Consolidated findings from 6 years research on the age-differentiated design of human-computer interaction

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Abstract. The fast aging of many western and eastern societies and their increasing reliance on information technology create a compelling need to reconsider older users’ interactions with computers. This paper summarizes the results of 6 years of research on the age-differentiated design of human-computer interaction. The well-known model of human information processing served as the theoretical framework. The model components “sensory processing”, “perception”, “working memory”, “decision and response selection” and “response execution” were analyzed exemplarily in task settings on project management. In seven empirical studies with a total number of 405 participants between 20 and 77 years the human-computer interaction was analyzed regarding effectiveness, efficiency and user satisfaction. For most but not all studies the results reveal that age-induced differences in human-computer interaction can best be compensated by an ergonomic “design for all”. In some cases however an age-specific approach is favorable.

Keywords: Human-Computer interaction, interface design, age-differentiated adaptation, aging

1. Introduction

The fast aging of many western and eastern societies and their increasing reliance on information technology create a compelling need for research and development on older users’ interactions with computers. In Europe, for instance, the population of the EU-27 countries on January 1st, 2010 was estimated to be 501.3 million. The EU population ages at varying speeds. Populations that are currently the oldest, such as Germany’s and Italy’s, will age rapidly for the next twenty years. In 2010, the median age of the EU population was 40.9 years, and it is projected to reach 47.9 years by 2060. The percentage of population aged 65+ is supposed to increase from 16% in 2010 to 29.3% in 2060 [13]. The importance of computer work is increasing likewise. In 2010, 52% of the European working population uses a computer at least one time per week [8].

The literature tells us that as people age, changes occur in their perceptual, cognitive and motor systems that have significant effects on their performance and well-being [3]. The so-called deficit models dominated the theoretical underpinning of aging in the past. Deficit models postulate a graceful degradation in human information processing and physical functions from the late twenties on [20]. However, in recent years, models of aging had to be revised. Nowadays the changes that occur with aging are supposed to be explained not only by physical functions but also by the experience and attitudes of the elderly [1]. The elderly dispose of a somewhat alternative performance spectrum as compared to the younger [1]. In fact, the scope of decrease is highly individual and depends on the abilities under consideration and the particular characteristic of the task. Against the background of an aging workforce and the importance of computer technology to human work it is necessary to get a deeper understanding of the interrelationships between age-related changes in functional and physical abilities.

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and the ergonomic design of future work systems. The German Research Foundation (Deutsche Forschungsgemeinschaft) responded to this gap of scientific knowledge by establishing the Priority Programme 1184 on Age-differentiated Work Systems in 2005. This interdisciplinary basic research programme brings together a total of 12 research groups from engineering, psychology and economics with the goal of studying the implications and effects of demographic changes in human work and developing lifespan models to create adequate working and learning conditions for employees of different ages. This paper summarizes the results of 6 years of research focusing on the age-differentiated design and evaluation of computer-supported project management software applications. Computer-supported project management is particularly interesting, as it requires complex cognitive skills as well as coordinated communicative abilities.

The seminal Wickens model of human information processing [30] served as a theoretical framework for the age-differentiated analysis and intervention (Figure 1). Regarding computer work with electronic information displays the model elements “Sensory Processing”, “Perception”, “Working Memory”, “Decision and Response Selection” and “Response Execution” were thought to have significant contributions to the effectiveness, efficiency and user satisfaction of human computer interaction.

![Fig.1: Model of human information processing](Adapted from Wickens [30]).

Based on a literature analysis on age-related changes in human information processing six adaption dimensions were identified: (1) **Angular font size of text and graphical symbols**, (2) visualization of network diagrams, (3) memorization of network diagrams, (4) interpretation of network diagrams, (5) devices for information input and (6) manual information input on large touch screens (for classification to the model of human information processing see numbered elements in Figure 1).

The first adaption dimension **angular font size of text and graphical symbols** refers to the encoding of information on electronic information displays. Due to changes of the visual system the ability to detect and differentiate nearby objects (visual acuity) naturally deteriorates with increasing age. Although most software systems support the user specific adaption of font size, this feature is rarely used by elderly computer users.

The second adaption dimension **memorization of network diagrams** deals with the perception of and the navigation in large graphical structures. It is known that the navigation in complex information structures is potentially strain ing, especially for the elderly.

The third adaption dimension **interpretation of network diagrams** concentrates on possible age-related changes in memorization of large graphical structures. Since computer work primarily addresses cognitive demands, an age-related decrease in working memory capacity also might have an effect on human performance measures. The state of findings concerning the effect of age on memorization performance of visual objects however is contradictory.

The fourth adaption dimension **interpretation of network diagrams** refers to possible age-related changes in memorization of large graphical structures. In this context interpretation is a general term referring to the mental processing, comprehension and decision making in information processing. Th e age-related decrease of motor skills influences the speed and accuracy of information input and potentially impedes the ease of use of conventional information input devices.

The sixth adaption dimension focuses on the manual information input on large touch screens as this interaction-technique was found to be beneficial for the performance of many user-groups, particularly for the elderly. However, the regular button size that is used in many software systems is optimised for mouse input and movements of the hand-arm system are error prone when buttons are located in the upper area of the touch screen. Thus, there is a necessity to develop basic concepts for an ergonomic information presentation and input on large touch screens.

**Fig.1: Model of human information processing (Adapted from Wickens [30]).**
2. Literature review

2.1. Exp. 1: Angular font size of text and graphical symbols

Eyesight is an ability of great importance for almost all work systems. Symptoms of an age-related eyesight degeneration process include a reduction of visual acuity, loss of power of accommodation or reduced color perception [18,25]. A loss of visual acuity in particular is often critical with regard to performance and safety. Normal visual acuity is represented by a visus value of 1.0, but it decreases with age. A 20-year-old normally has a visus between 1.0 and 1.6 whereas an 80-year-old’s visus value lies between 0.6 and 1.0. The generalized decrease in visual acuity of older people is of particular importance when working with electronic information displays.

2.2. Exp. 2: Navigation in network diagrams

Ergonomic information visualization [5,7,29] has become an important paradigm for human-computer interaction. There are different approaches to support the navigation in complex network diagrams. Interfaces with an overview map show the details of a network activity together with a structural overview of the entire chart and can improve subjective satisfaction [21] and efficiency [2]. By the use of interfaces which provide zoom function the information space is directly visible and can be manipulated through panning and zooming. The most common zooming technique is the geometric zoom, where the scale linearly determines the apparent size of the object. A fisheye view functions analogous to a wide-angle camera lens, the idea is to show “local” detail in full (the objects of interest to the user), while displaying successively less detail for information out of the focus of attention.

2.3. Exp. 3: Memorization of network diagrams

As stated in the introductory section, the effect of age on memory performance of graphical objects is indistinct. Many authors found evidence for an age-related decline in memory performance of the spatial locations of objects [24,11,6,14,17,22]. Other authors however could not detect age differences in recall performance of spatial object position [27,12]. In most studies on memory performance, the experimental stimuli are presented in a sequential order. There are, however, no age-differentiated studies on the memorization performance regarding complex graphical structures as network diagrams. Based on investigations conducted by Winkelholz and Schlick [32], it was assumed that an improvement of memorization performance will occur for horizontally rather than vertically arranged network diagrams, as well as for a purposeful modification in spatial spread of activities.

2.4. Exp. 4: Interpretation of network diagrams

Regarding the interpretation of complex network diagrams it is assumed that according to the Proximity Compatibility Principle [31] a small spatial spread between activities leads to better performance. A positive effect due to horizontal orientation is also expected in this case [32].

2.5. Exp. 5: Devices for information input

Effective, efficient and satisfying human-computer interaction is strongly influenced by the use of input devices. As a result, different input device characteristics pose different requirements on human abilities. Therefore the compatibility between device characteristics and the abilities of the user determines the objective and subjective input performance to a large extent. Changes in motor abilities as reduced muscle strength, reduced range of motion and greater difficulty executing fine movements are highly correlated with age [28] and of major importance for information input. Thus elderly computer users may need other input devices than younger users with less requirements on motor abilities and less complex visuo-motor transformations.

2.6. Exp. 6: Manual information input on large touch screens

Large touch screens provide an alternative to classical electronic information displays in application areas where one has to display and manipulate complex information at once (plant design, project management, architecture, etc.). Research has shown that this interaction-technique can be beneficial for many user-groups, particularly for the elderly [15,19,23]. The effectiveness and efficiency of information input however depends highly on the ergonomic design of the user-interface. When redesigning application software originally designed for classical
desktop computers for large touch screens one has to consider where to display menus, buttons or icons, and which size these elements should have in order to improve pointing performance. To determine ‘optimal’ target sizes and target positions Fitts’ Law [10] provides a highly satisfactory model. Fitts’ Law states that the movement time ($MT$) is linearly dependent on the index of difficulty ($ID$) of a pointing task. The $ID$ is defined as the dyadic logarithm of the quotient of amplitude of the movement ($A$) and horizontal target width ($W_h$):

$$MT = a + b \log_2 \left( \frac{2A}{W_h} \right)$$

(1)

Fitts’ original study only considered one-dimensional movements, however on large touch screens one has to deal with two-dimensional movements and bivariate targets. As a first step in building a concept for the ergonomic information input on large scaled touch screens Fitts’ Law had to be refined regarding two-dimensional pointing of bivariate targets.

3. Method

Over the 6 years of research 405 participants between 20 and 77 years participated in seven empirical studies regarding potential age-related differences in human-computer interaction.

3.1. Exp. 1: Angular font size of text and graphical symbols

The age-induced change in visual acuity and its impact on performance in a target detection task was investigated in an empirical study with 75 subjects aged between 20 and 72 years. Subjects were divided into three age groups (AG I: 20 -39, AG II: 40-59, AG III: 60-72 years) with 25 persons in each group. Acuity of vision was measured using the standardized eyesight Rodatest 302. In the target detection experiment Landolt rings of three different font sizes (12, 16 and 22 arc minutes) served as targets displayed on a TFT-LCD screen. The participants’ task was to react to a Landolt ring with a particular position by pressing the space key. The participants had to detect and recognize the previously specified target Landolt ring out of a sequence of 120 Landolt rings composed of 15 correct and 105 in correct Landolt rings. Each ring was shown for 1.5 seconds. After a five minute break, the procedure was repeated with the next permutation of font size, etc. The number of correctly detected Landolt rings (hits), the number of wrongly detected Landolt rings (false alarms) and the response time of correct responses were analyzed using ANOVA with repeated measures. The relation between visual data from Rodatest 302, the participant’s age in years and the response time in the target detection task was analyzed by correlation analysis.

3.2. Exp. 2: Navigation in network diagrams

The navigation in complex network diagrams was investigated with 90 participants between 20 and 75 years of age. Subjects were divided into three age groups (AG I: 20-39, AG II: 40-59, AG III: 60-75 years) with 30 persons each. Three different visualizations of network diagrams (overview map, detail window and zoom function) were tested against a network diagram which is found in many commercial off-the-shelf software packages. In this variant detailed information of the activities (name, starting time and duration) was given and the scrolling bar had to be used to explore the network diagram. In the overview map, the default network diagram was enriched by structural information displayed in a network window. For the other two visualization variants the information displayed on the activities was reduced. Thus, the whole network diagram was played on the screen and scrolling was not needed. By touching an activity detailed information was provided either at a fixed position in the upper left corner of the screen (detail window) or at the position of the respective activity (zoom function). The experimental task was carried out on a 17” touch screen. The participants had to execute typical project management tasks like changing the starting time or duration of an activity and connecting or deleting activities with each of the visualization variants. Execution time, errors, scrolling and search time as well as subjective mental workload (NASA-TLX) were measured as dependent variables.

3.3. Exp. 3: Memorization of network diagrams

The memorization of complex network diagrams was investigated with 90 participants between 20 and 75 years. Subjects were divided into three age groups (AG I: 20-39, AG II: 40-59, AG III: 60-75 years) with 30 persons each. Six network diagrams layouts
The diagrams differed regarding their orientation, horizontal (H) versus vertical (V), and their spatial spread: (1) no spread, (2) clustered, (3) uniformly spread. After an acoustical signal, a randomly created sequence of five activities was highlighted by color changing. Each activity was highlighted for two seconds. The end of a sequence was indicated by a second acoustical signal. The participant had to repeat the sequence by clicking the activities in correct order with a mouse. After five activities a short break was obligatory and the next sequence was presented. There were six randomly created sequences for each layout. The same six sequences corresponding to one layout were presented to each subject. The order in which the various layouts were presented was balanced. Execution time and the number of correctly repeated sequences were measured as dependent variables.

3.4. Exp. 4: Interpretation of network diagrams

The memorization of complex network diagrams was investigated with the sample of experiment 3. The six network diagram layouts depicted in figure 2 were used in a simplified form. Additionally, the start and end times for each activity were displayed within the diagram (see figure 3).

After an acoustical signal, one or two randomly chosen activities were highlighted. After two seconds, one of the following four questions concerning the highlighted activities appeared: (1) "Which activity has a longer duration?", (2) "Which activity ends first?", (3) "How many direct predecessors does this activity have?" (4) "How many direct successors does this activity have?". The subject had to answer the question by marking the correct activity, respectively, the correct number, by mouse click. Then the next question was presented. Each test subject had to answer identical questions in the same sequence per layout. The order in which the various layouts were presented was balanced between test subjects. Execution time and the number of correctly answered questions were measured as dependent variables.

3.5. Exp. 5: Devices for information input

Three input devices, (1) mouse, (2) touch screen and (3) eye-gaze control, were contrasted with one another on the basis of a two-dimensional pointing task. A total of 90 subjects between 20 and 75 years participated in the study. Subjects were divided into three age groups (AG I: 20-39, AG II: 40-59, AG III: 60-75 years) with 30 persons each. The pointing task had to be executed with each of the three input devices as fast and accurately as possible. When using the mouse, the cursor had to be positioned in the starting circle first and then moved to the target square. The start and target positions had to be confirmed with a mouse click. When using the touch screen, the task consisted of touching the starting circle, followed by touching the target square with the index finger. For the eye-gaze control, the task required first to visually fixate on a point within the starting circle and then to fixate the target square. The fixation dwell time on the target object was set to 100 ms. The execution time and the error rate were dependent variables.

3.6. Exp. 6: Manual information input on large touch screens

In the first study [26] the two most common target width definitions \( W_{\text{min}} \) and \( W' \) were analyzed in an empirical study with 30 right-handed subjects (20-73 years) in a pointing task on a large scaled touch screen (projection area 865 mm x 649 mm, 4:3 ratio). Subjects were divided into two age groups (AG I: 20-32, AG II: 58-73) with 15 persons each. The experimental task showed rectangular target ob-
jects at a constant angle of $0^\circ$ (movement to the right) which were rotated around their centre. Hereby, $W'$ was varied systematically, whereas $W_{\text{min}}$ was kept constant.

Fig. 4. Experimental setting for target rotations of $0^\circ$, $40^\circ$, $90^\circ$.

In the second study [4] the motion angle was investigated with 30 participants aged between 21 to 77 years. Subjects were divided into age groups (AG I: 21-36, AG II: 58-77) with 15 persons each. The angle between start- and target object was varied systematically in $10^\circ$ steps between $0^\circ$ (movements to the right) and $180^\circ$ (movements to the left). To eliminate influences of the target width, circular target objects were used.

Fig. 5. Experimental setup for a start position at $0^\circ$.

The mean response time of correct responses was calculated as a dependent variable.

4. Results

According to the experimental designs the data was analysed by an analysis of variance with repeated measures (ANOVA), correlation analyses and linear as well as nonlinear regression analyses. The significance level for each analysis was $p=0.05$. For significant main effects the effect size $\omega^2$ for repeated measures [9] was calculated. Only main results are reported. For a detailed analysis the reader is referred to the original publications.

4.1. Exp. 1: Angular font size of text and graphical symbols

The results from an ANOVA show a strong effect of font size ($\omega^2=0.73$) and a medium age-related effect ($\omega^2=0.48$) concerning the response time of correct responses. The interaction effect of font size and age group ($\omega^2=0.10$) shows that age-related differences in response time can be compensated by enlarging the angular font size from 16 to 22 arc minutes. Results from partial correlation analysis show that an age-differentiated adaptation of font size is recommended rather than a adaptation based on measurement of visual acuity.

4.2. Exp. 2: Navigation in network diagrams

The ANOVA of the execution time across all visualization variants shows a significant main effect of age group with a medium effect size of $\omega^2=0.66$. The visualization variant also has a significant effect on the execution time with a large effect size of $\omega^2=0.91$. Furthermore, the data show that for the 20-39 year-olds and 40-59 year-olds the shortest average execution times are reached by working with the detail window whereas the elderly participants (60-75 year-olds) performed best when using the zoom function. Regarding the number of errors, the ANOVA indicated significant effects of age group ($\omega^2=0.23$) and visualization variant ($\omega^2=0.13$). The lowest error rate was found for the detail window and zoom function. The control variant leads to longest searching times and the reduced network diagram with zoom function to the shortest. Scrolling time is shorter with the overview window compared to the control variant. Regarding the subjective evaluation of mental workload the zoom function leads to the least and the control layout to the highest workload.

4.3. Exp. 3: Memorization of network diagrams

For the number of correctly memorized sequences as well as the overall execution time ANOVAs confirmed significant age effects ($\omega^2=0.32$; $\omega^2=0.25$), with the highest memorization performance in the group of the 20-39 year-olds. The results of the layout design of the network diagrams show significant effects of spread ($\omega^2=0.68$) on execution time ($\omega^2=0.15$) and number of correctly repeated sequences ($\omega^2=0.68$). The layouts “cluster spread” and
“uniformly distributed spread” are beneficial for memorization performance (high amount of correct answers, low amount of required time). The layout without spread scores significantly lower. Regarding the orientation of the network diagram, a horizontal layout scores significantly higher than the vertical layout ($\omega^2=0.70$).

4.4. Exp. 4: Interpretation of network diagrams

Since there was very little variance in the number of correctly answered questions as almost no errors occurred, only the results of the response time were analyzed with an ANOVA. The results reveal that the age group ($\omega^2=0.41$) and the spatial spread ($\omega^2=0.27$) of the network activities have significant effects on response time. Post-hoc paired comparisons of means showed significant differences between all age groups. Response time increases with increasing age. Regarding the spatial spread, it was found that equally distributed spread lead to shorter response times than a cluster spread or a layout without spread. However, spatial orientation of the network diagram had no significant effect on response time.

4.5. Exp. 5: Devices for information input

The ANOVA of the execution times across all input devices shows a significant main effect in relation to age group ($\omega^2=0.55$). Post-hoc paired comparisons of means showed significant differences between AG I and AG II as well as between AG I and AG III. The input device also has a significant effect on execution time ($\omega^2=0.51$). The touch screen leads to significantly better performance than the eye-gaze control and mouse input. Furthermore, a significant interaction effect between age group and input device occurs. The data show that the average execution times of AG II and AG III differ significantly only for mouse input.

4.6. Exp. 6: Manual information input on large touch screens

Linear regression analysis shows that the movement time varies as a function of the target width in the direction of motion ($W'$). Furthermore, significant effects of the target height perpendicular to the direction of motion ($H'$) were found. The best empirical fit was found for a model taking into account the target width in the direction of motion ($W'$) and the target height perpendicular to the direction if motion ($H'$):

$$MT = a + b \log_2 \left( \frac{W}{H} + 1 \right) + c \log_2 \left( \frac{H}{H} + 1 \right).$$

The results of the second study reveal that movement time follows a sinusoidal curve depending on the angle. Based on the results of both studies a model for two-dimensional pointing and bivariate, rectangular target objects was derived:

$$MT = a + b \log_2 \left( \frac{W}{H} + 1 \right) + c \log_2 \left( \frac{H}{H} + 1 \right) + \frac{\sin(2\alpha)}{\alpha}.$$  

The formulas (2) and (3) are based on the Shannon formulation [16] by MacKenzie and Buxton.

5. Discussion

For a detailed discussion of the results in the light of the literature the reader is referred to the original papers. Because of limited space the results are broken down in consolidated “take home messages” for the age-differentiated design of HCI as follows:

- Elderly computer users benefit from a larger font size. In most cases it is not necessary to measure visual acuity, but simply to enlarge angular font size based on age up to 22°.
- If possible, reduce information displayed at once by the use of zoom functions. Eliminate or reduce scrolling activities.
- Arrange network diagrams (or similar graphical models) horizontally. Regarding the spatial spread of activities it depends on the task. If memorization is more important, use a large cluster spread, if interpretation dominates, choose a narrow equally distributed spread.
- Use touch screens for the elderly. For physically impaired computer user eye gazed input is a promising alternative.
- When designing software for large touch screens, the refined Fitts’ Law can be used to determine an ‘optimal’ angular position of buttons and interaction elements. Furthermore, the model can be used a priori to calculate the best proportions of the side lengths for buttons and interaction elements depending on the angle.
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References