The effects of sensory impairments on product experience and personal well-being

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ABSTRACT

To determine the roles the sensory modalities play in user-product interactions, one modality was blocked during the execution of eight simple tasks. Participants reported how they experienced the products and how they felt during the experiment. Blocking vision resulted in the largest loss of functional information, increased task difficulty and task duration, and fostered dependency. On the other hand, the other senses were used more and product experiences increased in perceived intenseness. When touch was blocked, the perceived loss of information was smaller, and participants reported that familiar products felt less like their own. Blocking audition resulted in communication problems and a feeling of being cut off. Blocking olfaction mainly decreased the intenseness of the experience. These outcomes suggest that vision mainly plays a functional role in everyday user-product interactions, whereas the main role for olfaction lies in the affective domain.

Statement on relevance

Sensory impairments change the way people experience products. Blocking a single modality during everyday tasks gives insight into the impact of impairments. These insights can be used to develop products for multiple user groups (inclusive design) or products used under extreme environmental conditions.

Keywords: perception, product experience, sensory deprivation, disability, multisensory

1. INTRODUCTION

During the interaction with a product, the user continuously receives information through the different senses. This sensory feedback is necessary to operate the product (e.g., Akamatsu *et al.* 1995). Each sensory modality is sensitive to a different type of energy and is stimulated by different product properties. As a consequence, the modalities usually provide different pieces of product information, although some of it may overlap. When a sensory modality does not function properly, the sensory information is no longer complete. The type and degree of impairment affect how that person experiences the product. A sensory impairment becomes a handicap if it affects behaviour and if it affects the emotional well-being of the person.

The assessment of people's sensory functions is an important aspect of ergonomics research. A thorough understanding of the roles the different modalities play in human-product interactions helps to predict the impact of a sensory impairment on how the product is experienced. In addition, it helps to evaluate whether some information could also be communicated through an alternative sensory channel. A product experience is defined here as the entire set of psychological effects a product has on a user. The product experience thus includes its perception, the identification process it triggers, the cognitive associations and memories it activates, the feelings and emotions it elicits, and the evaluative judgments it brings about (Schifferstein and Cleiren 2005; Schifferstein and Hekkert 2007).

In the present study, the roles of the modalities are compared by assessing people's experiences in everyday tasks while one of their sensory modalities is blocked (e.g., Stewart *et al.* 1979). The findings are related, on the one hand, to outcomes of highly-controlled laboratory studies of human perception and, on the other hand, to experiences reported by people who live with various types of handicaps. The outcomes of the present research are relevant for the development of products that can be used by multiple user groups (e.g., McFarland 1962, Gardner *et al.* 1993, Rogers *et al.* 1996) or for products that are used under extreme environmental conditions (e.g., Enander 1984).

1.1. The roles of the modalities in everyday life

Popular belief holds that vision dominates human experience. When people are asked which sensory modality they would miss most if they lost it, the majority are likely to indicate vision (Fiore and Kimle 1997). In an evaluation of the roles of the sensory modalities in user-product interactions, however, people reported that they found one of the other sensory modalities more important than vision for about half of the products tested (Schifferstein 2006). For example, for a computer mouse the tactual characteristics were reported to be most important, for a vacuum cleaner the sound it made, for a cleaning product its smell, and for a soft drink its taste. The relative importance of a modality for product usage in general may depend, for example, on the variation in sensory stimulation in that modality over products, the relevance of the sensory information for functional usage, and on its role in enjoying products.

Lindstrom (2005) used a structural equation model to quantify the impact of the different senses on three drivers of brand loyalty: leadership (the brand sets the trends, is most authentic, or most popular), clarity (the brand has a clear identity different from other brands), and great experience (the brand is enjoyed more and appeals more than other brands, has the highest quality). He found that all modalities affected all three drivers of brand loyalty except for vision, which did not contribute to having a great experience. He concluded that although vision plays a strong supporting role for the other senses, it has a less powerful influence on brand loyalty than the other modalities.

Processing visual information is very different from processing olfactory information. Hinton and Henley (1993) asked participants to write down whatever came to their minds when they perceived either a smell or a picture of a product. Responses cued by olfaction consisted of fewer words, were more personal, and had stronger affective components than responses cued by visual stimuli. Adjectives used to describe the smell usually referred to the smell experience itself (e.g., citrus, sweet, and sour for an orange), whereas the visual stimulus elicited remarks about texture, shape, and colour and evoked more cognitive associations (e.g., Florida, vitamin C, healthy).

The affective dimension seems to dominate olfactory cognition. Odour pleasantness plays an important role in odour categorizations and smell experiences are largely idiosyncratic (Dubois 2000). In addition, emotions play an important role in the memories elicited by odours (Herz and Schooler 2002). Visual input, on the other hand, seems to be linked most directly to stored knowledge, such as information on production method, region of origin, and product safety (Hinton and Henley 1993, Burns *et al.* 1995). The functional use of olfactory information is probably limited to a few specific product categories such as food, personal care, and cleaning products, which is illustrated by the high importance people attach to smell for these categories (Schifferstein, 2006).

Touch and audition seem to lie somewhere in between these two extremes. Tactual experiences are likely to possess a substantial emotional component, given the key role that touch plays in mediating interpersonal intimacy (Fischer *et al.* 1976). In addition, and similar to visual exploration, people gather a lot of information about a product through touching. On the one hand, this makes it relatively easy for people to identify many common objects by touch alone (Klatzky *et al.* 1985). On the other hand, this information is very helpful during functional product usage.

Because audition plays an important part in the expression of emotion, for example in the non-verbal aspects in human speech (e.g., Scherer, 2003) and in music (e.g., Herz, 1998; Krumhansl, 2002), product sounds may be expected to affect the emotional product expression. Furthermore, given that audition is critical in verbal communication by means of which factual information may be effectively distributed to others, one might perhaps expect that sounds play an analogous role in communicating factual information about products as well.

To assess the potential contribution of each sensory modality to product experiences, Schifferstein and Cleiren (2005) presented participants with multisensory products through a single sensory modality (vision, touch, audition, or olfaction) and asked them to describe their experience. They found that vision and touch provided the largest number of details about a product. In contrast to the prominent role of audition in verbal processing, product sounds were not all that informative. Product smells provided the least information about the product. The relatively large number of details obtained with vision and touch made product identification easiest and yielded the clearest associations to events, people, and other products. Because vision gathers information about many product aspects more rapidly than touch (Jones and O'Neil 1985), vision is likely to dominate product experiences in real-life situations. As a consequence, vision has been found to guide object exploration through other modalities (Heller 1982, Klatzky *et al.* 1993).

1.2. Consequences of missing sensory information

A person who misses some sensory information will have more difficulty in anticipating other sensory input, which increases the risk of missing other information as well. The lack of information makes it more difficult to make certain decisions and increases the possibility of making errors. In addition, a sensory impairment is likely to affect a person’s feelings.

Objects may be perceived as less stimulating and, consequently, a person may become bored more easily. The limited amount of information may cause feelings of uncertainty, confusion, or disorientation. When someone is unable to perform certain basic tasks, this is likely to cause frustration. Below, an overview is given of the consequences of living with various types of sensory handicaps.

When a sighted person's visual information is blocked, that person loses the reference frame for judging spatial locations. Without an external structure that is stable relative to oneself and to other points in space, there is no such thing as being oriented (Marcel and Dobel 2005). Visual impairment has been associated with functional disability. It restricts mobility and activity, fosters dependency on other people, and diminishes the sense of well-being. People with visual impairments have difficulty with daily activities, such as dressing and grooming, and they may have trouble in identifying food. The time needed to perform a number of tasks increases when the level of visual functioning decreases (Owsley *et al.* 2001). People with visual impairments have an increased risk of mobility disorders and of becoming injured by an accident, such as a fall or burn. Also, they are less likely to engage in social and recreational activities. Visual impairment may lead to feelings of fear (e.g., fear of getting lost), sadness, and frustration (e.g., due to the inability to see one's grandchildren). It has been found to be associated with depression, a decline in cognitive function, and with mortality (Rovner and Ganguli 1998, Anstey *et al.* 2001b, Scilley and Owsley 2002, Lin *et al.* 2004).

Missing the entire sense of touch is hard to imagine, because people can experience haptic, cutaneous, temperature and pain sensations with almost their entire body. When tactual impairments occur they generally tend to be local, and tactual functions may be taken over by other body parts. People who have lost their sense of proprioception are unable to feel the position of their body parts, which leads to a loss of control: the body may not be experienced as their own anymore (Cole 1991). Without feeling pain, a person does not feel when he or she is wounded (Rollman 1991).

Cole (1991) provides an elaborate description of the life of a man who at nineteen years of age, suffered from a neuropathy which affected only his sensory tactual perception, while leaving his motor nerves intact. This patient was deprived of proprioceptive and cutaneous sensations from his feet to his neck, but he was able to perceive thermal sensations, pain, subcutaneous pressure, and tiredness or tension in his muscles. At first, the man could not sit, stand, or feed himself, and he would make uncontrolled movements. In time, he found out that he could control the movement and position of his limbs if he watched them deliberately. Whereas proprioception is normally used unconsciously, this patient needed to think constantly about the location and desired motion of his limbs. This required a constant and enormous amount of mental effort, which he could not use for other activities. If the patient lost focus or if the lights were turned off, he would slide and fall to the floor.

The main consequence of hearing impairment is that it leads to a breakdown in communication. People find it harder to foster and maintain interpersonal relationships, resulting in a higher degree of social isolation. Hearing impairment has been associated with depression and mortality (Weinstein and Ventry 1982, Jones *et al.* 1984, Anstey *et al.* 2001a).

People who lose their sense of smell are less likely to detect health hazards, such as fire, toxic fumes, leaking gas, and spoiled foods. Many objects, products and buildings, but also animals and people are experienced through smell, often unconsciously. Smell plays an important role in social interactions, sexual behaviour, and personal hygiene. After smell loss the pleasures associated with eating are impaired, which may result in loss of appetite. Smell loss reduces overall satisfaction with life to 50% and may lead to symptoms of depression (Miwa *et al.* 2001, Blomqvist *et al.* 2004).

It should be noted that besides having disadvantages, a sensory impairment may also have some advantages, because the person is no longer bothered by unpleasant stimuli, such as noise or a bad smell. A sensory impairment may make it easier to shut out distracting stimuli and to concentrate on ongoing activities.

Each sensory system needs stimulation to function properly. Under conditions of complete sensory deprivation people may lose a sense of the boundaries of their own body (Smith and Lewty 1959, Zuckerman 1969). When a person is completely deprived of a certain type of sensory stimulation for a long period of time, he or she may start to experience hallucinations and phantom phenomena in that modality. According to Melzack (1990) these phantom experiences are generated by the brain. Hallucinations may be due to the ‘release’ of perceptual traces, as a result of disinhibition of processes normally held in check by receiving sensory input (West 1975). Because only short-term blocking of sensory modalities is investigated in the current study, these phenomena are not gone into any further here.

1.3. Adaptation to sensory impairment

If perception is (partly) lost, people will not perceive all the feedback on their actions anymore and this may lead to an observable change in behaviour. For example, a man who cannot hear his own voice anymore may start to talk louder, because he is unable to determine the loudness of his voice, or a blind woman who cannot check whether someone is listening may talk louder to make sure that she is heard. To compensate for a (partial) loss or bias in perception, a person will usually develop an adaptive strategy (e.g., Welch 1978). A person may use another modality to take over the original function. For example, a visually impaired person may use the sense of smell to determine whether food is ripe or spoiled. Analogously, localizing an object may be taken over by audition, and exploring an object may be performed by touch. However, if a function is taken over by another modality, this may require extra effort. In addition, it may be necessary to adapt body posture during interactions with the product, or to spend more time exploring the product elaborately.

If certain functions can be taken over by other modalities, the capabilities of these modalities may increase. Empirical studies have shown that blindness and deafness do not result in increased absolute sensitivity thresholds for the remaining modalities (Smith *et al.* 1993, Bavelier and Neville 2002), but they may result in performance differences on more complex tasks. Anecdotal evidence suggests that sighted individuals who are blindfolded for a week improve their abilities to orient to sounds, to judge distance by sound, and to discriminate between product brands based on their sounds. In addition, some individuals report an improved ability to differentiate surfaces and to identify objects by touch (Pascual-Leone and Hamilton 2001). Long-term sensory deprivation in one modality generally leads to a reorganization of cortical functions in the brain: primary sensory cortices can become colonized by the remaining modalities and multimodal brain areas show enhanced processing of input to the remaining modalities (see Bavelier and Neville 2002 for a recent review).

Limitations in sensory abilities can also be compensated for by using technical devices. For people with mild sensory impairments, devices are available that modify sensory stimuli, such as spectacles and hearing aids. In case of more severe impairments, peripheral sensory implants and brain implants may be developed for people with or without intact afferent nerves, respectively (Rauschecker and Shannon 2002, Zrenner 2002). Furthermore, specialized devices have been constructed that make the sensory information of one modality available in another modality. Examples of such sensory substitution devices transform a visual scene into an array of tactual stimuli (Bach-y-Rita 2004) or into a sound pattern (Meijer 1992).

2. METHOD

In an experiment the roles of the modalities in daily life were assessed by investigating the effects of short-term blocking of one of the modalities on the experience of products during user-product interactions.

2.1. Participants

The experiment was completed by 100 paid volunteers, who were mainly undergraduate students from Delft University of Technology. The 55 men ranged in age from 17 to 28 years (mean 22.9). The 45 women were between 18 and 27 years old (mean 22.7). Apart from corrected-to-normal vision, no participants reported any sensory impairment.

2.2. Experimental conditions

Four experimental conditions were created, in which one sensory modality (vision, audition, touch, or olfaction) was blocked. In addition, a control condition was used, in which participants could employ all their sensory modalities. Each participant was randomly assigned to one of the five conditions. The main objective was to create conditions in which the role of the modalities could be compared under conditions that were as realistic as possible. Because the authors did not want participants to adopt the role of a passive observer, they ensured that participants explored and used the product actively in all conditions.

All manipulations strived for the largest degree of blocking under conditions maintained to be as natural as possible. However, blocking a modality generally does not only affect the interaction with the product. For example, the manipulation may produce discomfort (e.g., the nose aches due to wearing a nose clip) or it may interfere with verbal communication. In addition, it may not be possible to achieve complete blocking for all modalities. To make sure that these limitations would not be overlooked, participants provided estimates of the effectiveness of the manipulations and of the impact of possible side effects.

In the condition where vision was blocked, participants put on ski goggles, of which the transparent parts were covered with black tape. The edges that came into contact with the skin were made from flexible foam, so that the goggles fitted all participants, and no visual information could penetrate at the edges. Audition was blocked by playing white noise at the maximum volume of a personal computer through a wireless headphone (Philips HC8410). To diminish any annoyance caused by the loud noise, participants also wore earplugs during the majority of the tasks. However, during two tasks in which most sounds were generated inside the head (eating a cookie, brushing teeth), the earplugs were temporarily removed. Tactual perception was blocked by wearing thick, inflexible cotton oven gloves (Blokker). The gloves were water-resistant, so they did not become wet or dirty during the tasks. This manipulation blocked cutaneous perception of surface properties (texture, temperature) and the ability to detect small product parts, such as buttons and switches. However, it still allowed the tactual determination of global object shape and heaviness. Also, wearing the gloves could hinder the participant during the interaction with the product. Nevertheless, this manipulation was selected, because the alternatives were either less effective in blocking touch (e.g., wearing rubber gloves) or gave the participant a passive role (e.g., observing someone else interacting with the product). Olfaction was blocked with an adjustable nose clip that is usually worn by swimmers during training (Speedo). Wearing this clip restricted the participant to breathing through their mouth.

Besides the modality that was blocked, experimental conditions also differed in the way responses were recorded during the experimental tasks. When audition or smell was blocked, the participants wrote down the answers themselves. When vision or touch was blocked, participants reported their responses verbally and the experimenter wrote the results down. To facilitate visualization of the 7-point response scale, the participants were provided with a cardboard version of a 7-point scale in the latter two conditions. To allow identification of the categories in the blinded condition, category boundaries and the numbers 1-7 were carved in the cardboard scale. To test whether the way of responding affected the outcomes, half of the respondents in the control condition reported their answers verbally, whereas the others wrote down their responses on the forms. The way in which responses were recorded differed only during the execution of the eight tasks; all other forms were filled out by the participants themselves in all conditions.

2.3. Products and tasks

Eight tasks were chosen to represent a number of common daily activities in which multiple sensory modalities were involved. For healthy individuals, these tasks were easy to perform. Low and mid price product variants were used, consisting of both retail and private label brands. The tasks were selected to be as realistic as possible, to enhance the ecological validity of the study. No attempts were made to equate the tasks in duration or difficulty.

For six tasks, the products were provided by the experimenter. These are referred to as the 'unknown products'. Participants squeezed an orange with an electrical orange juicer (RY 112A), they boiled water in an electric water boiler (Philips HD 4399/C), they cleaned a table with spray cleaner (Kruidvat keukenreiniger) and a cleaning cloth (Kruidvat huishouddoekje), they ate a chocolate cookie (C1000 mini chocos), they brushed their teeth with a toothbrush (Blokker) and toothpaste (Aquafresh), and they used an electric vacuum cleaner (Moulinex Powerclean 1250) to clean a carpet. In the latter task, the carpet was made dirty before the participant entered the room, by spilling flour and chocolate confetti on it. Two tasks were performed with the participants' own products (the 'familiar products'): Participants took off one shoe and put it back on again, and they composed an SMS message on their mobile phone. Detailed task descriptions are given in Appendix 1.

2.4. Procedure

To the participants in the experimental groups, the study was introduced as a study that aimed to understand how impairments bother people in their daily activities and how a handicapped person is likely to feel. To participants in the control conditions, the study was introduced as a study on the problems that people face while performing simple actions, and their effects on how this makes a person feel. Subsequently, all participants provided demographic information (age, gender, educational background), provided informed consent, and reported whether they had any sensory impairment.

Then they filled out a questionnaire of 56 items on how they felt *at that very moment*, just before the start of the study. The list contained the 20 items of the Dutch version of the Positive And Negative Affect Schedule (PANAS, Watson *et al.* 1988, Peeters *et al.* 1999): interested (geïnteresseerd), tense (gespannen), cheerful (opgewekt), upset (van streek), strong (sterk), guilty (schuldig), afraid (bang), angry (kwaad), enthusiastic (enthousiast), proud (trots), irritable (prikkelbaar), clear-headed (helder), ashamed (beschaamd), inspired (geïnspireerd), nervous (nerveus), determined (vastberaden), attentive (oplettend), hurried (gejaagd), active (actief), and worried (bezorgd). Based on a review of the literature, 36 items were added in anticipation that experiences might differ in certain respects between sensorially handicapped and non-handicapped people. Care was taken to phrase items both negatively (e.g., threatened) and positively (e.g., safe). These additional items were: dependent (afhankelijk), mobile (beweeglijk), evasive (afhoudend), bored (verveeld), alert (alert), sincere (oprecht), threatened (bedreigd), stupid (dom), sad (verdrietig), restricted (geremd), tired (vermoeid), sure (zeker), safe (veilig), confused (verward), connected (verbonden), abiding (afwachtend), frustrated (gefrustreerd), combative (strijdlustig), quiet (rustig), disoriented (gedesoriënteerd), energetic (energiek), amused (geamuseerd), spiritless (futloos), open (open), vulnerable (kwetsbaar), smart (slim), satiated (verzadigd), creative (creatief), disconnected (afgesloten), clumsy (onhandig), independent (zelfstandig), irritated (geïrriteerd), sharp (scherpzinnig), at ease (op mijn gemak), lonely (eenzaam), and free (vrij). The items were rated on a 5-point category scale as ‘not or barely’, ‘a little’, ‘fairly’, ‘strong’, or ‘very strong’.

Subsequently, the participants applied the materials that produced the sensory impairment and the experimenter checked whether they were installed correctly. Next, the participants were taken into another part of the room where the experimental products were located. The participants now performed eight simple tasks with products, whilst they had an induced sensory impairment. Before each task, all experimental materials were arranged in a particular way, so that each participant started from exactly the same position. The eight tasks were presented in random order, with the exception that the toothbrush was always presented later than the cookie and the orange juicer. This was done because brushing the teeth could have a large impact on the taste perception of cookies and orange juice.

Each task was described on a form, which was either read by the participant (tactual, auditory, or olfactory impairment) or read aloud by the experimenter (visual impairment). During the execution of the task, participants were encouraged to verbalize what they perceived, felt, experienced, thought, what problems they encountered, and what associations were evoked. The execution of each task was recorded on video.

After the spontaneous oral responses, a printed questionnaire for each product-task combination was filled out. Some of these questions have been used in previous research (Schifferstein and Cleiren 2005). First described are the questions that were asked only for the six products provided by the experimenter (orange juicer, cookie, tooth brush, vacuum cleaner, spray cleaner, and water boiler) and then the questions that were specific for the two familiar products (shoe, mobile phone).

The first question was open-ended, asking the participants to ‘Describe as elaborately as possible what exactly you perceived and felt when you performed this task’. This question was included to help the participants to focus on their subjective experience again, and to obtain a written summary of their oral responses on this topic. Subsequently, the participants filled out 7-point scales in reply to the questions ‘To what extent did performing this task give you an impression of the product’s details?’ (1=’no details at all’, 7=’very many details’) and ‘Did you have the opportunity to focus your attention on various aspects of the product, or could you perceive only one aspect at a time?’ (1=’just one aspect at a time’, 7=’many aspects simultaneously’). For the blocked modality they filled out ‘To what extent did perceiving this product elicit expectations about how the product looks/feels/sounds/smells when you use it?’ (1=’no idea’, 7=’clear impression’). The participants also reported on how often they normally used the product at home, and they indicated how similar they found the experimental product to the one they used at home on a 7-point scale (1=’not similar at all’, 7=’extremely similar’).

For the two products that were provided by the participants themselves, participants first described the particular characteristics of their product. They also described to what extent what they perceived and felt during the execution of the task differed from usual, because of the impairment. On two 7-point scales they rated the extent to which the product was experienced as different from usual (1=’not different at all’, 7=’extremely different’) and the extent to which they experienced the product as their own, familiar product (1=’it was very strange, like a different product’, 7=’clearly my own product’).

All other questions were identical for all products. Participants indicated how it was to use the product, without being able to see it/feel it with their hands/hear it/smell it (1=’not miss [modality] at all’, 7=’missed [modality] very much’). The next five questions evaluated the perceived seriousness of the handicap. Participants estimated the percentage of the product information they missed due to the impairment. In addition, they indicated the percentage of the task they performed themselves, without help of the experimenter. They also indicated whether the task was performed slower, equally fast, or faster than usual due to the impairment. If the task went slower or faster, they either gave a percentage (e.g., 30% faster) or they indicated the number of times it went slower or faster (e.g., twice as fast). The fourth question assessed how difficult it would be to perform *the current task* again on their own with this impairment and without any help (1='very easy', 7='almost impossible'). For the fifth question participants indicated on a similar scale how difficult it would be to perform a general version of the task *at home* on their own (e.g., squeezing an orange, vacuuming the house) with this impairment and without any help.

The last part of the questionnaire focused on the associations elicited by using the product. The section started with the question: 'To what extent did using this product evoke memories to things that have happened or did it remind you of other people or things?' Participants responded whether '0', '1', or '2 or more' of such associations were elicited and they described these in a few words. For the association that came up in their mind first, participants indicated to what extent they agreed with seven statements using a 4-point category scale (1='totally disagree', 2='disagree more than agree', 3='agree more than disagree', 4='totally agree'). The statements were: 'I could get a clear image of this event/person/thing in my mind', 'I only had a vague association to this event/person/thing', 'This is something that I seldom think of ', 'This event/person/thing plays a great part in my life', 'This event/person/thing is very important to me', 'It was very emotional for me to think back about this again', and 'I found it pleasant to think back about this again'.

Participants in the control conditions performed the same tasks, but without any induced impairments. All the questions addressing the experience of using the product with an impairment or addressing the sensory expectations elicited were not included in the questionnaire. Also, in the questions regarding the difficulty of the task, no impairment was mentioned. Questions for the two familiar products that addressed the extent to which the product felt different from usual were slightly rephrased, so that they assessed the extent to which the product felt different during the experiment compared to using it at home.

After completing the tasks for the eight products, the sensory impairment was removed and all participants completed the 56 item questionnaire again, which asked them to describe how they had felt *during the experiment*. In addition, participants in the experimental conditions filled out a questionnaire on their product experiences during the experiment. They reported whether they found the products during the experiment more or less pleasant (aangenaam), provoking (prikkelend), stimulating (stimulerend), good (lekker), intense (intens), predictable (voorspelbaar), verifiable (controleerbaar), and emotional (emotioneel) compared to usual (7-point scale from -3 to +3). In addition, they indicated whether they agreed or disagreed (4-point scale, see above) with a number of statements on how the impairment made them feel (see Table 3).

To evaluate the manipulations, the participants indicated the extent to which the medium that induced the impairment was painful, comfortable, and inconvenient (7-point scale). Also, they reported the percentage of the perception that was actually blocked by the medium. Finally, they reported on two 7-point scales how they would feel if they would always have the induced impairment (1='not miss [modality] at all', 7='miss [modality] very much' and 1='I would not care', 7='it would be extremely unpleasant').

For all participants a general, overall question was asked on how important they found the different senses (smell, touch, vision, taste, audition) on a 5-point scale (1='not important at all', 5='extremely important'). The sessions lasted approximately 60 min.

2.5. Data analysis

An aggregate data set combining the pre-test and post-test responses on the 56 feeling items was submitted to Principal Components Analysis with Varimax rotation. This yielded twelve factors with Eigenvalues above 1, explaining 64.5% of the variance. All items with factor loadings above 0.50 are used in the following description of each factor.

Factor 1 assessed *Decisiveness*, with the items sharp, energetic, proud, smart, active, combative, strong, clear-headed, attentive, alert, determined, and cheerful. Factor 2 measured the degree of *Perceived Handicap* with items with positive loadings dependent, disoriented, disconnected, confused, vulnerable, clumsy, restricted, and items with negative loadings safe, secure, free, independent, and at ease. Factor 3 measured *Perceived Anxiety* with afraid, threatened, upset, and worried. Factor 4 was a *Lethargic* factor with spiritless, satiated, and tired. Factor 5 measured *Anger* with frustrated, irritated, and angry. Factor 6 measured *Keeping Distance* with evasive and irritable. Factor 7 assessed *Interest* with positive loadings from interested and enthusiastic, and a negative loading from bored. Factor 8 measured *Social Exclusion* with lonely and ashamed. Factor 9 was an *Arousal* factor with a negative loading from quiet and a positive loading from tense. Factor 10 measured *Sincerity* with sincere and open. Factor 11 was a *Creativity* factor with creative and inspired, and Factor 12 was a *Mobility* factor with mobile.

For each of these factors, a scale was constructed. The internal consistency of each scale was checked using Cronbach's α. Items that reduced α were deleted. This only occurred for Factor 4, where the item satiated was not included in the final scale. The final α values and number of items for scales 1 to 11 were (0.89, 12), (0.89, 12), (0.73, 4), (0.73, 2), (0.69, 3), (0.50, 2), (0.64, 3), (0.58, 2), (0.44, 2), (0.58, 2), (0.60, 2). Scale 12 consisted of 1 item only. To keep the discussion of the 56 feeling items limited without losing too many interesting details, it was decided to perform all subsequent analyses on these twelve scales, even though the α values for some of the scales consisting of only 2 items were low. Mean scores were calculated over the items that formed each factor.

For each individual and each factor the difference between the scores obtained before and after the experiment (Post-test – Pre-test) were calculated. Whether the difference scores differed significantly from zero was evaluated with two-tailed *t*-tests. Furthermore, to test whether differences existed between conditions, MANOVA was performed with the twelve scales as multiple measures, followed by a one-way ANOVA for each measure separately.

The responses during the experimental tasks were investigated for each type of question separately. Repeated measures ANOVAs were used with Task as within-subjects and Condition as between-subjects factors. The factor Task had eight (all products), six (unknown products) or two (familiar products) levels. In accordance with Stevens (2002), the degrees of freedom were corrected with the Greenhouse-Geiser ε if $\varepsilon<0.7$, and the ε values from Greenhouse-Geiser and Huynh-Feldt were averaged when $\varepsilon>0.7$. Differences between conditions were tested in paired comparisons using two-tailed tests with Bonferroni adjustment of confidence levels.

The reports on how much faster or slower the task was performed compared to usual were transformed into a single relative duration estimate. When the duration was not affected by the task, the relative duration was set at 100. When the task was performed p times as fast, the duration was 100 / p. When the task was performed q% faster, the duration was 100 - q. If the task was performed r times slower, the duration was r × 100. If the task was performed s% slower, the duration was 100 + s. If the respondent answered that the duration would be infinitely longer, this was coded as 1000 similar to 10 times as long, which equalled the next largest response in the study.

The actual amount of time (in s) the participants spent on the eight tasks was derived from the video recordings. Unfortunately, due to repeated equipment failure approximately 40% of these data were lost. Nevertheless, enough observations were obtained to provide a reasonable indication of the duration of the experimental tasks. For each task, the time that elapsed between a specific starting action and endpoint was recorded. For the water boiler, the endpoint was defined as the time when the apparatus was switched on, because after this moment the time spent depended mainly on the amount of water in the boiler. For the cookie and the toothbrush, the endpoint was defined as the moment at which the product was put in the mouth. After that point, the time spent depended mainly on the proportion of the cookie that was eaten or the amount of time the participants wanted to spend on brushing their teeth. To test for the effect of experimental condition, a univariate ANOVA was performed for each task separately. For two tasks, additional information was recorded that could influence the duration of the task. For the shoe task it was recorded whether the shoe contained a zipper, shoe laces, or could be readily stepped in. The type of shoe was used as an additional explanatory variable in the ANOVA. For the table cleaning task, the proportion of the table that was cleaned was estimated. This proportion was used as a covariate in the ANOVA.

The responses on 4-point scales concerning the associations elicited could not be analyzed by repeated measures ANOVA, because of the large number of missing values. Therefore, MANOVA was used with Task and Condition as between-subjects variables. The statistical model for this analysis deviates from the actual situation in that it assumes that each participant performed only one task.

For the additional post-task responses, MANOVA was used with Condition as between-subjects variable. For all MANOVAs Rao's F is reported, which corresponds to Wilks' Λ. If the multivariate test was significant, F-tests for individual questions were performed. Post hoc tests were performed with Bonferroni correction. Responses for how the products were experienced during the experiment compared to usual (=0) were evaluated with two-tailed *t*-tests. The significance level was $p<0.05$, unless reported otherwise.

3. RESULTS

3.1. Comparison of the two control conditions

Half of the participants in the control conditions filled out the responses to the eight products themselves, whereas the experimenter filled out the questionnaires for the other half. This was done to check whether being able to fill out the questionnaires could explain a difference between the groups with visual and tactual impairments versus the groups with auditory and olfactory impairments.

MANOVA of the scores on the twelve feeling scales did not yield a significant effect for the main effect of Condition [$F(12,7)=1.2$, $p>0.20$] or the Time × Condition interaction [$F(12,7)=0.3$, $p>0.20$]. For the responses during each of the experimental tasks, a separate MANOVA was conducted for each task. None of these yielded a significant overall effect for Condition. Also, the post-test importance ratings for the five sensory modalities did not differ between the two groups [$p>0.20$].

Therefore, it was concluded that the results of the two control groups can be regarded as equivalent and that any differences between the four experimental conditions can be attributed to the differences between the impairments, and not to the way in which responses were recorded. The responses in the two control conditions are aggregated for further analyses.

--------------------Insert Figure 1 about here-------------------------

3.2. Feeling factors

In the four experimental conditions, one or more significant shifts in scores (Post-test – Pre-test $\neq 0$) were found for six of the twelve Feeling factors (see Figure 1). In addition, the control condition showed significant effects for the factors *Arousal* [$M = -0.35$, $p < 0.05$], *Sincerity* [$M = 0.28$, $p < 0.01$], and *Creativity* [$M = -0.83$, $p < 0.001$].

MANOVA of the difference scores showed an overall effect of Condition [$F(48,326)=3.6$, $p < 0.001$], which could be traced down to significant Condition effects for *Perceived Handicap*, *Anger*, and *Social Exclusion* in univariate ANOVAs, with $F(4,95)$ values of 12.2 [$p < 0.001$], 5.9 [$p < 0.001$], and 2.6 [$p < 0.05$], respectively. The increase in *Perceived handicap* was larger for the blinded condition than for all other conditions [$p < 0.001$]. No other paired comparisons reached significance for *Perceived Handicap*. The increase in *Anger* was larger when touch was blocked compared to when audition [$p < 0.01$] or olfaction [$p < 0.05$] was blocked, or the control condition [$p < 0.001$]. The *Social Exclusion* factor showed no significant differences in the paired comparisons.

3.3. Responses during tasks

Differences between tasks were analyzed for each dependent measure separately using repeated measures ANOVAs with Task as within-subjects variable and Condition as between-subjects variable. Only the main effects of Condition are reported here.

For all products, measures were obtained that indicated how difficult it was to perform the task independently (Table 1). These measures generally indicated that visual and tactual impairments made the tasks harder to perform: The difficulty of performing the given task or performing the task at home increased, and the estimated duration of the task approximately doubled. With an auditory or olfactory impairment, task difficulty was similar to the control condition. With a visual or tactual impairment, participants reported that they could no longer perform the entire task independently, as shown by a significant deviation from 100% [one-tailed *t*-tests, $p < 0.001$].

The actual measurements of task duration (in s) confirmed that increases were found only when vision or touch was blocked. Significant effects of Condition were found for all tasks except the water boiling task [$p>0.20$]. In the orange juicer task, blocking vision and touch both increased task duration compared to the control condition [98 and 101 versus 65, respectively, $p<0.05$]. With tactual perception blocked task duration increased for changing shoes [52 versus 18, $p<0.01$] and unwrapping a cookie [41 versus 11, $p<0.001$]. The blinded participants tended to take longer than controls for cleaning the table [117 versus 28, $p=0.061$], vacuuming [152 versus 78, $p<0.001$], composing an SMS message [240 versus 65, $p<0.01$], and preparing a toothbrush [75 versus 19, $p<0.01$]. Although the mean SMS task duration increased considerably when touch was blocked (190 versus 65), this increase just failed to reach statistical significance [$p=0.082$].

The Pearson correlation coefficients between the estimated relative duration (%) and the actual duration (s) for each task were all positive and varied from 0.11 (table cleaning) to 0.72 (eating cookie) [$42\leq N\leq 46$]. Four of the eight coefficients (boil water, put on shoe, compose SMS message, eat cookie) were significantly larger than zero [$p<0.01$]. These results indicate that the participants were able to estimate the degree to which the impairments affected task duration to some extent.

For the six unknown products, the visual impairment decreased the amount of product information more than the other impairments: the proportion of information missed was larger and the number of details perceived simultaneously was judged to be smaller. The visual and tactual information was missed more than the auditory and olfactory information. Participants experienced the two familiar products less as their own and different from usual when the visual or tactual senses were blocked. Note that the latter is the only effect that is larger for touch than for vision.

--------------------Insert Table 1 about here-----------------

In 72% of the cases, no memories or associations were evoked. Participants reported that 'one' or 'two or more' associations were evoked in 26% and 3% of the cases, respectively. Given that the latter number of cases was extremely small, it was assumed that only two associations were evoked in these cases. These responses were subjected to repeated measures ANOVA, which yielded a significant Task main effect [$F(7,665)=3.6$, $p<0.001$] and a Task × Condition interaction [$F(28,665)=2.3$, $p<0.001$]. Unfortunately, inspection of means did not provide an interpretable pattern for these outcomes. Although the number of associations tended to be somewhat higher in the control condition (0.42) than in the experimental conditions (0.20 – 0.37), the Condition main effect was not significant [$F(4,95)=2.0$, $p>0.10$].

The evaluations of the associations were analyzed by MANOVA with Task and Condition as between-subjects variables. The multivariate test yielded a significant main effect of Condition only [$F(28,643)=2.0$, $p<0.01$], which could be traced back to significant Condition main effects for the role the association had played and its emotionality [$p<0.05$]. However, paired comparisons showed only one significant effect: those who wore oven gloves reported that their associations played smaller roles in their lives than the controls [$p<0.05$].

3.4. Post-task responses

After performing the eight tasks, participants reported on how they had experienced the products during the tasks compared to usual (= 0) (see Table 2). Differences between the four experimental conditions were significant in MANOVA [$F(24,201) = 4.8$, $p<0.001$, $\eta^2=0.36$] and for 6 of the 8 individual questions [$F(3,76)>7.5$, $p<0.01$, $\eta^2>0.17$]. For all modalities, introducing an impairment made products less predictable and more difficult to verify. In addition, blocking visual perception made experiences more intense, although they also became less pleasant. Ratings for audition suggest a decrease mainly for provoking and stimulating. For touch the decrease is mainly found for the degree to which the product felt pleasant and good. Nonetheless, the largest effects of the impairment were found for smell, with convincing decreases for all items.

-------------Insert Tables 2 and 3 about here-------------

Participants also indicated to what extent they agreed with a number of statements regarding their experience with the impairment (Table 3). Participants with a visual impairment were sometimes afraid to move, probably because they were afraid to get hurt or to damage things. Also, they changed their posture. In accordance with Table 1 the visually impaired reported that they missed many product characteristics. On the positive side, it seems that the visual impairment gave the opportunity to think better and to pay attention to other product aspects.

Changes in body posture were also noted by the auditorily impaired. In addition, this group had trouble concentrating. They more often felt cut off from the outside world and they had trouble communicating with others. The latter problems may explain why they also started to speak louder. In all experimental manipulations, participants tended to agree with the statement that they used their other senses more due to the blocking of one modality. However, this effect was smaller for olfaction than for the other three. Furthermore, blocking the nose resulted in a decrease of appetite for food.

The experimental conditions did not affect the importance ratings for the five modalities: ratings were highest for vision (4.9), followed by touch (4.4), audition (4.3), taste (3.6), and smell (3.4). The differences between touch and audition and between taste and smell were not significant [$p>0.20$].

Ratings for the extent to which the modality would be missed and for how unpleasant it would be if the modality would always function as poorly as during the experiment, did not differ between conditions [$p>0.20$]. For the degree of missing, means varied from 6.2 (no touch) to 6.5 (blind or deaf); for how unpleasant it would be means varied from 5.7 (no olfaction) to 6.4 (no sight). This implies that when an impairment was experienced during an experimental setting, the participants were always convinced of the severity of such a disability.

3.5. Evaluations of experimental manipulations

The post-experimental evaluations of the experimental manipulations are given in Table 4. Here it can be seen that the conditions differed in perceived comfort and effectiveness. Wearing the nose clip was found to be the most painful and least comfortable. The oven gloves were most inconvenient. In terms of rated effectiveness, the blinding spectacles and the nose clip were judged to be more than 90% effective in blocking visual and olfactory perception, whereas the tactual and auditory impairments were less successful. These findings should be kept in mind when the outcomes of the study are discussed.

-------------Insert Table 4 about here-----------------

4. DISCUSSION

4.1. Evaluation of the roles of the modalities

The findings of the present study are generally in line with the literature discussed in the Introduction. However, several interesting additions were observed. For vision, confirmation was found for its large functional role in gathering product information and allowing for quick processing of that information. In addition, the visually impaired person tends to feel anxious, handicapped, and socially excluded. A new finding was that by blocking vision products were experienced as less pleasant and less familiar.

Surprisingly, some positive effects of blocking vision were also found: participants claimed that their experiences became more intense and that they paid more attention to their remaining sensory modalities. They even claimed that they could think better. This suggests that under conditions of normal vision the information provided by vision attracts the majority of attention, which is in line with claims based on controlled laboratory studies that participants preferably attend to the visual modality under conditions of divided attention (Posner *et al.* 1976, Colavita and Weisberg 1979). The present study suggests that this predominant attention for visual stimuli may distract from other sensory experiences as well as from ongoing cognitive processes. These outcomes are also in line with activation patterns observed in brain imaging studies. According to Marx *et al.* (2003) different states of mental activity can be distinguished between people who have their eyes open versus those who have their eyes closed. The former seem to be in an 'exteroceptive' state characterized by activation of the attentional and ocular motor systems, whereas the latter are in an 'interoceptive' state characterized by activation of various sensory systems, which may reflect both active sensory processing in multiple modalities and imagination during the recall of sensory experiences.

Touch was also found to play a relatively large functional role in the interaction with products, although somewhat smaller than vision. The extent to which familiar products were perceived as foreign, however, was larger for touch than for vision. Apparently, if the feel of a product is largely absent, this results in stronger feelings of alienation than if the product can no longer be seen. The large increase in anger observed in the tactual condition (Figure 1) might be due to feelings of frustration, because it was no longer possible to perform simple tasks. However, this effect may not be solely due to the blocking of tactual perception; it may have been amplified by the oven gloves used, which were rated as highly inconvenient (Table 4).

Blocking audition or olfaction did not significantly increase task difficulty, but participants did report that products became less predictable, less provoking, and less pleasant. In addition, blocking olfaction also made product experiences less intense and less emotional. This suggests that although the functional significance of these modalities in user-product interactions may be small, they may have a substantial effect on the emotional experience of products.

In conclusion, with respect to the amount of functional information provided, the present findings suggest that the visual modality is relatively important in human-product interactions, followed by touch, then audition and, finally, smell. This ranking is in line with the outcomes of previous investigations, in which people evaluated multisensory products through a single modality only (Schifferstein and Cleiren 2005). However, when people reported on how often they relied on the different modalities when evaluating products, smell was rated higher than audition (Schifferstein 2006). In the current study, it was found that the effects of blocking smell were particularly large in the post-task evaluations. Possibly, self-reported importance of smell is this high, because smell plays a considerably larger role than vision and audition in the emotional response to products. Smell may thereby provide the essential ingredients to make a product really delightful.

The discussion above makes use of the distinction between the instrumental, functional role and the affective, emotional role the senses may play in everyday user-product interactions (e.g., Holbrook and Hirschman, 1982). In line with previous studies (Hinton and Henley 1993, Dubois 2000, Lindstrom 2005), the present outcomes suggest that vision mainly plays a functional role and olfaction an affective role. Although touch has a large functional role, it can also play an affective role. For example, Peck and Wiggins (2006) have shown that tactual stimuli that provide no product-related information can elicit an affective response that influences consumer decision making. Furthermore, touch seems to be important in developing a personal relationship with a product: products may feel like they are ‘our own’ or ‘foreign’. Audition seems mainly responsible for feeling connected to the world.

The importance of a role fulfilled by a modality can increase or decrease, depending on product characteristics. For example, the affective role of vision for a toaster probably increases when a beautiful appearance is created. Similarly, olfaction will be used instrumentally when a new fragrance is introduced for a personal care product. Nevertheless, the tasks used in the present study were chosen to represent the majority of daily product interactions and, thereby, should give a good impression of the roles the modalities play in daily life. For example, olfaction is clearly involved in 6 of the 8 tasks used here (squeeze orange, take off shoe, clean table, vacuum carpet, eat cookie, and brush teeth). Therefore, although the functional role of olfaction may be somewhat bigger with specific products (e.g., evaluating the ripeness or quality of fresh fruit) or in specific contexts (e.g., visiting a sauna), its impact on daily life in general is unlikely to deviate considerably from the results presented here.

Next to the detrimental effects of impairments, the participants also experienced some positive effects. To compensate for the abilities that were temporarily lost, the impairments stimulated participants to find new ways to obtain the information, and to make use of the possibilities of the other senses. This led to different product experiences, in which previously unattended product characteristics now played a role.

4.2. Practical relevance

The outcomes of this study may be relevant to researchers in health economics, who try to establish how disabling various medical conditions are. In health economics, disability weights are derived on a scale ranging from 0 (no disability) to 1 (extreme disability). Because people who live with a disability are likely to adapt to their impairment over time, the experimental conditions in the present study are not entirely comparable to the situation of a disabled person. In addition, the disabling effect varies between countries, because the consequences of a disorder depend on the assistance available to people who live with a handicap, in the form of devices and social support. Nevertheless, it is believed that the outcomes may provide an indication of the severity of a specific impairment.

In the Netherlands, the country where the current study was conducted, disability weights for mild, moderate, and severe disorders of the visual system were estimated at 0.02, 0.17, and 0.43, respectively, whereas those for hearing disorders among the elderly were 0.04, 0.12, and 0.37, respectively (Stouthard *et al.* 1997, Stouthard *et al.* 2000). In a comparison of disability effects in 14 countries (Üstün *et al.* 1999) the weights for blindness were consistently larger than those for deafness in all 14 countries. The discrepancy between the two disorders was relatively small in the Netherlands, compared to the other countries: in the Global Burden of Disease study, the mean disability weight for blindness was 0.62, compared to 0.33 for total deafness (Murray and Lopez 1996). These estimates are in agreement with the present findings that visual impairments have more serious consequences for daily living than auditory impairments. Unfortunately, disability weights for other sensory disorders are not available.

The present results can also have implications for designing products for specific user groups. They suggest, for example, that the visually impaired rely mainly on tactual input during functional product interactions. As a consequence, a functional product may be designed in a way that it can be operated entirely by touch, without any need for visual input.

Furthermore, the finding that visual and tactual impairments increase the amount of time required to operate products is relevant for products that require users to respond within a certain time frame, such as mobile phones. In order to be usable for people with impairments, the timings used in these products may need to be adapted.

Additionally, the finding that the degree to which respondents rated the product as their 'own' was larger for touch than for vision, opens up new possibilities for product personalization strategies (e.g., Mugge, Schoormans, and Schifferstein). Personalization options usually rely on visual modifications, like choosing a design for a mobile phone cover or choosing the colour of a bicycle. Offering options that differ in tactile properties may be even more effective in enhancing the experience of a product as being personal and unique.

4.3. Limitations of the approach

The estimates of the degrees to which the modalities were blocked suggest even for vision and smell that perception was not 100% blocked (Table 3). However, there is no reason to believe that any visual or olfactory information could still be perceived.

According to the study participants, the manipulation was 77% effective for audition. Indeed, some sounds that were generated inside the head from brushing the teeth or from eating the cookie may not have been wholly blocked. In addition, the sound of the vacuum cleaner's engine was so loud, that it may not have been blocked completely. However, there are good reasons to assume that the effectiveness responses may be biased downward, because it is rather difficult for a participant to judge whether a sound is heard or not. For example, suppose that a woman presses the button to switch a product on: because she knows exactly when the sound begins and can easily imagine the type of sound the product makes, she may be quite confident that she can hear it, even if she would not have been able to detect the sound in a vigilance task. Therefore, it is thought that 77% underestimates the effectiveness of the manipulation.

Touch perception is difficult to block if participants are required to interact actively with an object. According to Table 4, the manipulation blocked only 66% of the tactual perception through the hands. Incomplete tactual blocking was expected, because the oven gloves allowed for the perception of object weight and overall shape. In addition, although the hands are involved in the majority of user-product interactions involving touch (e.g., Sonneveld 2007), they form only a small part of the human body and other body parts can take over their role in tactual perception. Nevertheless, despite the limited success in blocking tactual perception, the effects measured in the present study on product experience are substantial and in most cases exceed those for olfaction and audition.

The variation in manipulation effectiveness interferes primarily with a *quantitative* comparison of the impacts of the manipulations for the different senses. The present study may underestimate the effects of completely blocking the auditory and the tactual modalities. However, because blocking effectiveness was substantial for all the modalities, the present data probably do give a good *qualitative* impression of the effects of blocking. Comparing the four modalities clearly shows that each modality has a different experiential profile, each with its own consequences in terms of subjective feelings.

Another problem indicated by Table 4 is that the way tactual perception was blocked in the current study was found to be inconvenient and possibly interfered with the natural user-product interaction. Also, the way olfactory perception was blocked was judged to be uncomfortable and slightly painful. As a consequence, it cannot be certain that all the effects were solely due to missing sensory information. They could also have resulted from these unwanted side effects of the manipulations. In future experiments, manipulations may be used that do not produce these side effects, or additional conditions may be added to control for the unwanted effects.

Despite these limitations, the outcomes are very much in line with what previous studies have found. This suggests that the manipulations were rigorous enough to study the impact of sensory impairments on product experiences. For the same reason, the perceived discomfort in the olfactory condition is unlikely to have affected the results.

It should be noted that the present study only used simple, multisensory tasks as a representative of a number of activities necessary for daily living. Probably, more complex products are likely to involve more specific activities, and may thus be more specifically dependent on a particular modality. Although not discussed explicitly in the present paper, considerable product-specific effects were found in the various tasks. The variations in task duration show, for example, that blocking touch interfered with opening the package for a cookie or putting on shoes, whereas blocking vision did not. On the other hand, blocking vision interfered with the vacuuming and cleaning tasks, whereas blocking touch did not. Nevertheless, the aggregate data enable a meaningful comparison of the roles the different modalities play in daily life.

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Appendix 1. Detailed descriptions of the tasks

Orange juicer: You will now squeeze an orange with an electrical orange juicer. Take an orange off the plate on your right, cut it with the knife. Squeeze the orange with the orange juicer. Pour the juice in the glass on your left. If you want to, you can drink the juice.

Water boiler: You will now boil water for a cup of tea. Pour water in the water boiler for one cup of tea. Switch the boiler on. Warn the experimenter as soon as the water boils.

Shoe: You will now take off a shoe and put it on again. Take off your left shoe. Let your foot enjoy the extra space for some time. Then put on your shoe again.

Spray cleaner: You are now going to clean a table. In front of you are a spray bottle filled with cleaning fluid and a cleaning cloth. Spray the cleaning fluid on the table. Spread the cleaning fluid with the cloth, and wipe the table dry.

Vacuum cleaner: You are now going to vacuum a carpet. In front of you is a vacuum cleaner, which is ready to use. Switch the vacuum cleaner on and clean the carpet in front of you as well as possible. Then switch the vacuum cleaner off. Take the plug out of the socket and let the vacuum cleaner wind the cable.

Mobile phone: You are now going to compose and send an SMS message. Take your mobile phone and switch it on. Compose an SMS message with the following text: ‘Hi, I am participating in a nice experiment!’. If you want to, you can send this message to a fellow student.

Cookie: You are now going to take a cookie out of its package and eat it. In front of you is a cookie in its package. Take the cookie out of its package and taste it.

Toothbrush: You are now going to brush your teeth. First we walk to the sink. In front of you is a holder with eight new toothbrushes. Choose one of the toothbrushes and take it out of the holder. Put some toothpaste on it from the tube on your right. Brush your teeth. Rinse the toothbrush well under the tap.

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Table 1. Mean responses for the eight experimental tasks.

	Control	Blocked modality			
		Vision	Hearing	Touch	Smell
All products					
Proportion of task performed independently (0-100%)	100.0 ^{b}	93.3 ^{a}	99.8 ^{b}	97.1 ^{b}	98.9 ^{b}
Difficulty of performing this task (1-7)	1.1 ^{b}	2.7 ^{a}	1.2 ^{b}	2.6 ^{a}	1.1 ^{b}
Difficulty of performing task at home (1-7)	1.1 ^{c}	3.6 ^{a}	1.2 ^{c}	2.8 ^{b}	1.1 ^{c}
Estimated relative task duration (%)		202 ^{a}	104 ^{b}	219 ^{a}	100 ^{b}
Six unknown products					
Number of details (1-7)	4.6	4.4	4.6	5.1	4.5
Number of aspects simultaneously (1-7)	5.0 ^{b}	3.1 ^{a}	4.5 ^{b}	4.6 ^{b}	4.7 ^{b}
Clarity of expectations (1-7)		4.6	4.7	4.8	3.7
Degree of missing the modality (1-7)		4.2 ^{a}	3.2 ^{b}	4.4 ^{a}	2.7 ^{b}
Proportion of information missed (0-100%)		40 ^{a}	27 ^{b}	27 ^{b}	21 ^{b}
Two familiar products					
Experience as different (1-7)	1.4 ^{b}	2.9 ^{a}	1.7 ^{b}	4.0 ^{c}	1.1 ^{b}
Experience as own (1-7)	6.8 ^{b}	5.8 ^{ac}	6.6 ^{ab}	5.0 ^{c}	6.8 ^{b}

^{abc} Means with the same superscripts did not differ significantly in a post hoc test with Bonferroni adjustment [p>0.05]

Table 2. Mean responses for how a product was experienced compared to usual (=0; scale from -3 to +3).

	Blocked modality			
	Vision	Hearing	Touch	Smell
Pleasant	-1.00 $^{ab\,**}$	-0.50 $^{a\,*}$	-1.65 $^{b\,**}$	-1.10 $^{ab\,**}$
Good	-0.05 ^{a}	-0.35 ^{a}	-0.80 $^{a\,**}$	-1.85 $^{b\,**}$
Provoking	-0.20	-1.00 **	-0.80 *	-1.10 **
Stimulating	-0.55	-0.75 **	-0.55	-0.80 **
Intense	+0.85 $^{a\,**}$	-0.50 ^{b}	-0.30 ^{ab}	-1.05 $^{b\,**}$
Emotional	+0.40 ^{a}	-0.50 $^{ab\,*}$	-0.10 ^{ab}	-1.05 ^{b**}
Predictable	-1.80 $^{a\,**}$	-0.90 $^{b\,**}$	-1.45 $^{ab\,**}$	-0.55 $^{b\,*}$
Verifiable	-2.00 $^{ab\,**}$	-1.25 ^{ac**}	-2.40 $^{b\,**}$	-0.55 $^{c\,**}$

^{abc} Means with the same or no superscripts did not differ significantly between modalities in a post hoc test with Bonferroni adjustment [p>0.05]. It was also tested whether means differed significantly from 0 [two-tailed *t*-test; ** p<0.01; * p<0.05].

Table 3. Mean post-task ratings of agreement (4-point scale).

	Blocked modality			
	Vision	Hearing	Touch	Smell
I did not dare to move	2.50 [a]	1.75 [b]	1.00 [c]	1.25 [bc]
I was afraid that I would hurt myself	2.10 [a]	1.35 [b]	1.32 [b]	1.20 [b]
I was afraid that I would damage things	2.05 [a]	1.80 [ab]	1.84 [ab]	1.25 [b]
I changed my body posture	2.90 [a]	2.50 [ac]	2.00 [bc]	1.55 [b]
I could think well	3.25 [a]	2.80 [ab]	2.47 [b]	2.20 [b]
I missed many product characteristics	3.25 [a]	2.60 [ab]	2.68 [ab]	2.20 [b]
I felt cut off from the outside world	2.55 [ac]	3.20 [a]	1.90 [bc]	1.70 [b]
I started to speak louder	1.95 [ab]	2.60 [a]	1.32 [b]	1.40 [b]
I had trouble concentrating	1.60 [ab]	2.05 [a]	1.32 [b]	1.65 [ab]
I had trouble communicating with others	2.00 [b]	3.20 [a]	1.32 [b]	1.80 [b]
Certain product properties attracted my attention more	3.10 [a]	2.40 [ab]	2.67 [a]	1.85 [b]
I used my other senses more	3.75 [a]	3.25 [a]	3.11 [a]	2.65 [b]
My appetite decreased	2.15 [ac]	1.75 [bc]	1.21 [b]	2.80 [a]
I lost control over my perceptual abilities	2.05	1.90	1.84	1.70
Familiar products seemed unknown to me	2.00	1.70	2.16	1.50
I could judge many product characteristics no longer	2.25	2.25	2.37	2.00
I had trouble remembering things	1.95	1.65	1.37	1.40

[abc] Means with the same superscripts did not differ significantly in a post hoc test with Bonferroni adjustment [p>0.05]

Table 4. Evaluations of the impairment-inducing manipulations.

	Blocked modality			
	Vision	Hearing	Touch	Smell
Painful (1-7)	1.40 [a]	1.80 [a]	1.00 [a]	3.50 [b]
Comfortable (1-7)	3.90 [ab]	4.55 [a]	4.60 [a]	2.50 [b]
Inconvenient (1-7)	2.80 [a]	3.05 [a]	5.65 [b]	3.85 [a]
Effective (0-100%)	91 [ab]	77 [ac]	66 [c]	93 [b]

[abc] Means with the same superscripts did not differ significantly in a post hoc test with Bonferroni adjustment [p>0.05]

Figure 1. Mean difference scores (Post-test – Pre-test) (± SE) for six Feeling factors in the five conditions. Deviations from zero were tested with two-tailed *t*-tests [* p<0.05, ** p<0.01].

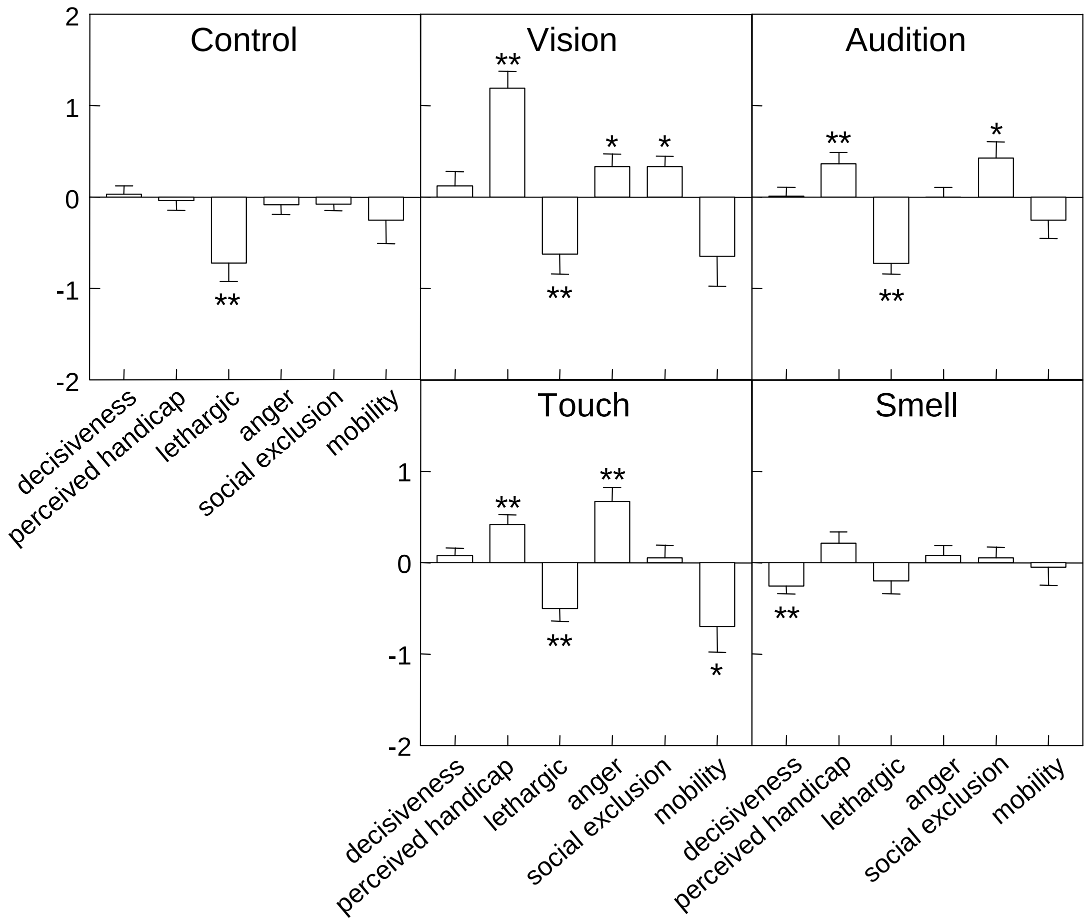

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Figure 1. Mean difference scores (Post-test – Pre-test) (± SE) for six Feeling factors in the five conditions. Deviations from zero were tested with two-tailed *t*-tests [* $p<0.05$, ** $p<0.01$].