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Effectiveness of Eye-Gaze Input System -Identification of Conditions that Assures High Pointing Accuracy and Movement Directional Effect-

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Abstract— **The condition under which high accuracy is assured when using an eye-gaze input system was identified. It was also investigated how direction of eye movement affected the performance of an eye-gaze input system. Here, age, the arrangement of targets (vertical and horizontal), the size of a target, and the distance between adjacent rectangles were selected as experimental factors. The difference of pointing velocity between a mouse and an eye-gaze input system was larger for older adults than for young adults. Thus, an eye-gaze input system was found to be effective especially for older adults. An eye-gaze input system might compensate for the declined motor functions of older adults. The pointing accuracy of an eye-gaze input system was higher in horizontal arrangement than in vertical arrangement. The distance between targets of more than 20 pixels was found to be desirable for both vertical and horizontal arrangements. For both the vertical and horizontal arrangements, the target size of more than 40pixels led to higher accuracy and faster pointing time for both young and older adults. For both age groups, it tended that the pointing time for the lower direction was longer than that for other directions.**

1. Introduction

Older people present an increasingly large portion of the population and are likely to be active users of IT. Issues surrounding IT and aging are, therefore, of much interest to not only researchers but also practitioner within the domain of human-computer interaction (HCI). Therefore, the development of an input device that is friendly to older adults and leads to higher performance is essential.

There are many reports suggesting that older adults exhibit deficits in various cognitive-motor tasks (Goggin *et al.* [1], Goggin and Stelmach [2]). Spatial abilities, that is, the capacity to acquire, manipulate, and use information on Web pages, have been shown to decline with age (Salthouse [3]), and this might account for the difficulties of older adults when navigating Web pages. Kelly and Charness [4] 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 [5] pointed out that reductions in processing speed are a common explanation for many age-related deficits in task performance.

Therefore, it is expected that decreasing motor function in older adults hinders the successful use of input devices such as a mouse and generally leads to a relatively longer pointing time and lower pointing accuracy in comparison with young counterparts.

The possibility of using the movement of users' eye or Electroencephalography (EEG) as a means of input to a computer has been investigated (Fray, White and Hutchinson [6]; Gips, Olivieri and Tece [7]; Goldberger and Schryver [8]; Huchinson, White, Martin, Reicher, and Frey [9]).Methods to use eye movements are mostly based on electrooculography (EOG)(Gipps et al [7]) or an eye tracking system (Goldberger and Schryver [8]; Huchinson, White, Martin, Reicher, and Frey [9]). As well as EOG-based system, an input system based on EEG(Walpow et al [10].) cannot be used to carry out continuous pointing.

The technology for measuring a user's visual line of gaze in real time has been advancing. Appropriate human-computer interaction techniques that incorporate eye movements into a human-computer dialogue has been developed (Jacob [11]-[16], Sibert and Jacob [17]; Murata [18]). These studies have found the advantage of eye-gaze input system. However, few studies except Murata [18] have examined the effectiveness of such systems with older adults. Murata [18] discussed the usability of an eye-gaze input system to aid interactions with computers for older adults. Systematically manipulating experimental conditions such as the movement distance, target size, and direction of movement, an eye-gaze input system was found to lead to faster pointing time as compared with mouse input especially for older adults. However, the condition (such as distance between targets and target size) under which high accuracy is assured when using an eye-gaze input system and how direction of eye movement affected the performance of an eye-gaze input system have nor been discussed systematically. Such an approach would be necessary to promote easy access to computers and/or IT for older adults.

Age, the arrangement of targets (vertical and horizontal), the size of a target, and the distance between adjacent targets were selected as experimental factors. The condition of distance between adjacent rectangles and target size under which high accuracy is assured when using an eye-gaze input system was identified. It was also investigated how direction of eye movement affected the performance of an eye-gaze input system.

2. Method

2.1 Participants

Sixteen participants took part in the experiment. Ten were male adults aged from 65 to 76 years (average: 68.9 years). All of the older adults had an experience of using a personal computer with an average of 9.9 years (1-21 years). Six were male undergraduate students aged from 21 to 23 years (average: 21.8 years). All of the young adults had an experience of personal computer with an average of 5.5 years (6-7 years). The visual acuity of the participants in both young and older groups was matched and more than 20/20. They had no orthopaedic or neurological diseases.

2.2 Apparatus

An eye-tracking device (EMR-VOXER, Nac Image Technology) was used to measure eye movements characteristics during the search task. This apparatus enables us to determine eye movements and fixation by measuring the reflection of low-level infrared light (800 nm), and also admits the head movements within a predetermined range.

The eye-tracker was connected with a personal computer (HP, DX5150MT) with an 15-inch (303mm x 231mm) CRT. Another personal computer was also connected to the eye-tracker via a RS232C port to develop an eye-gaze input system. The line of gaze, via a Rs232C port, is output to this computer with a sampling frequency of 60Hz. The illumination on the keyboard of a personal was about 175lx, and the mean brightness of 5 points (four edges and a center) on CRT was 108cd/m^2.

2.3 Experiment1 -Identification of conditions with higher accuracy and faster movement-Task -

The vertical and horizontal arrangements of targets are shown in Figures 1 and 2, respectively. Participants were required to point at a predetermined target using an eye-gaze input system. Participants fixated on a center circle that had a cursor overlapping it (See Figures 1 and 2). After participants fixated within the circle for about 1 s, a target was filled with red. Immediately after the target was presented, participants moved the cursor to the target by gazing at the target. Participants moved the cursor by turning their eyes on the target. During this process, the cursor moved like a mouse cursor. As a control condition, a similar task was carried out using a mouse.

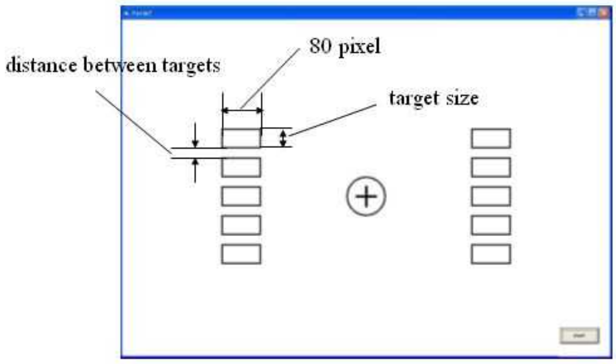

Figure.1 Vertical arrangement of targets

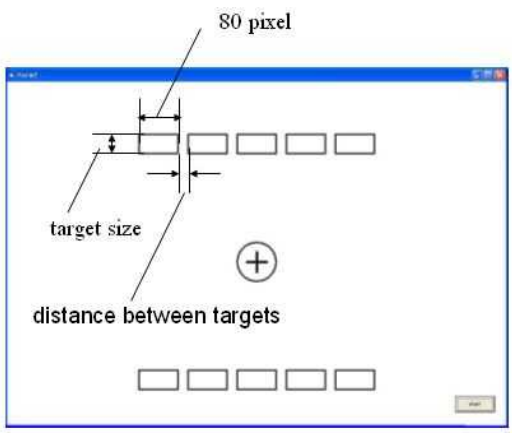

Figure.2 Horizontal arrangement of targets

2.3.1 Design and Procedure

The age (young and older adults) was a between-subject factor. The rectangle size *s* (four levels: 10, 20, 30, and 40 pixels) and the distance between rectangles *d*(four levels: 10, 15, 20, 30 pixels) were within-subject factors. A target was a rectangular with longer side length of 80 pixels. Here, the target size means shorter side length. As shown in Figures 1 and 2, the number of targets was fixed to 10. In the vertical arrangement, five rectangles were arranged to either left or right (Figure 1). In the horizontal arrangement, five rectangles were arranged to either upper or lower (Figure 2). The viewing distance was about 50cm.

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 pointing task and allowed a few practice trials. For each arrangement condition, the combination of distance between targets and target size (16 conditions) was repeated five times. In short, for each arrangement condition, a total of 80 pointing trials were performed. This corresponded one session. The order performance of 80 pointing trials was randomized across the participants.

For each arrangement condition, a total of three sessions were performed. The order of six sessions was randomized across the participants.

The termination of pointing task using an eye-gaze input system was determined as follows. When the sampled coordinate of line of eye gaze stayed within the allowanced target ten times in a row, we regarded this as the termination of pointing.

As a control condition, a similar task using a mouse was carried out according to a similar procedure.

The performance measures were the pointing accuracy and the movement velocity. The pointing accuracy was calculated as the percentage of correct pointing for each combination of movement distance and distance between rectangles.

2.4 Experiment2 -Effect of movement direction -

2.4.1 Task

Murata (2006) pointed out the effect of movement direction on pointing time. If these directional effects are systematically identified, this can be used to compensate for the effect. Therefore, in Experiment2, the effect of movement direction was explored. The arrangement of targets is shown in Figure 3. The target size and the movement distance were fixed to 80 x 80 pixels and 250 pixels, respectively. The viewing distance was about 50cm.

2.4.2 Design and Procedure

The age (young and older adults) was a between-subject factor. The movement direction (eight levels: right, left, upper, lower, upper right, lower right, upper left, lower left) was a within-subject factors. One session consisted of pointing each target presented one of eight directions. A total of eight pointing trials were carried out in one session. A total of ten sessions were carried out by each participant. Other procedures were similar to those in Experiment1. Only an eye-gaze input system was used in this experiment.

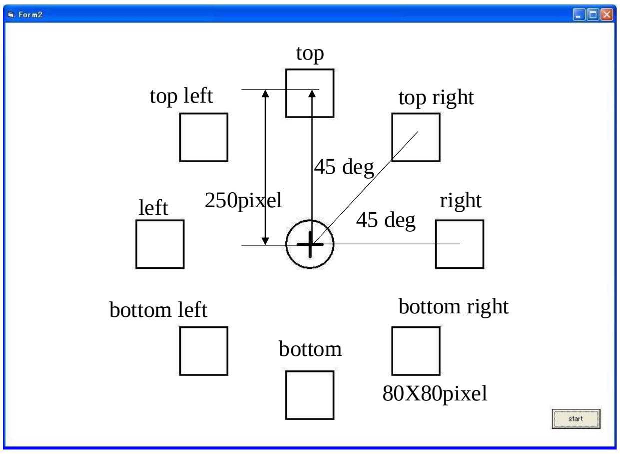

Figure.3 Arrangement of 8 directions

3. RESULTS

3.1 Experiment1 -Identification of conditions with higher accuracy and faster movement-

In Figure 4, the percentage correct is plotted as a function of target size *s*, rectangle arrangement, and age. In Figure 5, the percentage correct is plotted as a function of distance between adjacent rectangles *d*, rectangle arrangement, and age. A three-way (age by rectangle size by distance between rectangles) ANOVA was carried out on the percentage correct for each arrangement. As for the vertical arrangement, significant main effects of rectangle size ($F(3,45)=7.987$, $p<0.01$) and distance between rectangles ($F(3,45)=71.684$, $p<0.01$) were detected. A main effect of age was not detected. Fisher's PLSD revealed significant differences between s=10pixels and other size conditions. A similar analysis revealed significant differences for all combinations of *d*. Concerning the horizontal arrangement, significant main effects of age ($F(1,15)=27.087$, $p<0.01$), rectangle size ($F(3,45)=7.987$, $p<0.01$) and distance between rectangles ($F(3,45)=71.684$, $p<0.01$) were detected. Fisher's PLSD revealed significant differences between s=10pixels and other size conditions. A similar analysis revealed significant differences for all combinations of *d* except the combination of d=15 and 20 pixels.

In Figure 6, the movement velocity is plotted as a function of target size, rectangle arrangement, and age. In Figure 7, the movement velocity is plotted as a function of distance between adjacent rectangles, rectangle arrangement, and age. A three-way (age by rectangle size by distance between rectangles) ANOVA was carried out on the movement velocity for each arrangement. As for the vertical arrangement, significant main effects of age ($F(1,15)=23.218$, $p<0.01$), rectangle size ($F(3,45)=363.118$, $p<0.01$) and distance between rectangles ($F(3,45)=28.768$, $p<0.01$) were detected. Fisher's PLSD revealed significant differences of movement velocity for all combinations of *s*. A similar analysis revealed significant differences of movement velocity for all combinations of *d* except the combination of d=15 and 20 pixels. Concerning the horizontal arrangement, significant main effects of age ($F(1,15)=14.519$, $p<0.01$) and rectangle size ($F(3,45)=449.415$, $p<0.01$) were detected. No significant main effect of *d* detected. Fisher's PLSD revealed significant differences of movement velocity for all combinations of *s*.

In Figure 8, the movement velocity is compared between young and older adults, and between eye-gaze input system and mouse. As for the young adults, the movement velocity when using an eye-gaze input system was faster by 49.9 pixels/s than that when using a mouse. As far as the older adults are concerned, he movement velocity when using an eye-gaze input system was faster by 79.0 pixels/s than that when using a mouse.

In Figure 9, the movement velocity in the vertical arrangement is compared among rectangle sizes, between young and older adults, and between eye-gaze input system and mouse. In Figure 10, the movement velocity in the horizontal arrangement is compared among rectangle sizes, between young and older adults, and between eye-gaze input system and mouse. For both vertical and horizontal directions, when the rectangle size was more than 10pixels, the mouse became faster than the eye-gaze input.

In Figure 11, the movement velocity in the vertical arrangement is compared among distance conditions, between young and older adults, and between eye-gaze input system and mouse. In Figure 12, the movement velocity in the horizontal arrangement is compared among distance conditions, between young and older adults, and between eye-gaze input system and mouse. Irrespective of arrangement conditions, the eye-gaze input system became faster than the mouse for all conditions of distance between adjacent rectangles.

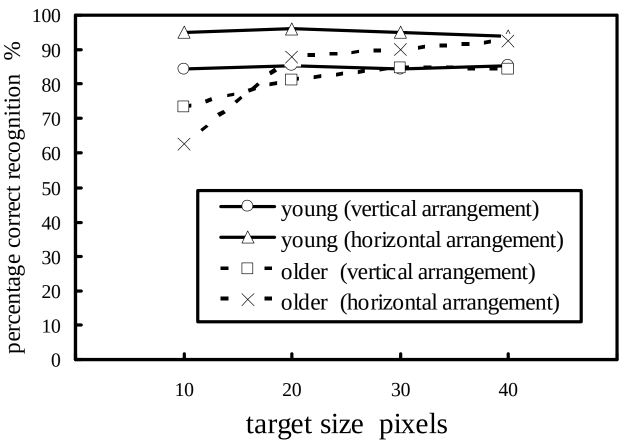

Figure.4 Vertical direction arrangement of target

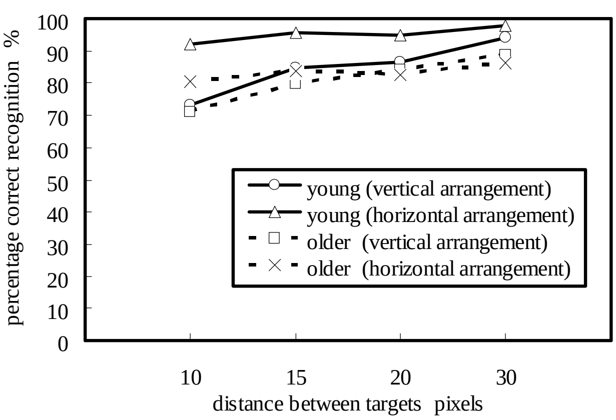

Figure.5 Vertical direction arrangement of target

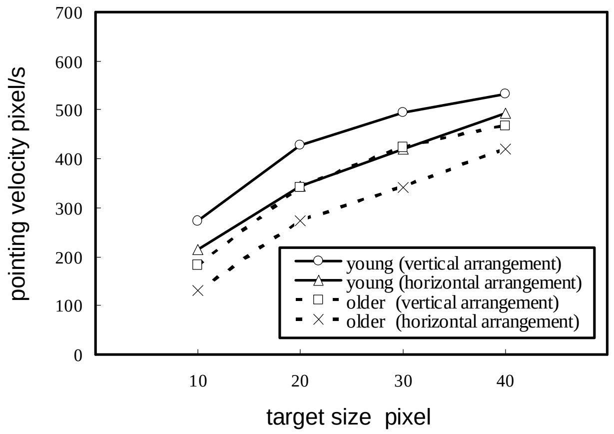

Figure.6 Vertical direction arrangement of target

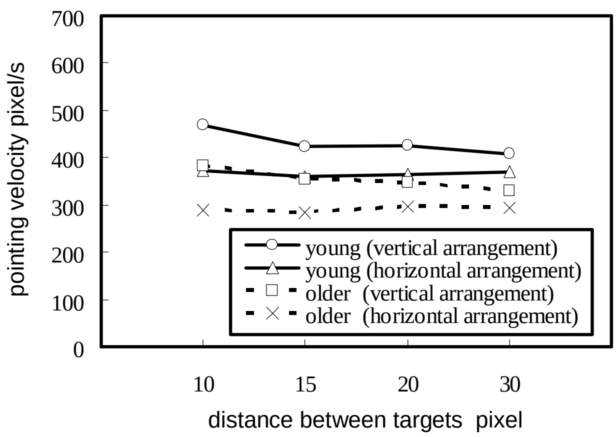

Figure.7 Vertical direction arrangement of target

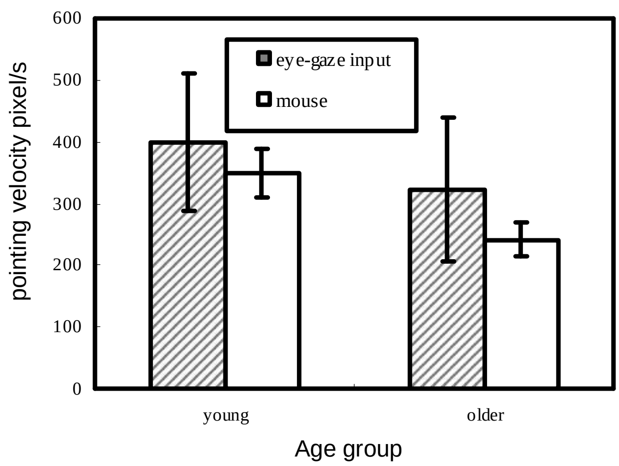

Figure.8 Pointing velocity as a function of age and input device.

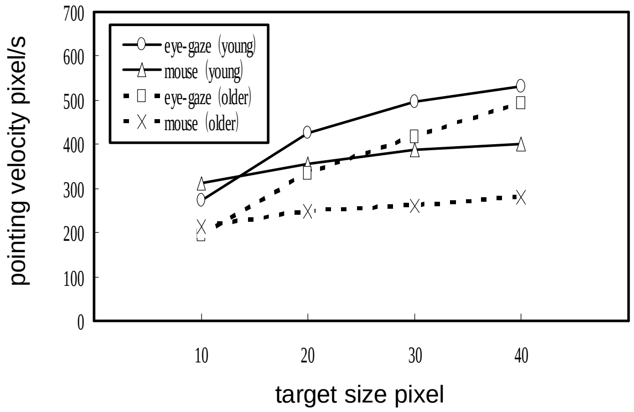

Figure.9 Pointing velocity as a function of age, input device and target size(vertical arrangement).

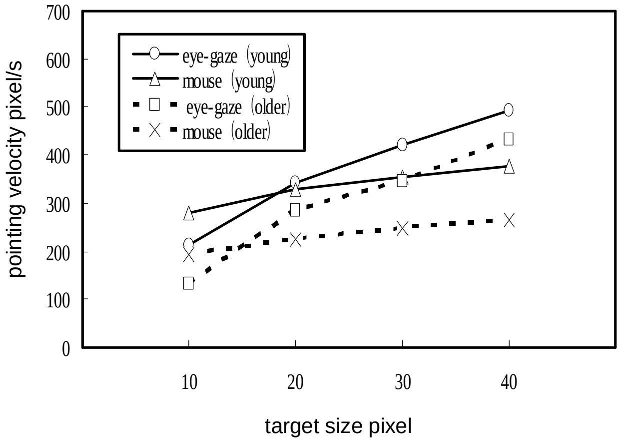

Figure.10 Pointing velocity as a function of age, input device and target size(horizontal direction).

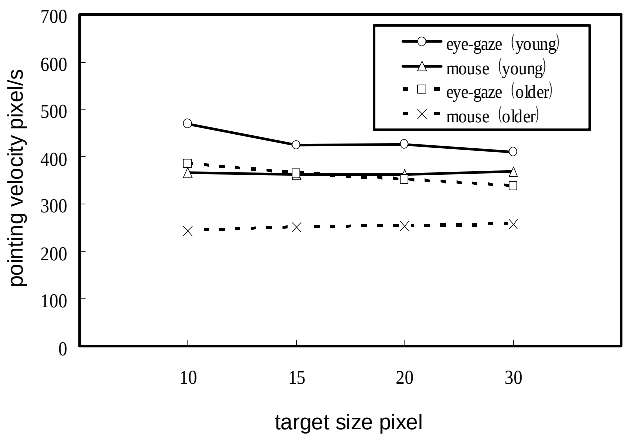

Figure.11 Pointing velocity as a function of age, input device and distance between targets(vertical direction).

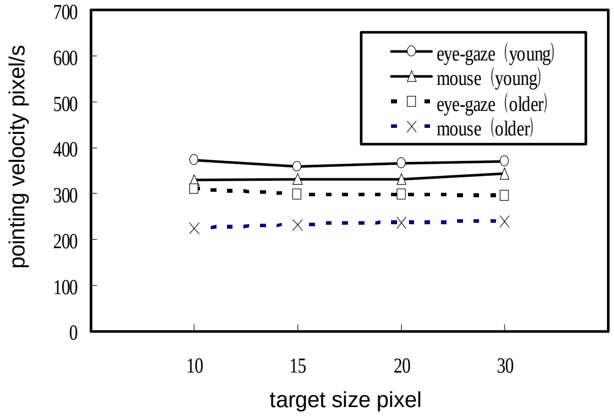

Figure.12 Pointing velocity as a function of age, input device and distance between targets(horizontal direction).

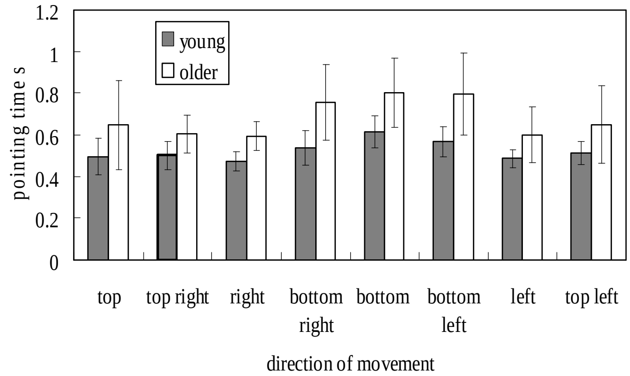

Figure.13 Pointing time as a function of age and direction of movement.

3.2 Experiment2 -Effect of movement direction -

In Figure 13, the pointing time is compared among eight directions, and between young and older adults. A two-way (age by direction) ANOVA carried out on the pointing time revealed main effects of age ($F(1,15)=23.218$, $p<0.01$) and direction ($F(7,105)=7.080$, $p<0.01$).

4.DISCUSSION

4.1 Experiment1 -Identification of conditions with higher accuracy and faster movement-

The horizontal arrangement, as a whole, led to higher accuracy in pointing (See Figures 4 and 5). A rectangle size s=10pixels cannot be recommended for both vertical and horizontal arrangement. A rectangle size s of more than or equal to 20pixels and a distance between rectangles d

Of more than or equal to 30pixels should be used in an eye-gaze input system.

For both horizontal and vertical arrangements, the movement velocity tended to increase with the increase of rectangle size *s* (Figure 6). Moreover, the movement velocity of the vertical arrangement tended to be faster than that of the horizontal arrangement. This must be due to human's eye movement characteristics that our eye moves more quickly in the horizontal direction than in the vertical direction. Comparing Figure 7 with Figure 6, the rectangle size *s* affected more strongly to the movement velocity than the distance *d* between adjacent rectangles.

As shown in Figure 8, the eye-gaze input system was effective especially for older adults. For both vertical and horizontal arrangements (See Figures 9 and 10), the rectangle size *d* affected the movement velocity of both input devices (eye-gaze input system and mouse) for both young and older adults. It also must be noted that the distance *d* between adjacent rectangles affected more strongly to the movement velocity than the rectangle size *s* (Compare Figures 9and 10 with Figures 11 and 12*)*.

4.2 Experiment2 -Effect of movement direction -

For both young and older adults, it was found that it was difficult to point to a target located at lower, lower right, and lower left (See Figure 13). In general, it is recognized that vertical eye movement is slower than horizontal eye movement. In this study, the pointing time to the upper target was not so long as compared with that at the lower target. The reason must be explored in more detail. In the range of this experiment, it is recommended that targets should not be arranged at the lower area. In Experiment2, the target size and the movement distance were fixed. Future research should explore how these conditions affect the directional effect.

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