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Web Design that is Friendly to Older Adults
− Effects of Perceptual, Cognitive and Motor Functions and Display Information on Web Navigation Time −

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Abstract— **Older internet users are increasing more and more world widely. The information accessibility standard for Web contents (JIS X 8341-3) had been established. Although many researchers are pursuing the usability of Web site, we cannot design a usable Web site only by improving Web pages. One of the reasons is inferred that we didn't consider perceptual, cognitive, and motor functions especially of older adults in the design of Web pages. The aim of this study was to propose a method to evaluate perceptual, cognitive, and motor ability and to explore the effect of perceptual, cognitive and motor abilities, and display information on Web navigation. We proposed a method to calculate display information on the basis of number of links. It was explored how display information, age, and the test score of perceptual, cognitive, and motor abilities influenced Web navigation time. This effect was examined using a multiple regression analysis. Display information influenced Web navigation performance for both young and older adults. The more the quantity of display information was, the longer the Web navigation time was. In addition to this tendency, the depth of display layer was found to affect the Web navigation time especially for older adults. We found that the perceptual, cognitive, and motor abilities of older adults, in particular, the spatial memory, spatial rotation ability, and mouse operation ability, led to longer Web navigation time. These results implies the necessity of designing Web site for older adults that considers the decline of perceptual, cognitive, and motor ability.**

1. INTRODUCTION

During the past decade, the World Wide Web (WWW) has become one of the most important Internet applications. Currently, older adults constitute the fastest growing WWW user groups. Although older adults are willing to use computers via the WWW pages, older adults experience more frequent problems than young adults when using the WWW. The problems include difficulty in finding broken links, viewing smaller texts and graphics, and retrieving new information.

There are many reports suggesting that older adults exhibit deficits in various cognitive motor tasks (Goggin et al. 1989, Goggin and Stelmach 1990, Stelmach and Nahom 1993). Spatial abilities, that is, the capacity to acquire, manipulate, and use information on Web pages, have been shown to decline with age (Salthouse, 1992), and this might account for the difficulties of older adults when navigating Web pages. Kelly and Charness (1995) showed that spatial abilities may be important for mediating the effects of age on computing skills. Processing speed refers to the ability to acquire, interpret, and respond to information quickly and accurately. Salthouse (2000) pointed out that reductions in processing speed are a common explanation for many age-related deficits in task performance.

Therefore, it is predicted that older adults require more time to complete a navigation task on the WWW. Working memory is defined as the ability to actively manipulate, store, and update information to perform a given task. Browsing Web pages have working memory demands, and require users to carry out several tasks concurrently. Such tasks also involve decision making and problems solving using working memory.

On the basis of such discussion, it is questionable whether most of the current Web pages are universally usable for both young and older populations, as the above mentioned cognitive motor functions are clearly different between young and older populations.

Graham, Laberge, and Scialfa (2004) investigated reaction time, eye movements, and errors during visual search of Web pages to determine age-related difference in performance as a function of link size, link number, link location and clutter. Increased link size improved performance for both young and older groups. Increased clutter and links hampered search behavior, especially for older adults. Parush, Shwarts, Shtub, and Chandra (2005) explored the effects of visual layout factors on performance during visual search of Web pages. Although the age-related differences in performance during visual search was not examined, they found that performance was particularly poor in Web pages with many links and variable display densities. Laberge and Scialfa (2005) investigated the effects of age, subject matter knowledge, working memory, reading abilities, spatial abilities, and processing speed on Web navigation. They found that age was associated with slower search time, and this effect remained significant even after controlling for working memory, processing speed, and spatial abilities. In other words, the search performance of older adults was found to be inferior to that of the young adults due to the declined working memory, processing speed, and spatial abilities. These studies successfully identified the factors that should be taken into account when designing Web pages for older adults.

In most studies on Web site usability that aim at providing older adults with user-friendly design, the participant's age is used to classify participants as young or older. Few studies investigated how perceptual, cognitive, and motor abilities affect Web navigation performance.

2. METHOD

2.1 Participants

Twenty participants took part in the experiment. Ten were male adults aged from 65 to 76 years (average: 69.6 years). Seven of the older adults had an experience of Web navigation with an average of 4.3 years (3-8 years). Ten were male undergraduate students aged from 21 to 24 years (average: 22.3 years). All of the young adults had an experience of Web navigation with an average of 6.5 years

(6-7 years). The visual acuity of the participants in both young and older groups was matched and more than 10/20. They had no orthopaedic or neurological diseases.

2.2 Apparatus

The stimuli were presented using a personal computer (DELL, Inspiration1300) with an 15-inch CRT. Web pages (site maps) were created using HTML editor of Home Page Builder (Ver.9, Japan IBM). Six types of site maps were prepared.

2.3 Experiment1

First, the perceptual, cognitive, and motor abilities necessary for carrying out Web navigation was classified to develop a test set for measuring perceptual, cognitive, and motor abilities when navigating Web sites.

2.3.1 Classification of perceptual, cognitive, and motor abilities

Spatial ability refers to the capacity to acquire, manipulate, and use information presented in two- and three-dimensional space. Spatial ability may help us navigate Web site by aiding in the creation of cognitive maps, that is, the internal representations of the physical environment such as Web sites that are used for navigation. More concretely, for navigating Web sites, the arrangement of links, and the structure of Web sites must be recognized and understood. Such abilities were classified into three abilities 1)-3) below. Moreover, motor ability of hand and finger is necessary to navigate Web sites using an input device such as a mouse or a keyboard. Therefore, the ability 4) below was also added to the test contents.

1) Ability to remember correctly the contents of Web pages

It is expected that the number of lost in navigation can be reduced by remembering previously accessed links and the information on previously viewed Web pages. Therefore, spatial and verbal working memories are necessary for navigating Web pages. Better working memory would support more effective cognitive Web maps, allowing spatial information to be stored, processed quickly, and understood.

2) Ability to perceive the structure of Web pages

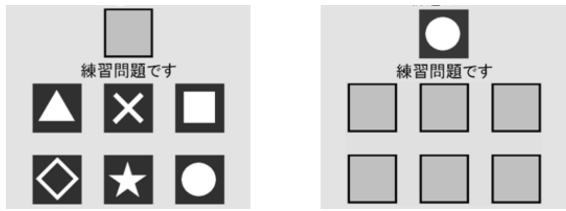
Navigating Web sites properly also requires the ability to acquire, interpret, and respond quickly and accurately to displayed information. Such an ability might be represented by processing speed, that is, an ability to search for information quickly and accurately.

3) Ability to understand the structure and contents of Web page

As well as remembering the contents and perceiving the structure in Web navigation, more cognitively higher ability might be necessary to understand the structure and the contents of Web sites. Such a spatial ability help us navigating Web sites effectively, and eventually constitute Web site's cognitive map.

4) Motor ability of hand and finger

Motor ability of hand and finger to effectively use an input device such as a mouse or a keyboard is necessary to comfortably navigate Web sites.



(a) (b)

Figure 1 Visuospatial working memory test.
(a) Presentation of the memory cards.
(b) An example of task.

Figure 2 Verbal working memory test (reading span test).

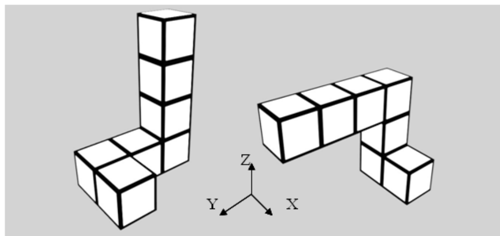


Figure 3 Spatial ability test (mental rotation test).

2.3.2 Task (Contents of perceptual, cognitive, and motor tests)

According to Laberg et al. (2005), the following test items had been developed. Althugh Laberg et al.(2005) did not point out the necessity of motor ability of hand and finger, this ability was added to the test items based on the rationale mentioned above.

A)Language memory test (Ability 1))

Reading Span Test (RST) developed by Daneman and Carpenter (1980) was used to evaluate an ability to remember correctly the contents of Web pages. This is a test for measuring verbal working memory. The outline of this test is shown in Figure 1.

B)Spatial memory test(Ability 1))

Visuospatial working memory test shown in Figure 2 was also used to evaluate an ability to remember correctly the contents of Web pages.

C)Spatial understanding test(Ability 3))

Memtal rotation test (See Figure 3) proposed by Shepard(1971) was used to evaluate an ability to understand the structure and contents of Web page.

D)Spatial search test(ability) (Ability 2))

A spatial search task shown in Figure 4 was used to evaluate spatial search task.

E)Motor ability test of hand and arm (Ability 4))

In order to measure motor ability of hand and arm, a pointing task by a mouse was used (See Figure 5). The relation between index of difficulty and pointing time was modelled using Fitts' law (Murata, 1996). Fitts' model can

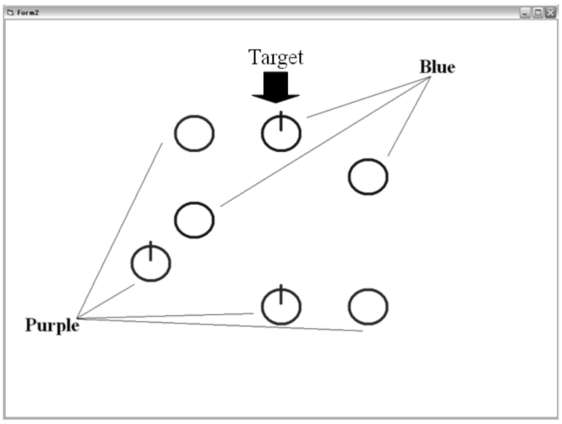


Figure 4 Visual search ability test.

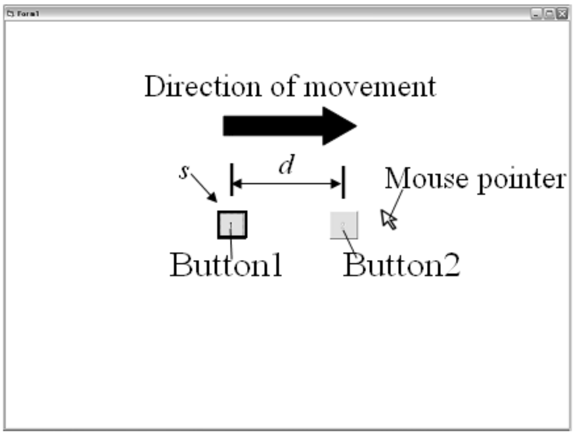


Figure 5 Mouse operation ability test (*s*:50 x 50pix, *d*:200pix, Direction of movement：from left to right).

be described using movement distance *d* and target size *s* as follows.

$$pt=a+b\log_2(d/s+0.5) \quad (1)$$

where *pt* is pointing time, and parameters *a* and *b* are empirically determined by model fitting to Eq.(1).

2.3.3 Procedure

The five ability tests above were carried out in the following order: D), B), A), C), and E). The interval between ability tests ranged from 5 to 10 min. This was to reduce participants' fatigue during the test period. Before performing each test, the participant was allowed to make a practice.

A)Language memory test

Participants were required to remember the underlined word. The experimenter provided a participant with two, three, or four sentences. The score in this test was obtained as follows. Four problems were prepared for each sentence condition. The number of correct answers for i=2, 3, 4 is denoted by a_i. The basic score i_o was regarded as follows.

$$i_0=\max_{i=2,3,4}\{\, i \mid a_i = N\} \quad (2)$$

When there exists no condition where all problems were correctly answered, i_0 was set to 1. The additional score i' was obtained using a condition of i_{0+1} sentences as follows.

$$i'=a_{i0+1}/N \quad (3)$$

When i_0 equalled i_{max}, i' was set to 0. Thus, total score P was obtained as follows.

$$P=i_0+i' \quad (4)$$

B) Spatial memory test

As shown in Figure 2, six different figures were presented. The participant was given 10 s to remember this. After 2 s from the end of presentation of the stimulus, a stimulus in Figure 2(b) was presented to the participant. The participant was required to click by a mouse the position where the stimulus was presented. Twelve problems were presented to each participant. The percentage correct was used as a performance measure.

C) Spatial understanding test

The participant was required to answer whether two figures such as shown in Figure 3 are the same or not. The mental rotation angles were 45, 90, 135, and 180 degrees. The rotation axis was one of X-, Y-, and Z-axis. The time to answer the question and whether the answer was correct or not were measured. A total of 12 problems were presented to the participant.

D) Spatial search test

The colour and the figure were combined to create a stimulus pattern (See Figure 4). The participant was required to search for the target stimulus. The target stimulus corresponded to a figure with only one pattern. If a target stimulus existed, the participant was required to point to it. If a target stimulus did not exist, the participant answered that no target stimulus existed. As soon as the answer was found, the participant was required to press a space bar. For each display, either six or seven stimuli were arranged. The mean of response time was calculated from correct trials.

E) Motor ability test of hand and arm

The moving distances *d* were 200, 400, and 600 pixels. The targets were square with 30 pixel, 40 pixel, and 50 pixel length. The target appeared one of the following eight directions: right, left, upper, lower, upper right, lower right, upper left, and lower left. A total of 72 combinations existed, and five pointing trials were carried out for each combination. Based on the measured data, Fitts' modelling (See Eq.(1)) was carried out to obtain the slope *b* and the intercept *a.* The smaller value of a means that the mouse operation is faster, and the smaller *b* shows that the effects of *s* and *d* on the pointing time is smaller.

2.4 Experiment2

In this study, the amount of information was derived on the basis of the number of links in the Web site. Three types of Web sites were prepared to investigate how amount of information and the number of layers in the Web site affected the Web navigation performance.

2.4.1 Amount of information

The probability of occurrence of event E is defined by $P(E)$. The amount of information $I(E)$ is given by

$$I(E)=-\log_2 P(E) \quad (5)$$

If the number of links per Web page is assumed to be n, $P(E)$ and $I(E)$ can be defined as follows.

$$P(E)=1/n \quad (6)$$
$$I(E)=-\log_2 n \quad (7)$$

Let the minimum path from the start page to the page where navigation target exist to be m. The number of links at page j is defined by n_j. The total amount of information is given by

$$H=\sum \log_2 n_j \quad (8)$$

where $\sum$ represents summation from j=1 to j=m-1.

Figure 6 Web browser and Web site used in the experiment (depth of display layer：deep).

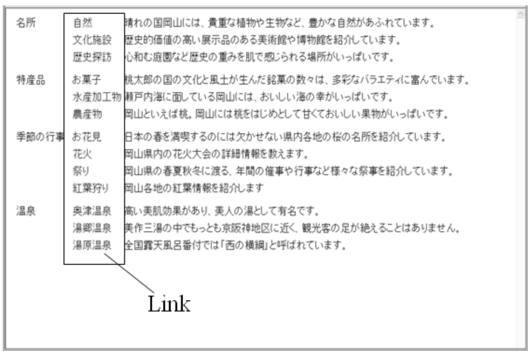


Figure 7 Web site used in the experiment (depth of display layer: moderate).

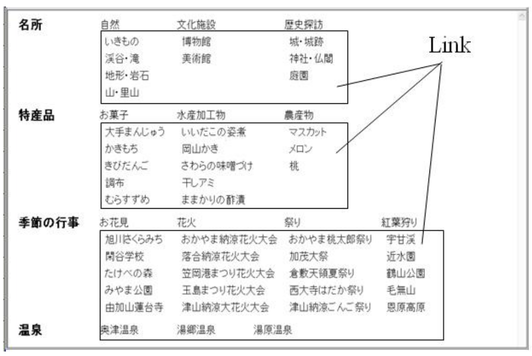


Figure 8 Web site used in the experiment (depth of display layer: shallow).

2.4.2 Layered structure of Web pages

The same contents were represented by Web sites with different number of layers to explore how the number of layers affected the Web navigation performance.

2.4.3 Task

Web site on sightseeing information in Okayama prefecture was prepared. Three types of Web sites with different number of layers were prepared. It must be noted that these site included the same contents. While a Web site with shallow layer includes more links per page, a Web site with deep layer includes few links per page. The difference of the number of links at a top page between shallow and deep layers becomes outstanding. Three types of Web sites were as follows. Deep layered Web site included 3-5 layers and had four links at a top page. Medium layered Web site included 2-3 layers and had 13 links at a top page. Shallow layered Web site included 2-3 layers and had 45 links at a top page. Although the numbers of layers of medium and shallow Web sites are the same, these two Web sites differ in that the number of three layers for the medium Web site is more than that for the shallow Web site. The percentage of three layered navigation for the medium and the shallow Web sites are 77% and 20%, respectively.

The deep, medium, and shallow Web sites are demonstrated in Figures 6, 7, and 8, respectively.

2.4.4 Design and Procedure

The age (young and older adults) was a between-subject factor. The layer (three levels: deep, medium, and shallow) and the amount of information (three levels: large, medium, and small) were within-subject factors. The experimental task was a search task in which the participants were required to search for the pre-specified target item included in each Web site.

Prior to their involvement in the experiment, participants signed an informed consent document. The participant was asked to adjust his seat so that the task could be comfortably performed.

Before the experiment began, participants were given instructions for the Web navigation task and allowed a few practice trials. Six navigation trials were carried out for each layered condition. The order of performance of six trials for each layered condition was randomized across participants.

2.4.5 Analysis method of data

The measured navigation time was classified according to the layer of Web page and the total amount of information. The Web navigation time was approximately divided into cognitive time and mouse operation time as follows. On the basis of the coordination of mouse pointer when clicking, and the result of motor ability test of hand and arm, the mouse operation time was predicted. The subtraction of the predicted mouse operation time from the navigation time corresponds to the cognitive time per trial.

3. RESULTS

3.1 Experiment1

Test A)

In Figure 9, the mean score of verbal working memory test is plotted as a function of age. First, the test of equal variance was carried out using an F test. As an assumption on equal variance was not statistically rejected, a test of difference of mean value was carried out using a t test. As a result, a significant difference of verbal working memory score between young and older adults was detected ($t(18)=4.7$, $p<0.01$).

Test B)

In Figure 10, the mean percentage correct of visuospatial working memory test is shown as a function of age. After confirming the equal variance by an *F* test (an assumption of equal variance was not rejected.), test of difference of mean value was carried out using a *t* test. A significant difference of the mean score between young and older adults was clarified ($t(18)=3.1$, $p<0.01$).

Test C)

In Figure 11, the mean percentage correct of spatial ability test (mental rotation test) is shown as a function of age. After confirming the equal variance by an *F* test (an assumption of equal variance was not rejected.), test of difference of mean value was carried out using a *t* test. A significant difference of the mean percentage correct between young and older adults was clarified ($t(18)=2.9$, $p<0.05$).

A similar significant difference of the mean reaction time between young and older adults was clarified ($t(18)=2.2$, $p<0.05$). The mean reaction times of young and older adults were 10.5 s (SD: 3.3 s) and 14.1 s (SD: 4.0 s), respectively.

Test D)

In Figure 12, the mean search time is plotted as a function of age. As well as the statistical test in Tests A-C, a significant difference of mean search time was detected between young and older adults ($t(18)=4.4$, $p<0.01$). A similar statistical analysis was carried out for the percentage correct. As a result of checking he equal variance by an *F* test, a significant difference was detected ($F(9, 9)=10.2$, $p<0.01$). Therefore, Welch’s t test was carried out for the percentage correct. No significant difference of the mean percentage correct between young and older adults was clarified. The percentage correct of young and older adults was 92.5% (SD: 10.0%) and 96.3% (SD: 3.07%), respectively.

Test E)

In Figure 13, the results of Fitts’ modeling are compared between young and older adults. For each direction of movement, similar statistical analysis were carried out on the slope *b* and the intercept *a*. The results are summarized in Table 1.

3.2 Experiment2

The amount of information for each navigation task was calculated to classify it into “small”, “medium”, and “large” information groups. The navigation tasks with total information ranging from 3.58 to 3.70 bit (average: 3.6 bit) were classified as “small” information group. The navigation task with total information from 5.49 to 7.02 bit (average: 6.1 bit) corresponded to “medium” information group. The navigation task, total information of which ranged from 5.49 to 7.02 bit (average: 7.7 bit), corresponded to “large” information group. Thus, the relation between the amount of information and the navigation time was obtained (See Figure 14). The total amount of information affected the Web navigation time for both young and older adults.

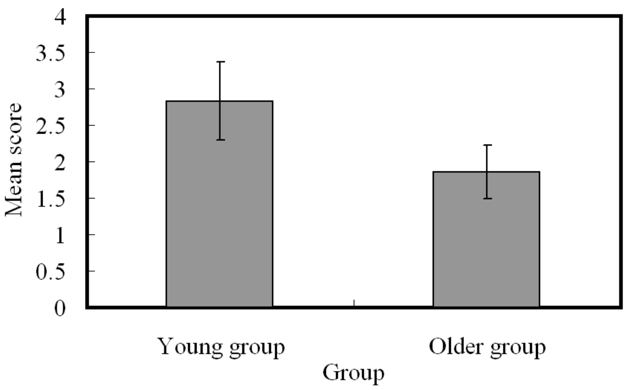


Figure 9 Mean score of verbal working memory test for each group.

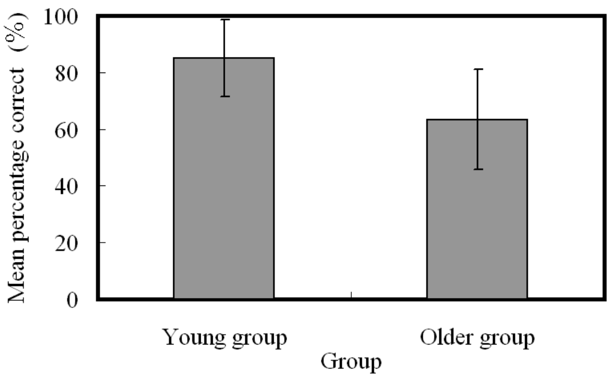


Figure 10 Mean percentage correct of visuospatial working memory test for each group.

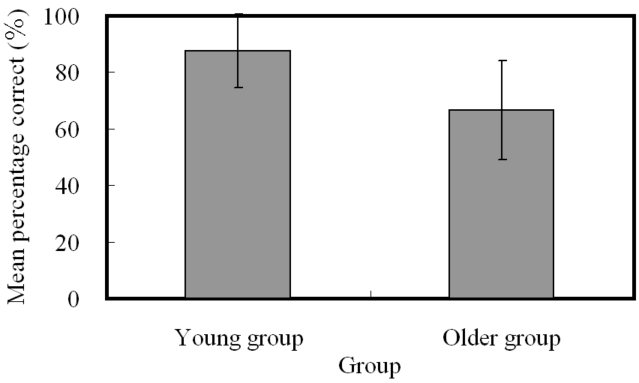


Figure 11 Mean percentage of correct spatial ability test (mental rotation test) for each group.

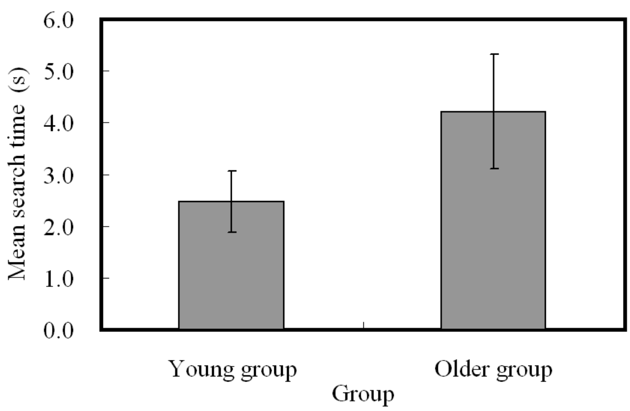


Figure 12 Mean search time for each group.

Table 1 Result of *F* test and *t* test conducted on *a* and *b* for each direction of movement.

Direction of movement	*a*		*b*	
	F test	*t* test	*F* test	*t* test
from left to right	$F(9,9)=9.5^{**}$	$t(10)=6.7^{***}$	$F(9,9)=3.0$ n.s.	$t(18)=2.3^{*}$
from right to left	$F(9,9)=31.7^{***}$	$t(9)=5.6^{***}$	$F(9,9)=23.9^{***}$	$t(9)=3.5^{**}$
from top to bottom	$F(9,9)=7.6^{**}$	$t(11)=5.2^{***}$	$F(9,9)=9.3^{**}$	$t(10)=2.5^{*}$
from bottom to top	$F(9,9)=22.5^{***}$	$t(9)=5.2^{***}$	$F(9,9)=14.9^{***}$	$t(10)=3.1^{*}$
from bottom left to top right	$F(9,9)=13.1^{***}$	$t(10)=6.4^{***}$	$F(9,9)=6.8^{**}$	$t(11)=2.9^{*}$
from top right to bottom left	$F(9,9)=17.7^{***}$	$t(10)=4.9^{***}$	$F(9,9)=9.7^{**}$	$t(10)=1.6$ n.s.
from bottom right to top left	$F(9,9)=31.4^{***}$	$t(9)=5.1^{***}$	$F(9,9)=11.9^{**}$	$t(10)=2.7^{*}$
from top left to bottom right	$F(9,9)=23.9^{***}$	$t(9)=5.5^{***}$	$F(9,9)=8.7^{**}$	$t(11)=2.2^{*}$

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$, n.s.: not significant

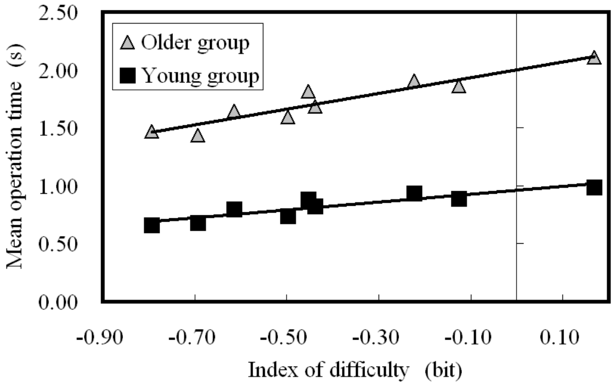


Figure 13 Relationship between index of difficulty and operation time for each group.

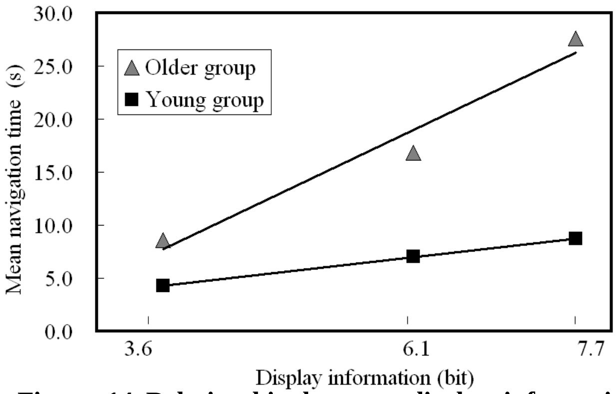


Figure 14 Relationship between display information and mean navigation time for each group.

The difference of Web navigation time between young and older adults increased with the increase of total amount of information, which means that older adults are more strongly affected by total amount of information than young adults.

4. DISCUSSION

4.1 Experiment1- Perceptual, cognitive, and motor ability-

In A) language memory test and B) spatial memory test, the older adults were significantly inferior to the young adults. As pointed out by Goggin et al. (1989), Goggin and Stelmach (1990), and Stelmach and Nahom (1993), it was confirmed that older adults' working memory degraded as compared with their young counterparts. In C)spatial understanding test, not only spatial memory ability (Test B)) but also the ability on spatial image was confirmed to degrade with age. In D) spatial search test, although the reaction time of older adults was longer than that of young adults, the percentage correct did not differ significantly between young and older adults. This must be due to the fact that few components of working memory were include in D) spatial search test. In E) motor ability test of hand and arm, Older adults tended to be affected more strongly by movement distance *d* and target size *s* than young adults.

4.2 Experiment2- Web navigation -

As shown in Figure 14, the difference of mean navigation time between young and older adults increased with the increase of total amount of information in Web site. The differences of mean navigation time between young and older adults at the "small", "medium", and "large" amount of total information were 4.3 s, 9.8 s, and 18.9 s, respectively. Older adults tended to be affected more remarkably by the total amount of information. This indicates that the total amount of information in Web sites should be as small as possible so that older adults can navigate more effectively and comfortably. However, due to many limitations related to the characteristics of Web pages, it is not so easy to keep the amount of information per Web page small.

Even if the total amount of information is the same, such a problem might be mitigated by controlling the number of layers. The effect of number of layers in Web site structure on the navigation time would be discussed. As shown in Figure 15, the shallow layer tended to lead to shorter navigation time as compared with the deep layered Web structure. This is indicative of the possibility that older adults would benefit from the shallow structured Web sites. In such a Web site, it is also expected that older adults are not easily get lost in the Web navigation.

In Figure 16, the relationship between display information (amount of information) and mean navigation, cognitive (thinking) and mouse operation time is depicted for each age group. Mouse operation time was not affected by the amount of information or the number of layers.

Using a multiple regression model, it was explored how the number of layers, the total amount of information, and perceptual, cognitive, and motor abilities affect the navigation time. In Table 2, the correlation matrix for eight dependent variables is summarized. The display information (total amount of information), the score of verbal working memory test, the percentage correct of spatial ability test, the mean time of spatial ability test, the mean search time, the slope *b* and the intercept *a* were entered as independent variables into the multiple regression model. It must be

Table 2 Correlation matrix of each independent variable.

variable	1	2	3	4	5	6	7	8
1.Display information	—							
2.Score of verbal working memory test	0.02	—						
3.Percentage correct of visuospatial working memory test	0.02	0.63	—					
4.Percentage correct of spatial ability test	0.004	0.34	0.43	—				
5.Mean time of spatial ability test	-0.01	0.35	-0.52	-0.60	—			
6.Mean search time	0.01	-0.62	-0.71	-0.79	0.63	—		
7.Slope(mouse operation time)	0.01	-0.54	-0.13	0.44	-0.48	0.53	—	
8.Intercept(mouse operation time)	0.003	-0.70	-0.40	-0.62	0.66	0.74	0.91	—

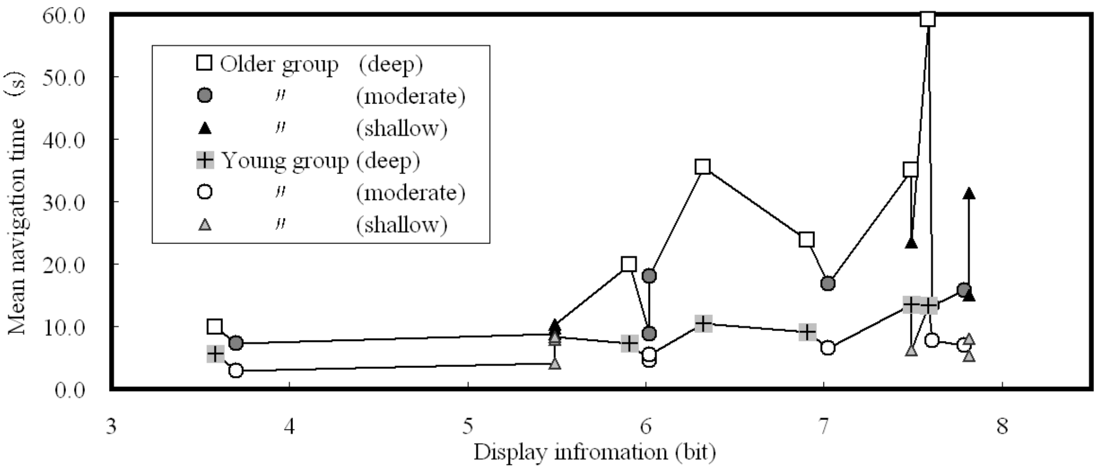
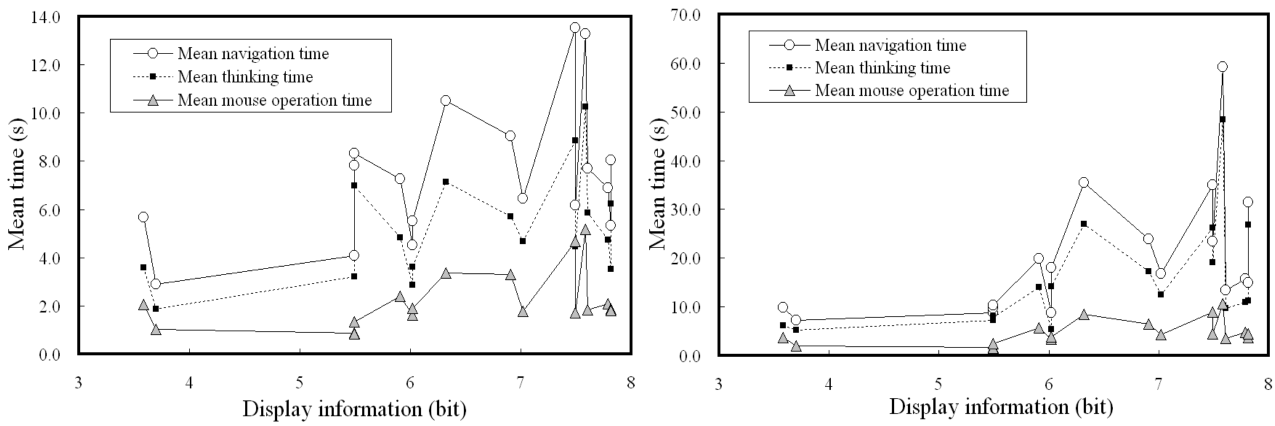


Figure 15 Relationship between display information, depth of display layer and mean navigation time for each group.



(a) **(b)**

Figure 16 Relationship between display information, depth of display layer and mean navigation, thinking and mouse operation time for each group. (a)Young group, (b)Older Group.

noted that each independent variable was standardized to unify their dimension. The following two result of modeling were obtained.

$$Y=4.2X_1-3.9X_2-2.7X_3+4.9X_4+13.9 \quad (R^2=0.51) \qquad (9)$$

where

X_1: total amount of information
X_2: spatial working memory
X_3: spatial understanding
X_4: motor ability of hand and finger

$$Y=4.2X_1-2.7X_2-4.1X_3+3.3X_4+13.9 \quad (R^2=0.49) \qquad (10)$$

where

X_1: total amount of information
X_2: verbal working memory
X_3: spatial understanding
X_4: motor ability of hand and finger

The modeling by Eq.(9) is plotted in Figure 17. These results show that especially abilities B)Spatial memory test(Ability 1: ability to remember correctly the contents of Web pages)) and D)Spatial search test (Ability 2: ability to perceive the

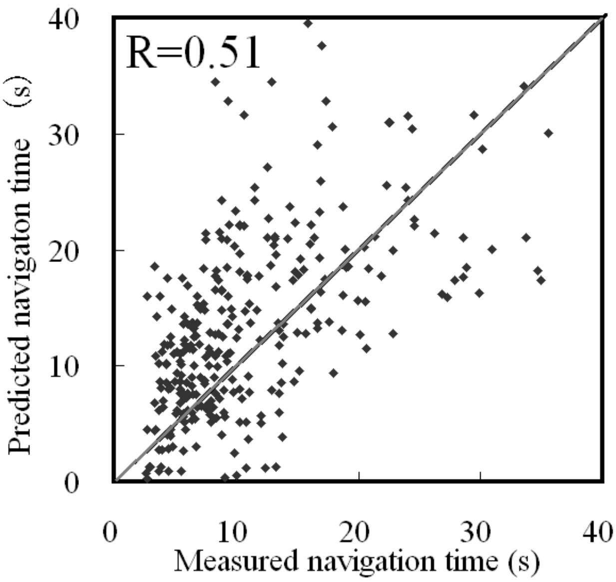


Figure 17 Results of multiple regression analysis. Measured vs predicted navigation time.

structure of Web pages)) as well as total amount of information are more influential to account for the variation of Web navigation time.

On the basis of the discussion above, the Web design friendly even for older adults can be proposed as follows. The spatial working memory, the ability to perceive the structure of Web sites, and the motor ability of hand and finger of older adults are inferior to those of young adults. These abilities were also found to have effects on the Web navigation time. To compensate for the degradation of these abilities, the shallow layered structure of Web sites are recommended especially for older adults.

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