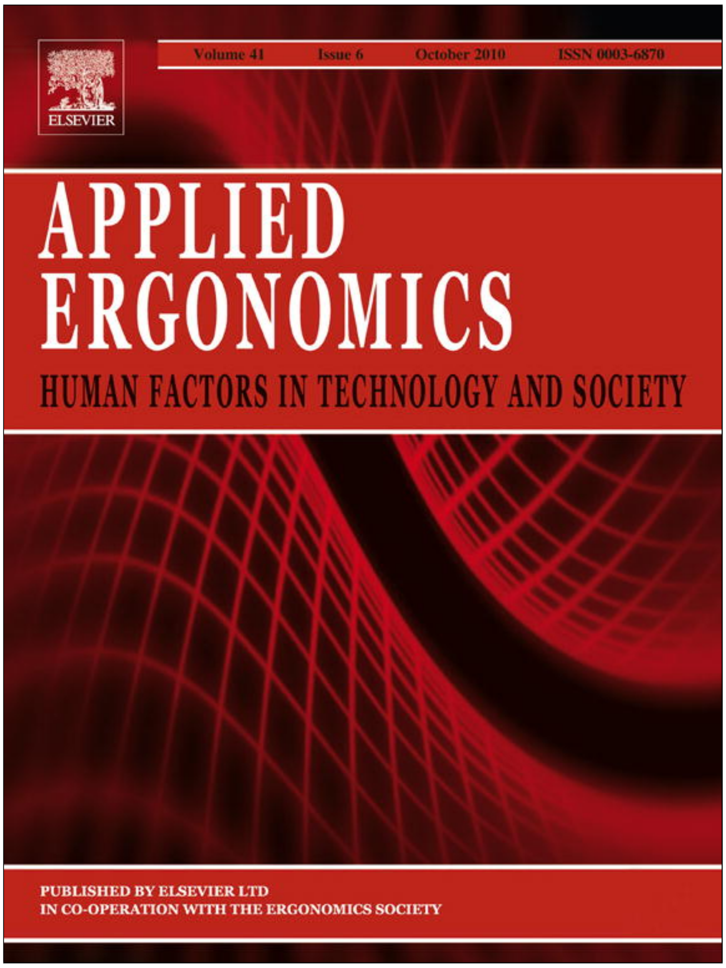
Volume 41 Issue 6 October 2010 ISSN 0003-6870
ELSEVIER
APPLIED
ERGONOMICS
HUMAN FACTORS IN TECHNOLOGY AND SOCIETY
PUBLISHED BY ELSEVIER LTD
IN CO-OPERATION WITH THE ERGONOMICS SOCIETY

Applied Ergonomics 41 (2010) 719–730

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Information presentation in small screen devices: The trade-off between visual density and menu foresight

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ARTICLE INFO

Article history:
Received 9 February 2009
Accepted 25 February 2010

Keywords:
Small-screen device
Older adults
Information design
Font size
Preview
Navigation performance

ABSTRACT

Small mobile devices are ubiquitous and must be designed with great care. One of the most serious challenges is how information on the small displays is presented optimally. This paper addresses the special problem of the increasing number of aged users. On the one hand, information displayed should be easily readable. This requires a low information density and a sufficiently large font size. On the other hand menu orientation is facilitated when the amount of information per screen is maximized and a large preview is allowed. This requires presenting as many functions as possible on the screen at a time. Thus, the tradeoff between readability and orientation demands is crucial. In the present study, this tradeoff was experimentally investigated. Two factors, font size (8 pt, 12 pt) and the size of the preview (one or five functions per screen at a time) were varied and effects on navigation performance were observed. Forty older participants solved nine common phone navigation tasks twice consecutively on a simulated mobile phone. Both factors contributed to performance, but there was a significant interaction: navigation performance was optimal when font size *and* the size of the preview were large. The lowest performance was obtained when the preview was small and the font size large, showing that proper orientation is more important than visibility demands. The results can be used in ergonomic guidelines to optimized information presentation on small screens.

1. Introduction

Information and Communications Technology has penetrated most professional and private areas in the last decades. Mobile technologies play a prominent role, and are increasingly used by, older and technically inexperienced people. Although it is widely accepted that usability issues are of great importance for older adults, research as well as user experience show that there are many ergonomic pitfalls that hamper the usage of these technologies. Effective and successful integration of mobile information technology and its full acceptance impose considerable challenges to modern societies. Several major trends can be identified that impact usable and barrier-free display and interface designs. These will be detailed in the next section.

1.1. Challenges for interface designs in mobile devices

A first trend refers to the profound demographic change with an increasingly aging population. According to census data in 2050 more than 30% of the population will be 65 years and older. More and more older adults will be confronted with various technical devices, which they need to learn and use. Research shows that older users face great difficulties in learning and using new computer applications (Arning and Ziefle, 2007a, b, 2009; Czaja and Sharit, 1997; Kelly and Charness, 1995; Ziefle and Bay, 2004, 2005). Due to profound age-related changes in sensory, physical, psychomotor, and cognitive functioning electronic displaying of information is a challenging issue (Armbrüster et al., 2007; Birren and Fisher, 1995; Fisk and Rogers, 1997; Gilbert et al., 2004; Haegerstrom-Portnoy et al., 1999; Kline and Scialfa, 1997; Oetjen and Ziefle, 2007; Pak et al., 2008; Park, 1999; Salthouse, 1996; Westermann, 1997; Ziefle and Bay, 2006; Ziefle et al., 2007). Contrary to current stereotypes, according to which seniors are unable or unwilling to learn new technologies, older users want to become acquainted with modern technologies (Arning and Ziefle, 2006, 2008; Melenhorst et al., 2006). However, they have greater demands on usable and useful information designs. Display designs of new applications are typically realized without considering to the needs elderly.

A second trend is the ongoing diffusion of technical devices in all parts of daily life. In the past sophisticated and technology prone professionals were the typical end-users. Today broad groups of

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doi:10.1016/j.apergo.2010.03.001

users take advantage of word processors, web browsers, Internet applications, ticket vending machines and online library catalogues, which have become deeply integrated into daily life (Arning and Ziefle, 2007a, b). Older users differ considerably with regard to their needs, abilities and competencies. To include older adults, an age-sensitive display design is needed, which allows users of all age groups and ability levels to interact with new technical applications.

As a third trend, technology itself is ever changing; the cycles of technology innovations become increasingly faster. This aggravates the situation for older adults, as the understanding of how technology works is largely formed by upbringing and cultural factors. Also, mobile devices are equipped with display technology which has visual ergonomic shortcomings, especially for older users (Oetjen and Ziefle, 2007, 2009). In addition, devices often have huge functionality (Weiss, 2002), which increases cognitive complexity of device usage (Bay and Ziefle, 2005; Lin, 2001; Ziefle and Bay, 2005).

1.2. Impact of information representation in small screen devices

Mobile technologies have the basic potential of supporting older adults in their daily needs, e.g. for medical monitoring, navigation, memory aids and personal data management. Also, mobile devices are increasingly used to communicate with remote computers, and they can be integrated in clothing (Leonhardt, 2006), furniture and walls (Streitz et al., 2003; Prante et al., 2004). However, the mobile character of these devices in combination with the small display represents a still higher usability demand compared to large display technologies. The limited screen space is extremely problematic for providing optimized information access (Zhao et al., 2001). Only a few items can be seen at a time and users navigate through a menu whose complexity, extension and spatial structure is not transparent to them as it is hidden from sight. Users have to memorize functions' names, their relative location within the menu and update their orientation.

Disorientation in handheld device menus is a rather frequent problem (Edwards and Hardmann, 1989; Kim and Hirtle, 1995; McDonald and Stevenson, 1998; Ziefle and Bay, 2004, 2006), especially for aged users or those with little computer-related knowledge (Arning and Ziefle, 2007a, b, 2008). At first glance, the challenge seems to be mainly related to visibility and readability (Omori et al., 2002). However, there is also the cognitive aspect of information displaying, the requirement that the presentation of information should help users to orientate themselves properly. In mobile phone menus functions are organized in a hierarchical tree structure. To find the desired function in deeper menu levels, the user has to decide at each point which of the alternatives leads most likely to the goal (the function for which one is searching). In this self-terminating search the user selects a menu item that seems appropriate. A comparison of different alternatives to choose from takes place, particularly because the labels in the menu are often not informative (Han and Kwahk, 1994; Norman, 1991; Schröder and Ziefle, 2005).

Beyond differences in physical dimensions, resolution, (color) contrast, and luminance, small screen devices differ in the display size and the number of menu items displayed at a time on the screen. Some devices show as many functions and some display images with one menu item per screen. For example, current mobile phones (e.g. models of Nokia, Motorola, Samsung, Sony Ericsson), have screen sizes of about 3.5–6 cm (length) and 2.5–5 cm (width) and display between two and eight lines. Letter sizes vary between 2 and 5 mm. Though, one could argue that the ergonomic issue of information representation and the cut-off between letter size and display size is increasingly of minor importance, given the current trend of larger displays in smart phones (as e.g. the Iphone®, which can display up to 20 functions on its 3.5″ multi-touch display). Yet, it should be kept in mind that the choice of a smaller or larger display is not exclusively a matter of aesthetics and appealing designs. There may be good reasons for keeping displays small, as for example in the medical context, in which the devices must be small to meet intimacy and/or acceptance demands (e.g. signal warning devices for blood pressure or diabetes).

1.3. Tradeoff between visual density and menu foresight

Ergonomically it is thus of central interest to find out how the access to the desired function can be optimized through information visualization. Two aspects may contribute here: One is the visual/perceptual facet, namely how menu items can be encoded best (quickly and most accurately) by the users. The other is the cognitive aspect, claiming that the presentation of information should help users to understand the available alternatives to chose from the menu.

The presentation of only one menu item at a time could be helpful, because it is widely known that the legibility and also the readability is hampered by increased density of text on the screen (e.g. Norman, 1991; Ziefle et al., 2005). In visual search tasks, for example, response times increase with text density due to what is called "visual load" (Nattkemper and Prinz, 1990). From this it can be deduced that visually demanding displays negatively influence information access. Accordingly, Tinker (1963) reported a negative effect of small line spacing on readability, which was especially pronounced in small fonts (6 pt or 8 pt). These difficulties are assumed to be caused by visual masking effects (Bouma, 1970).

The presentation of many menu items at a time (assuming good visibility) should provide "cognitive preview", which facilitates the process of structuring the information, comparing and cognitively discriminating the various alternatives to choose from. Seeing what is central for the next steps will help problem solving. From a cognitive point of view, displaying only one menu item at a time can be harmful; apart from not seeing the available alternatives to choose from, the overall tree structure and the hierarchical menu structure become less transparent to the user. In recent studies (Bay and Ziefle, 2008; Ziefle and Bay, 2004; Ziefle, 2008) it was shown that possessing conceptual knowledge of the menu's structure is of central importance for successful interaction with the device.

In large computer screens it is beneficial when in a menu the upcoming selections of the next (deeper) level are shown (Snowberry et al., 1983). The performance benefit is explained by the fact that the associations between target functions and category descriptor terms are rather weak. On small screens, where only small representations of the menu can be shown, it might be even more important to see many alternatives (Bernard et al., 2001). Han and Kwahk (1994) showed the negative impact of displaying only one menu item on navigation performance, especially for novice users (who have no overview of functions) and in deep menu structures (with a high probability of disorientation).

If the cognitive process of pre-structuring information is crucial for successful interaction with the device and, as a consequence, helps in the development of an appropriate mental representation of the menu structure, cognitive styles and abilities may influence the navigation outcomes in addition (Egan, 1988). Spatial abilities are essential for successful navigation (Willis and Schaie, 1986; Pak, 2001; Pak et al., 2008) in the menus of small screen devices (Ziefle and Bay, 2006; Ziefle et al., 2007). Field independence, the ability to separate an item from the context of which it is a part, exerts a strong influence upon navigation ability, as well as verbal memory abilities may also play a role in the integration of many items into a mental map. Therefore, these user characteristics should be assessed through standardized tests in order to provide insights into the underlying processes of information access in a menu-driven small screen device.

2. Questions addressed and logic of experiment

It is investigated which of the two processes – the influence from cognitive preview or effects of visual density – is decisive for the usability of small screen devices. With this aim, font size, information density, and cognitive preview in simulated mobile phones were experimentally varied, and the effect on navigation performance observed. Also, participants reported ease of using with the different display variants. As older adults are an increasingly key target group, which might have especially problems with information representation on small screens, a group of older adults was examined. In order to learn which of the age-related characteristics accompany the menu navigation performance, and the age-related performance decrement- users' technical experience, verbal memory, spatial visualization ability and level of field dependency were psychometrically assessed and related to navigation performance. The results enable one to make recommendations for ergonomic guidelines for information presentation in small screen devices.

3. Method

This section describes methodological details and the operationalization of the experimental variables.

3.1. Preliminary considerations regarding experimental realization

Device type: the question of information presentation in small screen devices is a generic problem, which should act independently from the device type. A mobile phone was chosen which is perceived as useful and valuable for many users. To meet requirements of ecological validity, a real mobile phone with a moderate function complexity was selected, which was formerly a mass model (Siemens S45). By this, familiarity effects with current mobile phones were ruled out which could have confounded navigation performance.

Font sizes and information density: How many items per display should be presented, and which font size should be selected? In order to segregate the influence from cognitive preview and effects of visual density on navigation performance, we chose sufficiently different conditions. For the preview variation, one and five functions per display were chosen, with letter sizes of 2.5 mm and 4 mm.

3.2. Experimental variables

Two independent variables were examined. Font size was varied in two steps: a small font size (arial, 8 pt) was compared to a larger font size (arial, 12 pt). The second independent variable was "preview size", also with two levels: small preview with only one function visible on the display at a time and a large preview with 5 functions displayed simultaneously. Thus four different display conditions were examined: (1) display 1: small preview/small font;

Fig. 1. Illustration of the four experimental display conditions in the simulated mobile phone.

(2) display 2: small preview/large font; (3) display 3: large preview, small font, and (4) display 4: large preview, large font (see Fig. 1, Table 1). In Fig. 1, the four different display conditions of the simulated prototype are illustrated.

As dependent variables, the effectiveness and efficiency of navigation performance and ease of use were reported using the standards for usability (En Iso 9241-11, 1997). In total, nine different dependent variables were surveyed. Three of the measures addressed navigation efficiency, one measure referred to effectiveness, and five measures were related to various aspects of ease of using the phone. The measures are described in detail below.

Efficiency: (1) the number of hierarchical returns to higher levels in the menu hierarchy. This measure indicated that users in the belief of having taken the wrong path went back to a known

Table 1
Experimental conditions.

		Font size	
Pre-view		Small (8 pt)	Large (12 pt)
	Small (1 function)	Small preview small font (Condition 1)	Small preview large font (Condition 3)
	Large (5 functions)	Large preview small font, (Condition 2)	Large preview large font (Condition 4)

position within the menu for re-orientation. (2) The number of returns to the top. This measure is known to reflect utter disorientation and complete helplessness in users orientating themselves in the menu (Ziefle and Bay, 2006; Ziefle et al., 2007). In order to get out of the menu, users go back to the start level. (3) As a third standard measure, the time needed to process the tasks was measured.

Effectiveness: for the task effectiveness, the number of successfully solved tasks was counted.

Ease of use: the ease of use was measured by the following five statements: (1) it was easy for me to solve the tasks. (2) While completing the tasks, I felt lost in the menu. (3) I often did not know where to go next. (4) I often did not know how to reach a specific function. (5) I often did not know where I was currently located within the menu. Each statement was assessed using a five-point-scale (1 = completely true, 2 = mostly true, 3 = partly true; 4 = mostly untrue and 5 = completely untrue).

3.3. Apparatus and materials

As mobile phone, a formerly widespread common model with moderate function complexity was chosen (Siemens S45). The size of the display corresponded to the original display size but the shell of the phone including the keys were enlarged in order to enable easy operation using the finger on the touch screen. The different display conditions were implemented in the software of the mobile phone. For this purpose, the Siemens S45 was simulated as software solution, run on a PC and displayed on a touch screen (TFT-LCD Iiyama TXA3841, TN, 15' with touch logic by ELO RS232C). The software mirrored the real phone regarding menu and navigation keys' functionalities, except for differences within the displaying of the information within the small screen of the mobile phone. Also, a logging tool was programmed specifically for experimental purposes which enabled us to record user actions on the key-stroke level. Thus, frequency and type of keys used, time spent on tasks and the navigational route could be reconstructed very precisely. In order to assure a comfortable and relaxed body posture while completing the tasks, participants sat on a table and worked on the touch screen, which was fixed to the edge of the table. Fig. 2 shows the touch screen mounted to the table.

3.4. Experimental tasks

Nine common telephone tasks were carried out by participants. The tasks represented a wide variety of frequently used telephone functions (Ziefle and Bay, 2006). Among those tasks 1–3 were tasks which could be solved by pressing the appropriate buttons on the first level menu. For other tasks 4–9, the menu of the phone had to be entered and in which, depending on the respective task, three or four menu levels had to be used for navigation. To assess learnability, the nine tasks were solved twice consecutively. The order of tasks was randomized over participants. Below the sequence of main menu points are given for each task in the text. Note that functions labels are translations of the original German terms used in the Siemens S45 phone.

Fig. 2. Snapshot of the touch screen mounted to the table.

Tasks to be solved without entering the menu:

- *Calling a number*: 11 keystrokes (steps), no menu (entering 10 digits and pressing one control key).
- Calling a person out of the internal phonebook: 9 keystrokes, no menu (selecting 'phonebook', scrolling downwards to the person that has to be called, and pressing one control key).
- Editing a number stored in the phonebook: 32 keystrokes, no menu (selecting 'phonebook', scrolling to the name of the person whose number had to be edited, selecting 'edit number', deleting number, entering 10 digits, selecting 'save number').

Tasks in which the menu had to be navigated through:

- Hiding one's own number when calling somebody: 14 keystrokes, menu depth: 4 levels (selecting the confirmation key to enter the menu, scrolling to 'settings' and selecting it, scrolling to 'during calling' and selecting it, selecting 'incognito', scrolling to 'all calls' and selecting it, selecting 'next call').
- Sending a text message to a number stored in the phonebook: 11 keystrokes, menu depth: 3 levels (pressing the confirmation key to enter the menu, scrolling to and selecting 'message', selecting 'new text message', selecting 'options', selecting 'send', selecting 'phonebook', scrolling to the person to which the text message had to be sent and selecting it, pressing the confirmation key. As the differences in the individual speed of typing was not of interest, the message was already provided and only had to be sent when participants had reached the adequate point in the menu).
- Making a call divert: 11 keystrokes, menu depth: 4 levels (selecting the confirmation key to enter the menu, scrolling to 'call divert' and selecting it, selecting 'all calls', scrolling to and selecting 'set', selecting 'mailbox', pressing the confirmation key).
- Accessing the voice entry mode for selecting another language: 7 keystrokes menu depth: 4 levels (selecting the confirmation key to enter the menu, scrolling to and selecting 'office', scrolling to and selecting 'voice control'; selecting ' choice of language').
- Changing of the ringing tone of the mobile phone alerting upcoming meeting: 14 keystrokes, menu depth: 4 levels (selecting the confirmation key to enter the menu, scrolling to and selecting 'audio', scrolling to and selecting 'melodies', scrolling to and selecting 'meetings').
- Activating the phone's voice mail to check unanswered calls: 9 keystrokes; menu depth: 3 levels (selecting the confirmation key to enter the menu, scrolling to and selecting 'office', scrolling to and selecting 'organizer', scrolling to and selecting 'missed calls').

3.5. Participants

Forty participants volunteered to take part in the study. They were between 55 and 73 years of age ($M = 58.9$; $SD = 7.4$). Ten participants each were randomly assigned to one of the four experimental conditions. Each group was balanced by gender, with five females and five males. Participants responded to a newspaper announcement in which a study of mobile phone usability was advertised. The motivation to join the study was high, since participants had a strong interest in taking an active part in improving the ease of using technical devices. Taken from their statements, current devices – and especially mobile devices – have a "shameful low usability" and do not meet the specific requirements of older users. Further, participants were all highly interested in their individual performance level.

3.6. Assessing users' previous experience with technical devices

To ensure that the navigation outcomes were influenced by the experimental variation, rather than by participants' experience with technical devices (PC, mobile phones) and the reported ease of using them, a detailed prescreening was carried out. First, all participants indicated to possess and rather frequently use a mobile phone, mostly for making and receiving calls and sending text messages. On a scale (1 = several times per day, 2 = once per day 3 = once or twice a week; 4 = once or twice per month), participants indicated to use the mobile phone and the PC about once a day. Regarding the ease of using these devices (1 = easy, 2 = rather easy 3 = rather difficult 4 = difficult) , the ease of using the mobile phone usage was rated as rather easy ($M = 2$; SD = 1.3) and the usage of the PC between easy and rather easy ($M = 1.7$; SD = 0.9). Overall, participants were quite experienced with the usage of mobile phones reporting not to have greater difficulties when using it. In order to learn if the experience when using the mobile phone and the PC as well as the reported ease of use is interrelated, correlation analyses (Pearson values were used for interval-scaled data, Spearman-Rho values for ordinal-scaled data and Eta values for nominal-scaled data) were carried out. Also, age and gender of participants were correlated with the usage of technical devices.

The frequency of using the PC revealed to be positively correlated to the ease of using the PC ($\epsilon = .76$; $p < 0.05$). Also, the frequency of using the mobile phone showed a significant interrelation to the rated ease of using the phone ($\epsilon = 0.89$; $p < 0.05$). In addition, the PC usage was significantly correlated to the frequency of using the mobile phone ($\epsilon = 0.57$; $p < 0.05$). Neither the frequency of phone and PC usage showed a correlation with age, nor did the rated ease of using these devices. However, there were significant correlations of device usage with the gender of participants. Female users reported to use the mobile phone ($\epsilon = -0.36$; $p = 0.05$) and the PC ($\epsilon = -0.62$; $p < 0.05$) less frequent than male users. No gender differences were found respecting the rated ease of using the mobile phone and the PC. The interest in modern technology was not correlated with age, but with gender ($\epsilon = -0.36$; $p < 0.05$) and revealed a considerable lower interest in female compared to male users.

Finally, it was checked if the four experimental groups differed with respect to the previous technical experience. Statistical testing showed that the four experimental groups did not differ within age, and technical experience (PC, mobile phone usage).

3.7. Psychometric tests used to assess user characteristics

Beyond the experimentally variation which is in the central focus, a significant source of variation stems from user diversity. It is therefore of central interest to have a closer look into user characteristics that possibly cause or at least interact with the disorientation problem.

Three different abilities – spatial abilities, verbal memory, and field dependency – were psychometrically assessed and related to navigation performance. These abilities were found in previous studies to be specifically important for the navigation in small screen device menus (Bay and Ziefle, 2003, 2008; Ziefle and Bay, 2006, 2008; Ziefle et al., 2007).

To assess spatial abilities, the paper-folding test (Ekstrom et al., 1976) was used. Each of the 20 items shows successive drawings of two or three folds made in a square sheet of paper. The final drawing shows a hole punched in the folded paper. Participants selected one of five drawings to show how the punched sheet would appear when fully opened. An exemplary item is given in Fig. 3.

From the 20 possible points that could be reached at the most, an average of 12.6 (SD = 3.8) were reached, with results ranging from 4 to 20 correct answers. Within the age range examined, no correlation of age and spatial abilities were found. Men showed a slightly higher spatial ability than women, however, the differences did not reach statistical significance.

Verbal memory ability was assessed by a verbal memory test (Bay and Ziefle, 2003; Ziefle and Bay, 2006; Ziefle et al., 2007). In this test, 15 Turkish words were presented in succession for three seconds, each. Directly after the presentation, participants had to recognize the target items among three distractors, each, being phonologically or visually similar. Fig. 4 shows an exemplary item. The maximum score to be reached was 15.

Results showed that the correct answers ranged from 5 to 14 ($M = 10.1$; SD = 2.7). Neither age nor gender differences in verbal memory abilities were found.

The extent of field dependence (Witkin et al., 1962) was measured by subtest 10 (embedded figure test) of a common psychometric performance test (Horn, 1983). Thus, this test assesses the ability to detect the substantial information within distracting details. In Fig. 5, an example item is illustrated. Participants were required to solve the 40 problems in a time limit of three minutes. A maximum test score of 40 was to be reached.

From the 40 points, an average of 35 (SD = 6) was reached. The range of answers reached from a minimum of 18–40 points out of 40. For this ability, significant gender differences were revealed. Female users showed a higher performance ($M = 37$; SD = 3.1) than did males ($M = 33$; SD = 7.6), indicating a higher degree of field independency in the female group compared to the male group.

The correlation of field (in)dependency and spatial ability turned out to be highly significant ($r = 0.6$; $p < 0.05$). Verbal memory did not show interrelations with spatial abilities on the one hand and field(in)dependency on the other.

3.8. Design and procedure

The study was based on a two-factorial design. Both main factors (font size and preview) were combined such, that four different display conditions resulted (small font/small preview; large font/small preview/large font/small preview and large font/large preview). In each of the conditions, 10 participants completed the phone tasks twice consecutively. In the beginning of the experiment, participants' technical experience was assessed and, field dependency, verbal memory and spatial abilities were

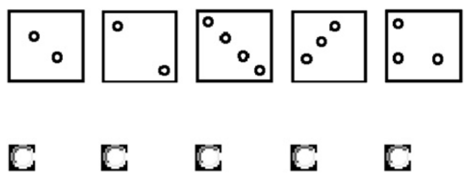

Fig. 3. Item example of the paperfolding test (upper line) and answering alternatives (lower line) (Ekstrom et al., 1976).

TATIL

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Fig. 4. Item example for the verbal memory test (Bay and Ziefle, 2003).

determined. Then, the nine tasks were to be solved twice, in order to determine learnability effects. A fast *and* thorough working style was instructed, however, a time limit of five minutes per task was set. The time limit was tested in a series of similar experiments and showed to be appropriate in order not to overly burden and frustrate participants (in case of not solving a task successfully). If a task was solved successfully, a 'Congratulations' – message appeared on the display. User manuals were not provided. To avoid any biases, participants were not informed about the different display conditions. It was instructed that the experiment was concerned with the usability of mobile phones. After task completion participants rated the ease of completing the task, and answered different questions regarding the orientation within the menu hierarchy. After the experiment, participants were gratified for their efforts with a small present. Depending on the individual working speed, the whole experiment lasted about 80–90 min.

4. Results

The results were analyzed by multivariate analyses of variance assessing effects of 'font size' and 'size of preview' on navigation performance in terms of effectiveness (number of tasks solved) and efficiency (number of hierarchical returns in menu hierarchy, returns to the top, and time on task). The significance of the omnibus *F*-tests was taken from Pillai values, followed by the description of the single *F*-tests. The significance level was set at $p < 5\%$.

In a first step, the performance of all tasks was summed up and means for the different groups are reported. Regarding the analysis of task efficiency, two strategies can be considered: One strategy only includes users that successfully accomplished the tasks; the other one includes all participants, independently from their tasks' success. Both strategies are basically "sensible". On a first sight, the selection of successful task performers for further analysis seems to be advantageous as their results can be directly related to effectiveness. However, if only a rather small proportion of participants were able to solve a certain task, only small and unequal samples would have entered statistical analyses. Moreover, from an ergonomic point of view, it is more insightful to learn about the ergonomic shortcomings and navigation difficulties and to consider all user actions – even if users failed in end (if a task was not completed in the given time limit, 300 s (5 min) were taken as processing time). Analyses showed that result patterns for "task solvers" and "non-solvers" were quite similar. Therefore, task efficiency was statistically analyzed comprising the total group.

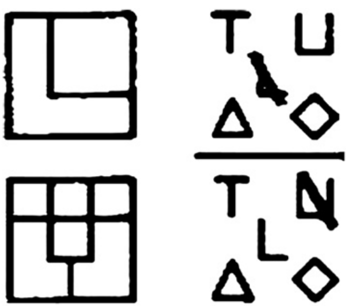

Fig. 5. Example item of the sub-test 10 (embedded figure test) of the psychometric test "Leistungsprüfsystem" (LPS) (Horn, 1983).

To assess learnability effects, the performance of the nine tasks in the first trial was contrasted to the task performance in the second trial by carrying out analyses for repeated measurements. The effects of the navigation aids on the different task types were evaluated. The performance of the single tasks was of minor importance in this context. A basic question was if displaying information affects the tasks with a flat menu hierarchy and deep menu hierarchy differently. The performance in tasks with no menu navigation (tasks 1–3) was compared to tasks where it was necessary to navigate three or four menu levels (tasks 4–9). Finally, the outcomes in subjective measures were compared with performance. User judgments were analyzed by means of non-parametric Kruskal–Wallis tests.

4.1. Overall performance

The MANOVA yielded a significant omnibus effect of the size of the preview ($F(4, 33) = 2.5$, $p = 0.05$). Font size did not significantly affect performance. However, there was a meaningful interaction of font size and size of the preview ($F(4, 33) = 3.3$, $p < 0.05$). Thus both factors, font size and preview did contribute to performance outcomes, with a stronger impact on the size of the preview. Descriptive outcomes (means for all dependent measures) can be found in Table 2.

As can be seen from Table 2, the font size did not significantly influence navigation performance. However, the size of the preview affected the disorientation measures also on the single *F*-test level (returns in menu hierarchy): $F(3, 39) = 2.1$, $p < 0.05$; returns to the top: $F(3, 39) = 9.9$, $p < 0.05$). Descriptive outcomes for the preview effect are illustrated in Fig. 6.

Interacting effects were found for all navigation measures (effectiveness: $F(3,35) = 8$, $p < 0.05$); time on task: $F(3,35) = 10.4$, $p < 0.05$); returns in menu hierarchy: $F(3, 35) = 5.1$, $p < 0.05$; returns to the top ($F(3, 35) = 5.7$, $p < 0.05$). In Table 3, descriptive values of the interacting effects are given. The best performance was obtained for the combination of large font size and large preview (condition 4, gray shaded fields in Table 3).

The lowest performance was found for large font/small preview (condition 3). With the advantageous display, (large font/large preview), participants solved 16.5 (SD = 1.4) out of the 18 tasks in combination with a processing time of 24.2 min (SD = 486 s). With the disadvantageous display (condition 3), in contrast, only 14 tasks (SD = 2.5) were solved correctly with a processing time of 38 min

Table 2
Descriptive values (means) and MANOVA outcomes of the main effects size of preview and font size (N = 40).

Font size	Small (8pt)	Large (12 pt)	Omnibus F Test: (F (4,33) = 1.3 p > 0.05)
Effectiveness (max=18)	14.7	15.1	F (1,36) = 1.5; p>0.05
Time on task (min)	36.1	31.1	F (1,36) = 2.3; p>0.05
Returns in menu hierarchy	112.2	108.1	F (1,36) < 1; p>0.05
Returns to the top	17.2	12.6	F (1,36) = 2 p>0.05
Size of preview	Small (one function)	Large (five functions)	Omnibus F Test: (F (4,33) = 2.6 p < 0.05)
Effectiveness (max=18)	14.9	15.2	F (1,36) <1; p>0.05
Time on task (min)	35.2	31.9	F (1,36) = 1.4; p>0.05
Returns in menu hierarchy	125	99	F (1,36) = 2.3; p<0.05
Returns to the top	20	9.7	F (1,36) = 10.5 p<0.05

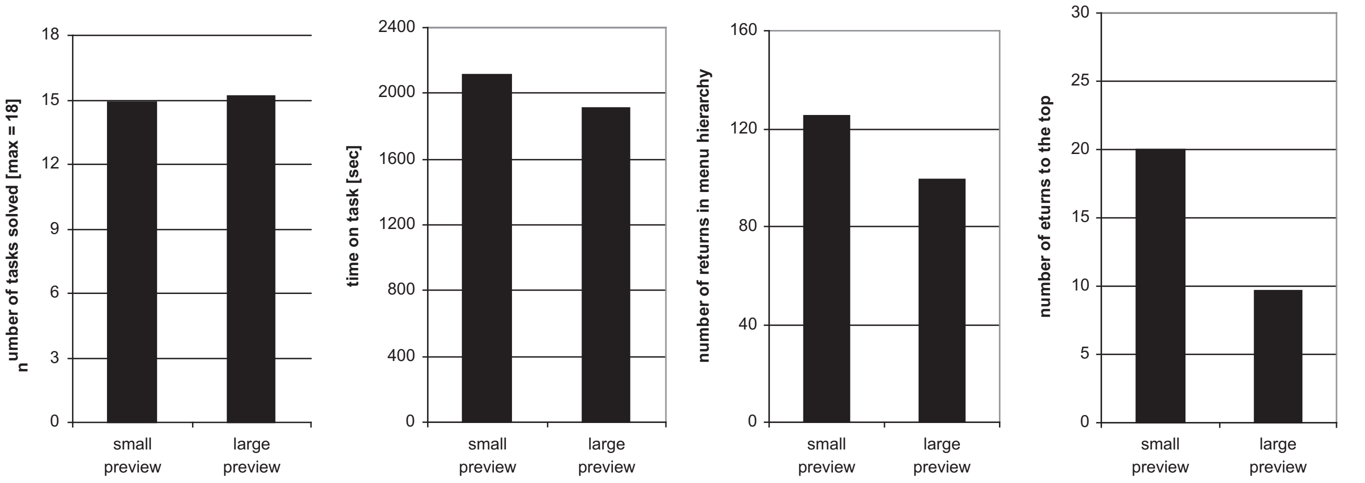

Fig. 6. Main effect of the size of the preview for all dependent measures (from left to right: task effectiveness, time on task (s), number of returns in menu hierarchy, number of returns to the top).

(SD = 649 s). The superiority of the large font/large preview display was prominent also in the disorientation measures: users stepped, on average, "only" 82.3 times (SD = 31.8) back to higher levels in the menu and returned 8 times (SD = 5.6) to the top menu level to re-orientate themselves. With the disadvantageous display (condition 3, small preview/large font), users returned, on average, 150 times (SD = 78) in menu hierarchy and, carried out, on average, 26.3 (SD = 15) complete re-starts, beginning from scratch. The interaction effects are illustrated in Fig. 7.

4.2. Learnability effects (performance in the first vs. the second trial)

The main interest was to analyze whether performance improved in the second trial (compared to the first) and if this improvement is equally large for all preview/fontsize combinations. The analyses showed that there was a considerable performance increase from the first to the second trial, however, the differences between display conditions did not vanish.

Significant improvements were found for task effectiveness ($F(1,36) = 14.7$; $p < 0.05$), however, learnability was not different for the preview and font size conditions. In the first trial, 7.2 (SD = 1.3) of the nine tasks were solved and 7.9 tasks (SD = 1.1) in the second trial. Regarding the time needed to process the task, users solved the tasks more quickly in the first compared to the second trial ($F(1,36) = 129.8$; $p < 0.05$), needing on average about 30 min (SD = 401 s) to solve the nine tasks in the first trial and the processing time decreased by 32% to 13.5 min (SD = 327 s) in the second trial. Also, an interacting effect of learnability and the size of the preview was present ($F(1,36) = 4.8$; $p < 0.05$). Looking at the number of hierarchical steps back in the menu structure, a significant learnability effect was detected ($F(1,30) = 4.5$; $p < 0.05$), though being equally large for all display conditions. In the first trial, participants carried out 60 returns in menu hierarchy (SD = 29), and 52 returns (SD = 33) in the second trial, corresponding to an improvement of 13%. No interacting effect was revealed, showing that the learnability effect was a general effect, not differing depending on the specific display type and preview/fontsize combination, respectively. From an ergonomic point of view is an interesting finding that there was no learnability effect in the dependent variable which reflects utter disorientation. In the first run, participants returned about 10 times to the top menu level, and still 6.8 times in the second run, beginning from scratch. It is important to note that, independently of learnability effects and the performance increase from the first to the second run, the very same display condition revealed to provide the most helpful information design (large font, large preview, condition 4), and the very same display to be most impedimental for navigation performance (large font, small display, condition 3). Fig. 8 illustrates the learnability effects for all dependent measures.

Table 3
Descriptive values of the interacting effect of preview × font size as well as MANOVA outcomes ($N = 40$).

Interaction of preview × font size	Small preview	Large preview	Omnibus F test: ($F(4,33) = 3.3$; $p > 0.05$)
Effectiveness (max = 18)			
Small font	15.4	14.4	$F(1,36) = 8.1$; $p < 0.05$
Large font	14	16.5	
Time on task (min)			
Small font	32.5	38.1	$F(1,36) = 10.4$; $p < 0.05$
Large font	39.6	24.2	
Returns in menu hierarchy			
Small font	100.7	149.9	$F(1,36) = 5.5$; $p < 0.05$
Large font	115.6	82.4	
Returns to the top			
Small font	13.8	26.3	$F(1,36) = 6.2$; $p < 0.05$
Large font	11.4	8	

The condition with the best performance is gray shaded.

4.3. Effects of menu depth

Up to now, the performance outcomes were based on the analysis of the overall performance, comprising the nine different tasks. This procedure allows an evaluation of general performance across a large variety of tasks. However, it is reasonable to assume that the benefit of specific information designs in small screens might not be equally strong for all tasks. Conversely, one could expect that any specific preview and font size combination is more or less bootless when users do not need to navigate through deeper menu levels, especially as the preview component, which helps to reduce disorientation, does not come into fore whenever the menu has not to be entered. Following this argumentation, the difference between display types should be smaller in the tasks in which the menu had not to be entered and should increase in the deep menu level tasks. A MANOVA was carried out, with the size of preview and font size as main factors and the effectiveness and efficiency as dependent variables, for the low and the deep level tasks.

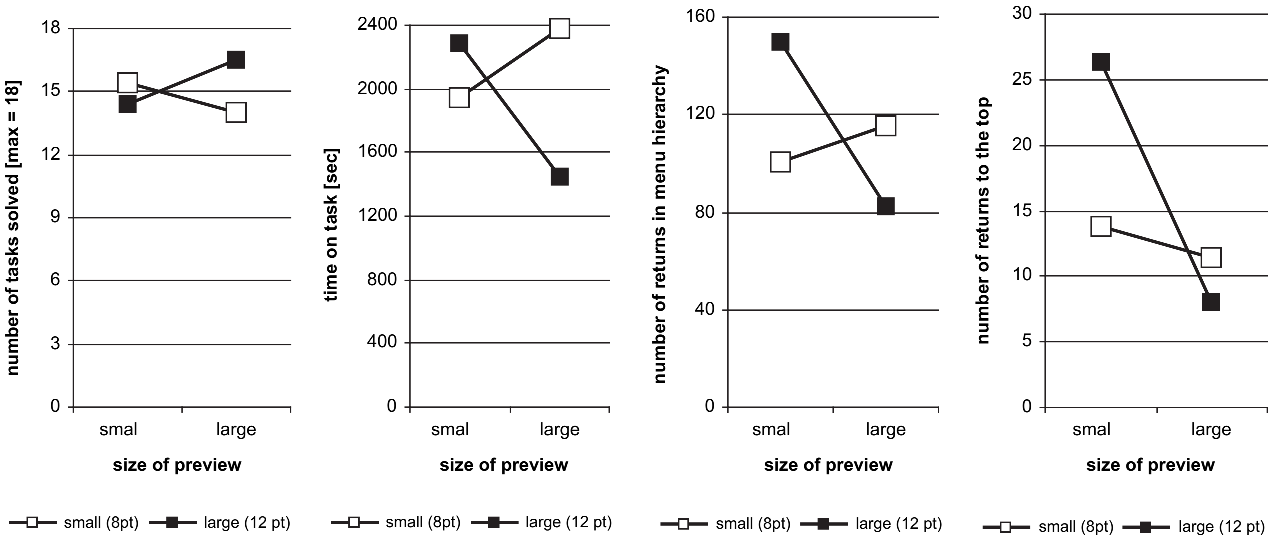

Fig. 7. Interacting effect of font size and size of the preview for all dependent measures (from left to right: task effectiveness, time on task (s), number of returns in menu hierarchy, number of returns to the top).

In the following sections, the performance outcomes are described for those tasks, in which the phone's menu had not to be entered, thus tasks with a flat hierarchy (1, 2, and 3) and contrasted to those tasks where users had to navigate through three or four menu levels (deep hierarchy as given in task 4–9). Key outcomes of the flat hierarchy tasks are given in Table 4, those of the deep hierarchy tasks in Table 5.

For the tasks to be solved without entering the menu, the first three tasks (calling a number, calling a person out of the phones' internal phonebook, edit a number stored in the phonebook) were comprised for both trials. Statistical testing revealed neither significant effects of the preview and font size nor a meaningful interaction between both factors. Thus, tasks' effectiveness was high (at about 5.8 solved tasks out of 6), and nearly all users were able to solve the tasks correctly. The processing time equaled about 6 min, accompanied by 7.9 returns in menu hierarchy and 1.7 returns to the top (Fig. 9, left side, shows the outcomes for the returns in menu hierarchy and the returns to the top).

Whenever tasks are focused in which deep menu levels were to be navigated through (tasks 4–9), the picture changed considerably. The MANOVA showed significant omnibus values for the size of the preview ($F(4,33) = 2.9$; $p < 0.05$). While the main effect of the font size missed the significance level ($F(4,33) = 1.4$; $p > 0.05$), the interaction of both factors yielded significant effects ($F(1,21) = 4$; $p < 0.05$). Consistently, menu disorientation is less pronounced when the preview and the font size is large, and it is considerably increased whenever participants use a display type in which only one menu item is displayed.

The interacting nature of the size of the preview and the font size is illustrated in Fig. 9 (right side), for the disorientation measures (returns in menu hierarchy and returns to the top).

4.4. User judgments with respect to the ease of use

The judgments regarding different aspects of ease of use were analyzed by non-parametric Kruskal–Wallis tests. The different statements had to be confirmed or denied on a five-point-scale (1 = completely true, 2 = mostly true, 3 = partly true; 4 = mostly untrue and 5 = completely untrue).

In Table 6, outcomes (means and standard deviations are given).

From Table 6 it can be seen, that participants rated the ease of using the phones as comparatively difficult, confirming to "mostly" or "partly" not knowing where in the menu they were, where to go next, how to reach a targeted function, and overall, to have lost their bearings within the menu. These ratings confirm the overall performance, with many detouring routes and returns in menu hierarchy. However, the size of the preview and the font size did not have a significant impact on the ease of use ratings.

4.5. Interrelations between user characteristics, performance, and ease of use

A final consideration refers to the impact of user characteristics and the question, which of the user characteristics might possibly cause or at least interact with the disorientation problem in small screen devices. This is especially meaningful in the aging group, as aging is going along with a decrease in cognitive functioning. Verbal memory abilities did not show meaningful correlations with navigation performance. However two of the user judgments showed significant correlations with verbal memory abilities. The statements "I often did not know how to reach a specific function" ($r = 0.35$; $p < 0.05$) and I often did not know where I was currently located within the menu" ($r = 0.45$; $p < 0.05$) were less frequently affirmed the higher memory abilities were. Navigation performance was significantly correlated to spatial abilities (effectiveness: $r = 3.9$; $p < 0.05$; time: $r = -2.9$; $p = 0.05$) showing that with higher spatial abilities the tasks were solved faster and more successful. Also field dependency showed to have a similar effect on performance (effectiveness: $r = 3.2$; $p < 0.05$; time: $r = -2.9$; $p = 0.05$) than spatial abilities, which is confirmed by the fact that both cognitive facets are highly interrelated ($r = 0.6$; $p < 0.05$). The cognitive variables did not affect the performance in the different display conditions differentially. From this it can be derived that the effect of font size and size of the preview is rather generic, not influenced by individual abilities and aptitudes.

5. Discussion

The present research examined how the information design of small screen interfaces of mobile phone can be optimized for older users. A simulated mobile phone was used, a very prototypical

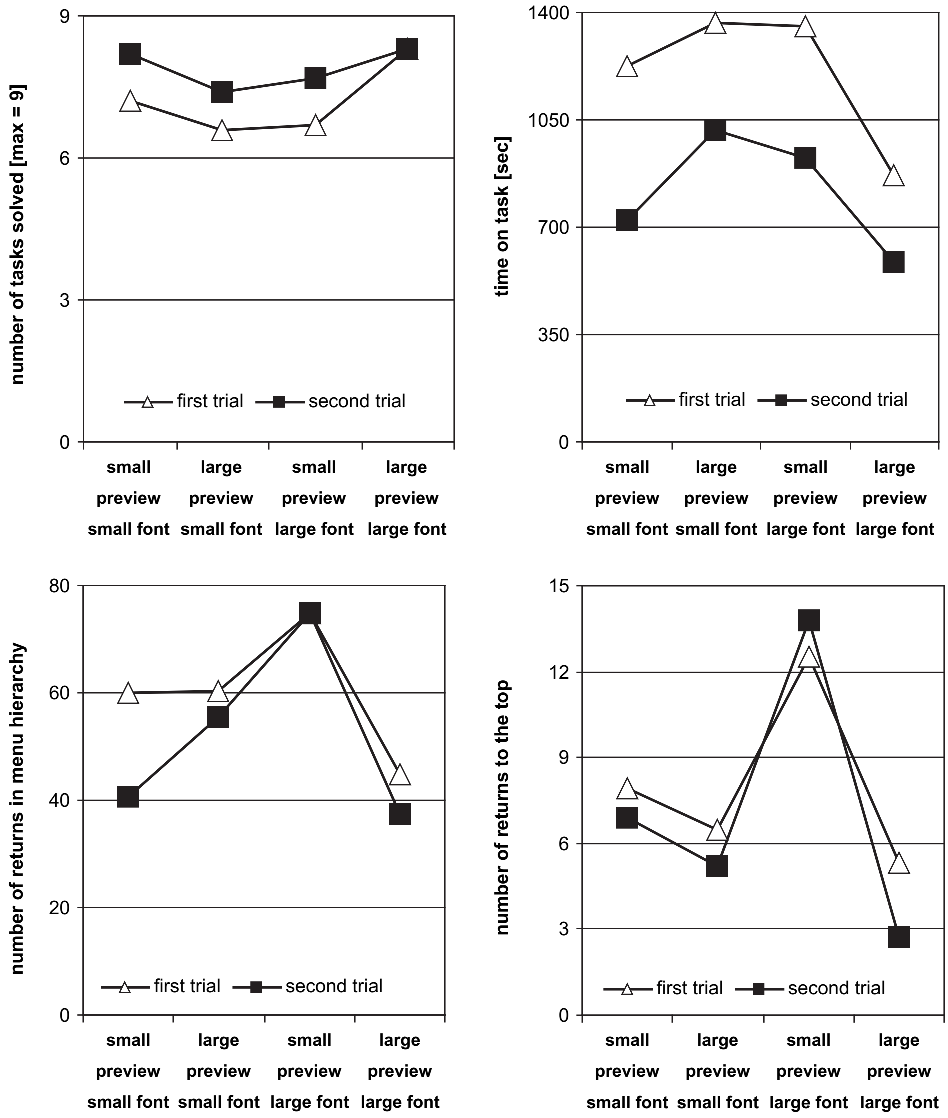

Fig. 8. Learnability effects for the four display conditions (small preview/small font, large preview/small font, small preview/large font; large preview/large font) for all dependent measures (from left to right: task effectiveness, time on task (s), number of returns in menu hierarchy, number of returns to the top).

device standing for a whole class of devices with small screens but a high complexity of functions implemented. It was a general question if visibility issues – large font sizes and low information density – or orientation concerns – maximal information per screen and high information density – is more decisive for proper menu navigation performance. From an ergonomic point of view, both factors can be argued to play a prominent role for a barrier-free information access in mobile displays. As visual abilities decrease with increasing age (e.g. Birren and Fisher, 1995; Schieber, 2005), it seems on a first sight that dense information and small fonts should generally be avoided in order to facilitate fast encoding. On the other hand the information presentation in small screen devices is aggravated by the fact that most of the menu parts are hidden; users only see single functions of a complex menu at a time and do not understand what other functions are available. As a consequence, it is difficult for users to establish a proper mental representation of the menu, and as a result users often loose their orientation in the menu and get lost (Lin, 2001; Ziefle and Bay, 2004, 2006). The orientation problems are common for all ages (Ziefle and Bay, 2008), but are especially prominent in the older group (Lin, 2001; Ziefle and Bay, 2006). Facing these orientation problems, it is meaningful to maximize the information per screen and allow users a sufficient menu preview. Both demands though are contradictory and require a very sensitive balancing respecting the information design of small screen devices.

5.1. Key outcomes to be considered for usable information designs

The outcomes clearly revealed that both visibility issues and orientation concerns are of major impact on older users' navigation performance. This can be taken from the fact that the best navigation performance – in terms of effectiveness and efficiency – was obtained for the display design with a large font size and a large preview. However, when weighing the relative impact, proper orientation in the menu is more decisive for the older group compared to visibility effects. The lowest performance resulted from the display with large font size. Visibility was therefore good, but the preview small, providing only one function per display at a time. Even in the second trial, which revealed a general increase of performance, the disadvantage of having a small preview was still present, confirming that the orientation component has a stronger impact on performance than the visual component (at least within

Table 4
Tasks with a flat menu hierarchy (tasks 1–3): descriptive values of the interacting effect of preview x font size as well as MANOVA outcomes ($N = 40$).

Interaction of preview × font size	Small preview	Large preview	Omnibus F test: ($F(4,33) < 1$; n.s.
Effectiveness (max = 6)			
Small font	5.8	5.8	$F(1,36) < 1$; $p > 0.05$
Large font	5.6	5.9	
Time on task (min)			
Small font	6.5	6.7	$F(1,36) < 1$; $p > 0.05$
Large font	6.4	4.6	
Returns in menu hierarchy			
Small font	8.3	10.2	$F(1,36) < 1$; $p > 0.05$
Large font	6.6	6.5	
Returns to the top			
Small font	1.5	2.8	$F(1,36) = 2.3$; $p > 0.05$
Large font	1.7	0.9	

The condition with the best performance is gray shaded.

the font sizes examine here). Furthermore, the importance of orientation in small screen devices was corroborated again in the data obtained for navigation at deep menu levels. The benefit by a proper information design – having a sufficient menu foresight and a high visibility – was especially large in the deep menu tasks.

Confirming earlier findings in the literature (Bay and Ziefle, 2004; Egan, 1988; Kim and Hirtle, 1995; Norman, 1994; Pak et al., 2008; Ziefle et al., 2007), high spatial abilities and a low field dependency considerably facilitated the orientation in technical menus. In contrast, high verbal memory abilities had less effect on navigation performance and did not hinder users from getting lost in the menu. Interestingly, however, none of the user characteristics under study produced a significant interaction with the specific display conditions. From this it can be derived that the effect of information designs on performance is not modulated by older adults' cognitive abilities but rather revealed to be a general effect, allowing a design-for all approach.

5.2. Limitations and duties for future research

Even though results were clear and allow useful recommendations for inclusive information designs, there a number of limitations which should be addressed in future studies.

It could be critically questioned if information designs as examined here are still topical or timely given the current trend of larger screens in smart phones. In the Apple Iphone®, for example, which enjoys great popularity at the moment, up to 20 functions can be displayed on its 3.5″ touch screen. So, one could demand that displays of small screen devices must be simply enlarged in order to rule out any problems with usable information designs. Yet, this argumentation might not be fully applicable in all fields and should be treated with caution. The trend of miniaturization of technical devices is still increasing, not only in external devices as in current information and communication technology (e.g. mobile phones). Increasingly more devices in the medical and eHealth sector (e.g. signal warning devices for blood pressure or diabetes) are developed for implementation in watches or clothing (e.g. Leonhardt, 2006). They are also combined with other technologies (e.g. integrated in driver assistance systems in cars). Under these circumstances the devices must be small to meet intimacy and/or acceptance demands or to face physical space restrictions. In addition, the application areas in which small screen devices are employed, are more and more extended. Thus, functionalities of these devices are not limited to fun, entertainment, communication or data management services anymore. The small screen devices of the future will provide serious, vital and indispensable functions, as in medical devices. Here it is of essential importance that interfaces are easy to learn and use by patients and caretakers as well as the nursing staff and physicians.

Table 5
Tasks with a deep menu hierarchy (tasks 4–9): descriptive values of the interacting effect of preview x font size as well as MANOVA outcomes ($N = 40$).

Interaction of preview × font size	Small preview	Large preview	Omnibus F test: ($F(4,33) = 4$; n.s.
Effectiveness (max = 12)			
Small font	9.6	8.6	$F(1,36) = 10.8$; $p > 0.05$
Large font	8.4	10.6	
Time on task (min)			
Small font	26.8	32.1	$F(1,36) = 13.8$; $p > 0.05$
Large font	34.1	20.5	
Returns in menu hierarchy			
Small font	92.5	140.4	$F(1,36) = 5.8$; $p > 0.05$
Large font	109.4	76.8	
Returns to the top			
Small font	13	24.2	$F(1,36) = 5.8$; $p > 0.05$
Large font	10.2	7.5	

The condition with the best performance is gray shaded.

The use of a simulated mobile phone in a static environment is highly artificial and generally underestimates the difficulty which is present when using small screens in real situations. Mobile small screen displays are conventionally used in a multiple task environment, in which several actions have to be accomplished simultaneously and which might be especially harmful for older users. In mobile contexts, further factors might have an influence on information designs, as for example the walking dynamics which could modify the relative impact of visibility issues.

Presumably, there is an upper limit regarding the information density on small screens. In this research, five functions were shown at a time, and negative effect of visual masking were not identified. Future studies should determine when the positive effect of having a large foresight and proper orientation is exceeded and the negative effect of information density and visual overload comes into fore.

Even though a broad older age range (55–73 years) was studied here, it should be taken into account that the participants were rather healthy and not bothered by any specific age handicaps. Also, visual performance was normal, and none of the participants reported to have a history of severe eye illness. Therefore, the research scope should be broadened examining also users with visual handicaps in order to learn if the tradeoff between visibility and orientation concerns still holds in these user groups.

5.3. Conclusions

On the basis of the present results, the following recommendations for application-oriented interfaces of mall screen devices can be derived.

(1) Mobile displays must be designed to be in agreement with older users' characteristics. Ergonomic research has to focus on design solutions which do not discriminate against the "weaker" users, whether due to age or low technical experience. Design approaches must take the user-perspective seriously. Older adults' behavior with current technical devices must be carefully studied and user abilities and barriers, which affect the interaction and the acceptance of mobile devices must be identified.
(2) This is particularly important as the functionalities of small screen devices are not limited to fun, entertainment, communication or data management services. The small screen devices of the future will provide serious, and indispensable

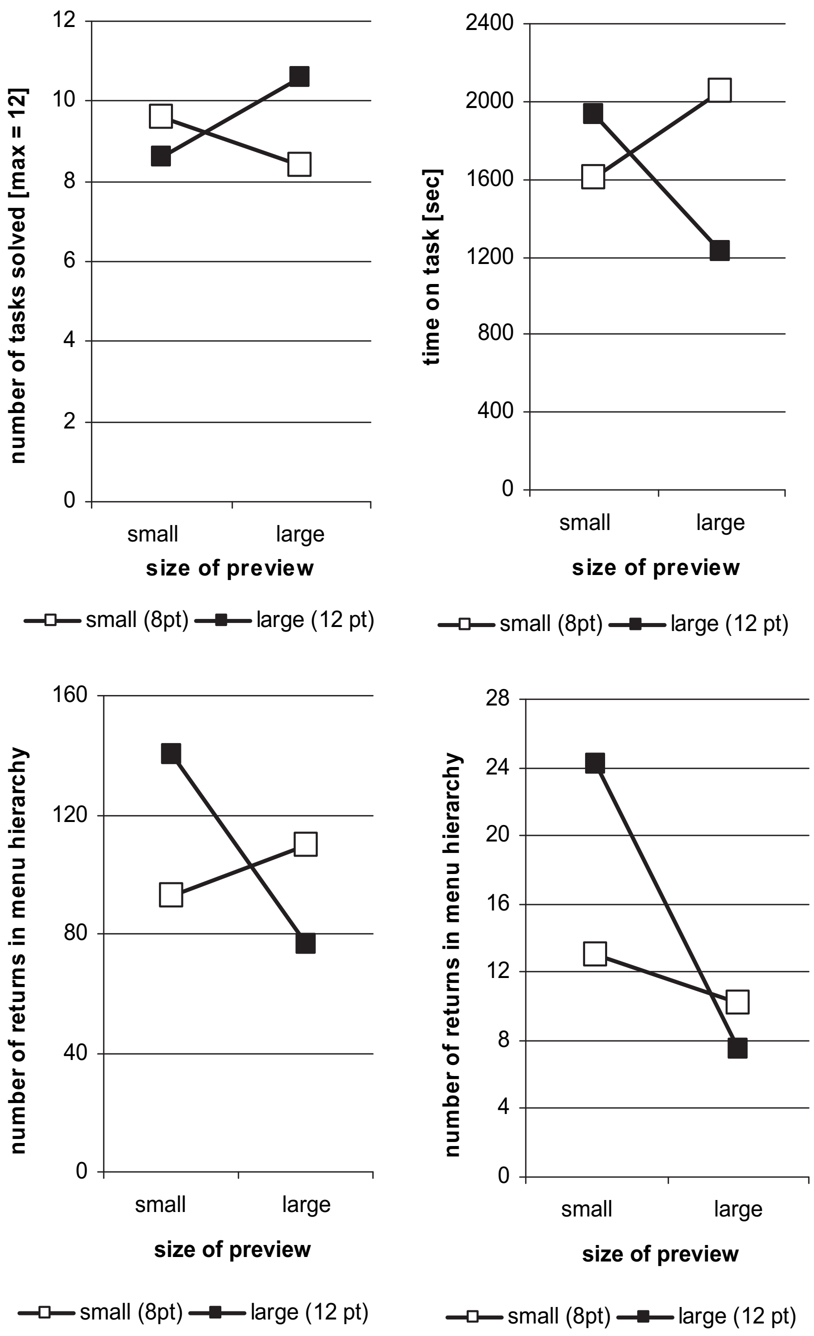

Fig. 9. Performance outcomes in the two disorientation measures (number of returns in menu hierarchy, number of returns to the top) for the task with a flat menu hierarchy and a deep menu hierarchy.

Table 6
Outcomes (mean, standard deviations) in the ease of use statements ($N = 40$).

1 = Completely true, 2 = mostly true, 3 = partly true; 4 = mostly untrue and 5 = completely untrue	*M*	SD
It was easy to solve the tasks.	2.67	0.9
I felt lost in the menu.	2.7	0.9
I did not know where to go next.	2.3	0.8
I did not know how to reach a specific function.	2.5	0.9
I did not know where I was currently located within the menu.	2.3	1

functions. Thus, older users as well as handicapped people, will use technical devices to control vital functions. Ergonomists and designers must seriously focus on the usability of interface solutions for older adults.

(3) For usable information designs, visibility *and* orientation issues are of importance and should be considered within information presentation in small screens. However, proper menu orientation is still more important than visibility effects, at least in the older age group considered here, which was a healthy old user group, not bothered by strong visual handicaps.

(4) For small screens as it is the case in conventional mobile phones, it is crucial to provide more than one menu item at

a time on the display. For five items shown in the small display, performance turned out to be manageable and usable, without the risk of overloading the screen.

Acknowledgements

Special thanks to Susanne Bay, Tessa Heisig, Stephan Lücke, and Eugen Yu for their helpful research assistance. Many thanks also to three anonymous reviewers for their constructive comments on an earlier version of this manuscript.

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