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How older adults meet complexity: aging effects on the usability of different mobile phones

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In this experiment, older and younger novice mobile phone users were examined when using handsets of different complexity. The independent variables were user age (young: 20 – 35 years; old: 50 – 64 years) and cognitive complexity of two mobile phones (Nokia 3210; Siemens C35i). The cognitive complexity of the phones was defined by the number of production rules applied when processing the four experimental tasks. Dependent variables were effectiveness and efficiency as taken from user protocols and the reported ease of use. The less complex phone (Nokia) performed significantly better than the complex one (Siemens). However, the benefit from the lower complexity was much larger than theoretically predicted. Thus, defining cognitive complexity of technical devices by the number of production rules does not account for the real difficulties which users experience. Older users had a lower navigation performance than younger users, however their performance matched younger users' when using mobiles with low complexity.

1. Introduction

The distribution of mobile phones represents one of the fastest growing technological fields ever. Already by 1999, 500 million mobile phones were distributed worldwide. In the United States, the number jumped up from a few thousand in 1983, to over 10 million in 1992 and to about 112 million in 2001, with an increasing trend (Curry 2001). In the foreseeable future, mobile communication will affect entire modern societies even more than today, changing social, economic and communicative pathways by the broad insertion of mobile communication technologies, such as the Internet, UMTS (Universal Mobile Telecommunications System), Wireless LAN and WAP (Wireless Application Protocol) services.

The variety of functions capable of running on these small devices with small sized displays is enormous. However, it is rather difficult to implement the complexity of functions in such a way that the devices provide good usability and, consequently, allow universal accessibility. According to Dix *et al.* (1998), usability is conceived as the ease with which users interact with the device, achieving optimal performance with respect to effectiveness, efficiency and users' satisfaction (EN ISO 9241-11 1997). The claim includes the phone to be designed so that users' knowledge and experience in related areas can be adopted when confronted with an unknown device. As can be observed rather often though, the usage of modern technical devices is not conceived to be easy, but to impose considerable cognitive load on users. What makes the handling of hierarchically built technical systems – for example the cell phone – so difficult? A fundamental component leading to problems in its usage is the restriction of information access due to the small sized display. 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. As users have to memorize the functions' names and their relative location within the menu and build a mental map of the menu structure for a proper orientation, they may experience the feeling of having little control over the phone, often not knowing what to do next, when to do it and how to complete a targeted action successfully.

Recent studies substantiated the usability of mobile phones to be of central ergonomic concern, not only for

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technologically experienced younger adults (Ziefle 2002a, 2002b, Bay and Ziefle 2003a, 2004a, Ziefle and Bay 2004), but also for children (Bay and Ziefle 2005) that are commonly assumed to have less difficulties due to their early contact and high experience with technical devices. In contrast to a multitude of studies concerned with older adults interacting with technology in general, such as hypertext and internet (e.g. Vicente *et al*. 1987; Kim and Hirtle 1995, Westerman 1997, Lin 2001, Pak 2001, Gabriel and Benoit 2003, Kurniawan *et al*. 2003, Noyes and Sheard 2003) considerably fewer studies have focused on the older adults' requirements for usable mobile phones (e.g. Brodie *et al*. 2003, Maguire and Osman 2003, Tuomainen and Haapanen 2003, Ziefle and Bay, 2004). As the present study focuses on age effects in navigation performance in mobile phones differing in complexity, two subject areas are to be emphasised: the cognitive complexity imposed by technical devices and the specific user characteristics present in older adults, who are still part of the active working force.

1.1 *Cognitive complexity*

Using a technical device requires basic procedural knowledge stored in the long term memory and refers to knowledge procedures of how and when to do something in the man – machine-dialogue. The software implementation and the device's interaction style may more or less support the learning of production rules necessary to interact with the device properly. Kieras and Polson (1985) proposed a theoretical model (Cognitive Complexity Theory (CCT)) specifically dealing with the cognitive complexity of the interaction between user and device by describing the user's goals on the one hand and the reaction of the computer system on the other by means of production rules. Production rules can be expressed as the sequence of rules in the form of IF-condition (the display status) and THEN-action (key-stroke or input by the user). According to theory, cognitive complexity is defined as the number of production rules to be differentiated and learned in a specific action sequence or task set. For the definition of cognitive complexity given to mobile phones, the CCT approach is helpful as the definition of production rules (i.e. the specification of what the system says and how users react) comprises the different factors that may contribute concurrently to a phone's complexity (i.e. menu structure, number and modes of keys, transparency of functions' naming and their relative location in the menu). It is debatable, though, if the mere counting of production rules, assuming the different factors equally contribute to cognitive complexity, can realistically predict the difficulty perceived by users. But, as the model provides a formalism for cognitive complexity and allows the deduction of specific predictions which can be experimentally tested, it is taken as the theoretical base for the present experiment.

1.2 *Older users' characteristics*

Several characteristics of older adults' information processing can be referred to as being crucial for their interaction with technology. Generally, a slowing down of functions with age can be observed regarding sensory performance (Kline and Scialfa 1997, Ziefle 2001), motor performance (Vercruyssen 1997), and cognitive performance (Craik and Salthouse 1992). Among the cognitive factors, the decline of memory functions and spatial abilities with age is well known (Willis and Schaie 1986, Salthouse 1992, Norman 1994, Kelly and Charness 1995). As both abilities were shown to be crucial for proper navigation behaviour in hierarchically structured menus (Kim and Hirtle 1995, Westermann 1997, Lin 2001, Pak 2001, Bay and Ziefle 2003a, 2003b, Ziefle *et al*. 2004), older adults are rather penalised when confronted with tasks that require navigation through menu hierarchies of different depths and breadths (hypertext, computer programs). Accordingly, older adults were found to experience greater difficulties during navigation, spend more time on tasks accompanied by more detours, and, as they became lost within the menu, return more often to the top of the menu hierarchy than younger users (Vicente *et al*. 1987, Lin 2001, Pak 2001). Another factor that is likely to severely influence older adults' performance interacting with technology is that users, aged over 50 years as the participants here, were educated in times when technical devices were far less ubiquitous and complex than current mobile phones. A mental model of how technology works, built in a former time, should interfere with, or at least should not be sufficient for, proper interaction with devices currently available. Importantly though, older adults are willing to use modern devices and report to be rather interested in modern technology, but they do not feel that devices meet their demands for a usable design adequate for their abilities (Melenhorst *et al*. 2001, Gabriel and Benoit 2003, Noyes and Sheard 2003).

Since we live in societies characterised by a growing aging population, it is highly important to learn in detail the needs and the demands of the man – machine interface in older adults. The present experiment aims to contribute by comparing the performance in mobile phone handling of older and younger novice users.

2. *Method*

2.1 *Variables*

Two independent variables were under study. One refers to user age, comparing the navigation performance of younger (20 – 32 years) and older adults (50 – 64 years). The second variable was the cognitive complexity inherent in the mobile phones, defined by the number of production rules to be correctly applied when solving four tasks with the two mobile phones.

In Table 1, the predicted overall complexity of both phones is described as well as the number of production rules in the four tasks. As can be seen in table 1, on the basis of the complexity by production rules, the Siemens phone is more complex than the Nokia phone. Taking the 'easier to use' phone as a baseline, it should take in total approximately 25% longer to solve the tasks with the Siemens phone compared to the Nokia phone. However, on the task level, it can be seen that from the four tasks, two tasks (1 and 4) appeared to be less complex with the Siemens phone, therefore Siemens users should show slightly superior performance when effectuating a call (3 vs. 4 production rules) and when editing a number in the phone directory (9 vs. 10 production rules). The other two tasks (2 and 3) were less complex in the Nokia phone, so it is expected that users in the Nokia group outperform Siemens users in sending a short message (10 vs.14 production rules) and hiding their own number (12 vs.19 production rules). As the adequacy of user's task representation presumably varies from task to task (the knowledge about how to call a person should be more appropriate than how to hide their own number when calling) only comparisons between the two phones regarding each task will be undertaken, not between different tasks.

The specific production rules (the if – then condition pair sequences) to be applied per task and phone type are described in the section where the tasks are introduced.

As dependent variables, the effectiveness and efficiency of navigation performance and the reported ease of use were surveyed according to the standards for usability (EN ISO 9241-11 1997). In total, 10 different dependent variables were under study. One measure refers to the effectiveness, three measures are concerned with task efficiency and six measures are related to different aspects of the ease of use. The different measures are now operationalised in detail. For the task effectiveness, the percentage of successfully solved tasks was measured. Furthermore, three different efficiency measures were analysed: (1) the time needed to process the tasks, (2) the number of detour steps (i.e. the difference between the number of keystrokes actually effectuated and the number of keystrokes that were necessary to solve the task the shortest way possible) and (3) the number of returns to higher levels in menu hierarchy, indicating that users in the belief of having taken the wrong path, go back to a known position in the menu, consequently reorienting themselves. The ease of use was measured by the following six statements that had to be confirmed or denied (on a scale with four answering modes, 1 = I completely agree, 2 = I tend to agree, 3 = I tend to disagree and 4 = I completely disagree):

Table 1. Production rules to be carried out in the four tasks using the two phones. *The phone, which is expected to be easier to use, is set as baseline and the expected inferiority with respect to the task efficiency of the other phone is given in %.

	Number of Production Rules		Inferiority (lower efficiency) of the other phone*
Tasks	Nokia 3210	Siemens C35i	
(1) Call	**4***	3	33% (Nokia)
(2) Send text message	10	**14***	40% (Siemens)
(3) Hide own number	12	**19***	58% (Siemens)
(4) Edit entry in phone book	**10***	9	11% (Nokia)
Total	36	**45***	25% (Siemens)

I had a clear idea of what the functions meant.
The naming of functions is easy to understand.
I quickly found out how the navigation keys worked.
The buttons have an intuitive structure.
It was easy to solve the tasks.
Overall, the phone is self-explanatory.

2.2 *Apparatus and materials*

For the mobile phones, two models (Nokia 3210, Siemens C35i) with a comparable functionality were selected. Figure 1 shows snapshots of the phones.

The Nokia 3210 (left side) consists of three navigation keys. Two of the keys have modes with a maximum of 4 functions per mode key. The central key ('Navy key') is used to select the function that is shown above it in the display. Moreover, there are scrolling keys effecting up and down movements in the menu. The c-key is used for corrections of text and for returns to higher menu levels. The Siemens C35i (right side) consists of five keys and four of these have modes. Two rocker switches (with up to seven different functions per key) can be used for selecting and confirming actions, making corrections and scrolling, depending on the point of the menu. Additionally, there is an extra key with an icon (open book) to enter the phone directory, a big, centrally positioned key with a receiver sign for making and answering calls, and a smaller key with a receiver sign used to end calls as well as to make hierarchical steps back in the menu.

The mobile phones were simulated as software solutions run on a PC and displayed on a touch screen (TFT-LCD Iiyama TXA3841, TN, 15' with a touch logic by ELO RS232C). The software mirrored the real phones regarding menu and navigation keys. Avoiding biases towards a

Figure 1. Snapshots of the two phone models. Left: Nokia 3210; right: Siemens C35i.

specific brand, the simulated phones had identical looks and proportions in physical dimensions (width: 12 cm, height: 20 cm). In order to achieve good visibility, font size was enlarged (Arial, 18 pt). Three menu functions were presented in the display at a time. Users' actions were recorded online, so that the number and type of keys used, time spent on tasks and the navigational route could be reconstructed precisely.

2.3 *Tasks*

All participants solved four telephone tasks in the following order:

Calling a number from the phone directory. (Table 2). The production rules to be learned are specified in table 2. As can be seen, with the Nokia phone four different rules had to be differentiated and with the Siemens phone only three. Thus, the complexity of the Nokia phone is 33% higher than in the Siemens one (taken as the baseline).

Sending a text massage. (Table 3). Controlling for differences in the typing speed, the message was already provided and only had to be sent when participants reached the correct point in the menu. In table 3, the specific production rules in both phones are visualised. In sending a text message, 12 production rules had to be applied to the Nokia phone (taken as the baseline), whereas this task was more complex (by 40%) for the Siemens phone (14 production rules).

Hiding own number. (Table 4). When participants had to switch off their number's transmission, they had to process 14 production rules with the Nokia (baseline) in contrast to 19 production rules when using the Siemens (58% more complex).

Editing a number in the phone directory. (Table 5). In the last task, a number stored in the phone directory had to be edited. This was more complex to accomplish with the Nokia (10 production rules, corresponds to an increase in complexity of 11%) than with the Siemens phone (9 production rules, taken as the baseline).

Table 2. Production rules to be applied in task 1 (call Kathrin Kayser from the phone directory).

Task	Nokia 3210	Siemens C35i
Call	enter the menu with navy key select 'phone book' press 5 to reach entries starting with k call 'Kathrin Kayser' with navy key	enter phone book with phone book key press 5 to reach entries starting with k green receiver button

Functions are translations of the German terms, not the original English version of the phones.

2.4 *Participants*

32 participants volunteered to take part in the study. To exclude confounding effects from different levels of education, only academically educated participants took part. They had answered to announcements published on notice boards on the university campus, in which exclusively younger (20–30 years) and older (50–65 years) novice mobile phone users were searched for. Being a novice was defined in the announcement as having no or little experience in the use of mobile phones (no experience using the menu of the mobile phone). The announcement also informed that the experiment wanted to find out how younger and older adults come along with current mobile phones. The 32 users that responded were first matched by age and gender, i.e. the 16 younger users were equalized into two homogenous groups and the same was carried out for the 16 older novices. In the younger group, students of different academic fields volunteered. The older group consisted of academics of different professions (high school teachers, university professors (psychology, geography, literature studies, medicine), engineers, physicians and psychiatrists). Accordingly, half of the participants were between 20 and 32 years of age (M = 23.1 years). The other half was between 50 and 64 years (M = 55.5 years). Sixteen participants were assigned in a semi-randomised manner

Table 3. Production rules to be applied in Task 2 (sending a text message to Alexander Fischer).

Task	Nokia 3210	Siemens C35i
SMS	enter menu with navy key scroll from 'phone book' to 'messages' with arrow down button entry 'messages' with navy key scroll from 'message inbox' to 'message outbox' with arrow down button scroll from 'message outbox' to 'create message' with arrow down button select 'create message' with navy key select 'options' with navy key select 'send' with navy key select 'search' with navy key to reach stored numbers select 'Alexander Fischer' with navy key	enter menu with right softkey scroll from 'internet' to 'office and fun' with right part of left softkey scroll from 'office and fun' to 'messages' with right art of left softkey select 'messages' with right softkey select 'create message' with right softkey select 'own text' with right softkey select 'ok' with right softkey select 'send text' with right softkey press phone book key to reach stored numbers scroll from 'own number' to 'new entry' scroll from 'new entry' to 'Alexander Fischer' select 'Alexander Fischer' with right softkey select 'ok' with right softkey select 'send' with right softkey

Functions are translations of the German terms, not the original English version of the phones.

(eight of the younger (M = 23.4; SD = 3.7) and eight of the older (M = 56.4; SD = 3.3)) to the 'Nokia group' and 16 participants (eight younger (M = 22.9; SD = 2.1) and eight older (M = 54.9; SD = 4.6)) to the 'Siemens group'. The motivation to join the study was high, especially as it was emphasized that the experiment aimed at assessing the usability of mobile phones and not participants' personal abilities.

To ensure that differences in navigation performance are due to the different usability of mobile phones and not to different experience with other technical devices, a pre-experimental screening of participants' previous expertise with technology was carried out. Participants were to state if, and how often, they use technological products (ISDN (Integrated Services Digital Network) and wireless phone, fax, PDA, PC and video). Moreover, they had to rate their interest in technology in general. Both the younger and the older adults were rather experienced with technology. Seventy five percent of the participants (63% of the younger, 88% of the older group) indicated having no experience with an ISDN-phone, while a wireless phone was used by an overall 56% of participants (50% of the younger, 63% of the older group) several times per day. More than 70% of the participants (younger and older) stated using a PC daily. The PDA expertise was very low (none of the younger and only one of the older group indicated use of a PDA). A fax machine was used by 50% of participants (both ages) only once monthly. Two thirds of all participants (both ages) used a videocassette recorder about twice a month. Additionally, the interest in technology was medium in both age groups. Results from nonparametric Mann-Whitney tests showed no significant differences, neither between the Siemens and the Nokia groups nor between the age groups.

2.5 *Procedure*

As participants were novices in mobile phone handling, no time limit was set. If participants ran out of ideas of how to carry on constructively, the experimenter proposed trying the next task in order to avoid frustration. It was ensured that participants understood exactly what they had to do in each task, avoiding that the 'not knowing what to do' was confounded with the 'not knowing how to do it'. This was accomplished by a careful inquiry directly after the task instruction, by requesting participants to recapitulate in their own words what they had to do for each task and to ask any questions concerned with the task content, if unclear. Moreover, a fast and thorough working style was instructed. If a task was solved successfully, a 'Congratulations' message appeared on the display. User manuals were not provided. After they had finished the tasks, participants rated the ease of use. After the experiment, participants were gratified for their efforts with a small present (they could choose either a miniature portable radio or a bottle of wine).

Depending on the individual working speed, the whole experiment lasted between 30 and 50 minutes.

3. *Results*

The results were analysed by multivariate analyses of variance assessing effects of 'phone complexity' and 'user age' on navigation performance (including effectiveness as an overall measure and for the single tasks) as well as efficiency

Table 4. Production rules to be applied in Task 3 (hiding the own number).

Task	Nokia 3210	Siemens C35i
SMS	enter menu with navy key scroll from 'phone book' to 'messages' with arrow down button scroll from 'messages' to 'call register' with arrow down button scroll from 'call register' to 'settings' with arrow down button select 'settings' select 'call settings' scroll from 'Automatic redial' to 'speed dialing' with arrow down button scroll from 'speed dialing' to 'call waiting' with arrow down button scroll from 'call waiting' to 'send own number' with arrow down button select 'send own number' scroll from 'presettings' to 'on' with arrow down button select 'on' with navy key	enter menu with right softkey scroll from 'internet' to 'office and fun' with right part of left softkey scroll from 'office and fun' to 'messages' with right part of left softkey scroll from 'messages' to 'records' with right part of left softkey scroll from 'records' to 'profiles' with right part of left softkey scroll from 'profiles' to 'audio' with right part of left softkey scroll from 'audio' to 'time/costs' with right part of left softkey scroll from 'time/costs' to 'call divert' with right part of left softkey scroll from 'call divert' to 'settings' with right part of left softkey select 'settings' with right softkey scroll from 'menu range' to 'phone' with right part of left softkey scroll from 'phone' to 'security' with right part of left softkey scroll from 'security' to 'network' with right part of left softkey scroll from 'network' to 'during calls' with right part of left softkey select 'during calls' with right softkey scroll from 'call waiting' to 'incognito' with right part of left softkey select 'incognito' with right softkey select 'change' with left softkey select 'OK' with right softkey

Functions are translations of the German terms, not the original English version of the phones.

measures (time on task, detour steps and returns, as overall measure as well as for the single tasks). The significance of the omnibus F-Tests were taken from Pillai values. User judgements were analysed by non-parametric Man-Whitney-Tests. The level of significance was set at $p < 5\%$. For the overall measures, the performance in the four tasks was averaged and means (and standard deviations) are reported. The result section is structured as follows: first, the omnibus F-tests are described for the cognitive complexity (Siemens: higher complexity vs. Nokia: lower complexity) and age (older vs. younger users). For a better overview, first, effects of cognitive complexity on overall performance (effectiveness, efficiency and ease of use) are reported and contrasted to the predictions according to the Cognitive Complexity Theory. Then, on the task level, the performance is described for each task. Secondly, effects of age (older vs. younger adults) are addressed following the same reporting structure. Finally, the interaction of both variables on navigation performance is described.

The MANOVA analysis yielded significant main effects of both the cognitive complexity ($F(1, 28) = 4.62$; $p < 0{,}05$) and age ($F(1, 28) = 6.36$; $p < 0{,}05$). Further, the interaction of both variables yielded significant effects ($F(1, 28) = 4.47$; $p < 0{,}05$). Verbalising the outcomes, this means that the phone with the lower complexity outperformed the more complex phone. Moreover, younger adults had the better performance compared to older adults. Interestingly, and this can be taken from the interaction of the two factors, cognitive complexity and age, the profit from the lower complex phone is not equal for both age groups, but stronger for the younger adults. In addition, and this seems to be noteworthy from an ergonomic standpoint, older adults, using the less complex phone, can catch up their inferiority in navigation performance, even outperforming the younger adults working with the complex phone. In the following section, the results are now addressed in detail.

3.1 *Cognitive complexity*

3.1.1 Overall performance. Regarding the cognitive complexity of both phones, the effectiveness (number of tasks solved) did not differ significantly when comparing the Nokia (M = 89%; SD = 14.3) and the Siemens phone (M = 84%; SD = 13.3). However, with respect to task efficiency, significant differences between both phone types could be obtained. The time needed to process the four tasks was significantly different ($F(1, 28) = 13.6$; $p < 0.05$) between both phones. Participants using the Nokia were much faster in task solving (M = 2 min 37 s; SD = 86) than participants of the Siemens group (M = 4 min 16 s; SD = 111). Concerning the number of detour steps, the

Table 5. Number of production rules to be applied in Task 4 (editing Alexander Fisher's number in the phone directory).

Task	Nokia 3210	Siemens C35i
Edit an entry in the phone book	enter menu with navy key	enter phone book with phone book key
	scroll from 'search' to 'add' with arrow down button	scroll from 'own numbers' to 'new entry' with right part of left softkey
	scroll from 'add' to 'delete' with arrow down button	scroll from 'new entry' to 'Alexander Fischer' with right part of left softkey
	scroll from 'delete' to 'edit' with arrow down button	select 'option' with right softkey
	select 'edit' with navy key	scroll from 'show entry' to 'change entry' with right part of left softkey
	select Alexander Fischer 'edit' with navy key	select 'change entry'
	select name Alexander Fischer 'ok' with navy key	delete wrong number with left part of right softkey ('c')
	delete numbers with c-button	enter new number with number keys
	enter new number with number keys	select 'ok' with right part of right softkey
	confirm it with navy key	

Functions are translations of the German terms, not the original English version of the phones.

superiority of the less complex phone was corroborated ($F(1, 28) = 14.6$; $p < 0.05$): comprising all four tasks, Nokia users made less than half the number of detour steps ($M = 61.6$; $SD = 43$) as compared to the Siemens users ($M = 130.8$; $SD = 62$). Moreover, when the frequency of steps back to higher levels in menu hierarchy is regarded, the Nokia outperformed the Siemens phone once more ($F(1, 28) = 6.7$; $p < 0.05$). Using the Siemens phone, users stepped back 17.5 times ($SD = 9.9$), while this only occurred 10 times ($SD = 6.6$) using the Nokia phone, indicating that users did not go astray so often with the less complex phone. In figure 2, the mean task efficiency is illustrated for both phones.

3.1.2 Ease of use. From participants' ratings of the two mobile phones' ease of use, no meaningful results could be obtained, in contrast to the distinct differences in effectiveness and efficiency measures. Users' ratings ranged between 2 and 3 points (1 being best, 4 worst), indicating that the overall ease of use in both phone types is rated mediocre at best.

3.1.3 Comparison of the results with the prediction with the CCT. Regarding the number of production rules to be learned, the Siemens group was expected to show a time increase of 25% on task and 25% more detour steps compared to the Nokia group. Figure 3 shows that this prediction did not match the real difficulty when using the phones. It can be seen that participants of the Siemens group showed 63% longer time on task and made 113% more detour steps compared to the Nokia group.

3.1.4 Task level. The single tasks are now analysed separately with respect to the task effectiveness (table 6), the efficiency (table 7) and the ease of use.

Task 1. *Calling a person out of the phone book*. With respect to the effectiveness (percent succeeding), no meaningful differences between the two phones were found (table 6). Regarding the efficiency (table 7), however, the differences between both phone types were significant for all measures (time: $F(1, 28) = 8.9$; $p < 0.05$; detour steps: $F(1, 28) = 11.3$; $p < 0.05$; returns: $F(1, 28) = 9.4$; $p < 0.05$). When using the complex Siemens phone, it took 3 min 21 s ($SD = 169$ s) to call a person, accompanied by 94.6 detour steps ($SD = 83$) and 9.2 returns ($SD = 9.8$) to higher menu levels. With the Nokia, participants were nearly 3 times faster ($M = 1$ min 9 s, $SD = 55$), with only 20.3 detour steps ($SD = 19$) and 1.3 returns ($SD = 1.8$).

Task 2. *Text message*. When sending an SMS, Nokia and Siemens users were equally successful (effectiveness of about 70%). Also, the efficiency did not differ between the two mobiles phones statistically.

Task 3. *Hiding their own number*. The superiority of the phone with lower complexity was shown in task effectiveness ($F(1, 28) = 5.1$; $p < 0.05$): Using the Nokia phone, the task was successfully solved by 93.7% ($SD = 25$), while only in 18.8% ($SD = 40.3$) in the Siemens phone. Looking at efficiency measures, significant differences between the two phones were found for the time on task ($F(1, 28) = 4.1$; $p = 0.05$) and the number of detour steps (($F(1, 28) = 5.1$; $p < 0.05$). Using the Nokia, users needed 3 min 35 s on average ($SD = 140.8$), in contrast to the processing time of 5 min 44 s ($SD = 218.9$) in the Siemens group. Moreover, Nokia users made significantly less detour steps ($M = 89.4$ steps; $SD = 77$) than Siemens users did ($M = 200.6$; $SD = 175$). With respect to the number of returns, Nokia users made 14.8 returns ($SD = 15.2$) in the menu, whereas Siemens users went back twice as often ($M = 29$; $SD = 26.7$). This difference was not significant, though.

Task 4. *Editing a number stored in the phone directory*. Statistical testing revealed no significant differences between the phones regarding effectiveness and efficiency.

3.2 *Effects of age*

3.2.1 Overall performance. Regarding the effectiveness, 97% (SD = 5.6) of the younger users were successful in solving the four tasks, whereas only 76% (SD = 12) of the older users were. This difference showed to be significant $F(1, 28) = 38.2$; $p < 0.05$). With respect to the efficiency, the time spent on all four tasks differed significantly between both age groups ($F(1, 28) = 23.3$; $p < 0.05$). Younger adults spent on average 2 min 22 s (SD = 95) on each task while older adults needed nearly double the time (4 min 32 s; SD = 84). For the number of detour steps and returns to higher levels in the menu hierarchy, younger participants made, on average, 79 (SD = 69) detour steps and went back 11.4 (SD = 9.8) times in menu hierarchy, while older users made 113.6 (SD = 52) detour steps with 16.2 (SD = 7.9) returns in the menu. However, these differences between younger and older users did not reach statistical significance. Figure 4 visualises the results in task efficiency.

3.2.2 Comparison of the results with the prediction with the CCT. If the outcomes are now related to the predictions of CCT in both age groups, efficiency was expected to be 25% lower in the Siemens phone compared to the less complex phone. Figure 5 shows the prediction–outcomes comparison for the younger group and figure 6 for the older group.

It can be seen that the CCT does not account for the difficulties the younger and the older groups experience when using the phones. This was especially true for the younger group which spent 100% more time on task and made 149% more detour steps in the more complex phone even if only an increase of 25% was predicted by the higher number of production rules. The older users spent 47.5% more time on task and 14% more detour steps than predicted by the CCT. Thus, again, it must be concluded that the CCT underestimates the real cognitive load imposed by the handling of the phones. Moreover, it disregards the absolute differences in performance between older and younger users, with the older users' performance being two to three times weaker than the younger users.

3.2.3 Ease of use. The user judgments with respect to different aspects of the ease of use were analysed by non-parametric Mann-Whitney tests. When asking if users had a clear idea of what functions meant, no significant age differences were found. However, older adults rated the function terms (naming) as more difficult to understand than younger adults ($z = -2.2$; $p < 0.05$). Moreover, older adults rated the question, if the tasks were easy to solve, significantly more negatively than younger adults ($z = -3.8$; $p < 0.05$). Finally, when the phone had to be judged with regard to its self-explanatory quality, again, the ratings of the older adults were distinctly more negative: twelve out of 16 older participants completely disagreed that the phone is self explanatory, whereas only five of the 16 younger adults did so. This difference between the age groups was also significant ($z = -2.5$; $p < 0.05$).

3.2.4 Task level. Considering the four tasks separately, the performance of older users showed to be inferior to younger users. In table 8 the effectiveness, and, in table 9, the task efficiency is illustrated.

Task 1. *Calling a person out of the phone book*. Younger and older adults' performance did not differ in this task, neither with respect to effectiveness nor to efficiency.
Task 2. *Text message*. However, when a text message had to be sent, only eight out of 16 older users succeeded (50%; SD = 51), revealing a significant difference ($F(1, 28) = 8.8$; $p < 0.05$) to the performance of younger users with an effectiveness of 94% (SD = 25). The same picture was found for all efficiency measures (time: ($F(1, 28) = 21.2$; $p < 0.05$; detour steps: ($F(1, 28) = 8.1$;

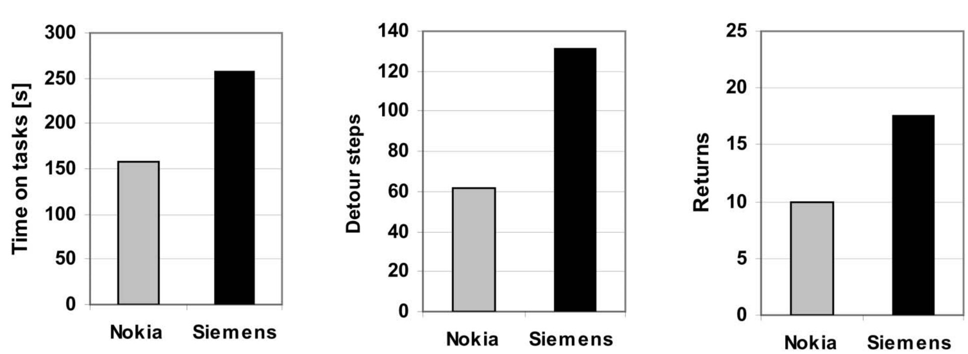

Figure 2. Efficiency measures in both phone types, comprising all four tasks (left: mean time on task(s); center: mean number of detour steps; right: mean number of returns).

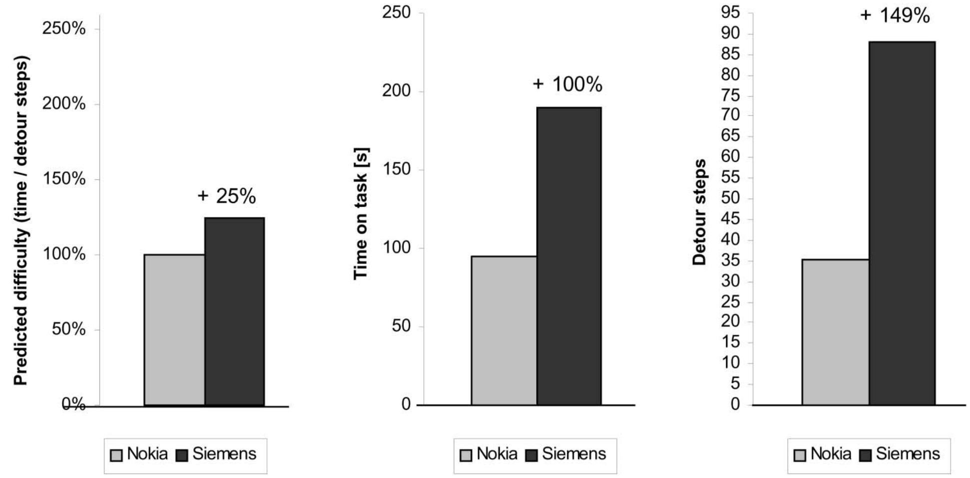

Figure 3. Cognitive complexity in the two phone models. Left side: prediction of the CCT; centre: time on task and right: detour steps. The Nokia phone was set as a baseline.

Table 6. Mean effectiveness (%) in both phone types for all tasks.

Effectiveness (%)	Nokia	Siemens
Calling	100	81
Text message	75	69
Hiding own number	69	44
Editing a number	69	81

$p < 0.05$; returns ($F (1, 28) = 7.3$; $p < 0.05$). In sending a text message, younger users needed 1 min 53 s (SD = 123), making 50 detour steps (SD = 70) and 7.5 returns (SD = 11.7). In contrast, older users needed three times longer (6 min 1 s, SD = 183). On average, they carried out 130 detour steps (SD = 93) and went 23.6 times back (SD = 18.7) to higher levels in the menu.

Task 3. *Hiding own number*. In this task, the difficulties of the older adults were most obvious. Only 19% (n = 3) of the 16 older users finished this task successfully, compared to 94% (SD = 25) of the younger users ($F (1, 28) = 45.8$; $p < 0.05$). With respect to efficiency, younger and older users were similar, revealing no meaningful age differences.

Task 4. *Editing a number stored in the phone directory*. This task could be handled somewhat better, however, the effectiveness of 56% (SD = 51) in older participants was significantly lower ($F (1, 28) = 7.4$; $p < 0.05$) than the performance of younger users (94%; SD = 25). When looking at efficiency measures, significant age differences were found for the time ($F (1, 28) = 6.6$; $p < 0.05$): younger users spent 2 min 2 s (SD = 97.8) on the task, while older participants needed nearly double the time (M = 3 min 50 s; SD = 137.2) for the same task.

Table 7. Mean efficiency measures (time on tasks and detour steps and returns) for all tasks and both phones. Results are presented for all (n = 16 in each phone type).

		Nokia n = 16	Siemens C35i n = 16
Calling	Time on task (s)	69.2	200.1
	Detour steps	20.3	94.6
	Returns	1.3	9.8
Text message	Time on task (s)	197.9	277.5
	Detour steps	65.7	113.8
	Returns	9.6	18.6
Hiding own number	Time on task (s)	215.7	344.2
	Detour steps	89.4	200.6
	Returns	14.8	28.9
Editing a number	Time on task (s)	146.8	206.1
	Detour steps	71	114.1
	Returns	14.4	13.4

Even though the number of detour steps and returns favoured the younger users once more (younger users: M = 70.8 detour steps (SD = 79) and M = 11.8 returns (SD = 10.9); older users: M = 114.5 detour steps (SD = 87) and M = 16.1 (SD = 16) returns in the menu), the differences between both age groups failed to reach statistical significance.

3.3 *Interacting effects of phone type and age*

Even if the MANOVA analysis yielded a significant omnibus F-value ($F (1, 25) = 4.5$; $p < 0.05$) for the interaction of cognitive complexity and age, none of the F-tests for the single measures reached statistical significance, alone. Apparently, only the co-acting of the measures is able to detect the interaction effect. In figure 7,

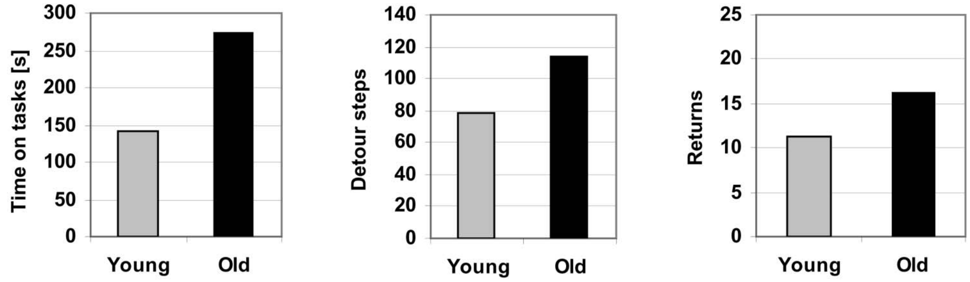

Figure 4. Efficiency measures in both age groups, comprising all four tasks (left: mean time on task(s); center: mean number of detour steps; right: mean number of returns).

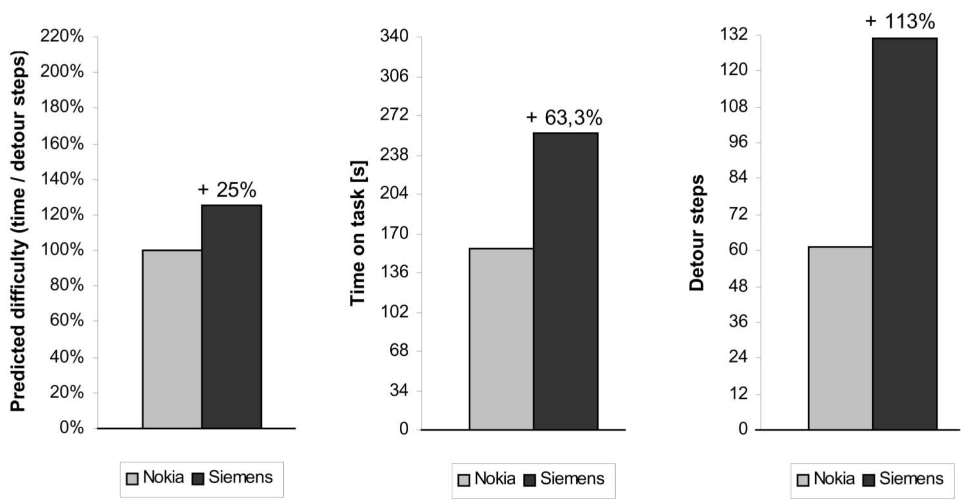

Figure 5. Cognitive complexity in the two phone models for the younger user group. Left side: prediction of the CCT; centre: time on task and right: detour steps. The Nokia phone was set as a baseline.

the interaction diagrams of phone complexity and age for efficiency measures are illustrated (though actually incorrect, the interaction is depicted by line diagrams, simply because the interactive nature of both variables can be demonstrated more clearly). From the detour steps and returns (figure 7) it can be seen that the younger adults' profit from a phone with lower complexity is larger than older adults'. Younger users make 3.5 times less detour steps and 2.6 times less returns with the low complex phone than with the complex one, while older adults make 'only' about 1.5 times fewer detour steps and returns.

4. *Discussion*

In this study, the usability of two mobile phones, the Siemens C35i and the Nokia 3210, with differing cognitive complexity was examined. In the Siemens, 25% more production rules have to be learned by the user compared to the Nokia to operate four common functions. Younger and older adults solved tasks on these phones, and task effectiveness, efficiency and the reported ease of use were assessed. Outcomes are now discussed with respect to their implications for the design of mobile phones for older adults.

4.1 *Effects of cognitive complexity*

Clear differences between the phones of different complexity were found. Participants using the less complex Nokia phone solved the tasks 14% more effectively than participants using the more complex Siemens phone. Considering efficiency measures, the advantage of the less complex phone was even more convincing: comprising all four tasks, participants spent 40% less time on task, making 50% less detour steps and disorienting less often, which is taken from the lower number (44%) of returns to higher levels in the menu hierarchy. However, the phone's

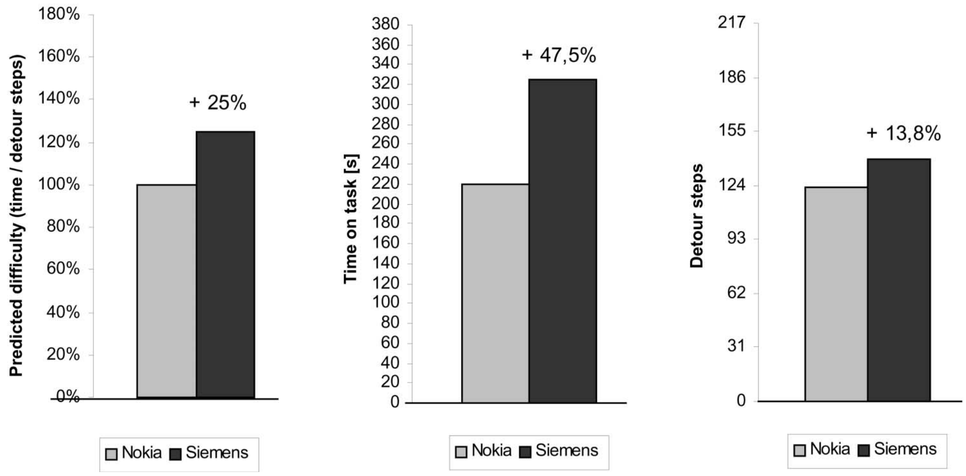

Figure 6. Cognitive complexity in the two phone models in the older user group. Left side: prediction of the CCT; centre: time on task and right: detour steps. The Nokia phone was set as a baseline.

Table 8. Mean effectiveness [%] in both age groups for all tasks.

Effectiveness (%)	Young	Old
Calling	94	87
Text message	94	50
Hiding own number	94	19
Editing a number	94	56

differences in cognitive complexity did not affect navigation performance for both age groups equally, but was clearly stronger for the younger adults who needed three times more detour steps and returns to solve the tasks on the more complex phone. In contrast, the older adults' loss in efficiency by the complex phone was only factor 1.5. This result is noteworthy as it may prove the widespread prejudice wrong that younger adults master technological demands anyway, independently of how complexly they may be structured. In addition, it should be accentuated that the two phones simulated and tested in this experiment, are rather conventional and widespread mass products, and, as was found out in an extensive pre-experimental screening, the menu structure is not extraordinarily basic or highly complex. Therefore, it has to be realistically assumed that those products are frequently bought and used, not only by the younger but also by the older group. Thus, arguing from the need for technical devices providing universal accessibility for a broad user group, the outstanding superiority of the usability of mobile phones with a low complexity was corroborated. However, this advantage is not restricted to novice users, as examined here, but was also found when examining expert users (Ziefle 2002b). In addition, a study focusing on children's interaction with mobile phones yielded the very same finding (Bay and Ziefle 2003b, 2005). Interestingly, the huge differences in performance between both phones were not reflected by usability ratings. Participants rated usability between two and three out of four possible points, indicating, that usability was not good (1) but surely not worst either (4). Importantly though, the ratings were similar for both phones. This striking discrepancy between performance measures and user ratings seems to be of special importance for the methodological claim of interface evaluation. Considering that the majority of manufacturers evaluate mobile phones primarily operating with user ratings for evaluation purposes, the measure's validity is highly disputable. As a matter of fact, preference ratings can be obtained much more easily, but they possibly

Table 9. Mean efficiency measures (time spent on tasks, detour steps and returns) for all tasks in both age groups. Results are presented for all (n = 16 in each age group).

		Young (n = 16)	Old (n = 16)
Calling	Time on task(s)	109	160.4
	Detour steps	60.3	54.7
	Returns	4.3	6.3
Text message	Time on task(s)	113.7	361.7
	Detour steps	50.2	129.3
	Returns	7.5	20.8
Hiding own number	Time on task(s)	223.2	336.8
	Detour steps	134.1	155.9
	Returns	20.1	23.6
Editing a number	Time on task(s)	122.4	230.4
	Detour steps	70.8	114.5
	Returns	11.8	16.1

do not reflect the real difficulties, and if a device is supposed to be accepted in the long run, the impact of determining effectiveness and efficiency is deciding.

4.2 *Effects of age*

Without doubt, user age is another crucial factor affecting performance when handling the interface of a mobile phone, substantiating results of studies dealing with older adults applying computer-based tasks (e.g. Lin 2001, Pak 2001). In general, older adults showed a distinctly lower performance which indicates that the technical device is not fully understood and not transparent with respect to the menu. Their task solving was lower compared to younger adults (43%). In addition, older adults spent more time on task (48%), with distinctly more detour steps (36%) and more returns to higher levels of the menu hierarchy (35%). However, in contrast to younger people, they clearly admit not to come to terms with the usage of the cell phones, not being able to cope with the difficulties raised by tasks, functions and keys. Taken from their ratings, evaluations of the given ease of use ranked rather low. Generally, the older adults' ratings differed from those of the younger adults. Especially the transparency of the functions' naming and the claim of mobile phones to be self-explanatory were rated most negative. From an ergonomic standpoint it is noteworthy though that older adults got along much better with the less complex compared to the more complex phone; they even performed better than younger adults using the complex phone.

4.3 *The appropriateness of the CCT for predicting difficulty using a device*

Cognitive complexity was defined on the basis of the theory by Kieras and Polson (1985) by the number of production rules that have to be differentiated by users when operating the device. This approach was pursued as the model provides a formalism for defining cognitive complexity and allows prediction of the difficulty of using the phones in terms of effectiveness and efficiency. However, as the outcomes showed, the definition of production rules only partly and superficially catches the problems and, finally, does not reflect the real difficulty of a device, neither for the younger nor for the older users. Even if the Siemens phone was predicted to lead to a 25% inferior performance (as, over all tasks, 25% more production rules have to be learned), efficiency was far lower than only 25% to the Nokia phone. This shows that the different factors (menu structure, difficulty of understanding the different navigation keys, location of functions and functions' naming) do not equally contribute to cognitive complexity as it is assumed by the counting of production rules. On the basis of the present data, it cannot be determined which of the mentioned factors are especially crucial. However, some insightful implications can be made from participants' remarks. One crucial factor is the function naming. Here, foreign expressions, abbreviations and technical terms should be avoided as well as the frequent usage of generic terms as category descriptor terms (e.g. 'settings', 'options' or 'profiles') because they always promise to lead the user to the targeted function even if they mostly do not. Another factor definitively aggravating the usage of the phone is the

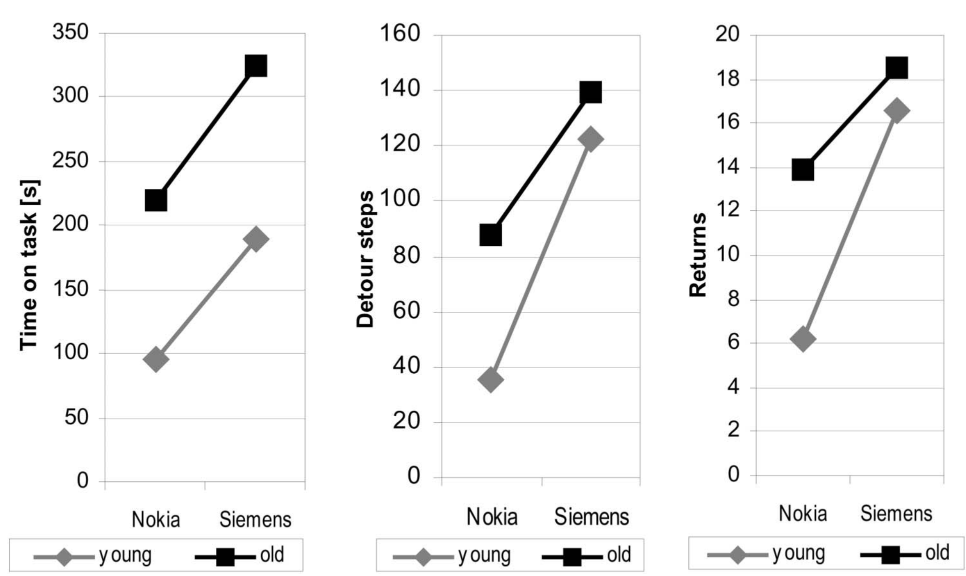

Figure 7. Interaction diagrams of phone complexity and age for efficiency measures (left: mean time on task(s); center: mean number of detour steps; right: mean number of returns).

number of modes of navigation keys. As the key solution in the Siemens phone is rather – and not necessarily – complex, with many navigation keys, exhibiting the additional complexity of having several modes (up to seven per key), this might have complicated their proper usage to a large extent. A recent study (Ziefle *et al.* 2005) corroborated the complexity of navigational key solution to be of essential importance for the usability of mobile phones, and, as was shown, the difficulty of handling the Siemens C35i is to a great deal caused by the complex and uneasy navigation key solution.

Furthermore, there are some observations on older users' behaviour that seem to have crucial implications for the design of technical devices because they enlighten older adults' needs and demands on the man – machine interface in interaction with technology in general.

4.4 *Complexity of functions*

Shneiderman (1998) pointed out that the cutoff between the extended functionality of a technical device and user needs has to be balanced carefully. While novices, for example, perform best if they have to handle simple tasks within a limited functionality, experts, in contrast, profit from a powerful system with a broad functionality. This sensitive cutoff can be strongly confirmed. In post-experimental interviews, older users expressed the claim that they expect a well-designed cell phone to meet their needs. Accordingly, the phone should be easy to understand, only providing few functions. Apparently, as it was appropriately described by Melenhorst *et al.* (2001), the perceived advantages of the broad functionality were not predominant in older adults. As a direct consequence, participants stressed not to be willing to struggle through a jungle of menu functions, and moreover, not to be about to search for a function, whether they need it or not. They want to have the functions within easy reach, maximal transparency and minimal ambiguity. This mindset is reflected by the senior's better performance with the less complex phone. However, the cognitive friction caused by an overload of functions may not be restricted to older adults interacting with technology, which can be taken from Cooper (1999): 'Most people react to cognitive friction in the same way, even apologists. They take the minimum they need from it and ignore the rest. Each user learns the smallest set of features he needs to get his work done, and he abandons the rest' (Cooper 1999: 33).

4.5 *Tolerance to trial and error*

Another crucial difference between older and younger users has to be accentuated from the present experiment. Even if in total the younger participants executed fewer steps, older adults executed a smaller number of keystrokes per time, thus pointing to a more reluctant and cautious navigating mode than was present in younger adults. This was already described by Lin (2001), where older adults showed to browse a smaller amount of nodes than younger adults did while perusing through different types of hypertext topologies. Furthermore, in contrast to younger users who made more and shorter detours, older adults, once entering a wrong path within the menu, consequently delved into distraction, not easily finding their way back, as if they were not able to decide which of the menu entries they had already passed and which part of the menu remains to be explored. This intolerance to a trial and error searching style is expressed by the older users, indicating to definitively prefer the use of an instruction manual for goal directed processing. Further research has to find out if and which kind of user instruction might be helpful for older adults (Bay and Ziefle 2004b).

4.6 *Limitations of the study*

Some final remarks are concerned with potential limitations of the study, with respect to two main points, the question if results may be generalised and the potential application of the outcomes.

4.6.1 Generalisation. Some arguments can be consulted suggesting that the performance outcomes, especially of the older users, are only the 'tip of the iceberg', thus representing an underestimation of the real situation. One argument refers to the sample of older users. It has to be taken into account that the older participants were 'only' between 50 and 64 years, they were busy, bright and highly educated, definitively not representing the typical aging society. Moreover, and this is also a clear difference to more typical seniors, the older users here reported to have high interest in and a reasonably good experience with technology in general, which might have facilitated their performance. A second argument is that the legibility of the displayed menu functions was distinctly better than present in real mobile phones: font sizes of 10 pt are common for text information in real devices, while the experimentally used font size was enlarged (18 pt). In addition, the button size was also enlarged (about one and a half to twice the size given in real phones). Considering that older users' visual and psychomotor ability is decreased, this is another factor that may have influenced the outcomes more positively than in reality. Further, three menu functions were presented on a display at a time, in contrast to real mobile phones, where up to seven functions are displayed concurrently. The information density by too many functions per display, causing visibility problems on the one hand and orienting problems on the other hand (Bay and Ziefle 2004a) was experimentally ruled out, probably also facilitating performance.

4.6.2 ***Potential application of the findings.*** The plasticity of the outcomes – a clear effect of cognitive complexity, clear age effects, and, furthermore, the interacting effect of both factors – could lead to the assumption that the usability problem in mobile phones is tackled, if not solved, by recommending phone companies simply to include existing research into their designs and at long last producing devices with a small complexity for all. Even if this is definitively the central message of this research, the present study does not allow the definition of what exactly makes a phone less complex. As existing phone types were under study – meeting demands of ecological validity – the relative contribution of the single factors to cognitive complexity cannot be determined. Is it most central to simply reduce the amount of functionalities? Or is it more important to have keys without modes? Which contribution comes from the transparency of function naming and which cognitive load is present by a suboptimal icon design? In other words, future studies have to address the single factors contributing concurrently to cognitive complexity and to determine their relative effect, their potential interactions, possibly compensating each other, in order to give practical and precise advice for an optimised phone design.

Altogether, it can be concluded from the present experiment that both older user age and complex interfaces in mobile phones are factors which result in performance deterioration. The experiment showed that a user-friendly design is definitively able to compensate performance decrements as present in older adults, thus meeting the demand of usability for a broad user group. Facing an increase in the usability of functions announced by manufacturers, this is of central interest. Independently of which and how many functions will be implemented in future devices, Coopers' (1999) warning will have to be exigently followed: 'You can predict which features in any new technology will get used and which not. The usage of features is inversely proportional to the amount of interaction needed to control it' (Cooper 1999: 33).

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