A primary problem with SMA is the slow response time. To overcome this it is necessary to use water cooling and position feedback for each pin from optical sensors.⁴² The size makes the display useless for small devices, which fit into a hand.

2.6.6 Micro-electro-mechanical system (MEMS-) tactors

Silicon is suitable for using the electrostatic effect to build tactors. Therefore flexible and conductive electrodes are fixed on both sides of a silicon layer. When voltage is connected the silicon is deformed by the electrostatic field. There are extremely light and very thin. A MEMS tactor array is shown in fig.20. The square dimensions of a single tactor are approximately 2x2mm. The centre square of each tactor is where the polyamide layer will bubble and create a sensation on the finger. Once the polyamide is applied, the centre square will be the inner chamber while the surrounding ring is the outer chamber. When a voltage bias is applied, an electrostatic force is created that causes the outer chamber to shrink. As the outer chamber deforms, the entrapped air rushes to the inner chamber, displacing the flexible polymer.⁴³

2.6.7 Piezo-electric tactors

Piezo-electric materials can be used to convert electrical energy into mechanical energy and vice versa. A piezoelectric tactor can produce extremely fine position changes down to the subnanometer range. The smallest changes in operating voltage are converted into smooth movements. They offer the fastest response time available and a wide

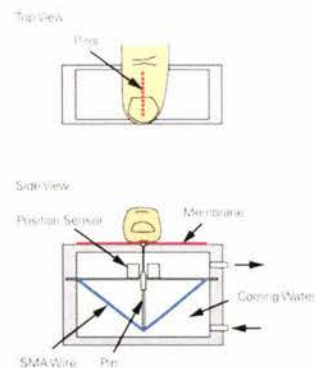


fig. 19 Function of a Shape-Metal-Alloy tactor

frequency range.⁴⁴

2.6.8 Mobile telecommunication technology

Without better mobile telecommunication systems, mobile use of tactor interfaces will be impossible. New standards in telecommunication technology will enable high rates of data transmissions between mobile devices. The emerging Universal Mobile Telecommunication Standard (UMTS) has a transfer rate ranging from 144 KB/s to moving vehicles in all areas up to 2MB/s in specific areas for static use. This transfer speed will allow the use of features that are hitherto limited to static machines and terrestrial tele-operations.⁴⁵

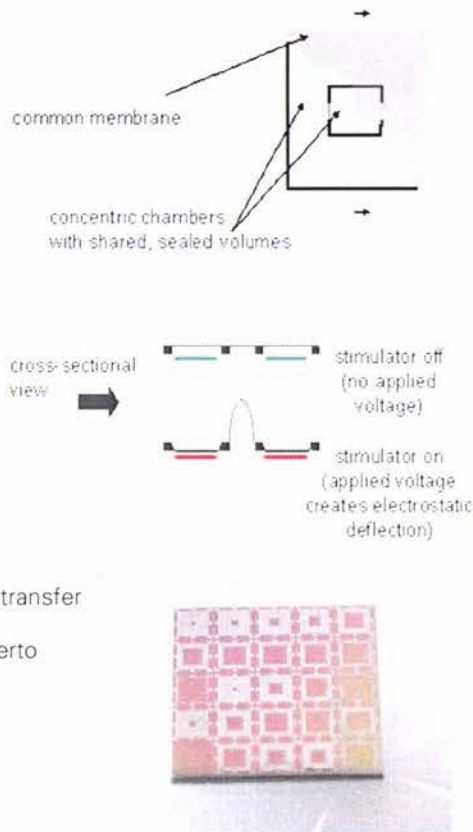


fig.20 MEMS Concept (above);
MEMS tactors in different sizes (below)

2.7 Summary of Secondary Research

The summary of secondary research on touch and the way it could be utilised in interface design constitutes the foundation of further primary research on tactile user interfaces and tactile human-computer interactions.

Unused capacities in human sensing encourage totally new designs. There exist a shift of interest away from abstract operations toward intuitive operations in human-computer interactions. The previously emphasis on functionality has become self-evident. Reliability, natural semantics, and easy operations are important requirements to match user-interfaces with the increasing complexity of multi-functional devices. The research has described the current knowledge in human sensory research and presented the potential and the advantage of tactile interac-



fig.21 Piezo-electric tactor

tion in device operations.

The most important part was the investigation into the human sensory system. Biological structures of human sensing organs need to be considered in product and interface design. Current human-computer interactions that demand adaptation to poor interfaces and unnatural processes are still common. Cell-phones, for example, demand abstract operations and provide only one channel of perception. Cumbersome operations and rudimentary telecommunications have little in common with face-to-face communications. In the future, processes in telecommunications should include multi-sensory perceptions similar to face-to-face communications, which can include sight, hearing, touch and smell. The more senses will be involved the more information can be sent and received.

Not much research work on multi-sensory applications has been found in the literature. The separation in different scientific disciplines results in very specific research fields about single modalities. The attention is directed either towards visual, acoustic, or tactile sensing but not into their natural team work. The use and manipulation of each sense is extensively represented in literature but little previous research has been found on manipulations between different senses.

This survey shows linkages between the five human senses that give deeper understanding. A knowledge of the similarities in the performance of different senses is important. Alternative interface designs will be developed on the extension or substitution of one perceptive channel through another one. Synaesthesia, a research field in cognitive psychology views the possibility to influence or replace one sense through another sense. Full substitutions seem to be impossible, but limited substitutions can be sufficient to compensate total failures or overloads of single perceptive channels. The literature shows that extensions or substitutions of visual or acoustic channels are possible and significant in specific tasks.

Touch is the only sense that combines acting and sensing, which makes it predestined for integration into human-computer interactions. It can be used as separate feature or as con-

firmation of visual and acoustic sensations. Sight and hearing are distance perceptions, touch is a contact perception. It has a complex meaning in cognition which constitutes a 'feeling'. Feelings are the final conclusion of multi-sensory perceptions and the integration of feelings into interfaces will create intuitive human-computer interactions in the future.

Multi-sensory interfaces provide safe transfers because they involve more than one information channel. For some user groups the support of additional channels is more important than for others. The community of sight and hearing impaired as well as for people with speech disorder would benefit most. Also, professions which demand high levels of concentration and multi-tasking would benefit from multi-channel interfaces significantly.

With respect to cognitive capabilities of human beings, interface designs that use tactile signals to transfer information are feasible in various fields. Force feedback devices that have been developed in military and medical sectors are the avant-garde in tactor devices. The entertainment sector is currently growing rapidly in the application of this technology. To achieve realistic multi-sensory experiences of computer games, force feedback joysticks, mice or steering wheels are becoming more tactile. Such devices are likely to become models for other sectors like automotive and office products. Tactile signals in navigation, for example, do not interfere with visual orientation or acoustic information. Tactor interfaces have potential to reduce stress, because they use a perceptive channel that is not yet occupied with other tasks.

Multi-sensory interfaces do not discriminate impaired people because they provide new ways to overcome the handicap. Accordingly, tactor interfaces are the logical extension of visual and acoustic interfaces. They match with differing sensory capabilities of users, they ease learning and understanding of human-computer interactions, and they are reliable.

As far as the technology is concerned, not much knowledge could be found about tactile transduction methods through tactors. The predominant tactors are piezoelectric but MEMS tactors that are currently developed have advantages in size, weight and power consumption. There have not been any further investigations because performance of dif-

3 Primary Research

3.1 Outline and Methodology

The primary research emphasises tactile signal transductions as part of multi-sensory human-computer interactions. It is aimed at extending the knowledge about touch perception as an information channel in mobile tele-operations. The ability for people to be mobile is an increasing value in modern life. To ask what enables mobility and what is comfortable or disturbing is the task of product designers. The main character of mobility is the freedom to move. Movement as parallel action to communications and operations demands concentration on two or more different operations at the same time, known as multi-tasking. Multi-tasking stands for high efficiency and time saving, but it is also the source of stress, strains and errors.

Investigations into tactile perceptions and operations are undertaken to evaluate the advantages of tactile information transfers: their intuitive perception, their directness and reliability. The main aim is to explore how tactile human-machine interactions can become part of new user interfaces, new processes, and new products.

The primary research is partitioned into:

- Questionnaires, that have been performed to gain information about use, advantages and disadvantages of mobile digital devices, particularly cell-phones.
- Experiments, that have been conducted to evaluate the best placement and layout of factors onto the lower arm.
- Concept ideas about product, that use tactile augmentation to ease their use.
- Final conceptualisation of two factor devices, that present the potential of tactile signal transmission in telecommunication and navigation.

3.2 Questionnaire about the Use of Mobile Digital Devices

Mobile digital devices are the key to mobile lifestyle enabling users to perform teleoperations at any time and at any place. In order to gain information about acceptance and use of mobile digital devices a questionnaire has been conducted by e-mail. 50 persons took part, 50 percent female and 50 percent male. Their age ranged from 18 to 60 years. 60 percent were students between 18 and 32 years. The rest were employees and self-employed people aged between 32 and 60 years.

The questions have been designed to find out users' preferences in the use of mobile digital devices. Four different device categories were chosen to represent four specific preferences. A mobile music player for mobile entertainment, an organiser for mobile data storage, a digital camera for mobile observation, and a cell-phone for mobile communication.

(1) What kind of mobile digital devices do you use?

| - | number | average age |
|---------------------|--------|-------------|
| Mobile Music Player | 15 | 28 |
| Organiser | 4 | 33 |
| Digital Camera | 7 | 29 |
| Cell-Phone | 35 | 32 |

(2) How often do you use them?

| - | every day | average age | every week | average age | every month | average age |
|---------------------|-----------|-------------|------------|-------------|-------------|-------------|
| Mobile Music Player | 3 | 28 | 7 | 29 | 5 | 28 |
| Organiser | 4 | 33 | 0 | | 0 | |
| Digital Camera | 0 | | 2 | 34 | 5 | 28 |
| Cell-Phone | 29 | 31 | 3 | 34 | 3 | 35 |

Questions 3 and 4 are only for cell-phones users.

(3) Remember the first use of your cell-phone. Was it easy to understand the interface?

| - | number | average age |
|-----------------|--------|-------------|
| Very easy | 3 | 25 |
| -Easy | 12 | 30 |
| -Difficult | 12 | 32 |
| -Very difficult | 8 | 36 |

(4) How do you estimate the percentage of features you use regularly on your cell-phone compared to all features it provides?

| - | number | average age |
|------------------------------|--------|-------------|
| I use all features regularly | 0 | |
| I use less than 50 percent | 25 | 32 |
| I use more than 50 percent | 10 | 30 |

(5) If you want to send a message like: "I will meet you at 12.00 for lunch."

Do you tend to send it as:

| | number | average age |
|--------|--------|-------------|
| E-mail | 4 | 37 |
| SMS | 11 | 28 |
| Call | 35 | 36 |

3.2.1. Findings from Questionnaire Survey

The survey is not representative for the market of mobile digital devices, because the number of participants was limited. Nevertheless the outcome has significance for

research because it provides information about general trends, characteristics of use and experiences with the most common mobile digital devices.

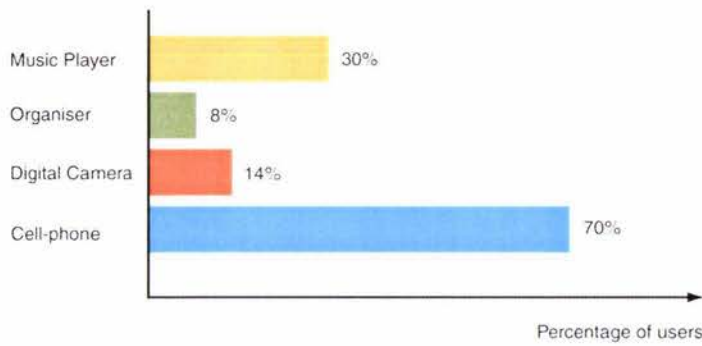
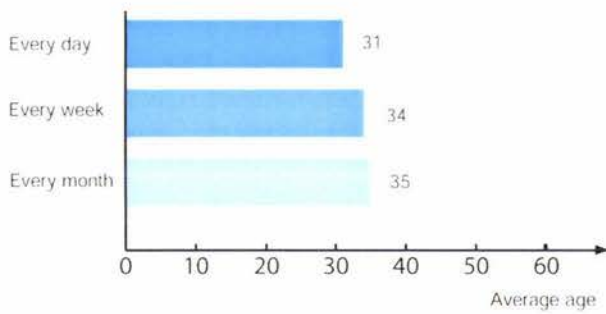


fig.22 Statistics about the use of mobile devices (result of question 1)

The results of the questionnaire clearly show that cell-phones are much more used than music players, organisers, and digital cameras. They also reveal a relationship between use of mobile digital appliances and age of users. 70 percent of all volunteers use a cell-phone at an average age of 32 years (fig.22). The majority, i.e. 83 percent of these cell-

(a) Use of cell-phones



(b) Use of mobile music players

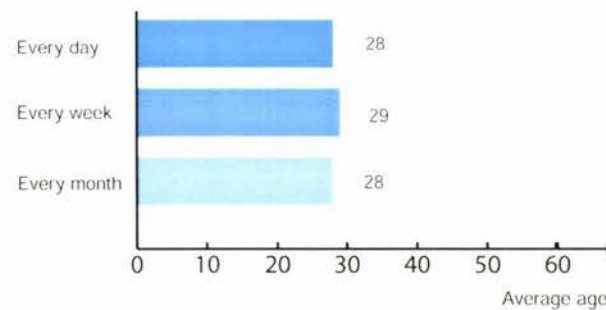


fig.23 Statistics about the frequency of use of cell-phones (a) and mobile music players (b) considering the average age of users (results of question 2)

phone users use their device at least once every day.

Their average age is 31 years. Only 8.5 percent use their cell-phone once every week, and 8.5 percent once every month. On an average they are aged 34 and 35 (fig.23a). This result indicates a more frequent usage of cell-phones by young users than by the elderly.

Similar to cell-phones, the use of mobile music players

is more popular among young people. 30 percent of all volunteers use them (fig.22). Their average age of 28 is much lower than the average age of all volunteers which is 35 years. However, mobile music players are used less frequently than cell-phones, only 20 percent use their mobile music player every day (fig.23b).

In comparison to cell-phones and mobile music players, the use of organisers and digital cameras is insignificant. Among 50 volunteers there were only 4 users of handheld organisers and 7 users of digital cameras (fig.22).

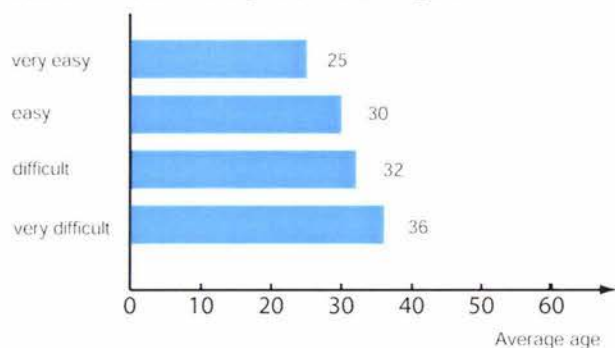


fig.24 Statistics about the understanding of cell-phone interfaces at first use considering the average age of the users (results of question 3)

Asked about the difficulties at first use 12 respondents reported they found it difficult and 8 people very difficult to operate their cell-phone, whereas 12 found it easy and only 3 very easy. The age split shows an obvious relation between understanding and age. The younger the volunteer the easier the understanding of cell-phone interfaces and functions (fig.24).

Question 4 asks about the general use of features provided on cell-phones to find out if

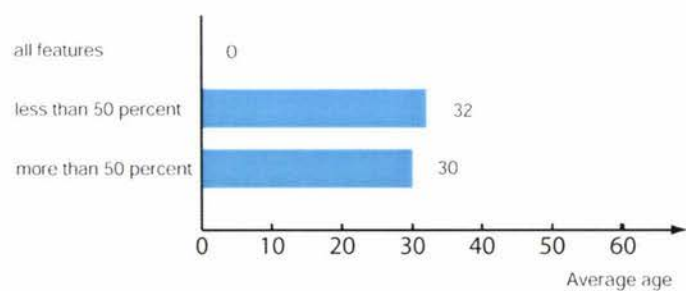


fig.25 Statistics about the approximate use of features on cell-phones considering the average age of users (results of question 4)

there are too many features or not. To limit the questionnaire to this main aspect only the approximate use is asked without details on every single feature. The answers show that 25 of 35 cell-phone users were aware of less than 50 percent of all available features on their cell-phones. There is a small gap of two years in the average age between those users who use less than 50 percent (average age 32 years) and users who use more than 50 percent of all features (average age 30 years) shown in fig.25.

The answers to question 5 show that 35 of 50 participants prefer making calls by mobile phone or landline for short messages and 11 sending a SMS. E-mail is used by 4 people

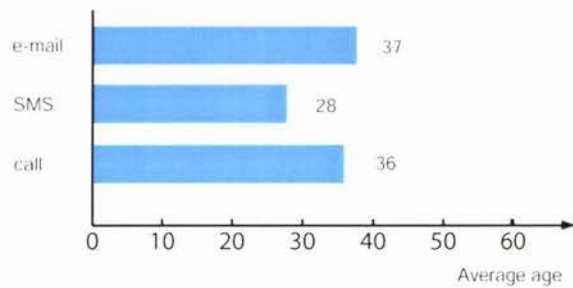


fig.26 Statistics about the use of different media to send a message considering the average age of users (results of question 5)

for short messaging (fig.26).

In summary, the results of the questionnaire show a higher demand on mobile telecommunications (cell-phones) than on mobile entertainment (mobile music players), mobile data storage (organisers) or mobile observation (digital cameras). Current trends suggest that all four devices will merge into one product. Accordingly, the number of features will increase, although there might be few people who will use all features. Independently of which features are provided, the responses about features on current cell-phones that users are familiar with, indicate that many features are not known. Current cell-phones provide more features than necessary which makes intuitive understanding impossible. Their interfaces require learning and concentration for a certain period of time. It may also indicate that operations are difficult in general, but the users adapt to these difficulties and learn to overcome them. For example, typing SMS might not be convenient to do on cell-phones because of a limited number of keys. Nevertheless, most people seem to get

used to doing it and after a short time do not notice the intricacy. The age split specifies another problem. Young users adapt more easily to mobile digital devices than the elderly. They use them more frequently, they find it easier to operate them at first use and they use more features once they know their device.

Multifunctionality of future mobile digital devices demand an interface design with focus on their main features to avoid confusions. Understanding at first use independently of user's age has to be the aim of successful designs. The incorporation of tactile feedback into interface design may help to distinguish different functions or to signal wrong or right use.

The result of question 5 shows that direct telecommunications such as calls are still preferred for short messages compared with indirect telecommunications by SMS and e-mail. The advantage of direct communications is the immediate confirmation from the person being contacted, the disadvantage is that the person being contacted has to be available to talk and might be disturbed by frequent short calls. This outcome is of interest in developing tactile signals as an alternative channel in direct telecommunication. Tactile calls would not disturb other direct conversations or telecommunications.

3.3 Conceptualisation

In order to put the theories and technologies described in the secondary research into new developments, various ideas were explored which result in two major concepts.

3.3.1 Design concepts

In this phase design concepts were developed by brain storming. All ideas integrate tactor interfaces into devices to ease human-machine interactions. Various concepts are presented which include new products with tactor interfaces and improvements of existing digital devices by tactor interfaces:

- Tactor Wristband:

Tactor Wristbands provide tactile telecommunications based on tele-touch codes.

They convert words, alphabets, numbers, or shorthand into vibrations. It might be possible

to receive or send physical information by simulating touch. Tactile feedback similar to hand-shakes, for example, are comfortable to start and end telecommunications. Tactor Wristbands might be beneficial for deaf or hearing-impaired people who want to telecommunicate.

- Tactor Memory Stick:

Handling small objects during speech seems to be a common habit of people that is used similar to gestures. Although most of these actions have no specific purposes, like playing with a pen, a glass, or a tobacco pipe that fits into hands, handling things or moving their hands probably helps people to think and to articulate. Some objects might be used as tactile reminders. Existing conventional and non digital tactile reminders are knots in handkerchiefs as used in Germany to remind the users on something they should not forget or also carvings in Maori Talking Sticks as described in chapter 2.5.6. Reminders with electro-mechanical tactile actuators could generate various signals to remind about different things, like time, appointments, shopping list, calls, or thoughts.

- Tactor Organiser:

Face to face conversations will remain the most important way of personal information exchange but in telecommunications personal-digital assistants (PDA) will help to handle the increasing amount of tele-operations. The success of PDAs like PALM or COMPAQ handhelds show a demand for devices which help to organise and structure digital information that has to be stored before, within, or after conversations. Only devices that can be described as 'digital secretaries' will make it possible to handle the increasing amount of information that users have to face during work. Digital secretaries will help to organise work, they will make calls and receive and answer calls and e-mails. Today's answering machines are simple digital secretaries, but they are passive. In the future, they will interact with the users and will probably know the users intentions. They will order food and do maintenance via digital appliances. Digital secretaries could use tactile signals to inform their users without being disturbing to others.

- Tactor Orientation Aid:

Tactor orientation aids are useful in difficult environments for fire fighters, pilots, divers, or visually impaired persons, for example. They can convey information to the brain when visual and audible information channels are stressed or not accessible. Visual information may need to be co-ordinated with tactile information to resolve redundant or complimentary data.

- Tactor Cane

Tactile aid to support sight-impaired people. It uses vibrations or impulses to support spatial perceptions. They can enhance accessibility to environments by converting obstacles into vibrations. The obstacles are detected by laser or radar scans covering a range of several metres.

- Tactor Machine Tools:

Machine tools that use tactors within the handles to inform the users about the state of the working process, for example:

- milling cutters can signal the right deepness and direction of the cut,
- electrical screwdrivers can signal the capacity of the batteries and the right pressure for screwing,
- hot air guns can signal temperature and distance to the work-piece (fig.27),



fig.27 Conventional tools with highlighted parts, where tactors could be placed.

- Tactor Soles:

Soles for inner shoes that transmit tactile signals to remind users about moving their legs. The tactile perception of these signals would probably work without the attention of the users because the soles use human reflex reactions. Tactor Soles might be useful during long plane travels to

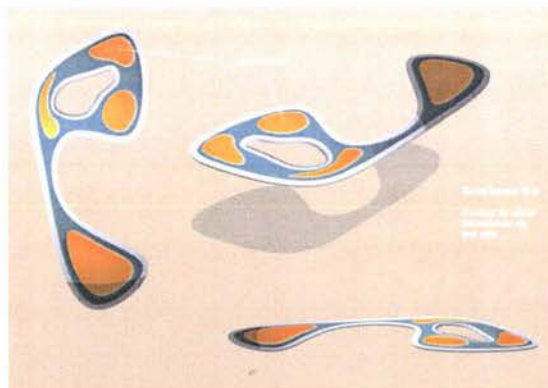


fig.28 Concept idea of Tactor Soles

avoid thrombosis or for office workers who do not move their legs for many hours. Because of their physiological similarities to hands, feet might be suitable for tactor transductions. Fig.28 shows an illustration of this idea, a sole design with four tactors.

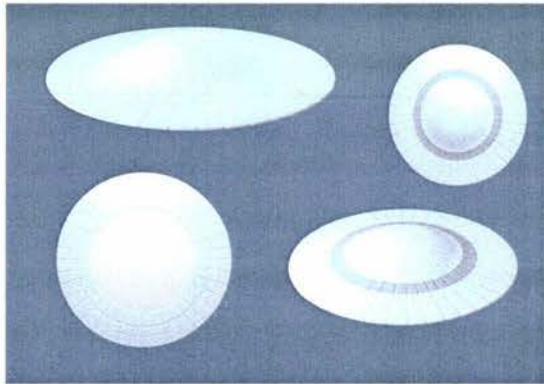


fig.29 Concept of Tactor Stickers

- Tactor Stickers:

Tactor Stickers are temporary tactile reminders that are connected to digital devices: Telephones that remind users on phone calls, kitchen appliances that remind about food to be bought, televisions that

remind on broadcasts.

Users could use several Tactor Stickers onto their body to remind them on different things without disturbing other people. In conjunction with PDAs like PALM organisers, Tactor Stickers can receive signals via radio signals. Tactor Stickers can be used in meetings, conferences, or theatres to remind people about the beginning or end of an event by receiving tactile impulses instead of acoustical signals. Participants would obtain Tactor Stickers instead of tickets.

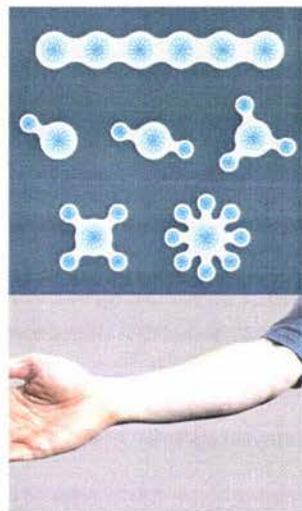


fig.30 Tactor Sticker for Biomechanical-Muscle-Stimulation

Another potential use of Tactor Stickers is the medical sector (fig.30). They could help to use a successful method of muscle regeneration known as biomechanical muscle stimulation

(BMS) that is currently performed by static tactor devices. Vibrations can stimulate the blood circulation within injured muscles increasing the healing process.⁴⁶

3.3.2 Selection of two concepts for further investigations

The potential use of tactor interfaces is huge as the list in the previous paragraph shows. Each of the ideas is a possibility in tactor interface design. For this research the number of

concept has been reduced to two case studies that are exemplary for mobile tactor devices. However, two concept designs to perform specific tasks for specific user groups have been developed to show the full potentials of human-computer interface design using tactor technology. Users with limited perception would benefit from tactile interface devices. Accordingly, these two very specific concepts were chosen that show best the benefits of tactile data processing. Both concepts deal with the improvement of the perceptive processes.

(1) Tactor Wristband

(2) Tactor Cane

The Tactor Wristband has been designed to improve mobile tele-operations like tactile telecommunication, tactile orientation, or tactile remote monitoring. The Tactor Cane uses tactile signals to improve blind peoples' orientation.

Both concepts use tactile interfaces that stimulate the skin. Concepts that go beyond this and consider integration or transplantation into or under the skin were not developed because of ethical reasons.

3.4 Initial Idea for a Tactor Wristband

Prior to the start of this thesis the author worked on a project that became a preparatory work for the Tactile Wristband concept called "Biometrical Digital Assistant". It provides new ways of interaction between users and personal digital assistants and integrates tactile signals into operations, such as digital money transfers.

The concept was submitted to the LG-Electronics Design Competition 2001 which asked for new ideas in human-computer interactions that are related to mobile telecommunication devices. The Biometrical Digital Assistant gained an Honourable Mention among 2000 entries.

3.4.1 Biometrical Digital Assistant (BDA)

BDA's enable new and intuitive ways of human-computer interactions to provide safe digital data transfers parallel to verbal conversations. The idea is to use visible physical actions to execute invisible digital processes of data transfer via radio signals. Currently, addresses, telephone numbers or ID numbers need to be entered when information is sent from one person to another. This is convenient when communicators are at different places but it can be disturbing and irritating in face-to-face conversations when people spend more time to interact with their personal digital assistant than with their conversation partners. To avoid the increasing dominance of human-device interaction, operation of Biometrical Digital Assistants uses more natural ways of interaction between humans to transfer digital data.

3.4.2 Size and functions of Biometrical Digital Assistants

BDA's are slightly bigger than wrist-watches (fig.31). They can be worn on the wrist or kept in the pocket. The size is 100x34x5mm. The screen display is about 60x25mm. Main features of BDA's are similar to Personal Digital Assistants (PDA) that are used in combination with cell-phones. BDA's help to organise, structure and transfer data. They use radio signals to transmit digital data from one BDA to another. In contrast to other devices data transfer is not performed by entering address, ID or PIN numbers, but by touch selection, fingerprint identification and manual "handing over" of data. BDA operations utilise physical actions as metaphors to visualise digital data transfers between two BDA's that are normally imperceptible.



fig.31 Biometrical-Digital-Assistant

3.4.3 Operation of Biometrical Digital Assistants

To start transfer operations data are selected on the touch display of the BDA using scrolling wheel and fingertip. The display is divided into an operative area where all files are

selected and a transfer area where all selected files are collected before they are transferred to other digital appliances. The transfer area contains a biometrical fingerprint scanner that activates the collected data if the fingerprint identification has been proceed. A vibration confirms the correct fingerprint verification and indicates the transfer of the active files as



fig.32 BDA operation

encoded radio signals (fig.32). To enable receivers to decode the data, senders move their index finger to the transfer area of the receivers' BDA or similar appliance, where another fingerprint check is taken. The fingerprint identification is the key to decode the radio signal. This procedure is as secure as PIN numbers or signatures and can be used as contract agreement between senders and receivers. Therefore, the system is suitable for money transactions.

Other potential fields of secure information transfers are confidential conversations with doctors, lawyers, or bankers. The physical interaction retains a feeling of control and directness in transferring digital data. It is natural to touch things to receive reliable information about an object. Following this idea, 'drag and drop' operations are a very natural way to transfer information. In general, most conversation that need to integrate digital data into verbal communications benefit from BDAs. They ease the combination of verbal and digital information exchange. Even common forms of information transfer such as naming internet links: "Take a look to www..." could be eased by a 'manual' transfer of the link.

3.5 Tactor Wristband Concept

By extending the idea of direct interaction through touch the Tactor Wristband carries forward the development of tactile operations. It is designed for telecommunications, navigation, or remote operations and works in conjunction with cell-phones. Currently, cell-phone interfaces occupy hearing and sight and demand high cognitive performances of the perceptive system. Tactor Wristbands do not need visual or acoustical awareness, they occu-

py touch perceptions for data reception and hands for data input. They are connected to cell-phones via bluetooth radio signals. Tactors placed on the inside of the wristband transform messages into tactile signals such as impulses or vibrations that can be detected on the wrist. The outside of the band is touch sensitive and records fingertip touch for data entry.

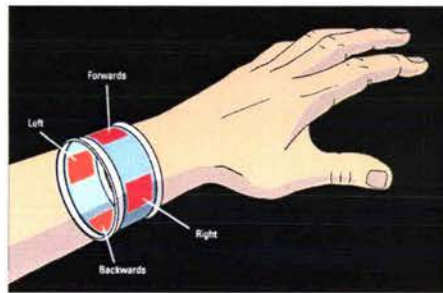


fig.33 Concept of a Tactor Wristband as orientation aid with four tactors on the inside

Operations on Tactor Wristbands demand the understanding of tele-touch codes that are necessary to send and receive information. Such codes might be based on Morse Code or other codes. Another option is the use of cell-phone keys to type words that are converted into tactile signals.

Professional users like fire fighters or divers and the community of deaf and blind people are the focus groups of the concept. They would benefit from an additional communication channel.

Four examples about possible uses of Tactor Wristbands as communication or orientation devices are presented (fig.33). The first two examples show tactile information processing as supportive communication channel in environments with information overloads or limited perceptions. The third and fourth example utilise tactile signals as orientation aids for blind and as alternative telecommunication channel for deaf people.

3.5.1 Tactor Wristbands in hospitals

Hospitals are places of fast information flow between staff or between machines and operators. Concentration and speed is demanded by differing activities. Working in emergency rooms or intensive care units is stressful because most of the information about patients' conditions is transferred visually. Only information about heart frequency is transferred acoustically.



fig.34 Surgeon operating a robot while receiving touch signals through a Tactor-Wristband

Tactor Wristbands could transmit signals to inform hospital staff about emergencies or if their help is required. Tactor calls would be perceptible for the receivers only. It would make a difference to emergency beepers, which are normally worn by hospital staff, because they would not disturb others. Conversations between staff and patients would not be interrupted by beep tunes that may irritate patients. Invisibility and inaudibility is the greatest advantage of tactile data transmission in environments where slightest irritations may cause stress.

Information about patients could be transferred to Tactor Wristbands on the way to them. Without extra concentration on hearing and sighting doctors or nurses could receive information by vibration signals which would make the interaction with patients faster. For example, detecting the patients' pulse on the own wrist could be helpful for doctors, because no interaction is required.

Fig.34 shows a possible future scenario. A surgeon on a computer station is steering robots to perform surgery. Nurses are not required. Machines are monitoring the body functions of the patient and a Tactor Wristband transmit information about these functions.

3.5.2 Tactor Wristbands for fire fighters

Fire fighters could benefit from tactile signals in stressful situations. During fire fighting, sight and hearing can be limited because of smoke and noise (fig.35). Keeping in contact with other fire fighters is essential and can be life saving. Especially collapsing buildings are hazardous. Tactile warning signals on Tactor Wristbands can warn fire fighters within buildings and could help navigating as well.



Specific fire fighter codes could help preparing missions. Such codes could be based on the

fig.35 Different types of fires could be catagorised as number codes to ease communication.

DeBono Code. It allows users to communicate complex information with very few signals. For example, scopes could be divided into 20 sectors and fires could be separated into different types. In an emergency a short tactile number signal like 16/4 for example would mean: "There is an emergency in sector 16. It is a gas explosion". A number code transferred via touch signals does not depend on language and could be helpful in international operations where different languages are spoken.

In this scenario tactile signals would mainly be used for mono-directional use to inform or warn fire fighters from outside.

3.5.3 Tactor Wristbands as orientation aids for blind people

Tactor Wristbands can be useful as orientation or navigation aids in unknown environments.

Tactile signals do not divert attention in the way visual and acoustical signals do and they do not interfere with other signals like traffic signs or announcements which might be important in orientation.

Tactor Wristbands would generate tactile signals to give information about four directions: forwards, backwards, left, and right. Even if

hands, eyes, and ears are occupied with other tasks, Tactor Wristbands are useful in orientation and help to find specific locations. Inner cities, stations, and airports are marked by high densities of visual and acoustical signals, information, and advertising, which can cause confusion. To resolve this problem, Local Positioning Systems (LPS) are helpful. In comparison to the satellite based Global Positioning System (GPS), infrared, radio or laser based LPS can work within buildings at high resolutions. Tactor Wristbands would receive LPS signals, state the current position and suggest directions to find the desired location. At airports, train stations, or in shopping malls, LPS can guide people to the correct terminals, platforms, or stores (fig.36).

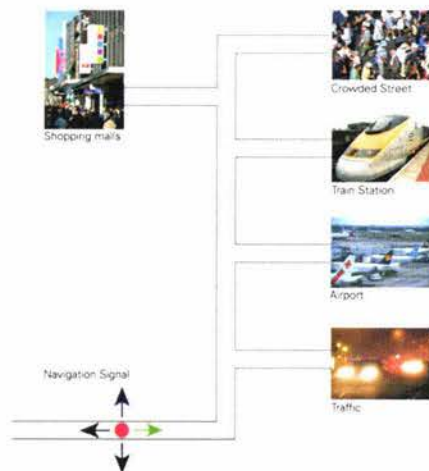


fig.36 Tactor Wristbands can help guiding users to their destination

3.5.4 Tactor Wristbands as telecommunication aids for deaf people

Tactile tele-operations through Tactor Wristbands could be particularly beneficial for deaf people. Those users are handicapped in telecommunication, orientation and reception of warning signals. The total missing of one perceptive channel views the necessity of substitutions.

Mobile telecommunications with cell-phones are inaccessible for profoundly deafened people. Only written and therefore asynchronous communications via SMS are possible but no synchronous telecommunications. Tactile information transductions may change this fact.

Tactor Wristbands are used in conjunction with mobile picture phones to emphasise gestures or to support lip-reading. Mobile picture phones that transfer pictures in real time will be available with UMTS technology. Tactor Wristbands and mobile picture phones together could provide new standards in telecommunications for deaf users.



fig.37 Hydraulic Tactor Array designed to test tele-touch

3.5.5 Experiments on tele-touch

Basic experiments on tele-touch were conducted with two hydraulic tactor displays (fig.37). The display arrays measure 10x10 centimetres containing 100 cells that are filled with water. Each cell on one display is connected via tubes to a cell on the other display. By pressing onto the cells on one display another person could feel the pressure increasing in the opponent cells. Tests with 30 volunteers were performed to receive general

information about touch in tele-operations. The participants were fellow students and friends of the author aged between 20 and 50. During the tests the participants put their hands or single fingers onto the display and start to interact with each other by pressing onto the cells. No sequence or plan of interaction was given to enable an intuitive and playful approach to the provided new channel of tele-interaction. Asked about their impressions, participants reported excitement when they felt the other ones fingers. Observations showed no inhibitions to touch other persons hands through tele-touch in a way they probably would not do in direct contacts.

The biggest problem was to locate the sensations. A hand could not cover all 100 cells of one display. It was reported to be uncomfortable to put the whole hand onto the displays, because the sensations were hard to localise and became rather confusing. Instead, the participants tried to scan the cells with the fingertips to find an active cell. Once an active cell was found the fingertip of the indexfinger intuitively moved to the active area and started to interact.

3.5.6 Tactor placement onto the human body

To enable tactile signal transductions, tactor interfaces need skin contact. Hands and faces are most sensitive areas to tactile stimuli, but it is difficult to attach devices without limiting body movements. The best placement for tactor devices that are connected to the skin without limiting movements is probably the lower arm and wrist. This area is not as sensitive as hands and faces, but it is still accurate compared to other skin areas. Products that are placed on the wrist are always accessible and ready for manual control.

Specific tests were executed through the mechanical stimuli of a pen tip to find the best possible number, placement and layout of tactors onto the lower arm. Purely mechanical tactor displays were designed to simulate sensations similar to electro-mechanical stimulation. The performance of electro-mechanical tactors have been simulated because they were not available for tests. The scope and effectiveness of this study could not determine what kind of electro-mechanical tactors are most suitable for the final concepts. Single tactors or tactor arrays are possible.

3.5.7 Tactor array simulation

To simulate an array of small tactors, a device was designed with an array of pin-heads that is pressed to the skin (fig.38). This array was used to test skin sensitivity to tactile stimuli in dense resolution. Within the lower arm and hand region not one volunteer was able to separate the activities of different pin-heads, only their fingertips could discriminate single pin-heads with a minimum two-point threshold of 2 to 20mm. This experiment shows that arrays of small tactors are only useful when fingertips are used for detection. Tactor devices designed for the wrist demand an array of single tactors with a threshold of at least 20mm in order to transmit clear signals to the skin. The bigger the distance between tactors the better their discrimination.



fig.38 Mechanical tactor array designed to test sensitivity on hand and lower arm

3.5.8 Single tactor layouts

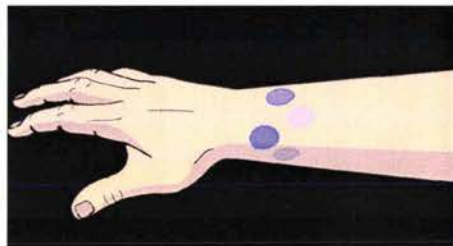
High tactor densities on the wrist can cause problems. Tactors are hard to separate when they are too close to each other. Localisation of tactile sensations becomes difficult and data transfers become unclear. For the next experiment, the number of tactors was set to four to provide enough distance between them. It examined the best tactor layouts. Three layouts were designed. One layout with tactors placed around the wrist and two layouts with tactors placed on one side of the wrist (fig.39). The layouts were drawn onto the skin of the volunteers: four circles numbered from 1 to 4 with a diameter of 15mm. The circles represented the tactor placements. Each separate layout was presented to the volunteers. To execute the tests the skin inside the circles was touched with a pen tip and the volunteers who had covered eyes were asked to localise the stimuli. The circles were touched randomly in sequels of four stimuli. 30 volunteers took part:

The result of the first layout was 94% correct stimuli localisation.

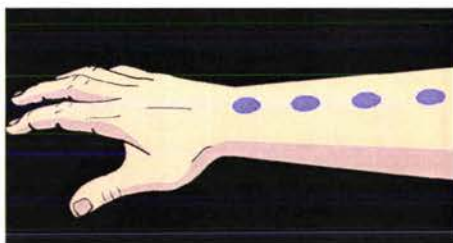
The result of the second layout was 91% correct stimuli localisation.

The result of the third layout was 56% correct stimuli localisation.

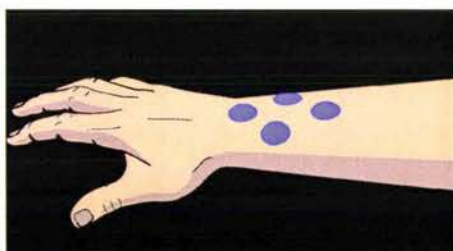
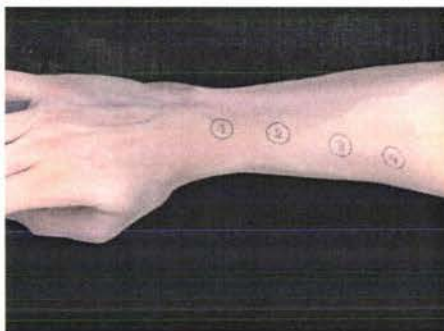
The experiment showed that a layout of four tactors around the wrist is superior to layouts on one side of the arm. Although touch sensitivity varies according to the placement on the inner or outer arm, the spatial localization of different spots around the arm, including less sensitive areas, is easier than the discrimination of different spots on one side of the arm. The experiments have shown that the wrist is suitable for tactile information trans-



(a) Tactor layout around the lower arm



(b) Tactor layout along the lower arm



(c) Tactor layout on top of the lower arm



fig.39 Tests to evaluate the best tactor layout on the lower arm.

fers. Wristbands with integrated tactors make tactile HCIs possible.

3.5.9 Tactile telecommunications

After defining the hardware structure of Tactile Wristbands the software concept need to be defined, asking how contents can be transferred to the users. One option is to transmit words as tactile signals. Two possibilities are of interest to integrate words into tactile telecommunications:

- Reconversion of voice into vibrations,
- Conversion of words into tactile impulses based on Morse Code or other codes.

Lip-reading on mobile picture phones can be supported by vibrations of reconverted voice bringing new possibilities of telecommunications to the community of deaf people.

To enable tactile telecommunication without any need of other information channels a tele-touch code is the only option. Possible tactile signals range from impulses with low frequencies up to vibrations with high frequencies. There are various options to use this range of signals to encode alphabets, numbers, or shorthand. The potential is there and touch codes have already been used by a small community of visually or acoustically impaired people. Technically, it makes no difference what kind of codes or languages are transmitted. Tactor Wristbands can generate various tactile signals in different frequencies.

To test which tactile impulses are comfortable for tactile telecommunications a force feedback mouse that can generate vibrations was fixed onto the wrist of volunteers (fig.40). 30 volunteers took part in the test. Stimulation from 1 impulse per second up to vibrations of 400 impulses per second were tested. The vibration bursts last 5 seconds and the frequency was increased in steps of 20 impulses per second. The participants were asked to report which vibrations feel uncomfortable and which



fig.40 Tests with different vibrations of a commercial force-feedback mouse fixed onto the lower arm.

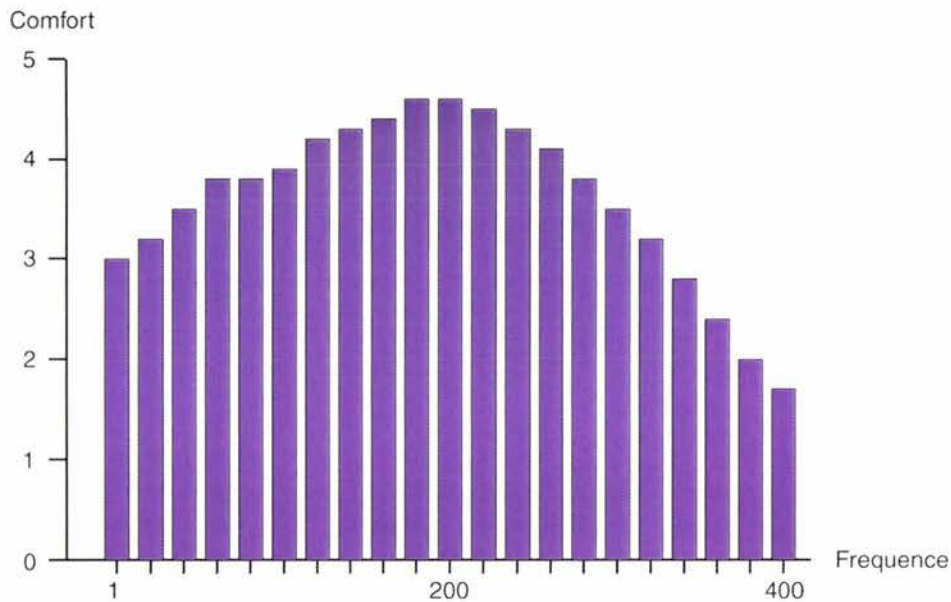


fig.41 Comfort-frequency diagramme

feel comfortable in a scale from 0 to 5.

The diagram (fig.41) shows that very low and very high frequencies are judged to be less comfortable than frequencies of around 200 impulses per second which are in the middle of the presented scale. In general, frequencies between 1 and 340 are judged to be comfortable whereas frequencies higher than 340 are becoming uncomfortable.

In tactile telecommunication it would be best to use frequencies of 200 hundred for normal contents transferred as Morse Code, for example. Fire fighters and pilots could use frequencies of more than 340 as warning signals.

Communication bits could be transferred by shorthand similar to the "SOS" signal that stands for "Safe Our Souls". In Morse Code this is transferred as: "...—...". Short common phrases could be encoded and transmitted in the same way: "How are you?" could be encoded into "HRU" or "Where are you?" into "WRU".

The popular shorthand for "See you later" is already existing: "CUL8R", or even shorter: "L8R".

3.5.10 Input and output operations

Data input can be performed indirectly by cell-phone keypads or directly by touch signals. Typing messages on cell-phones is similar to SMS. Receivers can choose whether they want to read messages on their cell-phone displays or if they want to receive them as tele-touch code on their Tactor Wristbands.

To perform tele-touch code input, the Tactor Wristband is turned on by touching two segments at the same time which causes a low current circuit. Touch sensors within the segments detect the fingertip touch on the outside surface and tactors on the inner surface generate the same touch on the lower arm.

Users get the impression that they can feel their fingertip inputs through the device.

The receivers' addresses can be selected from sequences of different vibrations, that are attributed to different addresses that are stored on the device. To send messages users have to push a defined short-key. Such short-keys are not developed in this study. They need to be worked out in context to a possible tele-touch code that needs to be defined in future research. The interaction process presented here is a suggestion to show the basic structure of use. It is not worked out in details and would demand further research beyond the scope of this study.



fig.42 Direct data input by tele-touch code

For data output the inner surface of Tactor

Wristbands needs direct skin contact in order to transmit tactile signals. A silicon membrane that covers the inner surface contains tactors. When Tactor Wristbands receive sig-

nals from connected cell-phones a pneumatic tube beneath the silicon membrane inflates and connects the tactors to the skin. The users can feel that a tactile call has been sent to them. Once the wristband is fully inflated, the tactors are active and tactile information can be transmitted. Fig.42 shows a Tactor Wristband in operation. The user receives a tactile call and uses his fingertip to answer by typing on the sensor areas of the wristband.

3.5.11 Design of the Tactor Wristband

The final design suggests an oval Tactor Wristband (fig.43). The wristband is divided into eight segments with one passive segment in between two active segments. The active segments have tactile sensors on the outside and tactors on the inside. The technical parts inside the wristband are an inflatable tube, a micro-compressor, a micro processor, a Bluetooth chip, and batteries.

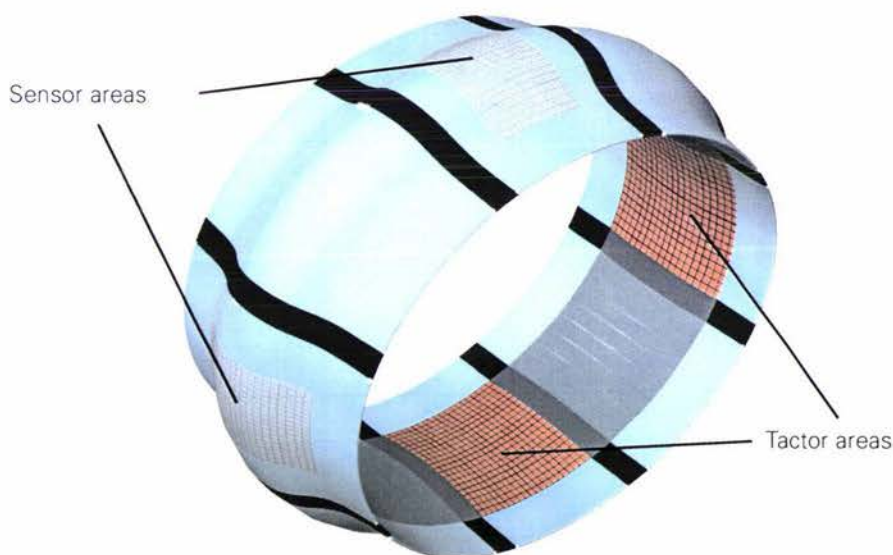


fig.43 Structure of the final Tactor Wristband design

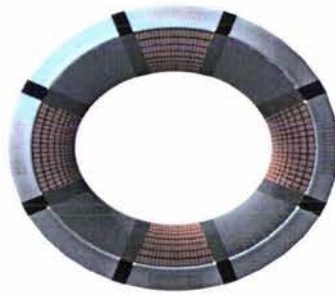
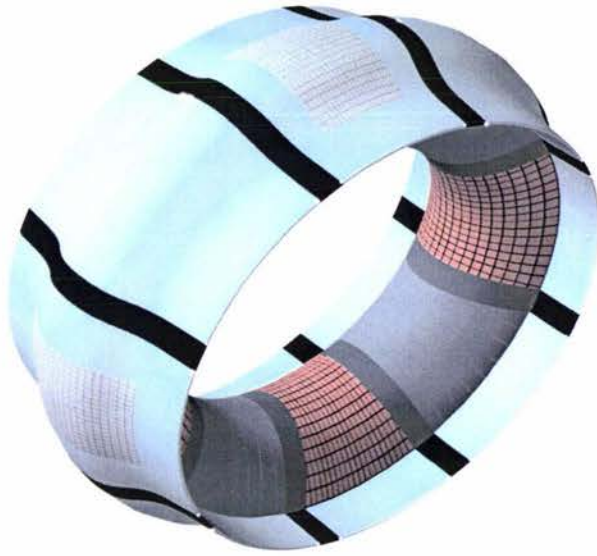


fig.44 An inflatable tube inside the Tactor Wristband enables direct contact between tactor areas and skin.

3.6 Tactor Cane

A long cane for blind people is a tool to compensate visual orientation. It creates a connection between user and space. It is a communication medium and mobility aid - a multi-functional product for the blind: a sign, a symbol, a tool, a toy, or even a weapon. The long cane tells other people to be aware that a blind individual is independently walking.

Long canes are warning systems. They provide a measure of protection, but they are not a safety-guarantee. The blind user still needs keen senses, good concentration, and monitoring skills. Tactile signals that are generated by the mechanical use determine the interaction with the cane.

Tactor Canes extend this interaction. They look similar to conventional long canes and their mechanical function is similar, but they provide new tactile functions. They extend the scanning range of conventional long sticks by using a laser beam. The lasers are integrated into the handle and move according to the cane. The beam

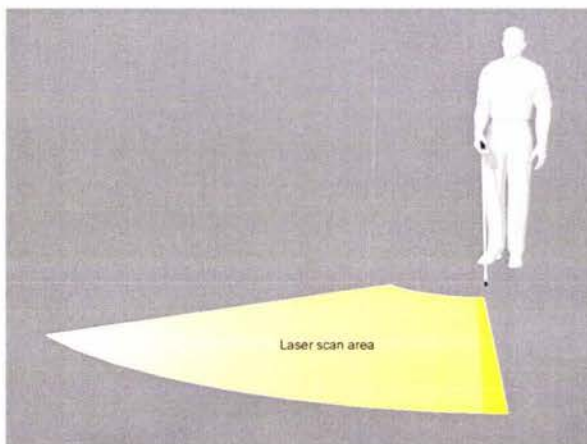


fig.45 Laser scan area of a Tactor Cane

has a maximum reach of 3.5 metres, more than three times the reach of a conventional long stick. Fig.45 shows the scanning area of the Tactor Cane.

Declination sensors control the handle position and adjust the laser direction automatically. When the laser beam hits an object, the light is reflected and the distance can be measured. In practice, users move the cane and receive tactile warnings when obstacles cross the laser beam. This tactile warnings are generated within the handle. The handle is separated into seven tactor rings, each ring represents 50 centimetres of the laser scanned area.

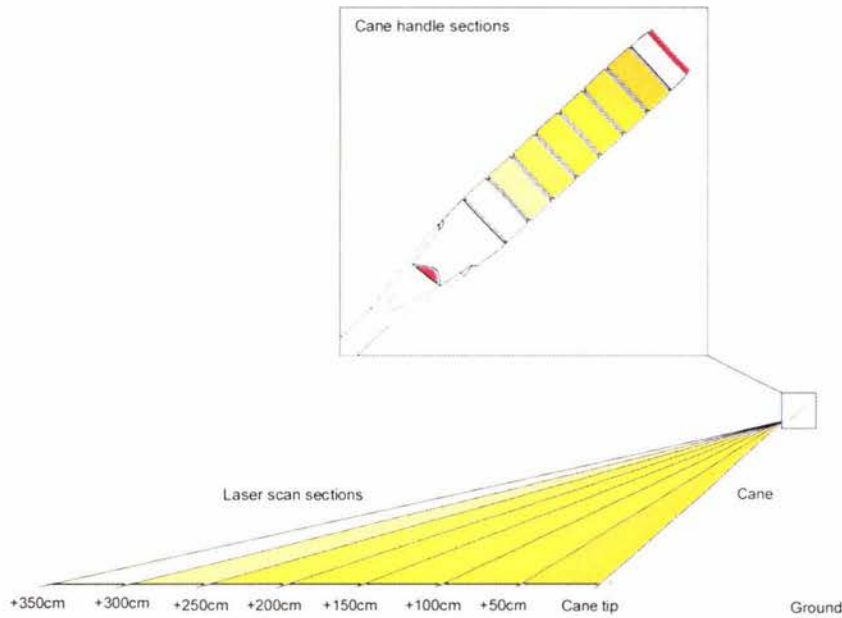


fig. 46 The spatial structure of the handle presents the spatial structure of the laser scanned area to the users.

Blind people use braille computers and tactile aids for map reading. Orientation and navigation through known and unknown areas are tasks, sight impaired have to manage every day. The Tactor Cane should help them to do so making the users more confident and more informed about their environment.

3.6.1 Using the Tactor Cane

Blind persons might be situated in unknown locations and need to know what kind of moving or static objects are around them. Probing the environment with conventional long sticks helps them to orientate within a range of 1 metre if there is enough space. The users have to react within a second, if they walk at a slow walking speed of 1 metre per second.

Using a Tactor Cane blind people get warned of approaching obstacles when the front part of the handle starts to vibrate. This means an obstacle is three metres away. Enough time to react and to direct the cane. When the obstacle gets closer the vibration signals moves through the handle from the front tactor rings to the rear tactor rings. Once the vibration reaches the rear part of the handle the cane tip is in reach of the obstacle (fig.46).

3.6.2 Design of the Tactor Cane

Given constraints in long cane design are some ergonomic measures and materials. The length of the unfolded cane is based on the height of the user. The normal measure for long canes is the distance from ground to breast. For a tall man this would be around 150cm. The maximum length of the designed model is 150 centimetre and the minimum 80 centimetres (fig.51). The diameter of the shaft-tube is between 10mm and 13mm. The wall thickness depends on the material, either steel, aluminium or carbon fibre. The model in the scale of 1:1 is made out of aluminium. The shaft ends in a rubber tip to scan the ground. The tip is available in different shapes according to the users' preferences.

First Tactor Cane designs (fig.47) show sketches of rigid short canes similar to canes that are used by disabled people. Adding tactor display to the handle was the first step to a new feature. Laser scanners were integrated into the handle tip to enable optical area scans and obstacle detection. The appearance was

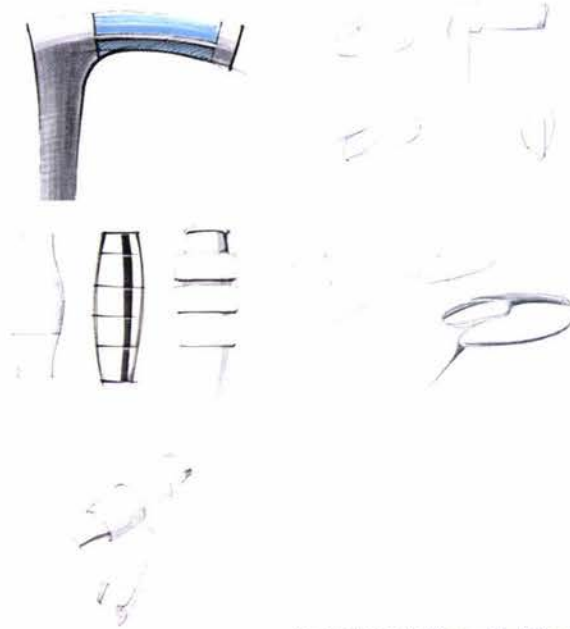
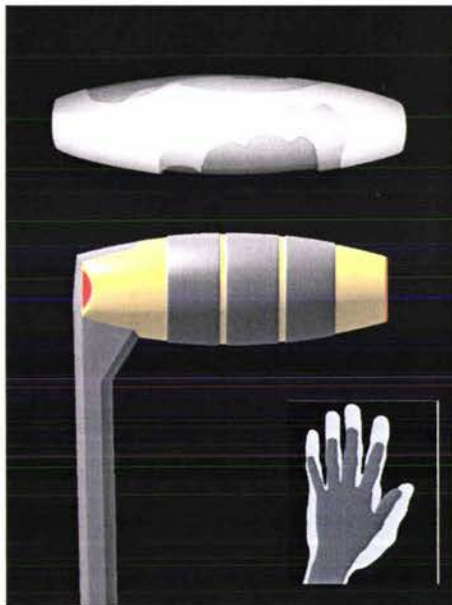
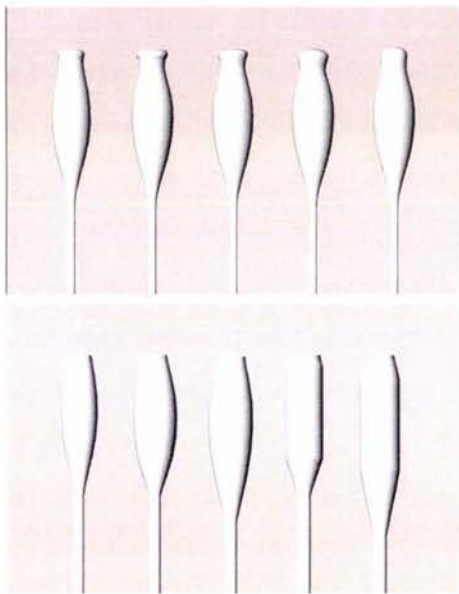


fig. 47 First sketches with different handle designs

unsatisfying because mobility aids for handicapped people have a negative image. The shape and appearance of Tactor Canes should not be a sign of lost mobility but of regained mobility. Accordingly, further designs were aimed at creating the look of a high-technology product that brings confidence and pride to the users. The authors observations and experiences with handicapped people gave the impression that they do not want to be regarded or treated as disabled.

The second cane designs were foldable. Various handle designs were created (fig.48) and different shaft lengths and handle positions were considered (fig.49). The angles between

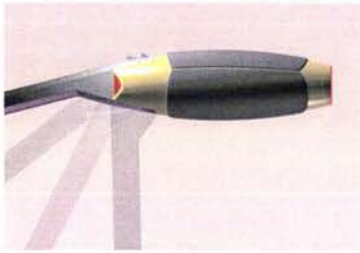


handle and shaft were continuously adjustable between 0° or 90°. Foldable canes need less space to store when unused. In areas where long canes cannot be used, foldable canes can be changed into short canes. The handle direction stays the same when the telescopic shaft is shortened and turned into an angular position.

The lasers are placed on the front tip of the handle, offering the highest position for area scanning. The higher the laser position the better the detection and separation of obstacles that appear on the ground.

fig.48 Plaster models to test different grip sizes

Long canes are mobility aids for the blind that are carried around permanently, because they are essential for orientation. This was the reason why all technical parts were integrated into the cane and no additional device was designed. Every second device would either occupy the free hand of the users or need to be fixed on other body parts or cloth-



ing.

The tactor display on the handle was divided into three tactor rings (fig.49). Concerns about differing handle sizes led to adjustable rings that can be slid back and forth. For this function the rings need to be cylindrical. Handles with various numbers of cylindrical tactor rings were tested and in the end their number was set to seven rings.

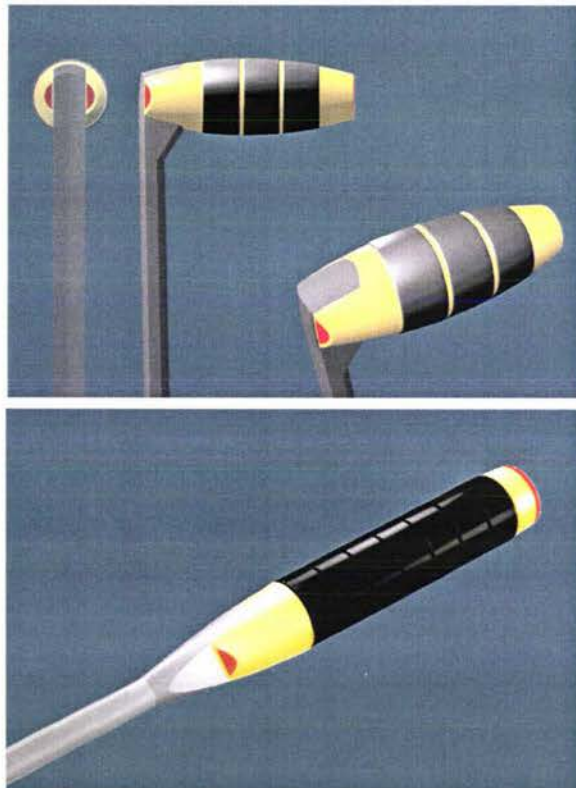
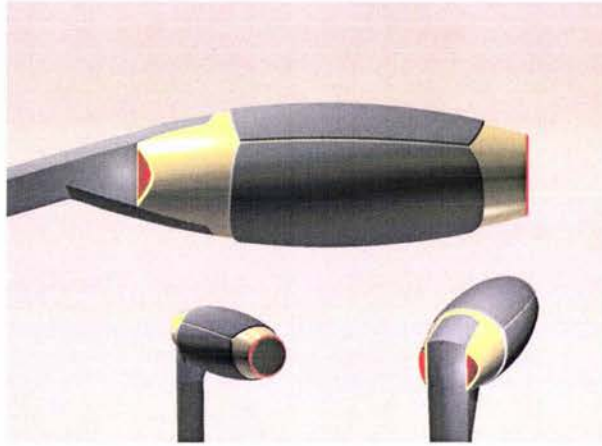
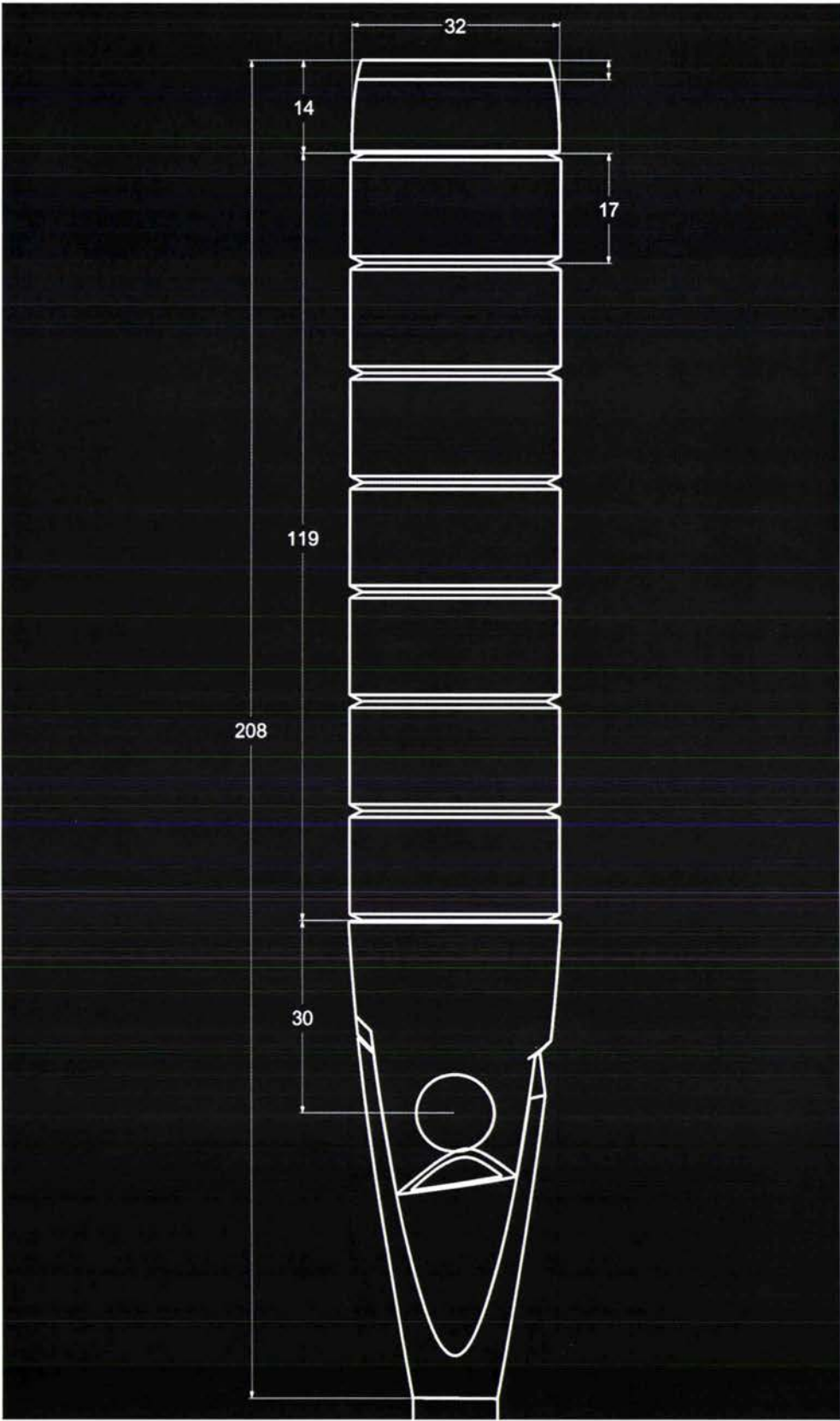


fig.49 Computer models of Tactor Cane handles



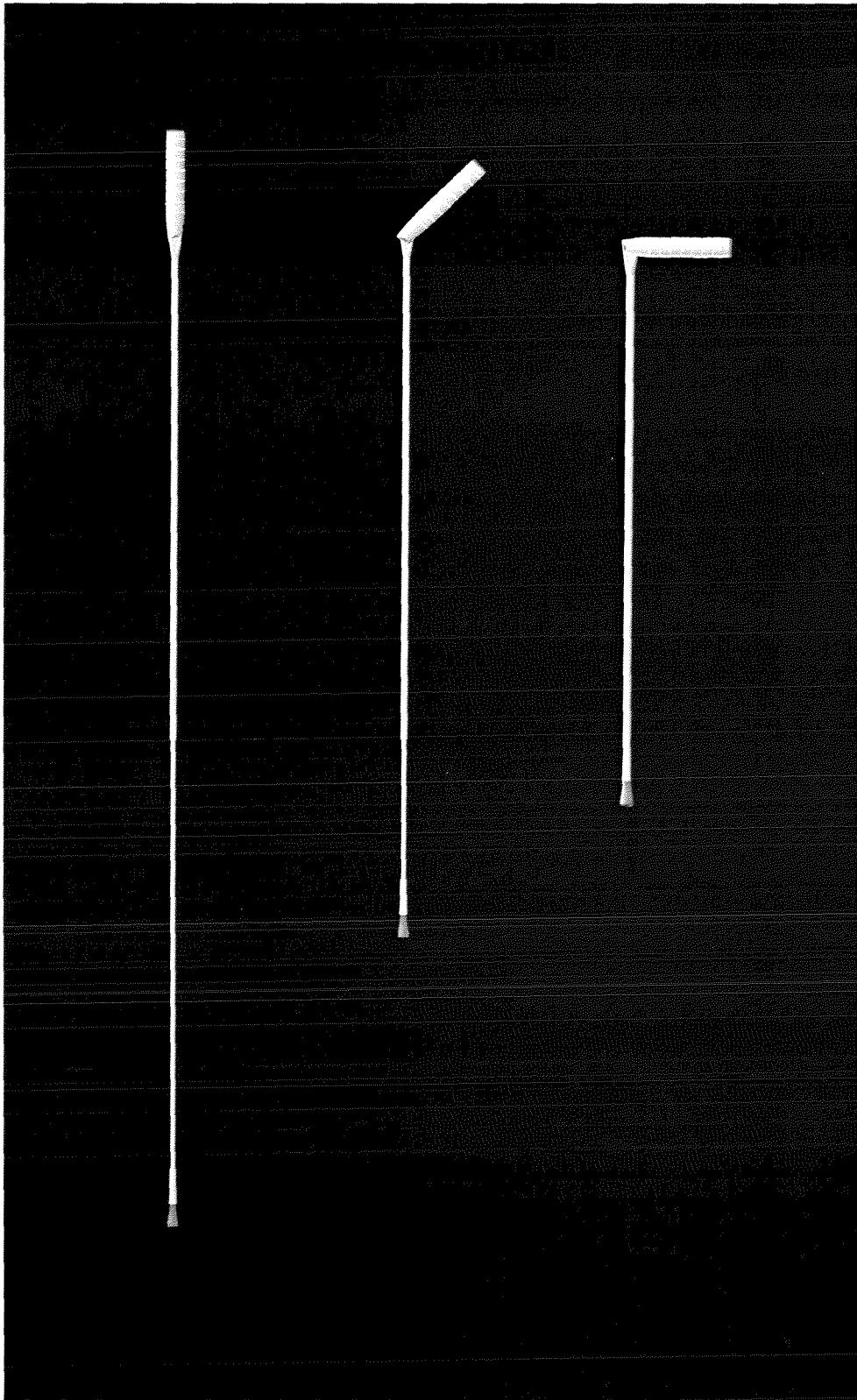


fig.50 (previous page) Technical drawing of Tactor Cane handle in scale 1:1
fig.51 Tactor-Cane in various lengths and handle positions

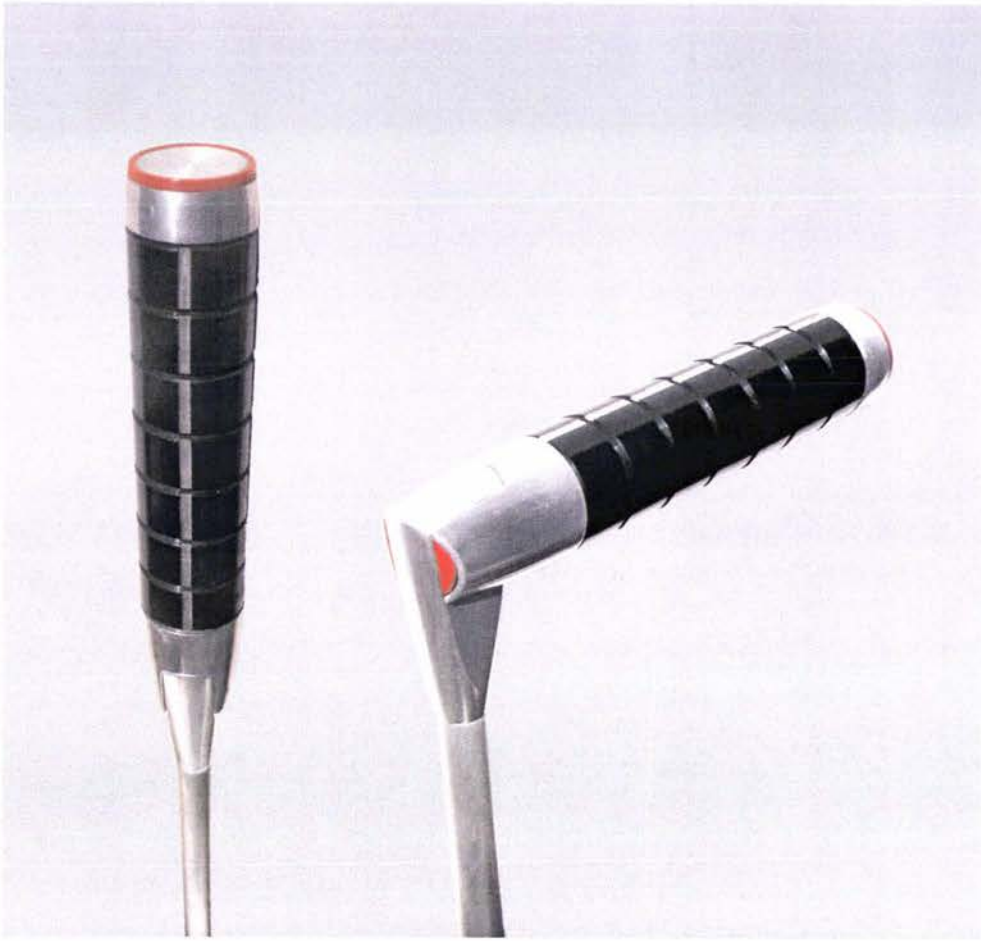


fig.52 Handle in 0° and90° position

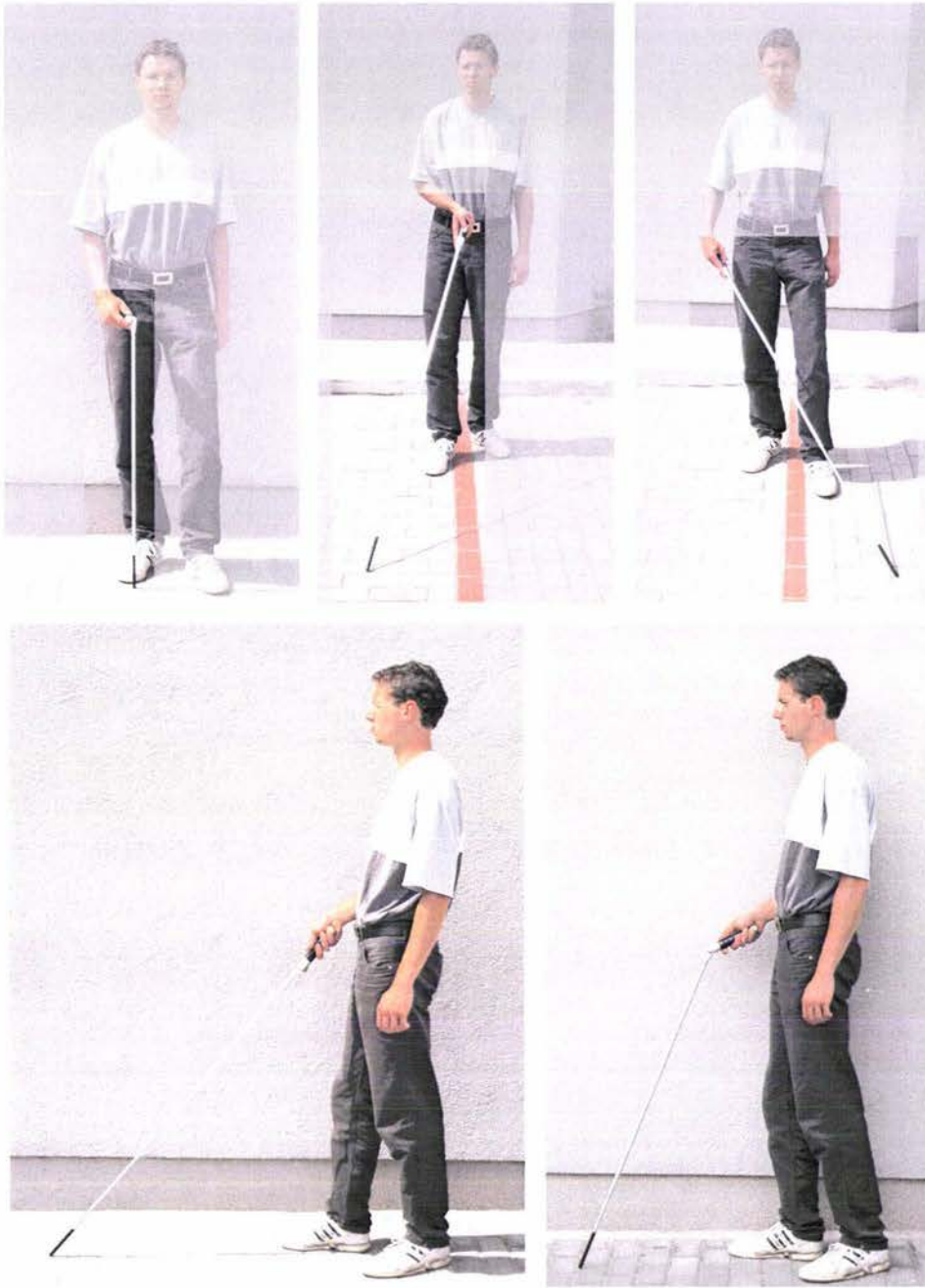


fig.53 Use of Tactor Cane as long cane and half-folded cane

3.6.3 Evaluation

To evaluate functions and ergonomics of the Tactor Cane design, a model was built and a questionnaire was prepared to gain information from the potential user group. A school for blind children, an association for sight impaired, a society for the blind, and a company that develops canes for the blind in Berlin/Germany were contacted to help evaluating the model. 35 blind people took part. The main aim was to estimate the potential of the Tactor Cane and to define further research that is based on this evaluation.

3.6.4 Questionnaire

The Tactor Cane design model was explained to the volunteers. In separate interviews each volunteer was asked to test the cane model. Although, the volunteers had to imagine how the vibration signals would work they could directly feel how the handle design would support this function in terms of ergonomic aspects such as handling and weight.

The following questions were given:

(1) Would the Tactor Cane improve the function of a long stick?

| | |
|-------------------------|----|
| Yes | 25 |
| No | 4 |
| Do not know | 2 |
| Do not use a long stick | 4 |

(2) How do you judge the ergonomic qualities of the handle shape?

| | |
|--------------|----|
| Insufficient | 3 |
| Sufficient | 8 |
| Good | 18 |
| Excellent | 6 |

(3) The handle is partitioned into seven factor rings. How would you categorise the tactile separation of the rings?

| | |
|--------------|----|
| Insufficient | 7 |
| Sufficient | 15 |
| Good | 12 |
| Excellent | 1 |

(4) The Tactor Cane is foldable from a long cane into a short cane with flexible handle position. How would you judge this new function?

| | |
|------------|----|
| not useful | 28 |
| useful | 7 |

(5) Do you have any general concerns about the Tactor Cane?

| |
|---------------------------|
| weight of the Tactor Cane |
| high costs |
| complexity in use |
| foldable handle |

3.6.5 Findings from questionnaire survey

A majority of 71 percent could imagine improvements in orientation by Tactor Canes. A similar number of volunteers judged the shape with "good" or even "excellent". Three reported insufficient ergonomic qualities of the handle model and eight judged it to be "sufficient". One blind volunteer mentioned that so-called "ergonomic" handle shapes that fit into the hand but support only one hand position are uncomfortable, because he uses different hand positions or want to be able to change them slightly during use.

43 percent judged the separation of the tactors to be "sufficient" and 34 percent to be "good". 20 percent reported insufficient tactile characteristics of the handle design model. Some of them mentioned that it is not necessary to separate every single tactor ring, because the spatial resolution into front, middle, and rear part of the handle is primarily important. It is not necessary to sense vibrations at the third tactor ring, but it is important to know that the vibrations are generated in the middle of the handle which presents the middle sector of the laser scanned area in front of them.

The outcome of question (4) was the most unexpected. 80 percent found it useless to combine flexible length with flexible handle position of a cane. Foldable long canes are essential because they might be disturbing when they are not needed. Flexible length is not necessary in use, because it is faster to shorten the grip than to shorten the whole cane. Turning the handle into various position is not necessary or is even prejudicial to the cane movement. Some people mentioned that a slight angle of the handle may help them to perform the scanning with their canes. It probably demands a more comprehensive testing period to get better impressions on various handle positions.

All volunteers immediately stated the heavy weight of the design model which is 650g. A conventional long cane weighs around 150-250g. Accordingly, working tactor canes including all electronic parts should not weigh more than 250g.

4. Conclusion

The conclusion of this research is based on two facts that will influence future interface designs:

- (1) The move to digital, mobile network technology in business and everyday life enables new and efficient human-computer interactions for all user groups, including impaired people.
- (2) Product design incorporates tactor interfaces into new mobile devices to ease tele-operations.

In summary, technologies with an information age focus on mobile tele-operations needs to be better utilised in future. They enable the design of interfaces that provide multi-sensory human-computer interactions on mobile devices. New features and functions face the need for more flexibility and efficiency in modern society. It has been found in this research that the use of tactor interfaces which provide tactile human-computer interaction is a new quality in multi-sensory information transmission.

To improve interface designs in the future, current mobile devices that reveal user-unfriendly interfaces have been analysed. They are not intuitive, are unergonomic and demand learning of abstract operations. Their multi-functionality is hard to understand and confusing.

The introduction of tactile information processing shows potential alternatives in mobile device operations. The Tactile Wristband for tactile telecommunication and the Tactor Cane for tactile navigation have been worked out as examples to present the advantages and benefits of tactile human-computer interactions. Their use has been proven by taking into account cognitive, communicative, ergonomic and technical aspects. Considering multi-functionality and multi-tasking on mobile devices, tactile information transfer is an innovation that is intuitive, fast and reliable.

Final conclusions of the two design concepts can be drawn within the knowledge of cogni-

tion and human factors that has been achieved. Tactile signals can enrich or extend human-computer interactions without interfering other sensory modalities. They are individual and do not disturb the environment of the users. Conducted experiments made it possible to define the range of vibrations that are useful for tactile signals.

Tactor Wristbands enable direct telecommunications without any need of hearing and sight. Their use is most suitable for user groups with limited perceptions in hearing and sight. Mobile picture phones in conjunction with Tactor Wristbands allow lip reading with tactile voice detection to facilitate mobile telecommunication for deaf people. Fire Fighters, hospital staff, pilots and other professions that have to operate in stressful environments may benefit from intuitive and reliable signals. It has been found that vibrations with high frequencies are suitable for warning signals as these frequencies generate discomfort and will be noticed.

The Tactor Cane presents an example of product improvement by tactile signals. The perceptive benefits of an alternative communication channel become obvious in comparison to perceptive deficits of blind people. The Tactor Cane may extend the conventional functions of a long cane and may open up new dimensions in mobility and independence for blind people. The laser beam together with the specific ergonomic design of the cane handle would enable a spatial sensing in distances that have not been accessible to the blind, so far. The Tactor Cane would be used in the same way as conventional long canes and would not demand any extra training.

4.1 Open issues

To carry forward the development of Tactor Wristbands and Tactor Canes, prototypes need to be designed that demand further research in micro-technology. The relevance of technical feasibility in this field has been underestimated, not in a way that form follows function but in a way that theoretical and empirical research should alternate.

It remains the task of further research to evaluate how touch can be encoded into language or tele-touch code to serve as communication channel. Ideas for tactile codes have

been developed but representative numbers of tests that use electro-mechanical factors to evaluate tactile communication are still required.

Research that goes beyond the scope of this thesis is only possible by testing prototypes and real teleoperations. Identification of the key elements of interaction will be crucial for interface design. More understanding of the research of cognitive science and human-computer interface design would quickly raise the standards of poor design currently in use.

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Download: 2002-03-05
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Appendix

Questionnaire - raw data

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- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: dirge@ihug.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Questionnaire

Datum: 03 Feb 2002 02:28:32 (MEST)

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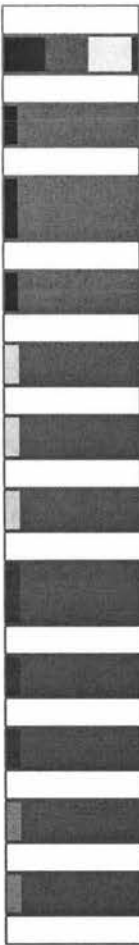
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> Mobile Music Player x
> Organiser
> Digital Camera
> Cell-Phone x
>
> (2) How often do you use them?
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> Organiser
> Digital Camera
> Cell-Phone x
>
> Questions 3 and 4 are only for cell-phones users.
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> (3) Remember the first use of your cell-phone. Was it easy to understand
> the
> interface?
> Very easy
> Easy x
> Difficult
> Very difficult
>
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> cell-phone compared to all features it provides?
> I use all features regularly
> I use less than 50 percent
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> Call
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> --
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>
> Jetzt ein- oder umsteigen und USB-Speicheruhr als Prämie sichern!

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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: gillnewland@clear.net.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Re: Questionnaire

Datum: 24 Jan 2002 09:46:26 (MEST)

Ordner

- Posteingang
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--> Als SPAM behandeln

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<-- Posteingang



Von: kiakaha@angfire.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 10:51:11 (MEST)

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

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- Spamverdacht
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--> Als SPAM behandeln

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neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: majak7@hotmail.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 21 Jan 2002 09:44:27 (MEST)

Services

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- Posteingang
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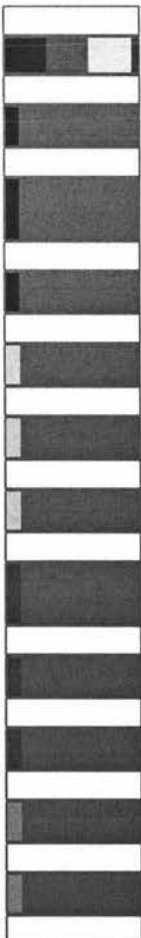
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 > (1) What kind of mobile digital devices do you use?
 > Mobile Music Player
 > Organiser
 > Digital Camera x
 > Cell-Phone x
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- SMS schreiben
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- e-card schreiben

<-- Posteingang



Von: annasbox@web.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 22:58:35 (MEST)

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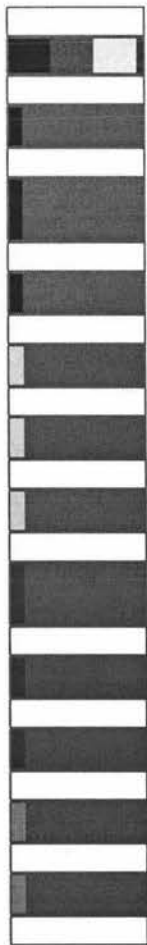
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- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: guy.brew@paradise.net.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 23:34:36 (MEST)

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- e-card schreiben

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Von: tpwk@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 23:42:28 (MEST)

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neue Message

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- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: mail@florian-vollmer.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 23:11:11 (MEST)

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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: jan.vietze@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 21:31:15 (MEST)

Services

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> (1) What kind of mobile digital devices do you use?
> Mobile Music Player
> Organiser
> Digital Camera
> Cell-Phone x
>
> (2) How often do you use them?
> every day every week every month
> Mobile Music Player
> Organiser
> Digital Camera
> Cell-Phone x
>
> Questions 3 and 4 are only for cell-phones users.
>
> (3) Remember the first use of your cell-phone. Was it easy to understand
> the
> interface?
> Very easy
> Easy
> Difficult x
> Very difficult
>
> (4) How do you estimate the percentage of features you use regularly on
> your
> cell-phone compared to all features it provides?
> I use all features regularly
> I use less than 50 percent x
> I use more than 50 percent
>
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> E-mail
> SMS
> Call x
>
> If you have any questions or concerns please feel free to contact me under
> tillmainz@gmx.de
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> --
> +++ GMX - Mail, Messaging & more <http://www.gmx.net> +++
>
> Jetzt ein- oder umsteigen und USB-Speicheruhr als Prämie sichern!

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neue Message

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- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: jo2c@hotmail.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 26 Jan 2002 08:21:39 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
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--> Als SPAM behandeln

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 > Mobile Music Player x
 > Organiser
 > Digital Camera
 > Cell-Phone
 >
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 > Organiser
 > Digital Camera
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--> Messages

? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: ullipaech@onlinehome.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 22:03:44 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

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

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> (1) What kind of mobile digital devices do you use?
> Mobile Music Player x
> Organiser
> Digital Camera
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> Jetzt ein- oder umsteigen und USB-Speicheruhr als Prämie sichern!

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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: steinieberlin@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 14:28:43 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

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> (1) What kind of mobile digital devices do you use?
> Mobile Music Player x
> Organiser
> Digital Camera
> Cell-Phone x
>
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: birkelbach@dhzb.de

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 12:28:32 (MEST)

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

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 > Digital Camera x
 > Cell-Phone x
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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: ralle02@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 23:42:13 (MEST)

Ordner

- Posteingang
- Spamverdacht
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--> Als SPAM behandeln

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 > Organiser
 > Digital Camera
 > Cell-Phone x
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 > Mobile Music Player x
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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: tt@3genllc.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 01:08:07 (MEST)

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- Mail Info Service

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- Posteingang
- Spamverdacht
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--> Als SPAM behandeln

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neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: workshop6@xtra.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 26 Jan 2002 08:21:39 (MEST)

Services

- Mail Info Service

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- Posteingang
- Spamverdacht
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 > Mobile Music Player
 > Organiser
 > Digital Camera x
 > Cell-Phone x
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: christinakellner@yahoo.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 28 Jan 2002 19:22:21 (MEST)

Services

- Mail Info
- Service

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- Posteingang
- Spamverdacht
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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: Barbara.blewman@atrix.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 03:44:33 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

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> (5) If you want to send a message like: "I will meet you at 12.00 for
> lunch."
> Do you tend to send it as:
> E-mail
> SMS
> Call x
>
> If you have any questions or concerns please feel free to contact me under
> tillmainz@gmx.de
>
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> --
> +++ GMX - Mail, Messaging & more <http://www.gmx.net> +++
>
> Jetzt ein- oder umsteigen und USB-Speicheruhr als Prämie sichern!

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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: dorthej@xtra.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 09:26:36 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

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>

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> (1) What kind of mobile digital devices do you use?
> Mobile Music Player
> Organiser
> Digital Camera
> Cell-Phone x
>
> (2) How often do you use them?
> every day every week every month
> Mobile Music Player
> Organiser
> Digital Camera
> Cell-Phone x
>
> Questions 3 and 4 are only for cell-phones users.
>
> (3) Remember the first use of your cell-phone. Was it easy to understand
> the
> interface?
> Very easy
> Easy
> Difficult x
> Very difficult
>
> (4) How do you estimate the percentage of features you use regularly on
> your
> cell-phone compared to all features it provides?
> I use all features regularly
> I use less than 50 percent x
> I use more than 50 percent
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> Jetzt ein- oder umsteigen und USB-Speicheruhr als Prämie sichern!

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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: fasdiagram@hotmail.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Questionnaire answers

Datum: 23 Jan 2002 17:55:03 (MEST)

Services

- Mail Info
- Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere

--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

Weiterleiten

Umleiten

Löschen

>Questionnaire:

>

> You are invited to take part in a study about tactile interface designs for mobile digital appliances by answering a questionnaire about your experience with mobile digital appliances.

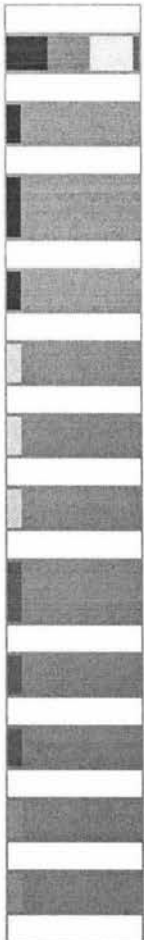
> I am currently a product design student at the College of Design, Fine Arts, and Music, Massey University Wellington.

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 > (1) What kind of mobile digital devices do you use?
 > Mobile Music Player x
 > Organiser
 > Digital Camera
 > Cell-Phone x
 >
 > (2) How often do you use them?
 > every day every week every month
 > Mobile Music Player x
 > Organiser
 > Digital Camera
 > Cell-Phone x
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 > Very easy
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 > Call
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: jordi-r@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 17:22:54 (MEST)

Services

- Mail Info Service

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- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

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Löschen

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 > (1) What kind of mobile digital devices do you use?
 > Mobile Music Player
 > Organiser x
 > Digital Camera x
 > Cell-Phone x
 >
 > (2) How often do you use them?
 > every day every week every month
 > Mobile Music Player
 > Organiser x
 > Digital Camera x
 > Cell-Phone x
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 > Very easy
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: leola.nick@xtra.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 28 Jan 2002 22:31:21 (MEST)

Services

- Mail Info Service

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- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

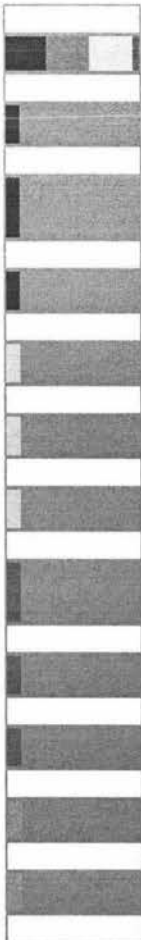
Weiterleiten

Umleiten

Löschen

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--> Messages

? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: kuketa1@yahoo.com

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Re: Questionnaire

Datum: 28 Jan 2002 05:31:51 (MEST)

Ordner

- Posteingang
- Spamverdacht
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--> Als SPAM behandeln

Verschieben nach ...

Antworten

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> Mobile Music Player
> Organiser
> Digital Camera
> Cell-Phone x
>
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> Organiser
> Digital Camera
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> Jetzt ein- oder umsteigen und USB-Speicheruhr als Prämie sichern!

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--> Messages

? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: realtype@xtra.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 03:11:55 (MEST)

Services

- Mail Info
- Service

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- Posteingang
- Spamverdacht
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=> Als SPAM behandeln

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Löschen

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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: martin@rinopai.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 01:34:49 (MEST)

Services

- Mail Info
- Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

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> (1) What kind of mobile digital devices do you use?
> Mobile Music Player x
> Organiser
> Digital Camera
> Cell-Phone x
>
> (2) How often do you use them?
> every day every week every month
> Mobile Music Player x
> Organiser
> Digital Camera
> Cell-Phone x
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> Questions 3 and 4 are only for cell-phones users.
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> (3) Remember the first use of your cell-phone. Was it easy to understand
> the
> interface?
> Very easy
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> Very difficult x
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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: sefese@web.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 20:25:07 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

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Löschen

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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: yvon.smits@quicksilver.net.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 21:21:36 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

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Löschen

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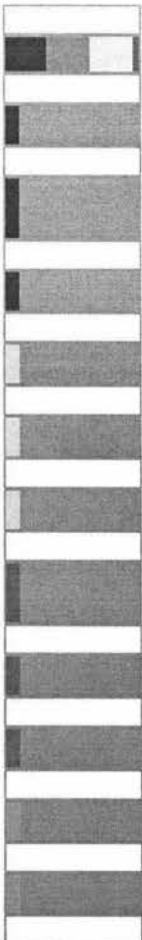
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: kendesz@hotmail.com

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Antwort auf Deine Fragen

Datum: 22 Jan 2002 14:15:57 (MEST)

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

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Allen antworten

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>Questionnaire:

>

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> Digital Camera
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: niko_mainz@de.hettich.com

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Dein Questionnaire

Datum: 26 Jan 2002 08:53:42 (MEST)

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

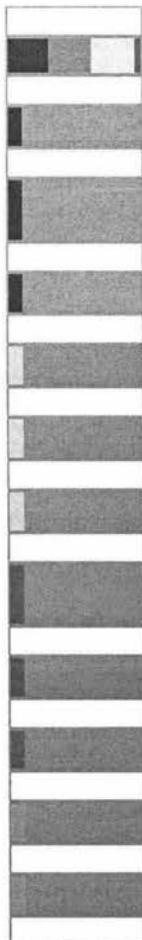
Weiterleiten

Umleiten

Löschen

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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: tatjanapanyoczki@hotmail.com

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Re: Questionnaire

Datum: 24 Jan 2002 05:02:17 (MEST)

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

Weiterleiten

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Löschen

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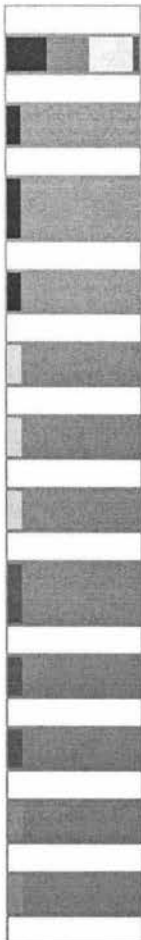
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> Digital Camera
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? E-MAIL
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neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: ch.wendt

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 19:12:36 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere

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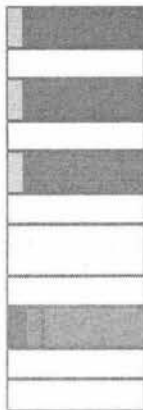
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: kayvandyk@paradise.net.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 03:24:47 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

Weiterleiten

Umleiten

Löschen

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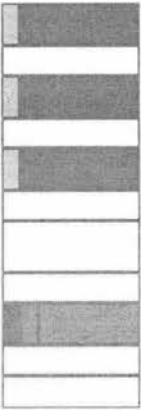
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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: d-gracie@ihug.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 03:24:47 (MEST)

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

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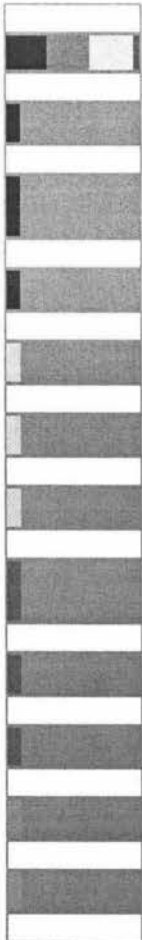
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neue Message

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- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: m.lechner@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 12:12:28 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere

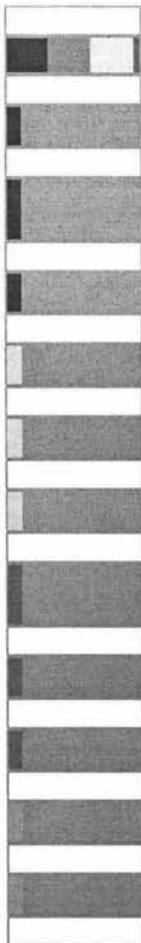
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Verschieben nach ...

Antworten | Allen antworten | Weiterleiten | Umleiten | Löschen

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Antworten Allen antworten Weiterleiten Umleiten Löschen



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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: schuenecke@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Re: Questionnaire

Datum: 26 Jan 2002 13:48:33 (MEST)

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- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

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Antworten

Allen antworten

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? E-MAIL
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neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: snawds@ihug.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Answers

Datum: 23 Jan 2002 07:23:48 (MEST)

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

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>
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> (1) What kind of mobile digital devices do you use?
> Mobile Music Player
> Organiser
> Digital Camera
> Cell-Phone x
>
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> --
> +++ GMX - Mail, Messaging & more <http://www.gmx.net> +++
>
> Jetzt ein- oder umsteigen und USB-Speicheruhr als Prämie sichern!

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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: carsten_sauer@yahoo.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Questionnaire

Datum: 01 Feb 2002 15:12:13 (MEST)

Services

- Mail Info
- Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

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Löschen

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> Digital Camera
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: bh.quoil@paradise.net.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 08:16:36 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

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Umleiten

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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: pete@elsbury.net

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 26 Jan 2002 05:33:16 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

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--> Messages

? E-MAIL
LESEN

<-- Posteingang



Von: berrys@paradise.net.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 21:38:21 (MEST)

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...



Antworten



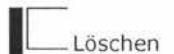
Allen antworten



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Löschen

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Antworten

Allen antworten

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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: ierle@staff.unitec.ac.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 28 Jan 2002 22:51:11 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

Weiterleiten

Umleiten

Löschen

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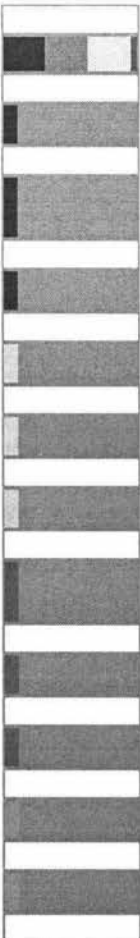
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 > Cell-Phone x
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 > Jetzt ein- oder umsteigen und USB-Speicheruhr als Prämie sichern!

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 Allen antworten
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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: maryalford21@hotmail.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Questionnaire

Datum: 25 Jan 2002 07:31:56 (MEST)

Services

- Mail Info
- Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

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? E-MAIL
LESEN

<-- Posteingang



Von: laing.aiken@xtra.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 24 Jan 2002 01:14:37 (MEST)

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere

Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: a.tappi@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Services

- Mail Info Service

Betreff: Re: Questionnaire

Datum: 23 Jan 2002 20:11:21 (MEST)

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- Posteingang
- Spamverdacht
- ... weitere

--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: vfrei@hotmail.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 24 Jan 2002 22:11:31 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

Antworten

Allen antworten

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 >
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- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: artscape@xtra.co.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 02:33:04 (MEST)

Services

- Mail Info Service

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- Posteingang
- Spamverdacht
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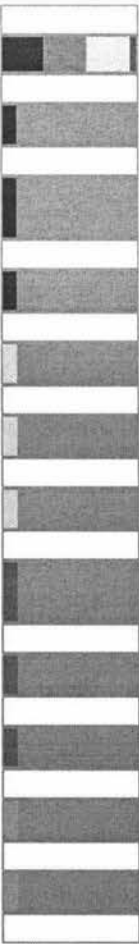
--> Als SPAM behandeln

Verschieben nach ...

Antworten Allen antworten Weiterleiten Umleiten Löschen

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> Mobile Music Player
> Organiser
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Antworten Allen antworten Weiterleiten Umleiten Löschen



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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: ngreen@clear.net.nz

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 25 Jan 2002 23:11:36 (MEST)

Services

- Mail Info Service

Ordner

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- ... weitere

--> Als SPAM behandeln

Verschieben nach ...

- Antworten
- Allen antworten
- Weiterleiten
- Umleiten
- Löschen

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Antworten Allen antworten Weiterleiten Umleiten Löschen



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? E-MAIL LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: juergen.mainz@gmx.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 22 Jan 2002 18:34:45 (MEST)

Services

- Mail Info Service

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- Spamverdacht
- ... weitere

--> Als SPAM behandeln

Verschieben nach ...

Antworten Allen antworten Weiterleiten Umleiten Löschen

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Antworten Allen antworten Weiterleiten Umleiten Löschen



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? E-MAIL
LESEN

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

<-- Posteingang



Von: dunconor@yahoo.com

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Answers

Datum: 25 Jan 2002 15:53:09 (MEST)

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere

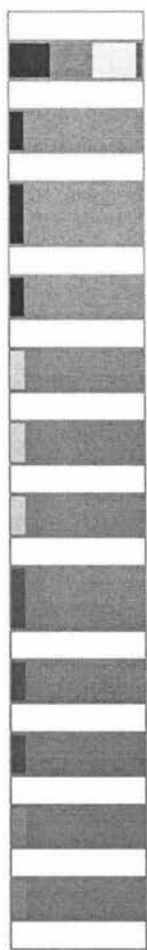
--> Als SPAM behandeln

Verschieben nach ...

Antworten | Allen antworten | Weiterleiten | Umleiten | Löschen

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Antworten Allen antworten Weiterleiten Umleiten Löschen



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? E-MAIL
LESEN

<-- Posteingang



Von: m.eins@t-online.de

--> ins Adressbuch

An: tillmainz@gmx.de

Betreff: Re: Questionnaire

Datum: 28 Jan 2002 20:21:47 (MEST)

neue Message

- e-mail schreiben
- SMS schreiben
- Fax senden
- e-card schreiben

Services

- Mail Info Service

Ordner

- Posteingang
- Spamverdacht
- ... weitere



--> Als SPAM behandeln

Verschieben nach ...

- Antworten
- Allen antworten
- Weiterleiten
- Umleiten
- Löschen

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Antworten Allen antworten Weiterleiten Umleiten Löschen

(1) What kind of mobile digital devices do you use?

| | | |
|---------------------|--|----------|
| Mobile Music Player | | 15 |
| AGE: | 33, 31, 27, 19, 28, 26, 32, 29, 27, 28, 28, 32, 21, 40, 26 | ∅ 28, 47 |
| Organiser | | 4 |
| AGE: | 32, 35, 33, 30 | ∅ 32, 5 |
| Digital Camera | | 7 |
| AGE: | 29, 23, 28, 32, 35, 30, 28 | ∅ 29, 3 |
| Cell-Phone | | 35 |
| AGE: | 33, 42, 31, 36, 29, 19, 23, 28, 26, 32, 29, 29, 26, 35, 48, 27, 30, 28, 35 28, 27, 27, 34, 32, 30, 43, 32, 42, 21, 40, 26, 30, 42, 38, 30 | ∅ 31, 7 |

(2) How often do you use them?

| | every day | every week | every month |
|---------------------|--|----------------------------|----------------------------|
| Mobile Music Player | 3 | 7 | 5 |
| AGE: | 27, 28, 28 ∅ 27, 7 | 33, 27, 28, 32, 29, 32, 21 | 31, 19, 26, 40, 26 ∅ 28, 4 |
| Organiser | 4 | 0 | 0 |
| AGE: | 32, 35, 33, 30 ∅ 32, 5 | | |
| Digital Camera | 0 | 2 | 5 |
| AGE: | | 32, 35 ∅ 33, 5 | 29, 23, 28, 30, 28 ∅ 27, 6 |
| Cell-Phone | 29 | 3 | 3 |
| AGE: | 35, 26, 29, 33, 42, 31, 36, 19, 23, 28, 26, 32, 29, 48, 27, 30, 28, 35, 28, 27, 27, 32, 21, 40, 34, 26, 42, 38, 30 ∅ 31, 1 | 29, 30, 42 ∅ 33, 7 | 43, 32, 30 ∅ 35 |

(3) Remember the first use of your cell-phone. Was it easy to understand the interface?

| | | |
|----------------|--|----|
| Very easy | | 3 |
| AGE: | 28, 27, 21 ∅ 25, 3 | |
| Easy | | 12 |
| AGE: | 42, 31, 29, 19, 23, 32, 29, 26, 35, 30, 28, 35 ∅ 29, 9 | |
| Difficult | | 12 |
| AGE: | 33, 36, 26, 28, 27, 27, 34, 40, 26, 42, 38, 30 ∅ 32, 3 | |
| Very difficult | | 8 |
| AGE: | 29, 48, 32, 30, 43, 32, 42, 30 ∅ 35, 8 | |

(4) How do you estimate the percentage of features you use regularly on your cell-phone compared to all features it provides?

| | |
|------------------------------|--|
| I use all features regularly | 0 |
| AGE: | |
| I use less than 50 percent | 25 |
| AGE: | 33, 31, 36, 23, 26, 32, 29, 26, 48, 30, 35, 28, 27, 27, 32, 30, 43, 32, 42, 30, 42, 38, 34, 26 ∅ 32, 4 |
| I use more than 50 percent | 10 |
| AGE: | 42, 29, 19, 28, 29, 35, 27, 28, 21, 40 ∅ 29, 8 |

(5) If you want to send a message like: "I will meet you at 12.00 for lunch."

Do you tend to send it as:

| | | |
|--------|--|----|
| E-mail | | 4 |
| AGE: | 28, 33, 35, 50 ∅ 36, 5 | |
| SMS | | 11 |
| AGE: | 33, 19, 26, 29, 35, 28, 28, 27, 34, 21, 26 ∅ 27, 8 | |
| Call | | 35 |
| AGE: | 42, 31, 36, 29, 27, 23, 32, 29, 26, 35, 33, 60, 48, 27, 30, 36, 28, 27, 56, 60, 32, 30, 43, 32, 42, 40, 30, 42, 38, 30, 20, 42, 30, 43, 34 ∅ 35, 5 | |

(1) Would the Tactor Cane improve the function of a long stick?

| | | |
|-------------------------|--|----|
| Yes | | 25 |
| No | | 4 |
| Do not know | | 2 |
| Do not use a long stick | | 4 |

(2) How do you judge the ergonomic qualities of the handle shape?

| | | |
|--------------|---|----|
| Insufficient | | 3 |
| Sufficient | | 8 |
| Good | | 18 |
| Excellent | 1 | 6 |

(3) The handle is partitioned into seven factor rings. How would you categorise the tactile separation of the rings?

| | | |
|--------------|---|----|
| Insufficient | | 7 |
| Sufficient | | 15 |
| Good | | 12 |
| Excellent | 1 | 1 |

(4) The Tactor Cane is foldable from a long cane into a short cane with flexible handle position. How would you judge this new function?

| | | |
|------------|--|----|
| not useful | | 28 |
| useful | | 7 |

(5) Do you have any general concerns about the Tactor Cane?

- weight
- high costs
- complexity
- foldable handle/cane