Interacting with Smart Walls: A Multi-Dimensional Analysis of Input Technologies for Augmented Environments

Felix Heidrich[1], Martina Ziefle[1], Carsten Röcker[1], Jan Borchers[2]
[1] Communication Science, Human Technology Centre (HumTec)
[2] Media Computing Group
RWTH Aachen University
{heidrich, ziefle, roecker}@humtec.rwth-aachen.de; borchers@cs.rwth-aachen.de

ABSTRACT
This paper reports on a multi-dimensional evaluation of three typical interaction devices for wall-sized displays in augmented environments. Touch, trackpad and gesture input were evaluated regarding a variety of usability dimensions in order to understand the quality profile of each input device. Among the three interaction devices, the touch input showed the highest scores in performance and acceptance as well as hedonic value.

Author Keywords
Large displays, Smart displays, Input devices, Interaction, Touch input, Trackpad, Gesture input, Performance, Acceptance, Physical strain

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces – Evaluation, Input Devices and Strategies, Interaction Styles

INTRODUCTION

Over the last decade, research in the field of smart environments gained considerable momentum and a variety of experimental spaces have been set up. While earlier approaches mainly focused on smart offices (e.g., [4], [22] [24] or [25]), more and more projects aim at supporting users in augmented home environments. One of the earlier systems is the *Aware Home* [13], an intelligent home environment equipped with different sensors capturing the state of the environment and its inhabitants. A similar approach was taken with the *Philips CareLab* [6]. Another example is the *Intelligent Sweet Home*, a roboter-equipped smart house, which is based on several robotic agents and aims at testing advanced concepts for independent living with elderly and disabled people [20]. Other examples of assistive environments include the *Gator Tech Smart House* [9], the *MavHome* [27], the *Microsoft eHome* [21], or the *House of Matilda* [10].

In most of these smart houses, large screens and interactive surfaces are an integral part of the environment and are used to provide personalized information and context-adapted medical services throughout the users' home. Looking at state-of-the-art systems shows, that there are generally three different ways of interacting with wall-sized displays in smart environments: directly on the screen (e.g., [11, 14, 24]) or remotely, either via mobile devices (e.g., [5, 17, 19]) or gestures (e.g., [8, 16, 26]).

Today, design decisions are mostly based on "theoretical" advantages of specific interaction concepts or are dictated by an existing technical infrastructure. While the importance of user-centered design approaches is widely recognized, the empirical knowledge about the actual requirements and preferences of potential users is very limited.

In this paper we undertake a comprehensive evaluation of three typical interaction devices for smart home environments. Touch, trackpad and gesture input were evaluated regarding a variety of usability dimensions in order to understand the quality profile of each input device. Beyond preference and acceptance judgments, we also included performance measurements on the base of Fitts' Law in order to estimate the efficiency of using these devices. In addition, we differentiated a short-term usage from a more extensive device operation and quantified the emergence of physical strain after usage. In order to adequately address aspects of user diversity, we did not only consider participants of a wide age range (24-82 years of age), but also a variety of individual characteristics (e.g., the subjective technical confidence to use these devices). This multi-methodological and multi-dimensional approach enabled us to gain profound knowledge about the individual quality profiles of different interaction methods.

MATERIALS AND METHODS

Variables

Two *independent variables* were examined. The first variable referred to the input modality, realized as a touch input (large interactive surface), a trackpad input (mobile device) and a gesture input (see the section of "Tested Input Devices" for more details). The second independent variable was the users' age, contrasting the performance of younger (24-33 years) and older participants (55-82 years). Participants were also surveyed regarding education level, technical expertise and the perceived technical self-confidence (STC). These individual characteristics were treated as moderating factors and related to evaluation and performance outcomes. As *dependent variables*, we collected nine different evaluation and performance aspects of the input devices under study. Participants rated five quality dimensions (fun, effort, visibility, menu overview and as well as the unfamiliarity with the device usage). Also, participants stated their intention to use these devices at home. For performance, we assessed selection times while executing point click tasks of varying difficulty. Finally, participants were asked to rate the physical strain in different body parts.

Sample

A total of 24 participants, 12 women and 12 men, in an age range between 24 and 82 years volunteered to take part in the experiment. Two age groups were formed. The younger group (8 females, 4 males) consisted of persons with ages between 24 and 33 years (M = 28.2, SD = 3.0). Participants with ages between 55 and 82 years (8 males, 4 females) formed the group of older adults (M = 64.2, SD = 8.2). Most of the younger participants were recruited in the university context and 83% held a university degree. Older users were recruited by announcements in newspapers, in which they were invited to take part in a study about future home environments. Older users had a broad range of professions and educational levels. 50% of the older group stated to be pensioners.

In order to assess participants' expertise with technical devices, participants were asked whether they own a computer, mobile phone, digital camera and GPS, how frequently they would use them and how they rate the ease of using each device. Overall, in both age groups devices were frequently used and rated as easy to use, even though the young group reported to be more familiar with using the devices. Regarding health status, participants were mentally fit and reported not to be hampered by strong age-related sensory and psychomotor limitations.

Beyond technical expertise, we also assessed the subjective technical self-confidence [3], which revealed to be a sensitive variable in explaining technical performance and acceptance. Technical self-confidence measures the subjective belief of a person regarding his/her competency when using technology. Participants were given the short version of the test containing eight items (e.g., "Usually, I cope with technical problems successfully"), which had to be rated on a 5-point Likert scale, ranging from 1 (totally disagree) to 5 (totally agree). The maximum score to be reached was 100 points. The reliability of the STC short version questionnaire is high (Cronbach's α scores vary between .89 [3] and .91 [2]). ANOVA analyses showed that both, age $F(1, 20) = 23$; $p < .05$ and gender ($F(1, 23) = 15.3$; $p < .05$) significantly impact STC ratings (see Figure 1). Female and older participants showed a significantly lower self-confidence when using technical devices.

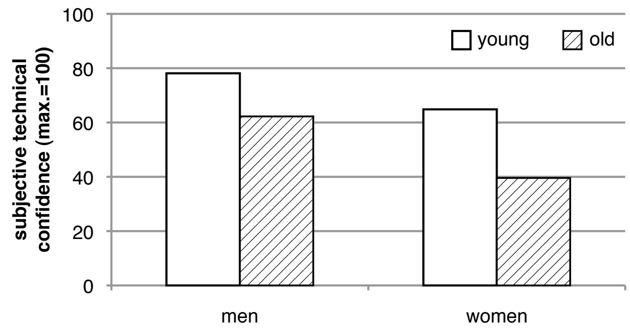

Figure 1. Gender and age differences in the subjective technical confidence.

Test Environment

All tests were conducted in the Future Care Lab at RWTH Aachen University. The lab provides a full-scale technical infrastructure in form of a simulated home environment (see Figure 2).

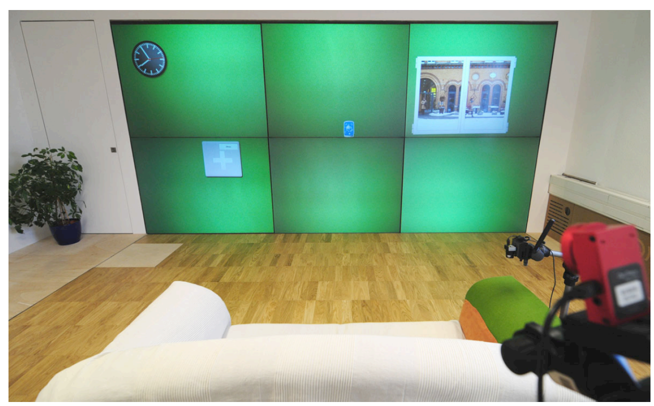

Figure 2. Wall-sized display in the Future Care Lab.

The lab provides an intelligent care infrastructure, consisting of different mobile and integrated devices, for supporting elderly and handicapped people. The setup of the lab enables in-situ evaluations of new care concepts and medical technologies by observing different target user populations in realistic usage situations. As the lab relies on a modular technical concept, it can be expanded with other technical products, systems and functionalities, in order to address different user groups as well as individuals with differences in their cognitive, health-related or cultural needs. The lab is equipped with an interactive wall, which was used as an output channel for all tests. The wall consists of six rear projection display elements and measures 4.8m x 2.4m with a total resolution of 3072 x 1536 pixels.

Tested Input Devices

In order to test the different interaction modalities, different technical prototypes for supporting direct touch control, a remote trackpad control and gesture control were developed for the user study. A demo application is used to display content on the large display and process the input event generated by the input devices. The following section briefly describes the developed prototypes.

Direct Multi-Touch Control

Multi-touch input is realized by *Rear Diffuse Illumination* technique [12]. The display elements are illuminated with infrared light from behind. The back of the acrylic wall surface diffusely reflects the infrared light and thereby avoids specular highlights, which can result from the infrared illumination. Infrared light reflected from fingers touching the wall is captured by six *PointGrey FireflyMV* cameras (Figure 3). The *Community Core Vision software* is processing the resulting bright blobs in the captured images. Six instances of this software, one for each camera, send *Tangible User Interface Object* (TUIO) messages to the demo application. These TUIO messages contain the touch coordinates and unique touch IDs. The demo application maps the touches to a common coordinate system and ensures that their IDs remain unique.

Figure 3. The multi-touch wall from behind.

Remote Trackpad Control

For realizing remote trackpad control, we use the touch screen of an *Apple iPod touch* as a trackpad. The iPod touch is intentionally called trackpad, since the integrated display is not used. The users' locus of attention should reside on the wall-sided display. When the device is touched, events containing the touch coordinates are sent to the demo application. The events are processed to generate relative input. The common trackpad gestures to trigger a click or start a drag-and-drop operation are used: Users can single-tap the display to click, or single-tap once and then touch the surface again to start a drag operation.

Remote Gesture Control

We use reflective infrared markers, which are attached to the users' hand to create a robust hand tracking system (see Figure 4). One marker is attached to the back of the user's hand. The position of this marker defines the pointing position. A second marker is attached to the user's forefinger, which allows the detection of clicking gestures. Reflected infrared signals are captured with a single commercial tracking camera (*Optitrack FLEX: V100* from *NaturalPoint*) located behind the users shoulder.

Figure 4. Gesture interface: Tracking is accomplished using reflective markers (left) on the back of the palm and the forefinger (right).

The hand tracking system was designed to be used by a sitting, non-moving user. During the system evaluation an individual coordinate frame, which depends for example on the user's sitting position and arm length, was defined for each user. Technically, the marker tracking was executed inside the driver from *NaturalPoint*, which runs on a Windows XP computer. The position and the hand state (pointing or clicking) were sent over the network to the demo application.

Design and Testing Procedure

The experiment was based on a 3 (input modalities) 2 (age) factorial design, with repeated measurements on the first factor. The order of conditions was fully balanced across participants, in order to minimize asymmetric training effects. In the beginning of the experiment, personal data was collected (age, sex, education level, technical expertise). In addition, the STC was psychometrically determined.

Participants were carefully instructed about the purpose of the experiment and the need for a sensitive testing of different input modalities with respect to their suitability for implementation in future smart home environments. All participants had a high usage motivation and were keen to experience the new input modalities. The experiment lasted approx. 1.5 hours, depending on participants' individual working speeds.

In order to familiarize participants with the setting and the input devices, the experimenter first demonstrated the three input modalities. Then participants were given some practice trials for enabling them to get used to the different device types. In the beginning of the user test, a blood pressure monitor and a scale, integrated into the floor of the lab, were used to demonstrate potential application scenarios of smart homecare environments. The evaluation of input modalities was accomplished in two phases (see Figure 5). In the first part, participants completed three short-term tasks with each input device. After that they rated the quality of the input devices and the interaction process regarding five different dimensions and stated their intention to use the devices. In the second part, a Fitts' Law test was performed. Participants had to execute serial point click tasks to targets with different *Indices of Difficulty* (ID) for a period of about 7 minutes per input modality. The movement speed was assessed as well as the physical strain of using each modality.

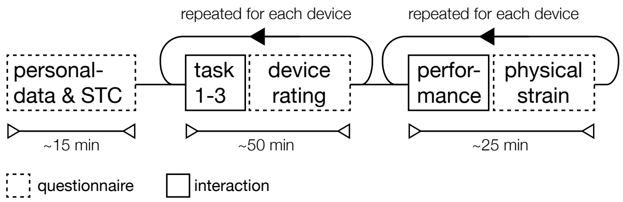

Figure 5. Experimental design.

Experimental Tasks

The evaluation of the input modalities was accomplished by different tasks and measurements.

Evaluation of Quality Profiles of Input Devices

In order to enable participants to assess the different qualities of the input devices, they completed three short-term tasks for each device. We used a simple healthcare application in form of a digital "medicine chest", which enables users to monitor vital parameters such as weight, blood pressure, blood coagulation, and body temperature. The application is implemented as a widget, which can be freely moved around the display.

Following a user-centered design approach, a pre-study was conducted, in which a group of potential users rated a first version of a paper prototype of the demo application and the widgets' layout. Iteratively, the design and configuration of elements as well as the button sizes were empirically determined (*N* = 5, 22 - 50 years). Figure 6 shows a snapshot of the demo application. Within this application three tasks had to be completed:

1. *Single Selection:* "Start blood pressure monitoring process." For this task, one click had to be completed.
2. *Menu Selection:* "Browse the medical chest's menu." A total of nine button clicks were to be executed.
3. *Moving of widgets:* "Move two different widgets across the wall-sized display."

Figure 6. "Medicine Chest" demo application.

Upon completion of these tasks, participants rated different quality dimensions of the input devices. (1) *Hedonism*: Using the device is fun, (2) *Unfamiliarity*: Operating the device is unfamiliar to me, (3) *(Cognitive) effort*: Operating the device is demanding, (4) *Visibility*: The displayed information is clearly visible, (5) *Overview:* While operating the device I had a good menu overview (6) *Intention to Use*: I would like to use the device at home. Answers had to be selected from a 5-point Likert scale, ranging from 0 (totally disagree) to 4 (totally agree).

Performance Evaluation

In the second part a target selection experiment was conducted. We displayed a sequence of targets with varying distance and size. The *Index of Difficulty* (ID) was computed using the Shannon formulation of Fitts' Law.

$$ID = \log_2\left(\frac{D}{W} + 1\right)$$

We used square targets with sizes (*W*) of 100 (15.6), 200 (31.2), 300 (46.9), and 400 (62.5) pixels (cm). The distances (*D*) were chosen so that a total of nine different *ID* values in the range from of 1 to 3 were covered. For the evaluation of the trackpad and the gesture control the entire screen estate was used to display targets. During the evaluation of the touch input we utilized a scaled-down version (by factor 0.2) of the test. The linear relationship of *D* and *W* guarantees the comparability between both test conditions. The active display area was set to a region that participants could easily reach without physically moving in front of the wall.

Ratings of Physical Strain After Using the Input Devices

After completing the performance test with each device, participants were asked to assess the physical strain on different body parts (finger, hand, arm, and shoulder) using a short questionnaire. Answers were given on a 5-point Likert scale ranging from 0 (very low) to 4 (very high).

RESULTS

Results were analyzed by bivariate correlations, nonparametric Friedman analyses for repeated measurements. In order to identify interacting effects, we used (M)ANOVA analyses in addition (as interacting effects can only be revealed by ANOVA procedures). The significance level was 5%; outcomes within the less restrictive 10% level were referred to as marginally significant.

First, we report the evaluation profile for the three input devices after short-term exposure and analyze whether evaluations are influenced by participants' age. Second, we identify the intention to use these devices. Third, performance outcomes in terms of Fitts' Law are reported. For different IDs we describe the movement speed when using the input devices and analyze the aging impact on performance. Finally, we describe the emergence of physical strain for different body parts and determine if strain ratings differ as a function of age.

Evaluation Profiles in the Different Input Modalities

For each input device, participants rated the following qualities: hedonism, visibility, overview, effort and familiarity on a five-point Likert scale. In Figure 7, descriptive outcomes are depicted. The input devices showed different evaluation profiles. With respect to the *perceived fun* (hedonism), input devices differed significantly ($\chi2$ = 19.5; p < .05) with the touch input showing the highest fun factor (*M* = 3.5 out of 4 points max. compared to the trackpad (*M* = 2.8) and the gesture input (*M* = 3)). Significant differences were also revealed for the *familiarity* with the input device ($\chi2$ = 13.5; p< .05), with the gesture input as the one, which is most unfamiliar to especially older participants, taken from the marginally significant interacting effect (*F*(2, 19) = 2.8; p < .1).

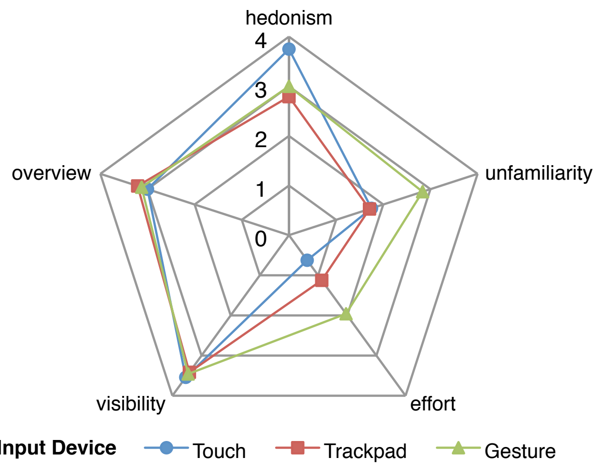

Figure 7. Evaluation profiles of the input devices. High scores reflect high approval to the respective evaluation dimension.

When focusing on the *cognitive effort* of using the devices, the results for gesture input were again most prominent with the highest cognitive load (*M* = 2), compared to the trackpad (*M* = 1.1 out of 4 points) and the touch input with the lowest effort overall (*M* = 0.62). Differences in the rated effort not only revealed significant effects between input modalities ($\chi2$ = 17.5; p < .05) they also revealed an interacting effect of age and input modality (*F*(2, 19) = 7.8; p < .05), showing that the effort is significantly higher in the older compared to the younger group.

The *visibility* of the information being displayed did not differ between input devices, but between age groups (*F*(2, 19) = 4.8; p < .05), showing that the older group rated the visibility as significantly lower than the younger group. Finally, the *perceived overview* of the menu did also not differ across input modalities, but again revealed an – at least marginally – significant effect of age (*F*(2, 19) = 2.7; p < .05) as older adults reported a lower overview of the menu compared to younger participants.

Intention to Use the Input Devices

At the end of part one after they completed all three tasks, participants were asked to state their intention to use the devices. When analyzing which of the variables under study is related to the intention to use these devices, an astonishing finding was revealed.

Neither the type of input devices nor the participants' age significantly impacted the intention to use these devices. Also, none of the quality dimensions (hedonism, effort, overview, visibility, familiarity) showed any relations to the intention to use these devices. (see Figure 8). But the degree to which a person believes in his/her own ability to master technical devices is the crucial variable for the intention to use the devices (interaction effect of input modality × STC: *F*(1, 18) = 4.6; p < .05).

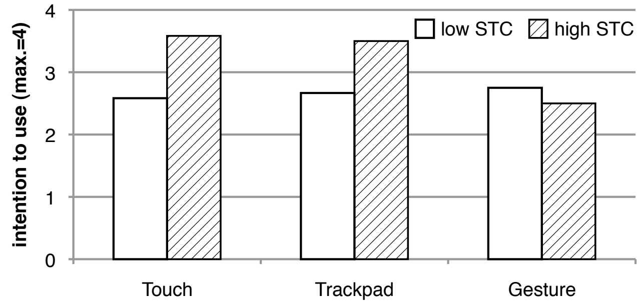

Figure 8. Interacting effect of subjective technical confidence and input modality.

Device Performance

In order to evaluate device performance, we calculated selection times (error-free trials) for the different ID conditions for each input device. We decided to focus on selection time and to exclude error trials from further analysis. As it is not an original Fitts' study, for which the speed-accuracy trade-off would be an essential requirement, we decided to meet requirements of ecological validity and aimed at a more "life-like" usage setting for older people. This includes that older adults, who are generally slower (age-related decrease in speed of behaviors), naturally focus more strongly on a successful operation than on how fast an operation might be. Therefore we instructed participants to prioritize hitting the target successfully and as fast as they would be able to. In Figure 9, selection times for each of the three input devices are depicted.

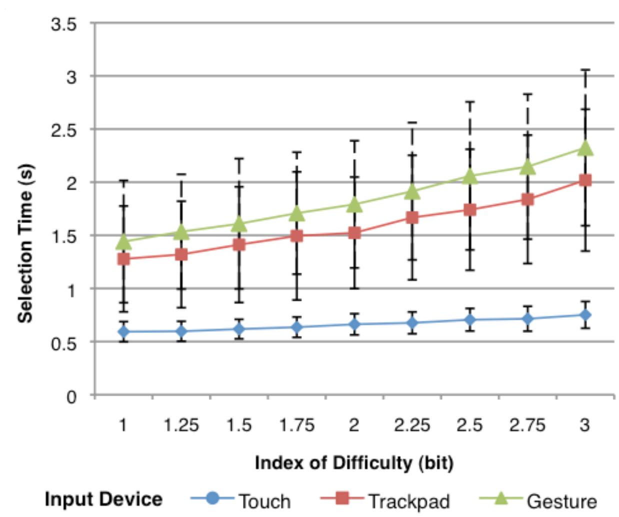

Figure 9. Overall selection times for the different input devices.

Selection times are significantly higher for trackpad and gesture input compared to touch input, which showed the fastest selection time (significant main effect, *F*(2, 19) = 12.8; p < .05). The increase of selection times by ID (main effect) was also significant ($F(8, 44) = 13.9$; $p < .05$). Taken from the significant interaction (input device × ID, $F(2, 44) = 4.4$; $p < .05$), the increase in selection time is not equally high for all input devices. The touch input shows a considerably lower increase compared to trackpad and gesture input. When analyzing age effects in combination with task difficulty and input device, a significant effect of age, ($F(1, 19) = 7.7$; $p < .05$) (see Figure 10) was revealed.

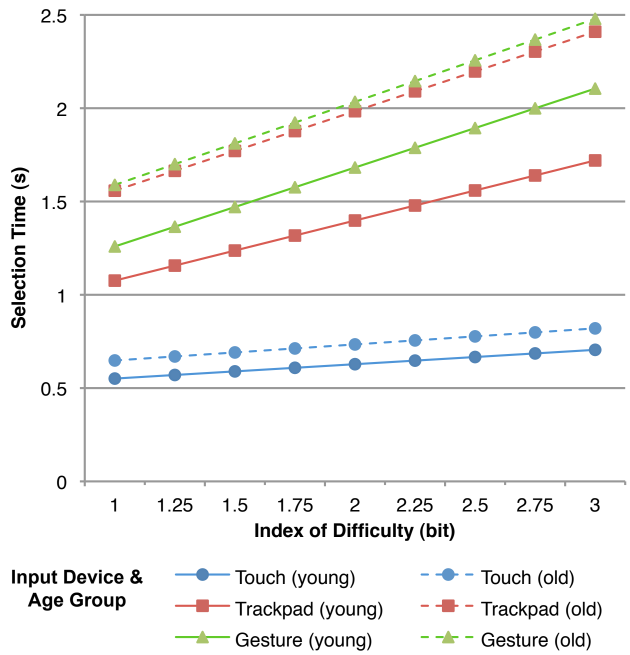

Figure 10. Selection times for both age groups with different input devices.

It was also found that increasing IDs decreased performance more strongly in older participants (interaction of age × ID, $F(1, 44) = 2.9$; $p < .05$). However, older adults showed equally good performance as younger participants when using the touch input (interaction input device × age, $F(2, 44) = 49.8$; $p < .05$). From an ergonomic point of view these interaction effects are especially meaningful. They show that age effects are minimized for the touch input while being most pronounced for the trackpad, with the gesture input ranging in between.

Physical Strain Judgments

Any input device can be evaluated quite positively after only short exposure. Nevertheless, such evaluations are not very realistic as long as the potential emergence of physical strain after a more extensive usage is not considered, especially in a usage context for older adults. Therefore, we analyzed the reported physical strains in several body parts (finger, hands, arm, shoulder) after participants had executed the point-click tasks in all input devices for twenty-five minutes. Figure 11 illustrates the strain ratings for different body parts caused by the usage of the three input devices. As shown there, the reported strain differed significantly between the input devices ($F(2, 21) = 28.5$; $p < .05$). While no strain differences were revealed for fingers and hand, the reported strain on the arm ($F(2, 21) = 19.9$; $p < .05$) and shoulder ($F(2, 21) = 49.3$; $p < .05$) differed significantly due to the more strenuous gesture input compared to touch and trackpad.

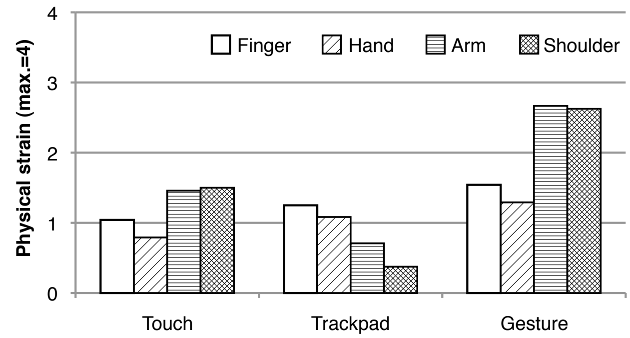

Figure 11. Physical strain ratings due to device usage separated for different body parts.

Beyond strain differences in individual body parts, a significant effect of age as well as a significant interaction of age × input device on strain ratings was found ($F(1, 18) = 4.6$; $p < .05$, see Figure 12).

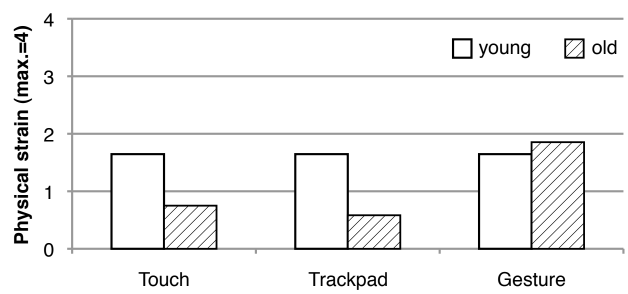

Figure 12. Ratings of physical strain for different age groups and input devices.

Contrary to our expectations (according to which older adults would be more receptive for physical strain), it is the younger group which shows higher strain ratings after the 20 minutes working period with touch and trackpad compared to older users. For the gesture input, which is rated as generally more strenuous than touch and trackpad, strain ratings are comparable across age groups.

DISCUSSION

With the increasing penetration of technology in private spaces, technology must meet the different roles, usage contexts and must comply with the needs of a diverse user group. This ambitious claim has consequences for the way future technologies have to be evaluated. In order to address the different requirements, the evaluation rationale should be broad (including different evaluation aspects) and, at the same time, fine grained (combining different measures) and it should be empirical, including the target users for which the technology is assumed to be beneficial (following a user-centered evaluation with different users).

This comprehensive approach is intricate and time-consuming and definitively more incommodious compared to usual procedures, in which "user tests" in HCI designs are carried out "last minute", examining some and more or less accidental users that do not necessarily reflect the needs and wants of the target group. However, the holistic evaluation approach justifies its effort as it yields very detailed insights and allows a context-adaptive and diversity-sensitive usage and conceptualization of technical products in different usage contexts.

The findings show that – basically – all input devices under study show a high potential and usefulness regarding their employment in smart homes. Regarding the basic ergonomic criteria, such as visibility and overview, all input devices yielded sufficiently good results. But also different insights across input devices were revealed: the gesture input is quite unfamiliar to participants and requires more (cognitive) effort than the trackpad and the intuitive touch input, which received the highest hedonic value (note that the rating of the hedonic value nearly reached the maximum score). Participants, younger and older, were absolutely enthusiastic about the large display wall for both ease and fun of using it. Interestingly though, none of these evaluation criteria did significantly impact the intention to use the devises. Instead, it is the extent of self-confidence when using technology that is decisive for the willingness of participants to use those devices at home.

When including performance outcomes based on Fitts' Law evaluations, all input devices show a basic fit to usability demands of input devices in terms of efficient handling. As expected by Fitts' Law predictions, selection times showed to be significantly impacted by task difficulty [28, 23], especially in the older group. These findings corroborate earlier research according to which older adults show a distinctly reduced performance when working with different input devices [5, 1]. The disadvantages of age had been attributed to the ongoing slowing down of psychomotor abilities over the life-span and the greater difficulties to precisely position and control an input operation. It is a promising finding of this research that the pointing performance of older adults did not show the well-known age-related decline. In fact, older users' pointing performance was almost as good as the younger adults' performance in the touch interface. Apparently, pointing is less sensitive to ageing effects than the usage of indirect input devices. The superiority of pointing might be due to the fact that the direct input allows an easy mapping operation, whereas any device-mediated input operation (trackpad or gesture) requires users to indirectly map the hand movement to the cursor movement on the screen. Furthermore, users have to learn the specific transformation and the visuo-spatial characteristics of the input device, which is not required by touch input. Pointing is facilitated by highly natural and intuitive movements that can be inferred from different contexts and situations in everyday life. Also, no specific expertise with touch interfaces is needed.

A final evaluation keystone can be taken from physical strain judgments after executing point-click tasks for a more extensive time period. Except for the gesture input which caused the largest strain for all participants, trackpad and touch input yielded only small levels of physical strain, showing that they are appropriate even for more extensive usage. Contrary to expectations, older users reported lower strain levels than younger users. This counterintuitive finding cannot be fully explained on this database. Naturally, reporting bias in the older group (e.g., disallowing strain feelings) cannot be fully excluded. Nevertheless, results show that input devices can minimize age-related performance and acceptance barriers and allow a broad access. Overall, touch interfaces can be highly recommended in order to meet usability demands for a diverse user group. Outcomes also corroborate users' strong wish for hedonic input devices.

The duty of further research efforts is to systematically integrate user diversity into evaluation procedures. It is a central claim that future technologies are designed to be in line with users' specificity and diversity. Design approaches should therefore take the user-perspective seriously.

LIMITATIONS AND FUTURE RESEARCH DUTIES

With respect to methodological aspects and the generalizability of our findings, some potential limitations need to be addressed. A first point refers to the selection of a rather healthy and unrestrained older adult group. In addition, the older sample was well educated and showed a comparably high experience with technology. It should therefore be kept in mind that we examined a kind of "best case" scenario. The promising findings of the high usability and acceptability of input modalities examined in this study should be validated by users which show more severe age-related impairments. A second remark refers to the comparably small range of input modalities that were in the experimental focus of this study. Within smart home environments, these devices represent only a small selection of a broad range of possible input mechanisms. In our further research, we will include additional devices, including interactive room elements and furniture, as alternative input modalities for users with restricted mobility [29]. A third point, which should be taken into account, is that the task difficulty was quite low. Future studies will have to corroborate the suitability of the tested input modalities for tasks of higher difficulty. A last point refers to the sample size examined here. Even though the results were clear, future studies are necessary to validate the findings with a larger sample size.

ACKNOWLEDGMENTS
The authors would like to thank all, but especially the older users, who courageously took part in this study and thereby allowed us to gain insights into a complex HCI field. Many thanks also to Yvonne Jansen, Kai Kasugai and Wiktoria Wilkowska for their research assistance.

REFERENCES

1. Armbrüster, C., Sutter, C., Ziefle, M. Notebook Input Devices Put to the Age Test: The Usability of

Trackpoint and Touchpad for Middle-Aged Adults. *Ergonomics 50*, 3 (2007), 426-445.

2. Arning, K., Ziefle, M. Different Perspectives on Technology Acceptance: The Role of Technology Type and Age. *HCI and Usability for e-Inclusion*, Springer (2009), 20-41.
3. Beier, G. Locus of Control When Interacting With Technology, *Report Psychologie 24*, (1999), 684-693.
4. Borchers, J., Ringel, M., Tyler, J., Fox, A. Stanford Interactive Workspaces: A Framework for Physical and Graphical User Interface Prototyping. *IEEE Wireless Communications 9*, 6 (2002), 64-69.
5. Cao, X., Balakrishnan, R. Visionwand: Interaction Techniques for Large Displays Using a Passive Wand Tracked in 3D. *Proc. Siggraph 2004*, ACM Press (2004), 729-729.
6. Charness, N., Holley, P., Feddon, J., Jastrzembski, T. Light Pen Use and Practice Minimize Age and Hand Performance Differences in Pointing Tasks. *Human Factors 46*, 3 (2004), 373-384.
7. de Ruyter, B., Pelgrim, E. Ambient Assisted-Living Research in CareLab. *ACM Interactions 14*, 4 (2007), 30-33.
8. Grossman, T., Wigdor, D., and Balakrishnan, R. Multi Finger Gestural Interaction With 3D Volumetric Displays. *Proc. UIST* 2004, ACM Press (2004), 61-70.
9. Helal, A., W. Mann, H. El-Zabadani, J. King, Y. Kaddoura, E. Jansen. The Gator Tech Smart House: A Programmable Pervasive Space. *IEEE Computer 38*, 3 (2005), 50-60.
10. Helal, S., Winkler, B., Choonhwa, L., Kaddoura, Y., Ran, L., Giraldo, C., Kuchibhotla, S., Mann, W. Enabling Location-Aware Pervasive Computing Applications for the Elderly. *Proc. PerCom 2003*, 531- 536.
11. Johanson, B., Fox, A., Winograd, T. The Interactive Workspaces Project: Experiences With Ubiquitous Computing Rooms. *IEEE Pervasive Computing 1*, 2 (2002), 67-74.
12. Kaltenbrunner, M., Bencina, R. Reactivision: A Computer-Vision Framework for Table-Based Tangible Interaction. *Proc. Tei 2007*, 69-74.
13. Kidd, C. D., Orr, R., Abowd, G. D., Atkeson, C. G., Essa, I. A., MacIntyre, B., et al. The Aware Home: A Living Laboratory for Ubiquitous Computing Research. *Proc. CoBuild* 1999, 191-198.
14. Kristensson, P. O., Arnell, O., Björk, A., Dahlbäck, N., Pennerup, J., Prytz, E., Wikman, J., Åström, N. InfoTouch: An Explorative Multi-Touch Visualization Interface for Tagged Photo Collections. *Proc. NordiCHI 2008,* 491-494.
15. Laleci, G. B., Dogac, A., Olduz, M., Tasyurt, I., Yuksel, M., Okcan, A. SAPHIRE: A Multi-Agent System for Remote Healthcare Monitoring Through Computerized Clinical Guidelines. *Software Agent Technologies and Autonomic Computing*, Birkhäuser (2008), 25-44.
16. Malik, S., Ranjan, A., Balakrishnan, R. Interacting With Large Displays From a Distance With Visiontracked Multi-Finger Gestural Input. *Proc. UIST 2005,* 43-52.
17. McCallum, D. C., Irani, P. Arc-Pad: Absolute+Relative Cursor Positioning for Large Displays With a Mobile Touchscreen. *Proc. UIST 2009*, 153-156.
18. Myers, B., Hollan, J., Cruz, I., Strategic Directions in Human Computer Interaction. *ACM Computing Surveys 28*, 4 (1996), 794-809.
19. Myers, B. A., Peck, C. H., Nichols, J., Kong, D., Miller, R. Interacting at a Distance Using Semantic Snarfing. *Proc. Ubicomp 2001*, 305-314.
20. Park, K. H., Bien, Z. Intelligent Sweet Home for Assisting the Elderly and the Handicapped. *Proc. ICOST 2003*, 151-158.
21. Poulson, D., Nicolle, C., Galley, M. *Review of the Current Status of Research on 'Smart Homes' and Other Domestic Assistive Technologies in Support of TAHI Trials.* Loughborough University (2002).
22. Röcker, C., Prante, T., Streitz, N. A., van Alphen, D. Using Ambient Displays and Smart Artefacts to Support Community Interaction in Distributed Teams. *Proc. OZCHI 2004*.
23. Soukoreff, R. W., MacKenzie, I. S. Towards a Standard for Pointing Device Evaluation, Perspectives on 27 Years of Fitts' Law Research in HCI. *Int. Journal of Human-Computer Studies 61*, (2004), 751-789.
24. Streitz, N. A., Geißler, J., Holmer, T., Konomi, S., Müller-Tomfelde, C., Reischl, W., et al. i-LAND: An Interactive Landscape for Creativity and Innovation. *Proc. CHI 1999*, 120-127.
25. Streitz, N. A., Magerkurth, C., Prante, T., Röcker, C. From Information Design to Experience Design: Smart Artefacts and the Disappearing Computer. *ACM Interactions 12*, 4 (2005), 21-25.
26. Vogel, D., Balakrishnan, R. Distant Freehand Pointing and Clicking on Very Large, High Resolution Displays. *Proc. UIST 2005*, 33-42.
27. Youngblood, M., Cook, D. J., Holder, L. B. Managing Adaptive Versatile Environments. *Proc. PerCom 2005*, 351-360.
28. Zhai, S., Kong, J., Ren, X. Speed-Accuracy Tradeoff in Fitts' Law Tasks on the Equivalency of Actual and Nominal Pointing Precision. *International Journal of Human-Computer Studies*, 61 (2004), 823-856.
29. Zimmer, Z., Chappell N. Receptivity to New Technology among Older Adults. *Disability and Rehabilitation 21*, 5/6 (1999), 222-230.