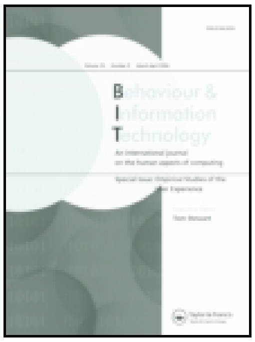

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Age differences in the performance of information retrieval tasks

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Abstract. In two experiments younger (18–25 years) and older (60–70 years) participants performed an information retrieval task in which they searched for the answers to questions in a hierarchical menu structure. Participants' movement speed, spatial ability, spatial memory, working memory capacity and reasoning speed were measured. Results showed older participants to be slower than younger participants on overall latencies on the information retrieval task. This slowing increases with each consecutive step in the menu structure. Regression analysis showed that movement speed, reasoning speed and spatial ability predicted the overall latencies accurately. Modelling the consecutive steps showed that latencies on the first selection are predicted by movement speed and reasoning speed. Memory and spatial measures are predictors for latencies on steps further into the menu structure only. This finding is consistent with increased slowing of older participants for later selections and suggests that deep menu structures are less suited for older users.

1. Introduction

In recent years, people have been confronted with increasing amounts of interactive equipment. Apart from the increase in the amount of interactive equipment, there has also been an increase in the number of options this equipment offers the user. As the number of control elements that one device or screen can hold is limited, there is a development towards either having control elements serve multiple functions, or them being organized hierarchically. A common means of doing the latter is through the use of menu structures. However, the use of menu structures may not be as appropriate for all groups of users. This paper focuses on age as a possible complicating factor in the use of menu structures.

That the use of menus is not without its problems is shown by the number of studies aiming to optimize performance of users while they navigate through menu structures. Such studies have addressed trade-offs between depth and breadth of menu structures (Van Hoe *et al*. 1990) and effects of different categorizations of choices or concepts. Though some authors have claimed that menu structures are particularly helpful for novice users (Liebelt *et al*. 1982) because the user has to recognize an option rather than recall it (as is the case in command languages), others have claimed that (novice) users may 'get lost' in the hierarchy or become disoriented (Kim and Hirtle 1995). Nevertheless, the ease with which users navigate in menu structures is likely to be influenced by a number of factors (see e.g. Westerman 1997). It seems plausible, for instance, that users navigate a database more efficiently when its organization matches the cognitive organization that the user has of that data base. Such an effect was reported by Roske-Hofstrand and Paap (1986), who showed that, relative to random organizations, users perform better on information retrieval tasks when the organization of the data base matches their cognitive organization (as measured by 'pathfinder' networks (Schvaneveldt *et al*. 1985)). Though matching the data base organization to the user's cognitive organization thus seems beneficial for information retrieval, its applicability is limited by individual differences in the cognitive organization of a domain. However, participants' speed of operation may also be affected by more general cognitive processes. This paper focuses on the role played by age-related differences in cognitive ability in the performance of information retrieval tasks.

2. Cognitive ability and information retrieval tasks

A case for studying individual differences in Human-Computer Interaction has been made by Egan who

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claims that 'differences among people usually account for much more variability in performance than differences in system designs or differences in training procedures' (1988: 543). One variable that has been put forward as a possible cause of performance differences in interactive tasks is *spatial ability* or *visualization ability*. Tests of spatial ability often require participants to mentally manipulate images. As an example, in the VZ2 test from the Ekstrom *et al.* (1976) kit of factor referenced cognitive tests, participants are shown pieces of paper which are to be folded across indicated lines. After the paper has been folded a couple of times, an imaginary nail is driven through the paper. Participants then have to unfold the paper mentally and choose from a number of alternatives the drawing which indicates the positions where the nail would have pierced the paper. This type of test involves the recall and active manipulation of a mental image. Several authors have found that participants who score higher on tests of spatial ability are better able to learn to perform interactive tasks. Gomez *et al.* (1983) found spatial ability to be predictive of success at learning to use a computer text editor. Sein and Bostrom, who studied the mental model formation process of novice users of an electronic mail filing system, found that 'high-visual participants performed significantly better than low-visual participants' (1989: 197). Sein *et al.* (1993), who discuss five studies using filing and operating systems, suggest that people who score high on spatial ability are better able to keep track of their position in a hierarchical system. Spatial ability has also been shown to predict efficiency in retrieving information from a hierarchical database (Vicente and Williges 1988, Seagull and Walker 1992). Vicente *et al.* (1987) found that two variables, namely spatial ability and vocabulary score, predicted 45% of the variance in search latencies on an information retrieval task. They also concluded that participants with low spatial ability tended to get lost in the data-base. In general, spatial ability thus appears to affect performance on interactive tasks, though it is not clear what specific component of spatial ability is responsible for this effect. Seagull and Walker (1992) have suggested that individual differences in spatial ability are essentially differences in processing speed. Vicente *et al.*'s observation that low spatial ability participants tend to get lost in data-bases, as well as the Sein *et al.* (1993) findings suggest that high spatial ability participants are better able to build a mental representation of the system.

Spatial ability has been shown to decline with increasing age (see Salthouse 1992 for a review). As it appears to affect performance of interactive tasks, spatial ability has also been put forward as a possible factor explaining performance differences between younger and older users of interactive equipment. Kelley and Charness (1995), discussing several cognitive variables which might cause age differences in the performance of interactive tasks, state that '... the one that appears most promising as a mediating variable is spatial ability, which is both associated with age and predicts computer performance in several studies' (1995: 114).

3. Age differences in information retrieval tasks

A study by Westerman *et al.* (1995) examined how spatial ability, spatial memory and vocabulary score affect accuracy and latencies of participant groups of different ages in an information retrieval task. Participants in this study had to retrieve information from a data base that contained files with information about tropical fish. Participants were posed a question and had to locate a computer file in the database in which they could find the answer to this question. Participants were to navigate between files by selecting highlighted keywords in the file using the cursor keys and the enter key. Participants were to select the keywords they considered relevant until they located the file containing the answer to the question. Westerman *et al.* found older participants to be slower on this task though they were not less accurate. Since age differences in general processing speed and motor speed are well documented (Cerella 1985), longer latencies on the part of older participants should come as no surprise in such a task. In fact, the slowing of older participants signals greater difficulty with the task only when it exceeds this slowing in general processing speed. In order to separate the potential effects of motor or processing speed from more cognitive processes, participants in the experiment of Westerman *et al.* performed so-called *menu component tasks* as well as the information retrieval task. The menu component tasks required participants to simply select a target using the cursor keys. The menu component tasks were 'thought to demand primarily processing speed and psychomotor skill rather than more complex cognitive processing' (1995: 322). Westerman *et al.* found older participants to be slower than younger participants on the information retrieval task and found spatial ability to predict latencies (participants with low spatial ability had longer latencies). However, when latencies on the menu component tasks were used as a covariate, the main effect of age on response times in the information retrieval tasks was no longer significant. Longer response times of older participants on the information retrieval task thus appeared to be more dependent on general processing speed than on more cognitive factors. It should be noted, however, that Westerman *et al.* used a relatively younger sample. With a mean age of 50.5

years for older participants, no age differences on cognitive ability measures other than speed were found.

Though older participants were not slower on the information retrieval task when controlling for speed on the menu component tasks, Westerman *et al.* (1995) did find that learning rates differed for the two age groups. The slower responses of elderly participants were more pronounced in the first block of trials. Westerman *et al.* concluded that this may indicate an age-related delay in forming a mental representation.

4. Cognitive load in information retrieval tasks

One aspect of information retrieval tasks that has received relatively little attention is the fact that consecutive selections which participants have to make in the menu may involve different cognitive processes. One obvious suggestion would be that the selections made by a user proceeding through the structure differ with respect to the (working) memory load they pose. Given that a user encodes a question or search terms before making the first selection, the amount of time that elapsed since encoding will increase with every consecutive selection. As a result, the chance of items having decayed from memory is likely to increase with every selection. This memory load may affect the latencies of younger and older participants differentially, as age differences in short-term working memory have been well documented (Craik and Bosman 1992). Consequently, the extent to which latencies of older and younger differ may well depend on where the user is in the menu structure. Specifically, it can be expected that age differences will increase as the user goes deeper into the menu structure and working memory load increases.

Summarizing then, the cognitive demands inherent in information retrieval tasks may well be more taxing for older than for younger users. It is not yet clear however, whether older users are slower in performing these tasks when age differences in processing speed have been controlled for. Secondly, the cognitive demands inherent in the task may increase with consecutive selections, leading to increased slowing for older users with consecutive selections. Thirdly, though some concepts have been put forward as predictors for latencies in information retrieval, it is not clear how the importance of these component abilities varies according to the demands of the task.

The studies discussed here thus aimed to answer the following questions:

- Is the slowing of older participants on information retrieval tasks larger than can be expected on the basis of the slowing on simpler movement tasks?
- Does this slowing increase with consecutive steps in the menu structure?
- Does the role of component abilities change with step number? That is, if an increased slowing with step number is found, can it be attributed to specific changes in the cognitive demands of the task?

In order to answer these questions, participants were asked to perform an information retrieval task in which they had to search for answers to specific questions in a small menu structure. Participants also performed a ‘simple selection task’ and some ability measures. The simple selection task was meant to provide a measure of processing speed comparable to Westerman *et al.*’s menu component tasks. In order to assess what cognitive factors are predictive of participants’ latencies in information retrieval, some ability measures including spatial ability and working memory were also administered.

5. Experiment 1

5.1. *Method*

5.1.1. *Participants*: In total, 32 participants participated in experiment 1. The 16 elderly participants were between 60 and 70 years old ($M = 64.7$, $SD = 3.22$). The 16 younger participants were between 18 and 25 years old ($M = 21.3$, $SD = 5.19$). Older participants were selected through an advertisement in a local newspaper. As the response to this advertisement was not sufficient, additional participants were recruited through the social network of older participants who had participated in an earlier experiment. All older participants had received education at a higher vocational training level. Younger participants were selected through an advertisement at an educational institution for (non-technical) higher vocational training. A person who has completed higher vocational training has had at least 15 years of formal education. Of the 16 younger participants, two were students at a University. Participants were paid NLG. 8.- per hour for their participation. No measures of computer experience were collected.

5.1.2. *Equipment*: Tasks were administered using an IBM compatible computer with a colour screen. A track-ball was used as an input device. Presentation programs for these tasks were written in Visual Basic 3.0 under Microsoft Windows 3.11. Due to the characteristics of mouse port timing, response time measurements had an uncertainty window of maximally 50 ms. Though this is relatively coarse, it was considered accurate enough given the expected response times and effect sizes.

5.1.3. *Procedure*: Participants performed a total of five tasks. The order of tasks was the same for all participants. The order of trials within tasks was randomized.

5.1.4. *Task 1: 'simple' selection*: All participants started with a simple selection task, aimed at providing a basic measure of processing speed. In this task, four buttons appeared on the computer screen. The buttons were labelled with the digits 1, 2, 3 and 4 from left to right. On each trial, a message appeared in the top part of the screen instructing participants to 'press' a specific button (e.g. 'press button 3'). Participants were requested to move the cursor to the button in question and to select this as quickly as possible by pressing the button on the track-ball. The next trial was displayed after participants pressed a 'start' button. The simple selection task was considered to pose a minimal cognitive load and measure mainly motor speed (though obviously some visual processes are involved as well). As such, this task was comparable to the menu component task of Westerman *et al*. (1995), though it probably was more complex. In Westerman *et al*.'s menu component task, subject moved the cursor using the cursor keys. Also, the target in Westerman *et al*.'s study was a row of four X's, amidst three rows of four O's. The present simple selection task thus probably incorporates more aspects of psycho-motor skill. Participants were given 16 practise trials in this task, to familiarize them with the track-ball operation. After the practise trials, participants completed eight experimental trials, in which each button appeared twice. It is not clear whether there were any age differences with respect to experience in using this input device. However, since a within-subjects design was used, a participant's performance on one task was compared to that same participant's performance on another task. This minimizes the potential role of expertise differences concerning variables other than the manipulated ones. Also, one might argue that 16 practise trials may have been relatively few for some (older) participants. If this were the case, this would lead to an overestimation (participants would have shorter latencies with more practise) of the latencies on the first of the experimental tasks, i.e. the menu selection task. Since the menu selection task was a base measurement against which other latencies were pitted, this would result in an underestimation of effect sizes.

5.1.5. *Task 2: information retrieval*: In the information retrieval task, participants were asked to answer questions concerning attributes of animals, a domain that was expected to be equally familiar to all participants. They pressed a start button, after which a question like 'what colour is a canary?' appeared on the screen. The buttons in this task were in the same positions as the ones in the simple selection task, except for the start button, which was still in the horizontal middle of the screen but was displaced vertically, being slightly lower than in the simple selection task. All questions could be answered by pressing a sequence of three buttons. First, participants had to make a choice concerning category membership (press 'insects', 'mammals', 'fish' or 'birds'). This selection took the participant to a second menu screen, in which four attributes (e.g. 'colour', 'number of young' etc.) were listed. Participants were to press the relevant attribute, which took them to a third menu screen, in which the name of the animal concerned was to be pressed. This resulted in the answer to the question being displayed when the correct sequence of buttons had been pressed. When an incorrect sequence was pressed, a message indicating that an incorrect choice had been made was displayed. Participants were instructed that, if they made a mistake, they were to 'continue down the structure' and finish the trial even if this led to an incorrect response. Data from incorrect trials was not used for the analysis. Response times were measured for each button press separately and latencies between button presses were computed. The time that elapses between pressing the start button and making the first selection constitutes the latency for screen 1. The latencies between selections 1 and 2, and between selections 2 and 3 constitute latencies in screen 2 and 3 respectively. Participants received two practise trials and eight experimental trials in the information retrieval task. Figure 1 shows an example of the first screen of the interface.

A manipulation of the procedure for moving from trial to trial was included in this task. This manipulation was included to see if it would increase the participants' familiarity with the menu structure. If older participants are slower at building a mental representation increased familiarity might reduce their latencies. The manipulation concerned the trial to trial procedure only. Half the participants moved from trial to trial by pressing a 'next' button after the answer to the question appeared. Pressing this 'next' button took them directly to the top level of the structure. Here, pressing 'start' displayed the next trial. The other half of the participants pressed a 'return' button which took them up one level in the menu structure (taking them from the 'answer screen' to the 'attributes screen'). In the attributes screen, another return button had to be pressed to return to the top level. Here, pressing a 'start' button displayed the next trial. Furthermore, in this condition participants were

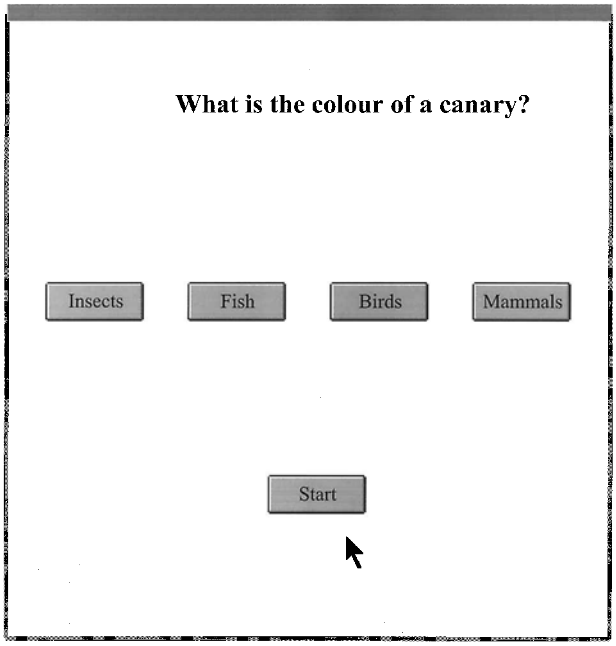

Figure 1. An example of a (first) screen in the information retrieval task.

allowed to repeat incorrect trials, unlike participants in the other condition. Thus half the participants saw the various options more often, which might increase their familiarity with the structure.

5.1.6. *Task 3: Working memory*: After the information retrieval task, three cognitive ability tests were administered. First, participants performed a working memory task similar to that described by Baddeley (1986). The Baddeley task was chosen because it provides a measure of both memory ability and (verbal) reasoning ability. The first selection in the information retrieval task requires participants to extract category membership. Since this requires retrieval from memory, but may also be dependent on reasoning ability, the Baddeley task appeared a suitable choice. In the working memory task, participants were shown a sentence describing the order of two letters followed by two letters (e.g. 'A comes after B – BA'). Participants were instructed to decide whether the sentence correctly described the sequence of letters and to respond by pressing a 'right' or 'wrong' button. This part of the task is essentially a verbal reasoning task. All sentences were phrased in the active form, and both 'AB' and 'BA' occurred in the sentences and letter pairs. All presentations were administered in a positive and negative ('A does not come after B') form. This resulted in eight possible pairs. Participants received all eight pairs as practise trials. Every pair was used twice as an experimental trial, resulting in 16 experimental trials. The reasoning task was administered with and without a preload. In the preload condition, the reasoning task was preceded by the visual presentation of three letters that participants had to recall after they answered the reasoning task. Letters were presented at a rate of one per second and were drawn randomly from the alphabet. The letters A and B used in the reasoning task were not used as preload. All participants carried out both the version with and the version without preload. Half the participants received the task with preload before the one without. The other half of the participants performed the version without preload first. Dependent measures in this task were reaction times and accuracy on reasoning tasks and number of letters correctly recalled from the preload. The number of letters recalled is an indicator of the participant's memory capacity while performing a reasoning task. Such a measure might be predictive of latencies for selections deeper in the menu structure.

5.1.7. *Tasks 4 and 5: Spatial abilities*: Finally, participants performed the spatial ability (VZ-2, task 4) and spatial memory (MV-2, task 5) tasks from Ekstrom *et al.*'s (1976) kit of factor referenced cognitive tests. The spatial ability task is a paper folding task as described earlier. In the spatial memory task, participants study a city map with the locations of several buildings. After the study phase, they are given a 'clear' map where they have to indicate the locations of the buildings.

The entire experiment took between 60 and 90 minutes. Participants were allowed to take a break between tasks when they requested so.

5.2. *Results*

Relatively long latencies were expected in the experiment. Using latency data in cognitive ageing research requires a choice between modelling additive or multiplicative factors. A number of arguments can be put forward for fitting multiplicative rather than additive models. As argued earlier, age differences in general processing speed are well documented. This slowing has been likened to an increase in the cycle time of an internal clock. Cerella (1985) has shown that multiplicative models provide a good description of age differences in latencies across a wide range of tasks. The finding that longer latencies of older participants are associated with increasing variance provides a further argument for using multiplicative models (Ratcliff 1976). It thus seems more appropriate to log-transform latencies for analysis and describe differences in terms of slowing factors rather than absolute differences in latencies.

It was first checked whether the manipulation of the trial-to-trial procedure in the information retrieval task was successful. This was not the case; no significant differences in latencies were apparent between the groups. As the manipulation concerned the inter-trial interval only, data were collapsed over this condition. Reported results on the information retrieval task pertain to these collapsed data.

Data analysis was performed in the following way. First, learning rates on the information retrieval task were compared for the two age groups by comparing latencies for the first and last four trials. Subsequently, latencies were compared for the two age groups across tasks. Two analyses were then carried out on information retrieval latencies. First, it was assessed whether the delay on the information retrieval task relative to the simple selection task was more pronounced for the older participants. Second, the latencies of older and younger participants were compared for the three consecutive steps in the menu structure. After a comparison of the error rates of younger and older participants, a regression analysis was performed to assess the relative importance of the various measures that had been collected.

5.2.1. *Latency data*: For the information retrieval task, only latencies for correct answers were used for analysis. Participants made few errors in this task and error rates were not different for younger and older participants. Accuracy scores for the information retrieval task are reported in table 5.

5.2.2. *Learning*: In order to assess whether younger and older participants differed in terms of learning rate, latencies for the first and last four trials (blocks 1 and 2 respectively) were calculated. Log-transformed latencies were then entered into a 2×2 repeated measures ANOVA with block as a within-participants measure and age as a between participants variable. Average latencies are presented in table 1. This analysis showed older participants to be slower than younger participants ($F(1,30) = 55.87$, $p < 0.001$). Latencies on block 2 were shorter than those on block 1 ($F(1,30) = 9.89$, $p < 0.005$). The age $\times$ block interaction was not significant. The learning rate of younger and older participants thus does not appear to differ.

5.2.3. *Effects of age on latencies across tasks*: For this second analysis, log-transformed latencies for simple selection, information retrieval and reasoning with and without preload were entered into a multivariate ANOVA with age as an independent variable. Table 2 shows the scores on these variables. The multivariate analysis yielded a significant effect of age ($F(7, 24) = 5.41$, $p < 0.001$). Univariate analyses revealed that older participants were slower on all measures.

One specific question is whether older participants were delayed on the information retrieval task when controlling for their latencies on the simple selection task. A one-way ANCOVA was therefore carried out with log-transformed latencies on the menu task as a dependent variable, age as an independent variable, and log-transformed latencies on the simple selection task as a covariate. This analysis revealed a main effect of the covariate ($F(1,29) = 14.90$, $p < 0.001$), and age ($F(1,29) = 13.18$, $p < 0.001$). Thus, the delay on the information retrieval task relative to the simple selection task is more pronounced for the older participants.

In the final analysis of latencies, it was assessed whether the slowing of elderly participants was different for the three steps in the information retrieval task, as these steps may tax different processes. Response times on the three different steps are shown in table 3.

As can be seen in table 3, latencies decrease consistently as a function of step number for both groups. Though the absolute decrease in latency is similar for both age groups, the latencies for younger

Table 1. Latencies (secs.) on the information retrieval task as a function of age and block (exp. 1). Standard deviations are shown in parentheses.

	Block 1	Block 2
Younger	10.6 (2.76)	10.0 (2.46)
Older	20.3 (5.16)	18.1 (5.56)

Table 2. Latencies (secs.) on simple selection, information retrieval, reasoning without preload and reasoning with preload (exp. 1). Standard deviations are shown in parentheses.

Age	Simple selection	Information retrieval	Reasoning no preload	Reasoning preload
Younger	1.95 (0.36)	10.30 (2.47)	4.29 (0.92)	5.40 (2.25)
Older	3.26 (0.93)	19.32 (5.03)	6.29 (1.53)	7.72 (2.82)

Table 3. Latencies (secs.) on steps 1, 2 and 3 in the information retrieval task as a function of age (exp. 1). Standard deviations are shown in parentheses.

	Step 1	Step 2	Step 3
Younger	4.37 (1.23)	3.29 (0.90)	2.65 (0.59)
Older	7.13 (1.94)	6.35 (1.78)	5.78 (2.20)

participants are shorter to start with and, as a result, their 'room for improvement' is smaller. One way of expressing this is by dividing the latencies of the older participants by those of younger participants to obtain a slowing factor (Cerella 1985). Doing so yields slowing factors of 1.63, 1.93 and 2.18 for steps 1, 2 and 3 respectively. The slowing of older participants thus appears to increase with step number. This pattern of increased slowing is also borne out in a repeated measures analysis on log-transformed reaction times. An ANOVA with age as a between participants factor and step number as a within participants factor revealed a main effect of age ($F(1,30) = 60.37$, $p < 0.001$) and of step number ($F(2,29) = 28.29$, $p < 0.001$). The interaction failed to reach significance in the multivariate approach ($F(2,29) = 3.29$, $p = 0.052$), but was just significant in the Huynh-Feldt approximation ($F(1.86, 60) = 4.80$, $p < 0.05$).

5.2.4. *Correlational data*: Table 4a shows the correlation matrix for the three steps on the menu structure. It can be seen that the correlation between step 1 and step 3 is smaller than between step 1 and step 2. Apparently, step 3 differs more from step 1 than step 2 does. This is in support of the hypothesized increased memory demands for the later steps. Step 2 and 3 are more similar than step 3 and 1, which might again indicate that the memory load for step 2 and 3 is higher than it is for step 1.

Table 4b portrays the correlation matrix for the predictor variables that were collected. The implications of these correlations are discussed under 'predicting response times' below.

5.2.5. *Accuracy data*: Accuracy data, depicted in table 5 were analysed in a multivariate ANOVA with age as an independent variable. Since all accuracy data are proportional in nature, they were transformed to logits for analysis. The multivariate ANOVA yielded a significant effect for age ($F(6,35) = 9.46$, $p < 0.001$) with older participants being less accurate than younger participants. Univariate comparisons on the different tasks showed older participants to be less accurate on reasoning with and without preload, spatial memory and spatial ability (all p's < 0.05), but not on the information retrieval task or the number of letters recalled from the preload.

5.2.6. *Predicting response times*: One of the aims of the experiment was to establish the extent to which age differences in response times are predicted by the cognitive measures that were collected. To this end, all

Table 4. Correlation matrices for exp. 1. Table 4a: steps on the menu structure. Table 4b: predictor variables.

Table 4a

	Step 2	Step 3
Step 1	0.83	0.78
Step 2	–	0.91
Step 3	–	–

Table 4b

	Reasoning preload	Reasoning no preload	Spatia ability	Spatial memory	Letters recalled
Simple selection	0.52	0.79	0.43	0.25	0.41
Reasoning preload	–	0.76	0.43	0.44	0.54
Reasoning no preload	–	–	0.36	0.38	0.49
Spatial ability	–	–	–	0.36	0.22
Spatial memory	–	–	–	–	0.32

Table 5. Accuracy (proportion correct) scores on the information retrieval task and cognitive tests as a function of age (exp. 1). Standard deviations are shown in parentheses.

	Information retrieval	Reasoning no preload	Reasoning preload	Letters recalled	Spatial memory	Spatial ability
Younger	0.95 (0.09)	0.97 (0.05)	0.96 (0.06)	0.89 (0.07)	0.80 (0.19)	0.59 (0.20)
Older	0.87 (0.19)	0.91 (0.16)	0.85 (0.09)	0.84 (0.15)	0.60 (0.21)	0.36 (0.13)

variables were entered into a stepwise regression analysis (latencies were log-transformed for analysis). Before the regression analysis, the correlation matrix of the predictor variables was studied. This matrix showed a high (0.79) correlation between the reasoning task and the simple selection task. Such a large correlation poses a problem in a regression analysis for a number of reasons. Firstly, the high correlation constitutes a simple form of collinearity, which prevents accurate estimation of regression weights (Fox 1993). Thus, the high correlation makes it difficult to establish the relative importance of various predictor variables. On a more conceptual level, the high correlation between the simple selection task and a working memory task suggests that the simple selection task is not as basic a measure of movement speed as was hoped. One may wonder therefore, whether the set of predictor variables is sensitive enough to detect the shift in cognitive requirements that was hypothesized. The regression analysis resulted in the following equations. The weights reported are standardized weights or betas, and should be interpreted with caution.

$$\mathrm{Log(RT)}_{\mathrm{menu}} = 0.49\ \mathrm{Ssel} + 0.34\ \mathrm{Rnp} + 0.25\ \mathrm{SM} \quad R^2 = 0.79$$

where Ssel = simple selection
Rnp = Reasoning, no preload
SM = Spatial Memory

In order to assess whether the role of the predictor variables changes over the steps in the menu structure, separate regression analyses were carried out for each separate step:

$$\mathrm{Log(RT)}_{\mathrm{menu1}} = 0.49\ \mathrm{RP} + 0.48\ \mathrm{Ssel}, \qquad R^2 = 0.68$$

where Rp = reasoning with preload.

$$\mathrm{Log(RT)}_{\mathrm{menu2}} = 0.73\ \mathrm{Ssel} + 0.32\ \mathrm{SM}, \qquad R^2 = 0.74$$

$$\mathrm{Log(RT)}_{\mathrm{menu3}} = 0.41\ \mathrm{Rnp} + 0.41\ \mathrm{Ssel} + 0.23\ \mathrm{SM}, \quad R^2 = 0.75$$

As can be seen these regression analyses do not show a clear transition from one set of predictor variables to another. Though simple selection is important in all steps, the reasoning task is important only in the first and the last step, but not in the second (where simple selection is most important). Spatial memory is important for steps 2 and 3 but spatial ability does not enter any equation. Given the difficulties of interpretation with the high correlation between simple selection and reasoning, it was decided to run the experiment a second time, but this time with a more basic measure of movement speed.

5.3. *Discussion*

The most important results from experiment 1 can be summarized as follows. When differences in movement speed are taken into consideration, elderly participants were found to be delayed on the information retrieval task. When the different steps in the information retrieval task are viewed independently, some further differences become apparent. Though the factor by which older participants are slowed is equal for simple selection and the first step in the information retrieval task, this slowing factor increases as selections are made deeper down the menu structure (though all latencies decrease with step number). This effect seems consistent with an increasing memory load leading to longer latencies in the elderly sample. With the present data, however, it is not possible to specifically test for this possible effect of memory load. Firstly, younger and older participants do not differ with respect to the number of letters they recall from the preload. Secondly, the high correlation between simple selection and reasoning and the resulting collinearity prevents regression weights from being estimated accurately. Experiment 2 was conducted in order to allow a test of this effect of memory.

Younger and older participants did not differ with respect to learning speed. The number of trials was relatively small though. In experiment 2, the number of trials was therefore increased from eight to 16.

6. Experiment

Experiment 2 aimed to test for the possible effect of memory load. To this end, the simple selection task was modified to avoid the problem of collinearity. Furthermore, the pre-load in the working memory task was increased in an attempt to increase the variance on this measure. As the procedure for experiment 2 was largely the same as that in experiment 1, only the differences between the two experiments will be mentioned.

6.1. *Method*

6.1.1. *Participants*: A total of 25 younger ($M = 20.28$, $SD = 1.97$) and 24 older ($M = 62.74$, $SD = 2.96$) participants participated in this experiment. None of the participants in experiment 2 had participated in experiment 1. Older participants were recruited through a newspaper advertisement. Younger participants were recruited through lists posted at their educational institution. The participants' educational background was similar to that in experiment 1. Participants were paid NLG 8.- per hour (approx 4 US$).

6.1.2. *Procedure*: The simple selection task was changed for experiment 2, as the task in experiment 1 appeared to contain too many cognitive components. In experiment 2, a movement task was used in which one button appeared on an otherwise empty screen. The participant's task was to simply move the cursor to this button and select it by pressing the button on the trackball. By using this simpler task, it was hoped to avoid collinearity. The movement task was the first task participants performed in experiment 2. The second task was the simple selection task from experiment 1. This task was administered to allow for cross-experimental comparison. The information retrieval task (task 3) was changed from experiment 1 in the following ways: participants performed 16 rather than eight experimental trials. Every trial from experiment 1 was administered twice (in random order). Again half the participants received the version in which the next trial was started by moving 'back'. Participants in this condition were not allowed to repeat incorrect trials though. In the working memory task (task 4), the size of the preload was increased from three to five. This larger preload might result in increased variance and in number of letters recalled becoming a significant (age-related) predictor. Tasks 5 and 6 were the spatial ability and spatial memory tasks.

6.2. *Results*

As the manipulation of the inter-trial procedure did not affect latencies or error rates, data were collapsed over this condition. Data analysis was subsequently performed in the same manner as for experiment 1. First, it was assessed whether older and younger participants differed in terms of learning rate. Subsequent analyses were performed on latency and accuracy data. Finally, in a regression analysis, an attempt was made to predict latencies on the information retrieval task.

6.2.1. *Latency data*: Latencies for the first and last eight trials (blocks 1 and 2) are shown in table 6. Log-transformed latencies were entered into a 2×2 repeated measures ANOVA with age as a between participants factor and block as a within participants factor. The ANOVA revealed that older participants were slower than younger participants ($F(1,46) = 89.74$, $p < 0.001$). Participants performed the tasks in block 2 faster than in block 1 ($F(1,46) = 75.23$, $p < 0.001$.) Again, the age × block interaction was not significant.

Table 7 shows the latencies for experiment 2. In general, latencies for experiment 2 were much shorter than for experiment 1. Though simple selection was not intended to be used as a predictive variable, latencies are reported for the purpose of cross-experimental comparison. Latencies depicted in table 6 were submitted to a multivariate ANOVA with age as an independent variable. The MANOVA revealed a main effect of age ($F(5,43) = 16.69$, $p < 0.001$). Univariate comparisons showed older participants to be slower on all five measures (all p's < 0.001).

To assess whether the slowing factor of older participants increases from the movement task to the information retrieval task, log-transformed latencies on the information retrieval task were entered into a one-way ANCOVA with age as a between participants factor and movement time as a covariate. The ANCOVA revealed main effects of movement time ($F(1,46) = 43.54$, $p < 0.001$) and age ($F(1,46) = 14.43$, $p < 0.001$). As in experiment 1, there is a main effect of age on the information retrieval task, even when the slower latencies of elderly participants on the movement task have been controlled for. Older participants are slowed by a factor 1.48 on the movement task, but on the information retrieval task the slowing factor is 1.82.

The pattern of latencies on the information retrieval task (depicted in table 8) is very similar to that in experiment 1. Again, the difference between step 3

Table 6. Latencies (secs.) for the information retrieval task as a function of age and block (exp. 2).

	Block 1	Block 2
Younger	8.4	7.2
Older	14.81	13.4

Table 7. Response times (secs.) for experiment 2. Standard deviations are shown in parentheses.

Age	Move	Simple selection	Information retrieval	Reasoning no preload	Reasoning preload
Younger	1.28 (0.19)	1.70 (0.24)	7.85 (1.07)	3.52 (0.71)	4.30 (1.31)
Older	1.90 (0.39)	2.61 (0.71)	14.27 (4.80)	5.64 (2.76)	6.80 (2.47)

latency and movement latency is much smaller for younger participants (about 750 ms) than for older participants (almost 2500 ms.). A 2×3 repeated measures ANOVA with age as a between participants factor and log-transformed reaction times on steps 1, 2 and 3 as a within participants factor yielded significant effects of age ($F(1,47) = 89.45$, $p < 0.001$) and step number ($F(2,46) = 75.98$, $p < 0.001$) and a significant interaction ($F(2,46) = 6.05$, $p = 0.005$). As in experiment 1, on log-transformed reaction times, the advantage for younger participants becomes larger further down the menu structure. A more stringent test now would be to assess whether the interaction remains significant while actually controlling for differences in movement speed. (If the interaction remains significant when controlling for differences in movement speed this also rules out differences in expertise with the testing apparatus as a cause for the findings.) Therefore, a 2×3 repeated measures analysis of covariance was performed using age as a between participants factor, log-transformed latencies on steps 1, 2 and 3 on the information retrieval task as a within-participants factor and the log-transformed latency on the movement task as a covariate. The age×step number interaction approached significance for this comparison ($F(2,45) = 2.69$, $p < 0.08$). The power for this comparison was not very high though (0.50). In an attempt to increase the power for this comparison, the relevant data from experiment 1 and 2 were collapsed. Experiment 1 employed the simple selection task as a measure of movement speed. This task was changed to the movement task for experiment 2 because it correlated highly with the reasoning task. It was thought that this high correlation rendered the set of predictor variables relatively insensitive to detect a shift in the cognitive requirements of the task in the regression analysis.

Table 8. Latencies (secs.) on steps 1, 2 and 3 in the information retrieval task as a function of age (exp. 2). Standard deviations are shown in parentheses.

	Step 1	Step 2	Step 3
Younger	3.10 (0.52)	2.43 (0.46)	2.05 (0.28)
Older	5.43 (2.15)	4.49 (1.45)	4.36 (1.64)

The simple selection task can be used for the purpose of controlling for movement speed in an ANOVA though. Since the simple selection task was administered in experiment 2 as well (to allow for cross-experimental comparison), it is possible to pool the latencies for information retrieval and the simple selection task from both experiments, thereby increasing power. (The information retrieval task did not differ from experiment 1 to 2 except for number of trials and the possibility of repeating incorrect trials.) Using the data from both experiments (80 participants), another 2 (age)×3 (step number) repeated measures ANCOVA (with simple selection as a covariate) was conducted. This analysis revealed significant effects of the covariate ($F(1,78) = 83.95$, $p < 0.0001$), age $F(1,78) = 17.10$, $p < 0.0001$) and a significant interaction between age and step number ($F(2,77) = 4.30$, $p < 0.02$, power = 0.75). Thus, while controlling for simple selection speed, the factor by which older participants are slowed increases with step number.

6.2.2. *Accuracy data*: Accuracy data for experiment 2 are depicted in table 9. A multivariate analysis on these combined measures showed a significant effect of age ($F(6,41) = 8.89$, $p < 0.001$). Univariate analyses revealed significant effects for spatial ability ($F(1,46) = 30.08$, $p < 0.001$) and spatial memory ($F(1,46) = 20.13$, $p < 0.001$) only. The effect for letters recalled was marginally significant in a one-tailed t-test ($T(47) = 1.85$, $p < 0.05$).

6.2.3. *Regression*: Correlation matrices for the step numbers and the dependent measures are depicted in table 10. As in experiment 1, the correlation between step 1 and 2 is larger than between step 2 and 3. Different from experiment 1 though, the correlation between step 2 and step 3 is smaller than that between step 1 and 2.

A step-wise regression analysis was performed to predict latencies on the information retrieval task. The predictors entered were: movement time, latency on reasoning with and without preload, number of letters recalled, spatial ability score and spatial memory score. Spatial ability score and spatial memory score were logit-transformed, as they are proportional in nature.

Table 9. Accuracy scores (proportion correct) for information retrieval, reasoning tasks, letters recalled and spatial measures (exp. 2). Standard deviations are shown in parentheses.

	Information retrieval	Reasoning no preload	Reasoning preload	Letters recalled	Spatial memory	Spatial ability
Younger	0.96 (0.05)	0.89 (0.14)	0.89 (0.18)	0.85 (0.10)	0.85 (0.18)	0.79 (0.18)
Older	0.92 (0.12)	0.85 (0.19)	0.82 (0.18)	0.77 (0.17)	0.58 (0.23)	0.42 (0.26)

The resulting regression model for the entire task is described by the following equation. Weights reported in the regression equations are standardized weights or betas.

$$\text{Log(RT)}_{menu} = 0.62\ \text{M} + 0.22\ \text{RP} - 0.21\ \text{SA}$$

where M = Movement speed
RP = Reasoning time with preload
SA = Spatial Ability score

This equation explains 82% of the variance on the log-transformed information retrieval task. Inspection of the betas shows that movement speed is the most important variable. Spatial ability and reasoning with preload are about equally important; both betas are about one third of that for movement speed. These two variables explain about 6% of the variance over that explained by movement speed alone.

In order to assess whether slowing factors on the different steps are explained by different variables, three additional stepwise regression analyses were run to predict the latencies on these different steps. All above-mentioned variables were included in the analyses. These analyses yielded the following models:

$$\text{Log(RT)}_{Step1} = 0.68\ \text{M} + 0.27\ \text{RP}, \quad R^2 = 0.73$$

$$\text{Log(RT)}_{Step2} = 0.74\ \text{M} - 0.21\ \text{SM}, \quad R^2 = 0.74$$

$$\text{Log(RT)}_{Step3} = 0.53\ \text{M} - 0.19\ \text{SA} - 0.16\ \text{SM} + 0.15\ \text{RP} - 0.13\ \text{L}, \quad R^2 = 0.84$$

where L = number of letters recalled,
SM = Spatial Memory.

All three equations explain a substantial proportion of the variance. All collinearity statistics and intercept sizes are within the acceptable range (Fox 1993). None of the intercepts in the non-standardized equations contribute significantly to the regression equations.

Latencies on the first step are explained by movement times and reasoning times. Processes involved in this task include encoding of the question, extracting category membership and moving to the correct button. The first two of these would seem to draw on working memory or reasoning resources. Steps two and three of the menu involve recognition or retrieval of the attribute that is sought. On step two reasoning time does not explain any variance, but spatial memory does. Finally, on step three, spatial and memory measures as well as reasoning latency enter the equation. The beta for movement time remains the highest, but the combined beta weights of the other measures exceed that of movement speed. The other measures explain 11% of the variance over the amount explained by movement speed alone.

6.3. *Discussion*

The modification of the simple selection task to avoid collinearity was successful and, thus, allowed for a test of the effect of memory load. The increase in preload resulted in a significant age difference in number of letters recalled. Results of both experiments showed older participants to be delayed on the information retrieval task when controlling for their latencies on the movement task. The pattern of latencies on the consecutive steps in the menu structure was very similar to that in experiment 1 and, thus, lends credence to the fitted model. As a comparison between the two experiments, latencies of older participants were divided by the latencies of younger participants. Table 11 shows a comparison of the slowing factor for the latencies that were measured in both experiments.

Table 10. Correlation matrices for exp. 2.

Table 10a. steps on the menu structure.

	Step 2	Step 3
Step 1	0.90	0.84
Step 2	–	0.82
Step 3	–	–

Table 10b. predictor variables.

	Reasoning preload	Reasoning no preload	Spatial ability	Spatial memory	Letters recalled
Movement task	0.53	0.62	0.66	0.45	0.30
Reasoning preload	–	0.88	0.35	0.41	0.25
Reasoning no preload	–	–	0.44	0.47	0.25
Spatial ability	–	–	–	0.47	0.34
Spatial memory	–	–	–	–	0.21

Table 11 shows that the slowing factors seem remarkably constant across experiments, regardless of differences in absolute latencies. The younger–older difference for absolute latencies on the information retrieval task, for instance, is about 9 seconds for experiment 1 and 6.5 seconds for experiment 2. The difference in slowing factor is, however, only 0.05. This relative constancy of slowing factors lends support for the practice of fitting multiplicative rather than additive models in cognitive ageing research using latency data.

7. General discussion

The studies described in this paper aimed to answer three questions. The first question was whether older participants are delayed on information retrieval tasks relative to a movement task. This was found in both experiments.

The second question was whether the slowing of older participants increases for consecutive selections in the information retrieval tasks. This was true for both experiment 1 and 2. In experiment 2, this effect approached significance when latencies on the movement task were used as a covariate. This effect was significant when the data from experiment 1 and 2 were pooled.

The last question the studies aimed to answer was whether the importance of component abilities changes as a function of task demands. With respect to the entire information retrieval task, the best predictor of latencies turned out to be movement time. This factor alone explained 76% of the log-transformed latencies on the entire information retrieval task. This high proportion of explained variance can be understood given the data in table 11. Simple selection or movement is part of the information retrieval task and the slowing factors for simple selection and movement are slightly smaller than that for information retrieval. However, in contrast to the results of Westerman *et al.* (1995), more complex cognitive variables play a role as well. Though adding reasoning speed and spatial ability to the equation only resulted in a 6% increase in explained variance, beta weights for these two variables were about one third of the weight for movement time. Looking at the effect of the cognitive variables on latencies for the different steps, a shift is apparent from the influence of reasoning to spatial and memory measures. This suggests that participants with low scores on spatial and memory measures will have more difficulty with steps deeper into the structure. Consistent with findings of decreased working memory capacity and spatial abilities, the slowing factor of older participants increases for steps deeper into the structure. This holds true even when controlling for simple selection speed (and thereby for potential differences regarding expertise with the testing apparatus).

Though the effect of letters recalled can be interpreted in terms of increased working memory load, it is not quite clear what the exact role of spatial memory is. Spatial memory is measured by the ability to recall the position of objects on a map. Though this would qualify as a measure of short term memory, it is not clear whether its importance lies in its spatial component or its memory component. This distinction has implications for the optimal depth of a menu structure. The spatial component of spatial memory might reflect the ability to remember the position of the cursor as one moves from one screen to the next. Such an effect would seem to be constant regardless of the depth of the menu. If spatial memory exerts its influence through a memory component, one would expect latencies to increase with increasing depth of the structure. In general, however, the finding that the slowing of older participants is greater for steps deeper into the menu structure would suggest that deep menu structures are less suitable for older users.

Although spatial ability is predictive of overall latencies, it appears to be so only through its prediction of latencies on step 3. As with spatial memory, it is difficult to interpret this result, as it is not clear exactly what is measured by a test of spatial ability. The fact that it predicts latencies on steps deeper into the menu structure only seems consistent with claims that participants with high spatial ability are better at forming a mental representation of the system (Sein and Bostrom 1993). Spatial ability explained variance after the contribution of movement speed was taken into consideration. As movement speed is probably to a large extent dependent on processing speed, this suggests that

Table 11. Ratios of latencies of older participants relative to latencies of younger participants for experiments 1 and 2.

	Simple selection	Information retrieval	Step 1	Step 2	Step 3	Reasoning no preload
Exp. 1	1.67	1.87	1.63	1.93	2.18	1.43
Exp. 2	1.54	1.82	1.75	1.84	2.12	1.60

the factor through which spatial ability exerts its influence is not limited to processing speed, as was suggested by Seagull and Walker (1992).

Though the findings of the regression analyses do indicate a larger role of cognitive factors for steps further into the menu structure, the effect on memory is not as clearcut as might be expected or was hypothesized. The effect of letters recalled only comes in at step 3, and steps one and 2 are influenced by spatial memory and reasoning with preload which also incorporate some issues of memory. Since it is not clear how large the contribution of memory processes for these variables are, it is difficult to directly assess the effects of memory. Another issue which makes this analysis more difficult is the following. Though memory load increases with step number (suggesting longer latencies), a second process runs counter to this expectation. On step 1, the subjects need to store three items in memory (namely animal, attribute and species). With every selection in the task, one of the items is no longer necessary for the following selections. Thus, while the time since encoding increases with step number, the memory set decreases. The general shape of the curve of latencies over step numbers appears consistent with these two opposing process. With step number the latencies decrease, but the magnitude of this decrease becomes less with increasing step number. Apparently, a purely linear effect on memory is too simple an approximation of the task.

Different from the findings of Westerman *et al*., the two age groups did not differ with respect to learning speed. This may be a result of differences in sample, familiarity with the stimuli or number of presentations. The manipulation of the trial-to-trial interval which was supposed to increase familiarity was unsuccessful. This again may have been a result of the relatively small number of presentations and limited depth of the menu structure.

Finally, it might be mentioned that the present experiments may underestimate the role of spatial ability, as participants could not move up in the menu structure. Vicente and Williges (1988) suggest that people with low visual ability may get lost in the menu structure more easily. This will lead to longer latencies. Sein *et al*. (1993) have found that spatial ability was predictive of the speed with which participants formed a mental representation. Not allowing participants to move back and forth in the structure may have diminished the influence of spatial ability on latencies. A comparison of conditions in which participants are either allowed to move back and forth or forward only might shed light on the importance of visual ability for the formation of a mental representation (and thereby also on the question whether older participants are slower in forming a mental representation).

The experiments described in this paper were conducted in order to assess whether cognitive variables other than a measure of movement speed predicted the slowing of older participants on information retrieval tasks. Results showed that, although movement speed was a major predictor of latencies, cognitive factors did explain additional variance. It was also found that the slowing of older participants increases with the consecutive steps in the menu structure. This is consistent with the finding that the importance of cognitive measures other than movement speed increases for the consecutive steps in the menu structure. Taken together, these findings suggest that deep menu structures are less suited for older users. This finding has implications for the way in which options in interactive equipment are structured. As argued in the introduction, hierarchical menu structures are commonly used to organize the various options that equipment offers. As deep menu structures appear less suited for the older user, this suggests that designers aim to keep the number of available options low (thus avoiding the need for deep menu structures) or consider alternative means of structuring the various options.

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